

**LEVERAGING BUILDING INFORMATION
MODELLING TO ADDRESS THE BARRIERS THAT
PREVENT THE WIDESPREAD ADOPTION OF LIFE
CYCLE COSTING BY QUANTITY SURVEYORS**

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To all academics and practitioners in the built environment, may this work contribute to the enhancement of both education and practice.

Declaration

I declare that the work presented in this thesis entitled ‘Leveraging Building Information Modelling to Address the Barriers that Prevent the Widespread Adoption of Life Cycle Costing by Quantity Surveyors’ is my own work. To the best of my knowledge and belief, no material in this thesis has been previously published or written by another person, except where due reference is made.

This research includes material that has been published in internationally refereed journals and conference proceedings. Appendix 4 provides a list of publications of the candidate, which are a direct product from this thesis.

I certify that this thesis, which I now submit for examination for the award of Doctor of Philosophy, is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work. This research was prepared according to the regulations for postgraduate study by research of the University of Salford and has not been submitted in whole or in part for an award in any other Institute or University.

The work reported on in this thesis conforms to the principles and requirements of the University’s guidelines for ethics in research. The University has my permission to keep, or lend or to copy this thesis in whole or in part, on condition that any such use of the material or the thesis be duly acknowledged.

Signature of candidate:.....

Abbreviations

3D	Third Dimension
4D	Fourth Dimension
5D	Fifth Dimension
AEC	Annual Equivalent Cost
AEC	Architectural Engineering and Construction
ARM	Agreed Rules of Measurement
BCIS	Building Cost Information Service
BER	Building Energy Rating
BIM	Building Information Modelling
BLCC	Building Life Cycle Cost
BOQ	Bill of Quantities
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
BS	British Standard
BSI	British Standards Institute
BSRIA	Building Services Research and Information Association
CAD	Computer Aided Design
CAPex	CAPital Expenditure
CATO	Computer Aided Take Off
CIC	Construction Industry Council
CIC	Construction Industry Council
COBie	Construction Operations Building information exchange
CILECCA	Construction Industry Life Cycle Cost Analysis
CQS	Contractor's Quantity Surveyor
CWMF	Capital Works Management Framework
DIT	Dublin Institute of Technology
DPER	Department of Public Expenditure and Reform
DWF	Design Web Format
DXF	Data eXchange Format
EPA	Environmental Protection Agency
EPBD	Energy Performance Building Directive
EU	European Union
FM	Facilities Management
FV	Future Value
GIFA	Gross Internal Floor Area
GN2.2	Guidance Notes 2.2
GSA	General Services Administration
GSL	Government Soft Landings
iBIM	integrated BIM (defined as Level 3 in the UK BIM maturity levels).
ICE	Institute of Civil Engineers

ICT	Information Communications Technology
IES	Integrated Environmental Solutions
IFC	Industry Foundation Class
IPD	Integrated Project Delivery
ISO	International Standards Institute
IT	Information Technology
ICT	Information Communication Technology
KSN	Kerrigan Sheanon Newman
LCA	Life Cycle Analysis
LCC	Life Cycle Cost(ing)
LEED	Leadership Energy Efficient Design
M&E	Mechanical and Electrical
MEAT	Most Economically Advantageous Tender
MS	Microsoft
NBS	National Building Specification
nD	Infinite Dimensions
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NPV	Net Present Value
NRM	New Rules of Measurement
NS	Net Savings
NSBE	National Standard Building Elements
OGC	Office of Government Commerce
OMR	Operation Maintenance Replacement
OOCAD	Object-Orientated Computer Aided Design
OPex	OPERational Expenditure
PAS	Public Assessable Standard
PB	Payback Period
pBIM	pre BIM (defined as Level 2 in the UK BIM maturity levels)
PDF	Portable Document Format
PFI	Public Finance Initiative
POW	Plan Of Works
PPP	Public Private Partnership
PV	Present Value
QS	Quantity Surveyor
QTO	Quantity Take Off
RIBA	Royal Institute of British Architects
RICS	Royal Institute of Chartered Surveyors
SCA	Single Compound Amount
SCSI	Society of Chartered Surveyors Ireland
SFCA	Standard Form of Cost Analysis
SI	Statutory Instrument
SIR	Saving to Investment Ratio
SME	Small to Medium Enterprises.
SMM	Standard Method of Measurement

SPV	Single Present Value
TA	Thinking Aloud
TG4	Task Group No.4
UE	Usability Engineering
UK	United Kingdom
UPV	Uniform Present Value
US	United States
WBS	Work Breakdown Structure
WLC	Whole Life Cost
WLCC	Whole Life Cycle Cost(ing)

Abstract

Life Cycle Costing (LCC) is the consideration of all ‘relevant’ costs and revenues associated with the acquisition and ownership of an asset. LCC has a number of relevant applications, these include project appraisal; facilities management; procurement and tendering and as a means to evaluate sustainable construction. Although these advantages are well recognised, the process is underutilised due to a number of documented barriers to adoption. Notably these include lack of accurate historical databases; the perceived complexity and time consuming nature of the calculations; lack of a standard LCC methodology, and that the client is not requesting LCC. This research is framed in recognition of these barriers, investigating a process that could affect change by increasing efficiency in this area. A Building Information Modelling (BIM) approach to construction procurement is being increasingly utilised as a collaborative set of procedures and associated technologies that assist design and construction professions in conceiving, designing, constructing and operating the built environment. Although 5D BIM (Cost Modelling) is currently being used in Quantity Surveying (QS) practice, BIM is not extensively used in the application of LCC and there has been little research in this area. This research develops a 5D-LCC solution, where LCC is integrated into the 5D BIM process by embedding an LCC calculation model structure within an existing 5D technology. This process represents a change to the 5D BIM work-flow; adding on a facility for LCC through post-processing BIM data. The research is carried out under an action and design sciences research methodology, to develop and then evaluate the LCC process proposed in this research. An evaluation method known as ‘Thinking Aloud cooperative evaluation’ is used to gain feedback from a sample of QSs practicing in Ireland. The contribution to knowledge is the articulation of a process which extends 5D BIM for LCC, by leveraging an existing 5D technology. The research identifies that this process has an effect on a number of the reported barriers to LCC. The predominant benefit is that the process provides automation and efficiency in carrying out LCC, which addresses barriers such as LCC being a ‘time intensive process’ with QSs lacking ‘the know-how’ in carrying out calculations. The findings also indicate that the process provides a format to present LCC estimates, thus addressing a ‘lack of standardisation’.

1 Introduction

1.1 Introduction

This introductory chapter outlines the background to the research, providing a brief explanation of LCC and BIM and the scope of the research within that subject matter. The chapter includes a concise statement of the research problem, the aim emanating from that problem and presents a number of objectives to achieve the aim. The chapter also presents a brief statement on the research design, outlining the theoretical framework that will be followed in carrying out the research. The justification and significance of the research are also addressed and the structure of the thesis is presented.

1.2 Background to Research

The Quantity Surveying (QS) profession is a discipline in the Built Environment (BE) that deals with controlling and managing costs throughout the planning and construction of a built asset (Ashworth, Hogg, & Higgs, 2013; Kishk et al., 2003). QS practice traditionally focused on the CAPital expenditure (CAPex) of the construction project, providing measurement and pricing services for cost planning at pre-construction and cost management services during construction (Ashworth et al., 2013; Seeley, 1996). Very little consideration was given to the OPERational expenditure (OPex) or ownership costs of maintaining and managing the built asset after it was constructed (Cole & Sterner, 2000; Kirkham, 2012).

There have been a number of terms used over the years to describe the calculation of expenditure during the occupancy stage of a constructed asset. These include, ‘whole cost’, ‘through life cost’, ‘operational expenditure’, ‘terotechnology’, ‘cost in-use’, ‘cost of ownership’ and ‘running costs’ (Ashworth et al., 2013; Kirkham, 2012; Seeley, 1996; Gluch & Baumann, 2004). Kirkham (2012) maintains the plethora of terms used over the years and the variances in their meaning added confusion to a field that lacked a clear scope or standard definition. In the last number of decades the term Life Cycle Costing (LCC) has emerged as the most prevalent phrase to describe this concept in the QS profession (Ashworth et al., 2013; Kirk & Dell'Isola, 1995). The Construction Best Practice Programme (CBPP 1998, p. 7) define LCC as

“the consideration of all relevant costs and revenues associated with the ‘acquisition’ and ‘ownership’ of a constructed asset”. The International Standards Organisation (ISO) (BS-ISO, 2008) subsequently provided clarity on the scope of ‘acquisition’ and ‘ownership’ costs, further dividing LCC into construction; operation; occupancy; maintenance and end of life costs. They also outline the difference between LCC and Whole Life Costing (WLCC), stating that WLCC includes a broader economic matrix including ‘non-construction costs’ such as finance; site costs; enabling works and also ‘income’ generated during occupancy of the asset.

LCC has a number of applications in the Architectural, Engineering and Construction (AEC) industry, such as; the evaluation of operational costs in Private Finance Initiatives (PFI); a monetary mechanism for measuring sustainable construction and energy efficiency; evaluating the economic performance of building components over an extended period of time and controlling costs during Facilities Management (FM) (Ashworth et al., 2013; Clift, 2003; Cole & Sterner, 2000; Kirk & Dell’Isola, 1995).

Although the significance of LCC has been recognised on construction projects in United Kingdom (UK), as early as the 1980s, with substantial amounts of research into the field, the application has not been extensively implemented into standard QS practice (Clift & Bourke, 1999; Cole & Sterner, 2000; Opoku, 2013; Schaudé, 2011). The Latham (1994) and Egan (1997) reports also recognise the importance of OPex and identify LCC as a way to increase value for construction clients by focusing on minimising future occupancy costs. It is claimed OPex can account for as much as five times the initial CAPex (Evans, Haryott, Haste, & Jones, 1998), thus, there is reason to question why this is not part of the standard cost management service.

To carry out LCC, Qs must use a number of financial equations and apply the right equation to the right scenario. These calculations are utilised to take account of the ‘time value of money’ and provide a mechanism to evaluate future costs in a way that can be understood and compared to other design options (Davis Langdon, 2007; Kishk et al., 2003; RICS, 2015). This is one of the issues with LCC for Qs, as it is not their traditional area of expertise and they perceive these calculations as ‘complex, and time consuming’ (Fu, Kaya, Kagioglou, & Aouad, 2007; Olubodun, Kandwa, Oladapo, & Thompson, 2010). Other reasons it has not been implemented

into standard practice are; a lack of access and reliability of LCC data; a lack of standardisation and guidance documentation and that construction clients are not requesting it (Clift, 2003; Cole & Sterner, 2000; Oduyemi, Okoroh, & Dean, 2014; Opoku, 2013; Olubodun et al., 2010; Schaudé, 2011).

Due to the amount of variables that exist in LCC, spreadsheet software such as Microsoft (MS) Excel is predominantly used and adapted to perform and compute the calculations, building in a facility for key variables (OGC, 2007; Kehily et al., 2012). This is evidenced in a number of guidance notes and standards that include spreadsheet templates to support their documents and to provide a means to calculate LCC under their methodologies (BSI/BCIS, 2008; Churcher, 2008; Fuller & Peterson, 1996; Hunter, Hari, & Kelly, 2005; RICS, 2014). It is also demonstrated in the use of spreadsheet based LCC applications that support LCC within the jurisdictions they encompass and embed precoded LCC calculations in their cells (Gundersen, 1998; Kehily, 2011; SEMC, 2011). The use of spreadsheets are beneficial, but incorporating CAPex and LCC estimates in spreadsheet software disconnects the QSs Quantity Take Off (QTO) (which is predominantly carried out in estimating software) from their pricing and presentation (Eastman, Teicholz, Sachs, & Liston, 2011).

BIM is providing construction stakeholders with a different approach to traditional construction processes, that focuses on collaboration and integration across the construction supply chain, utilising the latest developments in virtual building technology (Fung et al., 2014; Eastman et al., 2011; Underwood & Isikag, 2010; Crotty, 2012). BIM advocates maintain that its capabilities are in delivering value throughout the whole building process including the asset's operational phase (Crotty, 2012; Eastman et al., 2011; Underwood & Isikdag, 2011). If their assertions are correct, there could be potential to utilise BIM to address LCC, as LCC considers costs from a holistic perspective.

BIM has the potential to help QS practices and construction companies to estimate the cost of a project with more detail and accuracy, while reducing time and expenses (Eastman et al., 2011; Goucher & Thurairajah, 2012; Matipa et al., 2008). Sabol (2008) points out that BIM makes it possible for QSs to provide alternative professional services by leveraging BIM technology and freeing up time that would have been spent on labour intensive activities in traditional QS processes. There is a

significant amount of literature available on the application of BIM for cost management and QTO, which is commonly referred to as 5th Dimension (5D) BIM, but little in regard to BIM and LCC (Goucher & Thurairajah, 2012; Mitchell, 2012; Whyte & Scott, 2010; Kehily et al., 2012). Whyte & Scott (2010) maintain that BIM, though sophisticated, can find itself restricted in providing efficiencies in LCC because it lacks the ability to compute LCC calculations and provide an integrated approach to both CAPex and OPex.

This study addresses the emergence of BIM and its application to construction design and management. It describes BIM's evolving use for cost management and purposes and isolates LCC as a potential area for further research in the area of BIM.

1.3 Justification and Significance

Despite the benefits LCC can offer both the QS and the construction client, it is not widely carried out in the QS profession (Chiurugwi, Udeaja, & Hogg, 2010; Hourigan, 2012; Olubodun et al., 2010; Opoku, 2013). There have been a number of standards and guidance notes published on LCC over the last ten to fifteen years, to help QSs in the production of LCC estimates and increase its use (BS-ISO, 2008; BSI/BCIS, 2008; Kehily, 2011; Fuller & Peterson, 1996; RICS, 2014). However, these methodologies are theoretical with little in the way of practical examples and process implementations to guide a cost professional through the process of calculating and presenting LCC.

The Capital Works Management Framework (CWMF) (Dept. of Finance, 2009) and the OGC (2007) provide guidance notes for the management and control of costs on publically procured projects in Ireland and UK respectively. The OGC and CWMF, which are government publications, do not legislate for LCC in the procurement process, but rather recommend that LCC should be carried out on public works. This recommendation seems to be largely ignored, evidenced in the low application of the service in both UK and Ireland, due to the barriers outlined previously. However, if QSs are to offer best practice services for their clients they should conform to these recommendations.

The EU has also enacted a number of directives recently on LCC. When these directives are transposed into legislation, LCC will be further engrained in public

procurement, thus necessitating cost management practitioners to overcome their issues in providing this service. Other drivers increasing the use of LCC are that it is used as an effective method of analysing long term operating costs on PFI projects (Davis Langdon, 2007; Swaffield & McDonald, 2008; Meng & Harshaw, 2013); that it provides an economic metric for evaluating sustainability and energy efficiency (Wong et al., 2010; Aye et al., 2000; Kelly & Hunter, 2009) and that it can be utilised to inform design decisions that potentially have an effect on maintaining and managing the asset during its operation (Kirkham, 2005; El-Haram et al., 2002; McAuley et al., 2013). An increasing focus on the occupancy stage and Facilities Management (FM) of the built asset will require a means to effectively evaluate OPex.

The success of implementing the requirements outlined in LCC guidance and standard documentation depends on a process that would allow for ease of calculation, ease of preparation and analysis in a uniform method. The process must also be adaptable to apply to different standard LCC methodologies and to apply to different projects.

Furthermore, Qs use a number of well recognised software applications such as Buildsoft, CostX, Vico and CATO. The majority of these applications tend to have a spreadsheet based workbook which could carry out LCC calculations in a format that is in line with the relevant standards. If LCC calculations could be incorporated into their spreadsheet functionality, it may provide a means to carry out LCC analysis in existing estimating applications.

A number of these applications also have the ability to utilise BIM by automating the QTO process, providing QS with more time to focus on value enhancing services to the client (Goucher & Thurairajah, 2012; Sabol, 2008). Currently Qs are utilising BIM for QTO and construction cost estimating but there has been limited research on how BIM could be leveraged for effective LCC and the evaluation of OPex (Goucher & Thurairajah, 2012; Kehily et al., 2013; Whyte & Scott, 2010). Slyvester & Dietrich (2010) and Shen et al. (2007) maintain that current BIM properties are not semantically rich enough to deal with the multiple conditions in LCC and the calculations required for variable analysis. Eastman et al. (2011) claim that no BIM tool has the computation capabilities of spreadsheet software and thus Qs need to

utilise a programme outside the current BIM work-flow to carry out effective estimating and LCC.

The primary research begins with the development of an LCC calculation model structure, which is informed from the latest methodologies and standards in LCC. Subsequently, the research investigates the possibility of appending an LCC calculation structure into a 5D BIM technology (with spreadsheet functionality). Thus, extending the 5D BIM work-flow to accommodate LCC by post-processing BIM data, integrating CAPex and LCC in the same process. This constitutes post-processing 5D BIM for LCC rather than developing and creating model definitions for LCC within design/authoring software. The rationale for pursuing a post-processing application of BIM for LCC is discussed in further detail in Section 3.5 and the development of this process is articulated throughout Chapter 5.

1.4 Problem Statement

The following paragraphs offer a brief statement of the problem to be addressed in this research. They summarise the background and justification of the research (discussed above) providing the backdrop to the research aim and objectives outlined in the next section:

Despite the significant amount of research in LCC in the last fifteen to twenty years, it has not been extensively implemented into QS practice. The benefits and applications of LCC have been well documented and there are a number of standards and guidelines published to provide support to QSs carrying out LCC. However, due to barriers that prevent LCC being widely practiced, these benefits have not materialised. QSs require a means to carry out LCC effectively in line with the relevant standards and guidelines.

BIM offers capabilities that can aid QSs increase efficiencies in their work practices. One of the primary benefits of BIM for QSs is that it can automate the QTO process and free up time to concentrate on activities that would add further value for their clients. LCC is identified as a value enhancing service, but there has been limited research on how BIM could be leveraged to increase efficiency in providing this service, by addressing the barriers to implementation.

1.5 Research Purpose

The following aim and objectives encapsulate the research purpose by providing an overarching question which is facilitated through five objectives:

Aim:

The aim of this research is to investigate how 5D BIM can be effectively utilised by Quantity Surveyors for LCC in order to overcome the reported barriers preventing LCC's widespread adoption.

Objectives:

Specific objectives to achieving the aim are as follows:

1. Determine the concept of LCC and WLCC in the context of the QS profession.
2. Investigate the existence of benefits and barriers to LCC in order to identify what actions can be taken to increase usage levels.
3. Determine the benefits and barriers of utilising BIM for cost management and address its opportunities for effective LCC.
4. Develop a methodology to add LCC dimension to the BIM process by extending current 5D BIM capabilities.
5. Evaluate this process to determine if the barriers preventing widespread application of LCC can be addressed.

1.6 Research Methodology

Figure 1.1 illustrates the development of a research design that is based on firm ontological and epistemological reasoning. The epistemological position is outlined here as advocacy/participatory and pragmatism, which forms the theoretical basis for an action research and design sciences methodology. Advocacy/participatory and pragmatism resonated in the context of this research as there is participation from the researcher in the research process to effect change in the built environment.

As illustrated in Figure 1.1, a hybrid action research and design science methodology is proposed in this research because there is significant participation from the researcher. Action research and design science are both action orientated research

strategies with common characteristics. A solution is proposed to a fieldwork problem with participation from the researcher and the solution is subsequently evaluated in use (Jarvinen, 2007; Johannesson & Perjons, 2012; Sagor, 2005; van Aken, 2005).

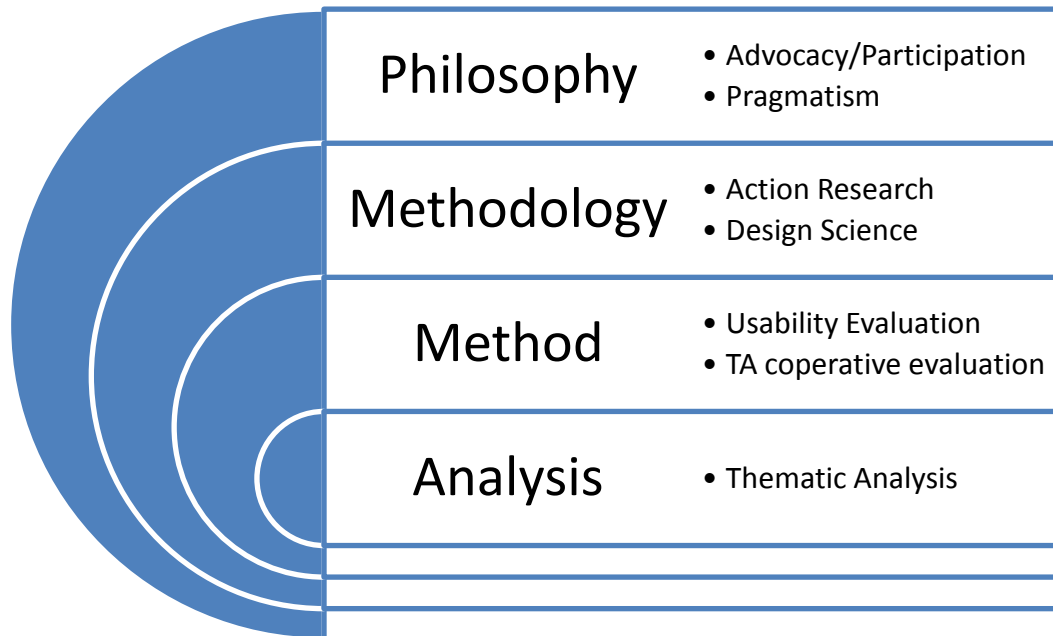


Figure 1.1: Research Design

The basis of selecting an action orientated research design emanates from the problem statement addressed in this chapter and the need for a solution which increases efficiency in the area of LCC. The premise of utilising a dual methodological approach is based on Jarvinen (2007) opinion that action research and design science are similar methodologies that are presented with different terminology. Both Jarvinen (2007) and Holmstrom, Ketokivi, & Hameri (2009) contend that the only real difference is that action research focuses on the social process element of the research and design science emphasises the technological change.

The aim of this research does not only deal with a technological change in QS practice but also the process implications to dealing with this change. In this circumstance, both action research and design sciences can complement each other and provide a mechanism to design a solution, implement that solution and evaluate change from both perspectives (social and technological) (Jarvinen, 2007).

There is a common staged framework to carrying out action orientated research (Azhar, Ahmad, & Sein, 2010; Holmstrom et al., 2009; Susman & Evered, 1978). This framework emphasises four main stages to action orientated research: to identify a problem that prevails in practice; to develop a solution to that problem; to evaluate the solution in action and to specify learning from the evaluation.

1. Identity Phase:

The research problem is outlined in the problem statement which notes that LCC is underutilised in QS practice as a consequence of a number of barriers to implementation. BIM is identified as holistic approach that could aid Qs in carrying out LCC.

2. Development Phase:

The development phase takes the form of a collaborative project with a 5D BIM software vendor, by embedding an LCC calculation structure, created by the researcher, into an existing 5D BIM estimating platform – extending the 5D BIM work-flow into LCC.

3. Evaluation:

As illustrated in Figure 1.1, a usability evaluation method known as ‘Thinking Aloud (TA) cooperative evaluation’ is proposed. It enables a functional evaluation of the technological change while also collecting data based on the subjective attitudes of the participants on the process they are engaged in.

4. Specify Learning:

The findings of the evaluation are specified based on feedback from the participants when engaging with the developed solution and also on how that solution changes current work practices.

The evaluation of the proposed change/solution is carried out in two stages. The first stage based on a proposed development in 5D BIM by extending LCC through post-processing BIM data. This is outlined in Chapter 5. The second stage evaluates a more developed version informed from feedback and recommendations on the first stage. Both evaluations are carried out by TA cooperative evaluation. The data generated from the TA cooperative evaluation are similar to data generated in an

interview and thus data analysis techniques associated with qualitative research will be investigated and employed. The data analysis method used in this research was thematic analysis.

1.7 Scope

This research proposes to investigate a solution to increase efficiency in LCC. Increasing efficiency is considered a product of how the barriers that prevent its widespread application can be addressed. The solution proposed in this research is essentially an LCC calculation model structure embedded in 5D BIM.

The study will focus on whether BIM can be utilised to increase efficiency in LCC. BIM has a wide scope and stretches across all elements of the construction procurement process, from initial brief to managing the built asset after construction. The different areas in the BIM landscape are encapsulated in a number of BIM dimensions. 3D BIM deals with visualisation of the building and is used by Architects and Engineers to produce the design in a virtual isometric view (Eastman et al., 2011). A 4D time model and 5D cost model can be produced by adding time and cost information to the 3D model respectively (Boon, 2009; Smith, 2014; Barnes & Davies, 2014). The dimension of BIM that this research focuses on is 5D, which recognises materials used within the model and where available, assigns costs to these components (Fung et al., 2014; Smith, 2014; Wu, Ginige, Wood, & Jong, 2014).

Infinite dimensions' (nD) is a term to describe the expanding application of BIM to include the broader aspects of the built environment. These attributes include sustainability, acoustics, maintenance, lighting and buildability (Aouad, Lee, & Wu, 2005; Eastman et al., 2011; Fu et al., 2007; Sawhney, 2014). In recent years 6D and 7D modelling embody the expanding universe of nD BIM, where BIM is utilised for facilities management and sustainability respectively (Smith, 2014; Barnes & Davis, 2014). LCC is an aspect of cost management and thus mainly falls within the 5th cost dimension of BIM (Barnes & Davis, 2014). However, LCC's scope evidenced in its definition includes a broader economic matrix which also addresses attributes in the 6D modelling sphere, such as maintenance, operation and energy efficiency. Thus LCC does not fit entirely into one of the dimensions but runs across both 5D BIM and 6D BIM, as it has concerns in both CAPex (5D) and OPex (6D).

Figure 1.2 illustrates the focus of this research in respect to BIM and LCC. The particular dimensions of BIM that the research is concerned with is ‘5D BIM’ and ‘6D BIM’, which are illustrated as purple circles. The small circles representing the dimensions are overlapped to accentuate the connectedness and collaboration process throughout the BIM work-flow (within the large BIM circle). The blue circles for CAPex (corresponding with 5D) and LCC/OPex (corresponding with 5&6D) illustrate their respective areas in cost management. The overlap between these circles (red dot) accentuates the area where the research seeks to add new knowledge, which is essentially integrating LCC into the BIM process.

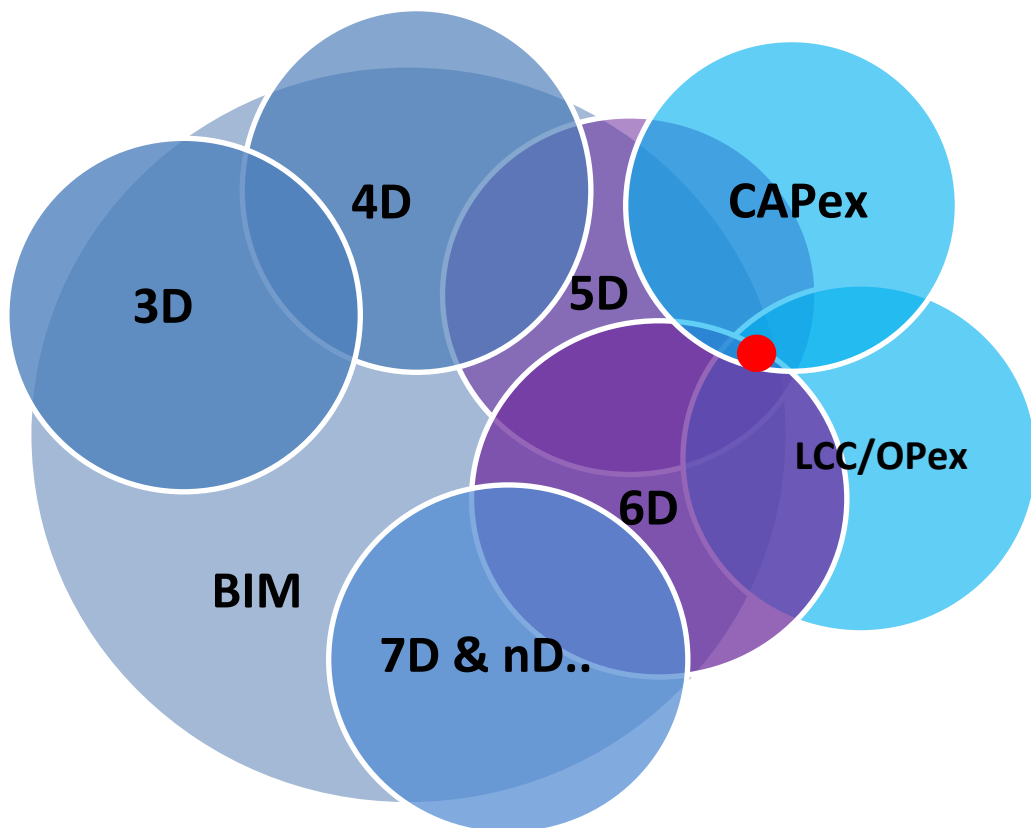


Figure 1.2: LCC/BIM

To add new knowledge in this area, the research deals with the development of what is called in design sciences a ‘technological rule’. This does not constitute a fully operational piece of 5D-LCC software but a technological process that could be replicated by QSs utilising 5D BIM technologies. Thus the research is not concerned completely with the success and usability of a finished piece of software but the change that it initiates in the BIM work-flow and the possible effect of this change on the barriers to LCC.

1.8 Contribution to Knowledge

This research develops a methodology which extends the 5D BIM process for LCC. This is based on the premise (discussed in the review of literature) that 5D BIM is the ideal environment to house the complexities of LCC calculations. It is outlined in the review of literature that creating the facility for LCC in the design model by adding LCC object definitions would not be successful. The reason for this is that BIM authoring software does not currently have the capabilities to test the variable conditions in LCC. BIM authoring tools do not have the computation capacity of 5D BIM. This led to the articulation and proposal of a methodology of post-processing BIM data from the authored model and linking that data to an LCC structure appended to 5D BIM. This is carried out by leveraging an existing 5D technology to incorporate an LCC calculation structure within the 5D system. This enables integrated CAPex and LCC analysis within the same process/system. The contribution to knowledge is the process of extending 5D BIM for LCC by leveraging an existing 5D BIM technology.

However, the primary focus of design science and action research is that the solution intervention can have an effect on the environment to which it has been introduced (Azhar et al., 2010; Hevner et al., 2004; Iivari & Venable, 2009). In this case this environment is QS practice and is benchmarked against its effectiveness in addressing the barriers to LCC. This research provided evidence that extending 5D BIM for LCC can have an effect on the barriers to LCC, mainly the complexity and time consuming nature of the process and standardisation of the process.

1.9 Structure of Thesis

This thesis is divided into eight chapters as set out in Figure 1.3 below. The following is a brief summary of the content of each chapter and the rationale to its structure:

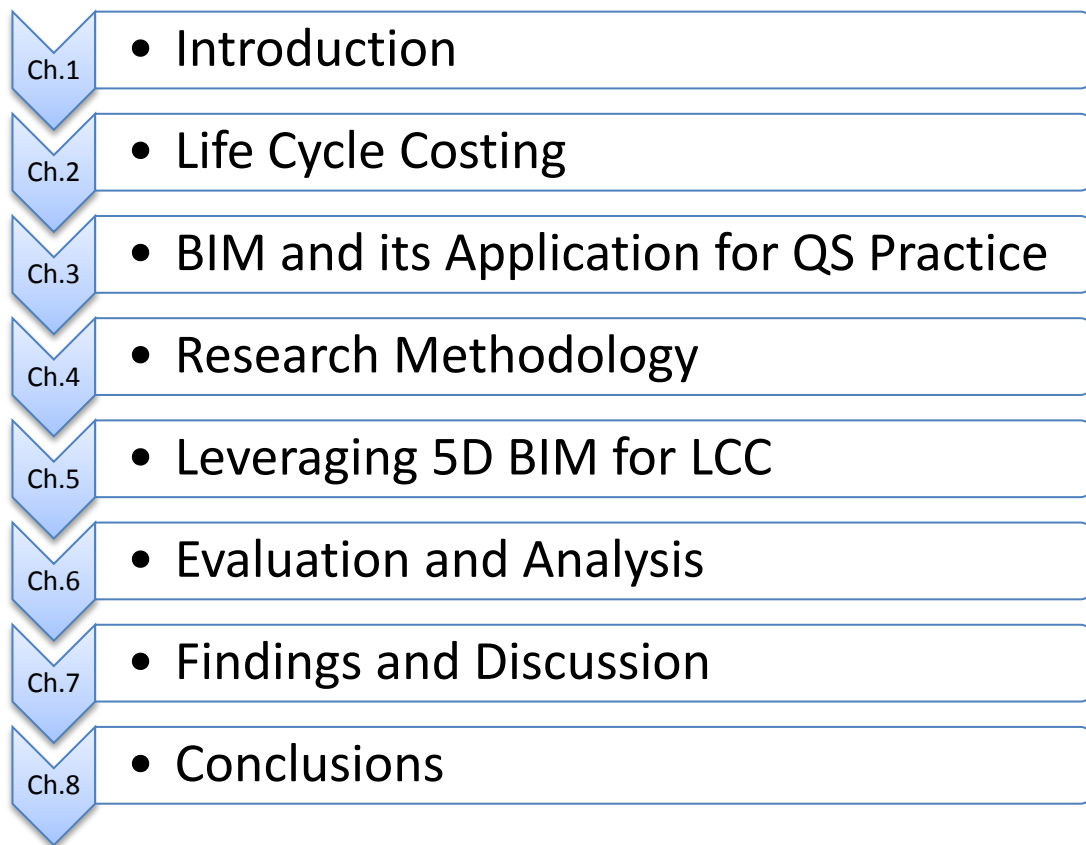


Figure 1.3: Chapter headings

In **Chapter 1** the background to the research is presented addressing the rationale for the study; the aims and objectives of the research; the structure of the thesis and a statement of the methodology. The scope of the work is discussed and is supported by the justification and significance of the research.

Chapter 2 and Chapter 3 deal with the subject matter of the research and are presented as a comprehensive **review of literature** on the scope of the research. These chapters isolate a research issue in existing publications which warrants further investigation. Embedded in the aim outlined above are two different processes and/or practices; LCC and BIM.

Chapter 2 firstly deals with LCC, describes how LCC has developed in QS practice and outlines the reasons it is gaining importance. A number of barriers that prevent LCC being widely practiced are discussed. The review of literature provides evidence that a process is necessary that could provide LCC in a formulated structure to potentially address these barriers.

Chapter 3 outlines the other subject matter addressed in the aim, that of Building Information Modelling (BIM). Developments in BIM are discussed

in the context of advances in technology and changes in work practices that promote a collaborative approach to the construction supply chain and exchange of information. Chapter 3 presents a comprehensive review of literature on BIM, firstly addressing its general principles and applications and subsequently narrowing the relevance to quantity surveying and then LCC. The potential application of BIM for LCC is discussed.

In **Chapter 4**, the **methodology** and procedures adopted to conduct this research are justified and discussed. A summary of what is entailed in this chapter is outlined in the previous section. The structure of this thesis, from this chapter on, follows an action orientated research methodology that promotes two main stages to the research process; the development and evaluation phases which are outlined in the following two chapters.

Chapter 5 describes the **development process** in coming up with a design sciences artifact, which proposes a technological rule and process change to the BIM workflow that could potentially address efficiency in LCC. The different stages of the development process are presented and the rationale for making decisions as the process is developed, are discussed. Ultimately the artifact is presented in the context of a process change to the existing 5D BIM work-flow, which is evaluated through the details outlined in Chapter 6.

Chapter 6 discusses the **evaluation** measurers employed to evaluate the process outlined in the previous chapter. The chapter adheres to the formulated structure of carrying out a TA cooperative evaluation. The **data analysis** techniques described in the latter half of the chapter outline that thematic analysis was utilised as the analysis method. Subsequently the staged analysis process is presented, leading to a framework that is used in writing the report.

Chapter 7 outlines the **findings** from the data analysed in the previous chapter. Findings are presented based on the themes that emerged during analysis. The findings are presented firstly based on the content of the review of literature but most importantly on the qualitative findings on the process the participants were engaged in. The latter part of the chapter **discusses** the findings of this research in comparison to that outlined in the review of literature and discusses the relevance and originality of this research within the context of BIM and LCC.

Chapter 8 presents the **conclusions** drawn from the analysis and findings of Chapter 6 and 7 respectively. The chapter highlights the contributions to knowledge from the research findings, proposes recommendations, outlines limitations and discusses potential future research in the field.

1.10 Summary

This chapter provides the background to the research, describing an area in QS practice that is concerned with the calculation of CAPex and OPex. The rationale to the study is presented in the context of the QS profession, where LCC is not in widespread practice due to a number of barriers to its implementation and that a solution is necessary that could provide efficiencies in LCC. The chapter also discusses BIM and how it is currently being harnessed to improve work practices in construction industry. The scope of the research is where LCC and BIM intersect developing and subsequently evaluating a LCC/BIM solution that could affect the barriers that prevent LCCs widespread adoption.

The aim of the research is articulated and the objectives are set out. This chapter explains that the research follows an action-orientated research philosophy which proposes an action research and design science methodology. These methodologies outline a structure that facilitates the development of a solution to a fieldwork issue and subsequently evaluates that solution with potential users. The structure of the thesis revolves around this framework outlining an issue in the literature review, proposing a solution and evaluating that solution.

2 Life Cycle Costing

2.1 Introduction

Traditionally within the construction industry, design professionals provide advice to clients based on the economic aspects of building development proposals but tend to primarily concern themselves with the initial CAPex (Ashworth et al., 2013; Kishk et al., 2003). Techniques such as LCC provide end users with a longer term view which includes maintenance and operating costs over a building's life, in addition to the initial construction CAPex (Opoku, 2013; BSI/BCIS, 2008; El-Haram et al., 2002). The use of LCC within the construction sector has become a prevalent topic in the last few decades but it is not used to its full potential (Clift, 2003; Cole & Sterner, 2000). This chapter describes how LCC has developed over the last twenty years and outlines the reasons it is gaining importance including efforts made to standardise the process through methodologies and guidance documents. A number of barriers that prevent LCC being widely practiced are presented along with the methods of calculating LCC to establish the most prevalent calculation methods, which provide the background to the technological applications that are used to automate the process. The literature provides evidence that a process is necessary that could provide LCC in a formulated structure.

2.2 Whole Life Cycle Costing and Life Cycle Costing

Before explaining the scope of the research on LCC, it is necessary to define the meanings of and difference between LCC and WLCC. Several definitions exist for both LCC and WLCC. Fuller & Petersen (1996, pp. 1-1) define LCC as:

an economic evaluation in which all costs arising from owning operating and maintaining a building over a certain study period or building life cycle are considered to be potentially important.

The International Standards Organisation (BS-ISO, 2008, p. 2) describe LCC as a:

methodology for the systematic economic consideration of life cycle costs and benefits over a period of analysis, as defined in the agreed scope.

Fuller & Petersen (1996, pp. 1-1) outline various reasons why these costs are 'potentially important', stating that the functions of LCC are for decisions in option appraisal, informing design decisions and cash flow forecasting of the built asset.

Pelzeter (2007) also addresses the function of LCC, maintaining that it could be used to provide an enriched cash flow forecast for the client over an extended period or to provide a comparative analysis of a number of design options. These functions will be discussed in greater detail in Section 2.5.

The International Standards Organisation (BS-ISO, 2008, p. 3) define WLCC as:

all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements.

Another definition of WLCC is presented by the OGC (2007) as:

the costs of acquiring the facility (including consultancy, design and construction costs, and equipment), the costs of operating it and the costs of maintaining it over its whole life through to its disposal – that is, the total ownership costs.

Although these definitions use different words and terminologies, the meaning is quiet similar, i.e. WLCC and LCC arise from an economic evaluation of not just initial ‘construction’ CAPex but also the ‘owning’ costs associated with ‘operating’, ‘occupying’, ‘renewing’ components and ‘maintaining’ the asset (BS-ISO, 2008). However, these definitions do not provide adequate clarity in respect to ‘what constitutes an operating cost as opposed to a maintenance cost?’ and ‘what exactly the difference is between LCC and WLCC?’ Thus, more clarification and classification in LCC was required.

The ISO published 15686-5 (2008, p.vi) to “*establish clear terminology and a common methodology for LCC*”. Figure 2.1 illustrates the hierarchical breakdown structure for WLCC from BS-ISO 15686-5 (2008). It illustrates that LCC is broken into a number of categories; initial construction costs; operation costs; occupancy costs; maintenance costs and end of life costs (3rd Tier Figure 2.1). A breakdown of the types of costs included in each category are provided in BS-ISO 15686-5 (2008, p.11-18). BS-ISO 15686-5 (2008) and its BSI/BCIS supplement (2008) will be discussed in further detail in Section 2.4.3 and 2.4.5.

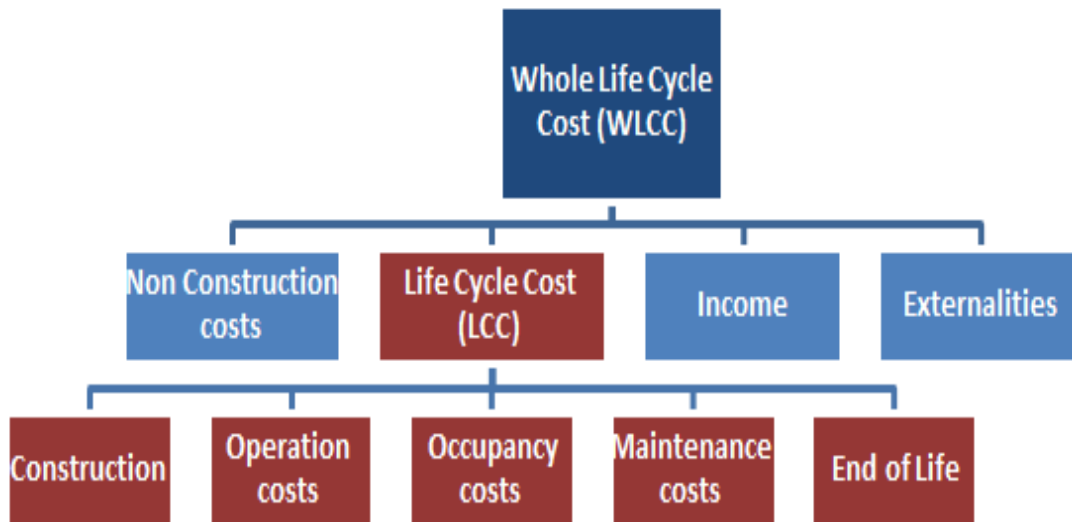


Figure 2.1: BS-ISO 15686-5 (2008)

Determining the differences between WLCC and LCC from the above definitions is not transparent. Section 2.4 addresses the standards and methodologies on LCC and reveals that WLCC includes a broader economic matrix, encompassing not only construction costs and LCC (3rd tier, Figure 2.1), but also ‘non-construction costs’ such as site purchase; letting or selling agent fees; procurement costs and the cost of finance (2nd tier, Figure 2.1) (BS-ISO, 2008; BSI/BCIS, 2008; TG4, 2003). Figure 2.1 illustrates that WLCC also includes ‘income’ from the built asset and any defined ‘external’ costs. The ISO describes external costs as ‘externalities’, which are costs not necessarily reflected in the transaction between provider and consumer, giving examples such as business staffing, productivity and user costs (BS-ISO, 2008).

In the AEC industry the term OPERational expenditure (OPex) is sometimes used to describe all future owning costs, even though its definition is not entirely correct per BS-ISO 15686-5 (2008). In accordance with the BS-ISO 15686-5 (2008) ‘operational expenditure’ is only outlined as one of a number of LCC costs illustrated in Figure 2.1, thus OPex is not an accurate term for LCC under ISO 15858-5.

2.3 Quantity Surveying Practice

Originally the QS’s primary role involved measuring and valuing of construction works based on the design and specifications (Carlidge, 2011; Opoku, 2013). To carry this out, a Bill of Quantities (BOQ) was produced to measure materials so that tendering contractors could price the works for the purposes of generating a price for

the job (Seeley, 1996). The technique of measuring quantities from drawings and specifications prepared by designers (Architects and Engineers) is known in the construction industry as Quantity Take Off (QTO) (Kirkham, 2012). Cartlidge (2011) states the use of BOQs and QTO dates back to the 18th century where costs for producing a BOQ were shared by the contractors who were tendering on the project. Gradually the client became responsible for paying the QS for the generation of the BOQ and a distinct profession of Quantity Surveying providing a cost management service for the client emerged (Drogemuller & Tucker, 2003).

Kirkham (2012) notes that particular issue with the traditional QS role was that the client did not know how much a building was going to cost until it was tendered. A more formulated staged process throughout the design period emerged in the 1960s as a way to provide cost checks up to the tender date (Ashworth et al., 2013; Cartlidge, 2011). This led to a cost management process known as ‘cost planning’ where there is a focus on maintaining a ‘target cost’ throughout the design and construction of the project (Cartlidge, 2011). Cost planning starts at inception when indicative costs are produced on the project brief. It then continues with preliminary estimates on early designs, as the design evolves more detailed estimating is carried out and eventually a BOQ is produced for final price checking and tendering (Ashworth et al., 2013; Seeley, 1996). Deviation from this target cost at any stage of the cost planning process indicates that the cost of the project has gone over budget and measures must be taken to get it back on track (Ashworth et al., 2013; Kirkham, 2012; Seeley, 1996).

Good practise in cost planning and cost control requires that the QS allocates the overall estimated costs into a number of cost holding categories known as ‘elements’ or Work Breakdown Structure (WBS). These elements are based on the functional components of the design, such as the substructure; external walls; internal walls and doors & windows (Ashworth et al., 2013; Dept. of Finance, 2009; Kirkham, 2012). Different jurisdictions have alternative elemental classification categories but operate in a similar manner. In Ireland the elements are organised in accordance to the National Standard Building Elements (NSBE). In UK these elements are arranged according to the framework from the Building Cost Information Service (BCIS). Elemental costs can be compared to the elemental totals in similar projects. They may also be compared to the cost of the corresponding element in the previous

estimate to isolate areas in the design that could have increased in cost (Ashworth et al., 2013; Kirkham, 2012).

Traditionally, the cost planning process was carried out in an ad-hoc manner. Many organisations had their own procedures and documentation and there was no industry wide approach to the measurement and description of building works for preliminary estimates and cost plans (Ashworth et al., 2013; Cartlidge, 2011). In 2009, the Royal Institute of Chartered Surveyors (RICS), in an effort to standardise the cost planning process, published the New Rules of Measurement 1 (NRM 1) (RICS, 2012a). NRM 1 sets out a process where cost plans and estimates are prepared by the QS at various stages of the Royal Institute of British Architects (RIBA) Plan of Work (POW) (Ashworth et al., 2013). The RIBA POW is an industry-wide recognised framework that organises the design and administration of the building into eleven sequential steps (Ashworth et al., 2013). The RICS has determined in NRM 1 that a series of six formal cost planning stages are mapped to the RIBA work stages. NRM 1 also outlines the structure and scope of what is included in the estimate at each stage of the cost planning process (RICS, 2012a).

The RICS followed the publication of NRM 1 with NRM 2 (RICS, 2012b) and NRM 3 (RICS, 2014). These publications form the NRM suite of documents, written to provide a standard set of measurement rules that can be applied throughout the full procurement process through to managing the built asset (RICS, 2012a). NRM 2 (RICS, 2012b) was published to replace and update the Standard Method of Measurement 7 (SMM7), which in various editions had been in operation for nearly one hundred years (Ashworth et al., 2013; Seeley, 2012; Kirkam, 2012). NRM 2 provides guidance on the detailed measurement and description of building works for the purposes of obtaining a tender price (RICS, 2012b).

The cost management process traditionally focused on the CAPex of the construction project. As outlined in the next section, there has been a growing awareness and movement to provide more value enhancing services for construction clients in the industry (Cartlidge, 2011; Kirkham, 2005; Smith, 2014). Kirkham (2012) and Kishk et al. (2003) maintain that the QS's role on construction projects now covers a range of activities which include financial appraisal, value management, risk management and WLCC.

Although reports such as Latham (1994) and Egan (1997) identified LCC as way to increase value for construction clients, it has not become standard practice by QSs providing cost services (Clift, 2003; Opoku, 2013; Schaude, 2011). The following section discusses a number of documents that have been published in the last ten years to provide guidance to QSs producing LCC estimates. As will be outlined in more detail in Section 2.4.3, NRM 3 (RICS, 2014) provides rules and guidelines for the quantification and measurement of building maintenance and renewal works for LCC (RICS, 2014).

2.4 Developments in LCC

2.4.1 History

Historically, QSs focused on minimising initial construction costs. Kishk et al. (2003) state that in the 1930s it became obvious that it was unsatisfactory to base the choice between different design alternatives on initial expenditure alone, because building users began to realise that running costs significantly impacted the occupiers' operating budget. This was evidenced post World War II in a move from 'cost' to 'value' on construction projects. Work practices and issues that are associated with 'value' rather than 'minimum cost' gained greater prominence, such as, value management; quality assurance; sustainability; risk management and costs in use (Ashworth et al., 2013; Kishk et al., 2003). These practices added credence to a more holistic approach, but there was no prevalent established methodology for the evaluation of value.

The use of LCC was first established in the mid-1960s, when it was used to advise the United States (US) Department of Defence on investment options for military equipment (Gluch & Baumann, 2004). The Institution of Civil Engineers (ICE) in UK, emphasised the need for 'real' cost analysis on construction projects (ICE 1969, cited in Seeley, 1996). Kirkham notes (2012, p. 97) to an extent this was engrained in the early 1970's "terotechnology" initiative carried out by the then Department of Industry, to encompass the life cycle requirements of physical assets. One of LCC's first applications in construction came in the 1970s in US, where LCC was developed as a service for assessing and comparing alternative energy options. However, it was not yet used in the context of a whole building analysis (Cole & Sterner, 2000; Fuller & Peterson, 1996).

Interest and research into LCC in construction, gained momentum in UK in the 1970s and 1980s with the publication of a number of studies and reports from the BSI (1974) and the RICS (1986, 1987) (Kishk et al., 2003). Kirkham (2012) explains that momentum continued (discussing the merits of LCC applied to construction) with a raft of publications in the 1990s, evidenced from authors including Ferry & Flanagan (1991), Kirk & Dell’Isolla (1995), Ashworth (1996) and Clift & Bourke (1999). These publications were crystallised by defining LCC in BS 3843 (1992) (Kirkham, 2012). Kirkham (2012, p. 97) maintains that BS 3843 did not “*act as the catalyst that many observers expected*” and despite numerous academic papers and text books on the topic in the late 1990s and early 2000s, there was ample evidence that LCC did not progress from research into practice in that period. This was largely due to a number of barriers including; the lack of accurate historical LCC databases; the perceived complexity and time intensive nature of the calculations; a lack of standardisation and guidance documentation and that construction clients are not requesting it (Ashworth, 1996; Opoku, 2013; Cole & Sterner, 2000; Hunter et al., 2005).

Commenting on the deficiencies in the construction industry at the time, the Latham report (1994) and the Egan report (1997) recommended LCC as a way in which the industry could deliver improved value for money (Chiurugwi et al., 2010; Opoku, 2013). In an effort to increase the use of LCC and overcome the barriers there have been a number of significant publications in the last decade developing and promoting methodologies and standardisation.

2.4.2 Developments in Standardisation

The National Institute of Standards and Technology (NIST) in US published ‘Handbook 135’ by Fuller & Petersen (1996), thirteen years before ISO 15686-5. The handbook contains practical examples of LCC calculations but has now become outdated and is more related to energy management rather than LCC for construction.

To improve the level of implementation of LCC in Europe, the Tripartite Working Group under the European Commission, set up four task groups to set out guidelines for sustainable construction in Europe in 2001. These recommendations proposed that a Task Group No.4 (TG 4) be established to prepare a paper on how LCC could be integrated into European policy making (TG4, 2003). TG 4 (2003) indicated the

lack of specific guidance and legislation in Europe and proposed that the service should be taken into account in member states. TG 4 (2003) recommended the development of ‘a common LCC methodology at a European level’, incorporating the overall sustainability performance of building and construction.

2.4.3 Standards in LCC

In 2006, the European Commission appointed Davis Langdon to undertake the task of developing a common methodology for LCC at a European level, which was recommended in Task Group 4 (Davis Langdon, 2007). The project commenced in January 2006 and work was concluded in March 2007, with the presentation to the European Commission of ‘*A common European methodology for Life Cycle Costing; as a contribution to sustainable construction*’ (Davis Langdon, 2007).

Davis Langdon’s report (2007) was a direct commission from the recommendations in the TG 4 report to develop a common European methodology. However, it failed to live up to its title as a ‘*European methodology for LCC*’ because it does not articulate a standard LCC structure or adequately present the tools to carry out LCC. The document seems to acknowledge this, as it recommends “*the soon to be published*”, BS-ISO 15686-5 (2008) methodology rather than encourage its own application. However, it does constitute a comprehensive commentary on LCC, comments on the level of LCC implementation in EU member states and calls for greater implementation by integrating LCC into public procurement practices (Davis Langdon, 2007).

In 2008, the ISO published ‘*ISO EN 15686 Part 5*’ (2008) which was briefly discussed in Section 2.2. ISO 15686-5 was, in turn, adopted almost immediately by the British Standards Institute (BSI) for ‘*BS-ISO 15686-5*’ (2008). BS-ISO 15686-5 forms part of the ISO’s wider standards giving guidance on various aspects of planning the service life of buildings and constructed assets. Part 5 “*provides guidelines, definitions, principles and informative text on the application of LCC techniques in the context of service-life planning*” (BSI/BCIS, 2008, p. 15). As discussed in Section 2.2, Figure 2.1 represents the cost breakdown structure applicable to the ISO document. This figure indicates that WLCCs are broken up into four classification categories; 1. non construction costs; 2. life cycle costs; 3.

income and 4. externalities. LCCs are, in turn, broken up into a number of sub-categories; construction; maintenance; operation; occupancy; and end of life costs.

Although the BS-ISO standard was published subsequent to the TG 4 report (2003) and Davis Langdon's (2007) European methodology, there is nothing in the ISO and BSI/BCIS documents to suggest they are a direct result of TG 4's findings, other than TG 4's unreferenced inclusion in the BS-ISO's bibliography. Furthermore, the BS-ISO is a valuable source of LCC information and provides a standard WBS, but it does not provide adequate clarity on how to carryout LCC calculations and how to present them in an LCC estimate.

2.4.4 LCC in Public Procurement

The Irish Government introduced the Capital Works Management Framework (CWMF) in August 2009 to achieve greater cost certainty and better value for money on publicly funded projects (Kehily, 2011; Kehily & Hore, 2012). These regulations became mandatory in May 2010 for all public works contracts whether procured traditionally or using design and build. The CWMF consists of a suite of best practice guidance, standard contracts and generic template documents that form four pillars that support the framework (Dept. of Finance, 2009). Pillars three and four are applicable to construction cost management. Pillar three consists of cost control, planning forms and suitability assessment forms for construction works. Pillar four provides guidance notes aimed at facilitating the implementation of the measures and forms in the previous three pillars (Dept. of Finance, 2009). Guidance notes on 'The Planning and Control of Capital Costs – GN 2.2' (Dept. of Finance, 2009, p. 54) published in support of pillar three states that "*whole life costs are an important consideration throughout the design process, and should be integrated at each stage in cost plan development*". However, there is little additional information or clarity on what is expected in terms of format and presentation and thus it is likely there is no uniformity in what is produced to conform to these guidance notes.

Similar positions to that of the Irish Government have been taken in Finland, Sweden, Luxemburg, Netherlands, Germany and UK on publically funded projects (Davis Langdon, 2007; Hunter et al., 2005). The OGC in UK has developed an established suite of guidance notes and tools encompassing project management and sustainability through the '*Achieving Excellence in Construction Procurement*

Guides' (Kirkham, 2012). 'A *guide for 'Whole-life costing and cost management'* is a guide for WLCC which forms part of the OGC suite. This guide outlines the principles of WLCC and describes a process made up of a framework for cost management and WLCC (OGC, 2007).

The OGC and the CWMF documents are guides rather than methodologies; they do not deliver adequate clarity on the scope of LCC or provide sufficient information to carry out a WLCC estimate (Hourigan, 2012), other than a fairly limited summary page in respect to the CWMF (Kehily, 2011). Kehily & Hore (2012) state that in order to carry out a detailed LCC or provide backup to the CWMF LCC summary page a QS carrying out LCC would have to consult one of the relevant international standards discussed in Section 2.4.3. In fact, the OGC (2007) refers the reader to BS-ISO 15686-5 (2008) when preparing LCC. As outlined previously, methodologies such as BS-ISO 15686-5 are very informative publications, but they are theoretical, with little in the way of practical examples, templates, and process implementations to guide a cost professional through the process of calculating and presenting LCC (Kehily & Hore, 2012). In the recent past there have been a number of guidance documents published that outline LCC in greater detail, provide examples, and present a format for carrying it out.

2.4.5 Guidance Notes and Rules of Measurement

Since the mid-2000s there has been a proliferation of LCC guidelines and standard methodologies outlining LCC deliverables for different industries and different jurisdictions. Notable examples include the Building Services Research and Information Association's (BSRIA) '*guide for Whole-Life Costing Analysis*' (Churcher, 2008); '*Life Cycle Costing for Sustainable Design*' (Kelly & Hunter, 2009); the Norwegian '*Users Guide to LCC*' (Gundersen, 1998); New South Wales Treasury's, '*LCC Guideline*' (2004) and Sweden's Environmental Management Council's '*LCC guide*' (SEMC, 2011). Four documents of note are discussed below due to their relevance and prevalence in UK and Irish construction industries.

BSI/BCIS Supplement to ISO 15686-5 (2008)

In 2008, the BSI and the British Cost Information Service (BCIS) in UK jointly published a document which put forward a standardised method for producing LCC (BSI/BCIS, 2008) applicable to the UK construction industry. The document

addresses some of the failings discussed previously, where the BS-ISO 15686-5 (2008) does not provide adequate clarity or guidance for QSs producing LCC estimates other than a standard WBS. The BSI/BCIS 15686-5 (2008) provides a cost data structure and a method of measurement for LCC, which aligns with BS-ISO 15686-5 (2008) and the UKs BCIS cost structure conventions. It delivers further detail in LCC calculations; provides templates to carry out LCC estimates; adds additional classifications to the BS-ISO 15686-5 WBS and furnishes clarity on what type of costs are attributed to each ISO category. Particular emphasis is put on practical application, where the document provides worked examples of LCC calculations and standard spreadsheets for the presentation of LCC during preconstruction and construction stages. One thing it does not do (which would be of benefit carrying out the calculations) is provide the formulae in the proposed templates for automating the LCC calculations. For example, the document provides a relevant WBS and examples of LCC estimates, but does not indicate in these examples how formulae could be constructed to automatically populate the LCC estimates. This is a prevalent issue in LCC and will be discussed in Section 2.6.

SCSI: Guidance Notes on Life Cycle Costing (2010)

In 2010, the Society of Chartered Surveyors Ireland (SCSI), the Irish wing of the RICS, recognising the need to educate their members, formed a '*Working Group on LCC*'. The working group published a '*Guide to LCC*' (Kehily, 2011) which provided practical guidance and assistance for the Society's members and QSs in Ireland carrying out LCC and producing LCC estimates in line with Ireland's CWMF (Kehily & Hore, 2012). The document is different from other guidance notes, as it provides detailed worked examples using financial tables to carry out the calculations and also provides guidance on how LCC calculations can be written as formulae into Microsoft (MS) Excel cells. The group supplements the guide with a LCC MS Excel template (including inherent LCC formulae) and a complete worked example of a WLCC estimate (Kehily, 2011). This is the only guidance document discussed in this section that provides a fully worked example of a WLCC estimate and offers functions in MS Excel to carry out automated calculations. However, it was published for SCSI members in Ireland to aid in producing LCC estimates under the CWMF framework - thus it is not applicable to other jurisdictions and methodologies. This work is included in Chapter 3 because it forms the basis of initial work in the development of the 5D LCC BIM solution.

BS 8544:2013 Supplement to ISO 15686-5 (2013)

BS 8544:2013 is the second supplementary guide to BS-ISO 15686-5. While the first supplement is for LCC analysis during design and construction, this document is a ‘Guide for life cycle costing of maintenance during the in use phases of buildings’ (BSI, 2013a). The guidance document aligns with the RICS’s NRM schema but because its remit is on cost management during the ‘in-use’ phase; its focus is on facilities management and not construction procurement (BSI, 2013a). However, it is an important document from a QS perspective because it provides a framework to collect data during the operation of the building which could then be used for estimating LCC on similar projects in the earlier stages of the procurement process.

New Rules of Measurement 3 (NRM 3) (2014)

In March 2014, the RICS introduced New Rules of Measurement 3 (NRM 3) (RICS, 2014). As discussed previously in Section 2.3, NRM are a suite of documents that has been developed to provide standard measurement rules for all construction projects in UK. While NRM 1 and NRM 2 deal with cost management for CAPex, NRM 3 (RICS, 2014) provides consistent rules and guidelines for the quantification and measurement of building maintenance and renewal works. NRM 3 is more than a guidance document, in that it provides a detailed set of rules and best practice procedures for different stages of the procurement process aligned to both BS-ISO 15686-5 (2008) and BSI/BCIS (2008) ISO supplement. NRM 3 follows the same methodology as NRM 1 and 2, where it constitutes the summary page, content of LCC estimates, and presents tabulated measurement rules to follow for maintenance and renewal works aligned to the RIBA plan of work. There is significantly more detail in NRM 3 than there are in the SCSi and BSI/BCIS documents or any of the standards discussed above. This could be seen as one of its disadvantages, as it has 250 pages and provides lengthy detail on ‘asset specific cost management’ during the occupancy stage, which Qs generally do not provide cost advice on. One of the main differences with the methodologies discussed above is that NRM 3 focuses on maintenance and renewal works, ignoring ISO 15686-5 WLCC categories such as operations and occupancy costs. By focussing on maintenance and renewal works, NRM 3 does not entirely encompass LCC or even WLCC, because it does not cover the entire ISO 15686-5 WBS illustrated in Figure 2.1. Thus, the WBS structure and classifications in NRM 3 for maintenance and renewal works does not fully align

with the BSI/BCIS ISO 15686-5 supplement, which is also an RICS (BCIS) publication, so there is reason to question the continuity in both documents and ultimately NRM 3's alignment with the BS-ISO 15686-5.

NRM 3 pays particular attention to post practical completion facilities cost management which aligns to BS8544: 2013 and presents templates that aid in the production of 'asset specific cost plans' (i.e. cost management during the use of the building). The RICS envisages that NRM 3 will become a document used throughout RICS affiliated jurisdictions promoting a standard approach worldwide (RICS, 2014). NRM 3 was published in 2014 after a lengthy consultation process; therefore it is yet to be established how successful it will be in promoting standardisation and whether it will be embraced by the QS profession. A telling sign in this regard is that the RICS are planning to publish a new '*Guidance Note in Life Cycle Costing*' (currently in the consultation process) (RICS, 2015). The new guidance note contains less detail and content than NRM 3. It is unclear what the relationship between these two documents is and whether the new guidance note replaces the NRM 3 - as both are designated as guidance notes by the RICS. This sends a confusing message, as the RICS feels there is a need to simplify and explain the basics of LCC, very soon after publishing complicated lengthy new rules of measurement.

Summary - Guidance Notes and Rules of Measurement

There is little evidence in the review of literature to indicate the extent of use of the standards or guidance documentation on LCC presented in this section. However, a trail of development can be seen through the references from one publication to the next, which suggests these documents have built on the previous ones and provide increasing clarity culminating with NRM 3. These guidance documents are not mandatory regulations or specifications but documents that provide users with recommendations and approaches for accepted good practice (RICS, 2015). However this is likely to change with a number of legislative proposals initiated by the European Union (EU).

2.4.6 EU Directives

Until now LCC has been scarcely used in Public Procurement due to the difficulties in carrying out LCC (Ashworth et al., 2013; Kirkham, 2012). US, Japan, Switzerland

and Norway apply LCC consistently as part of their procurement policy. Sweden, UK, Denmark, Germany, Netherlands, France and Austria report some form of LCC analysis. Some other countries such as Canada, Argentina, Spain, Italy, and Portugal report that they have experimented with LCC (Davis Langdon, 2007; Dragos & Neamtu, 2013). Davis Langdon (2007) and Dragos & Neamtu (2013) comment that in Europe Norway is the only European Union (EU) member state that has mandated LCC in public procurement. Other member states such as Sweden, Germany, France, UK and Netherlands have some level of implementation but do not have any legislation requiring LCC to be carried out as part of their public procurement processes (Davis Langdon, 2007).

The standards and guidance notes expound the benefits of LCC and in many instances provide a standard structure that was not there before their publication. However, they do not mandate the use of LCC on construction procurement in UK or Ireland. This leads to LCC being carried out on a voluntary basis by Qs and contractors using methodologies of their choice and their own in-house LCC tools (Dragos & Neamtu, 2013). The OGC and CWMF, which are government publications, do not legislate for LCC in the procurement process but are rather recommendations to carry out LCC on public works. This recommendation seems to be largely ignored, evidenced in the low application of the service in both UK and Ireland due to a number of barriers to implementation. (Chiurugwi et al., 2010; Hourigan, 2012; Olubodun et al., 2010; Opoku, 2013).

Though many procuring entities in the EU are using LCC as a decision making tool, its use is still far from systematic and the calculation methodologies are often adapted to the circumstances of the bid and left up to the contractor to present in a format and methodology of their choice (Pelzeter, 2007; Dragos & Neamtu, 2013).

On 26th February 2014, the EU introduced a new Directive on public procurement 2014/24/EU (EU, 2014). Dragos and Neamtu (2013, p. 19) state that the objectives of the new Directive are to “*improve the efficiency of procedures*” and to allow for the “*greater strategic use of public procurement to further environmental, social and industrial / innovation policies*”. The scope of LCC in EU member states has been expanded in the new Directive. Under the previous EU procurement rules (2004/18/EC) a contract could be awarded on either of two criteria; the lowest price tender or based on the Most Economically Advantageous Tender (MEAT) (EU,

2004). Dragos & Neamtu (2013) outline that under the previous Directive when MEAT was selected tenders could be evaluated on the basis of LCC and not solely on the basis of lowest purchase price.

Under Article 67 of the new 2014/24/EU Directive, LCC will not only be applied to the MEAT award criteria, but will also form part of the lowest price tender award criteria (EU, 2014). This new EU Directive makes LCC a key requirement in public procurement, mandating its use on public works contracts (Dragos & Neamtu, 2013). The distinction now between MEAT and lowest price is blurred but Dragos & Neamtu (2013) explain that the difference will be that LCCs considered in lowest price will be based on a monetary evaluation only, while MEAT may include non-monetised externalities that do not necessarily have an effect on cost such as social considerations and environmental performance.

The Directive mandates that EU member states must have in place a national methodology of LCC for repeated or continuous application. This directive is yet to be transposed into UK and Irish legislation. In Ireland, the Environmental Protection Agency (EPA), in response to this Directive, has stated its intent to explore “*the feasibility of developing a national methodology on life cycle costing for construction projects*” (EPA, 2014, p. 32). As noted in section 2.4.5, a methodology in this regard is provided by the SCSi in Ireland, but it is yet to be determined whether the Irish Government will implement this as the required methodology or instead develop a new national standard.

Another issue with engraining LCC in the Irish procurement process is that Ireland’s predominant procurement route is ‘traditional’, which means that the design must be complete prior to the tendering process (Hourigan, 2012). In traditional procurement and tendering the full design is already established prior to the contractor pricing the job and thus they have no real effect on the performance of the building in use because they have no input into the design. Thus a MEAT evaluation based on LCC would not yield any merit because all the contractors are pricing the same design and thus the building’s LCC should be the same no matter what contractor constructs it.

Another EU Directive which has promoted the use of LCC is the Energy Performance Building Directive (EPBD) (2010/31/EU) (EU, 2010). This Directive was a recast of the original EPBD transposed into Irish Law from 2006. The recast

Directive was subsequently transposed into Irish regulations by the Statutory Instrument (S.I), 243, in 2012 (Government-Publications, 2012). The EPBD and S.I. 243 obliges that energy performance information such as an energy performance Building Energy Rating (BER) is provided to building purchasers, tenants and users for consideration in property transactions (SEAI, 2015). A BER certificate is an indication based on an alpha-numeric scale of the energy performance of a building (SEAI, 2015). Article 11 of Directive 2010/31/EU states the building owner must receive “*information regarding the cost-effectiveness of the recommendations made in the building energy rating certificate. The evaluation of cost effectiveness shall be based on a set of standard conditions, such as the assessment of energy savings and underlying energy prices and a preliminary cost forecast*” (EU, 2010). This necessitates a monetary evaluation of the energy efficiency measures proposed by the BER assessor and is described in an advisory report submitted with the BER (SEAI, 2015). As will be outlined in the next section, LCC is the method used when evaluating building components and is especially applicable to sustainability and energy saving measures. LCC can do this by calculating the time it takes to payback an investment in an energy efficient technology (Gluch & Baumann, 2004; Kelly & Hunter, 2009). Although the Directive or related Irish legislation does not use the term LCC, it is evident that if a “*preliminary cost forecast is required*” an LCC of the energy efficiency measures will be necessary.

2.4.7 Summary

The importance of recognising the future costs of operating buildings over their lifetime has been discussed by academics and practitioners for many years. This has gained momentum during the last 15-20 years and there is now a raft of standards and guidance notes in LCC. Ireland and UK have published guidance documentation on LCC for providers of cost and value management services. The EU has recently enacted a number of directives which will further engrain LCC in public procurement, thus necessitating providers of cost management services to overcome their issues in providing this service. Despite the benefits of LCC there are a number of barriers that impede QSs providing LCC services on construction projects. These benefits and barriers are addressed in the next sections.

2.5 Benefits of LCC

Opoku (2013), BSI/BCIS (2008), Ashworth (1996) and Cole & Sterner (2000) state that LCC can provide value for money for clients, particularly on public projects. The OGC (2007) also attributes LCC to assessing value for money and emphasises that it is the relationship between LCC and benefits for the client that constitutes value for money. Clift (2003) and Kirkham (2012) maintain that the earlier an LCC exercise can be introduced during the procurement process the greater the possibility of achieving cost reductions and reducing the negative impact of a particular product or service on the environment. The central benefit of LCC is that it enables a whole cost approach to the acquisition of a capital asset, giving the client a total cost view of the project rather than only considering the initial CAPex. LCC facilitates more effective and economically sound decision making enabling the client to view current and future cost demands and use this to assist in their financial management (Clift, 2003; Cole & Sterner, 2000; Olubodun et al., 2010). The central benefit outlined here can be analysed into a number of themes based on the function of its application.

2.5.1 Evaluating Design

Ashworth (1996), Churcher (2008) and Kirkham (2005) agree that one of the main purposes of LCC is to compare several design options from a number of competing proposals. Kirkham (2005) advises that LCC should be used to inform decisions during design and to reassure clients that the overall performance of the building, for the entire life cycle, is taken into consideration through alternative design solutions. These purposes are in line with the BSI/BCIS (2008) standard methodology, which describes the process as a comparative tool for assessing alternative building components and options. Schaudé (2011) and Ashworth (1996) claim that LCC could demonstrate the cost savings over the life of an asset, from a more efficient but costly initial investment. The BS-ISO (2008, p. 18) concurs, stating that “*LCC analysis may be used to demonstrate whether or not higher acquisition costs are justified by lower in-use costs and/or enhanced performance*”. An example of LCC being used in the evaluation of building components is effectively demonstrated in Wong et al. (2010) where the economic feasibility of office buildings with conventional and Transparent Insulation systems (TI-Facades) were evaluated. The results of the analysis showed that LCC could be used to evaluate the feasibility of low carbon technologies.

WLCC can be used as a mechanism that can reveal construction costs within the context of its total life costs, where total cost of ownership of a building can be significantly more than its initial CAPex (Flanagan & Jewel, 2005; Cole & Sterner, 2000). However, Fuller & Petersen (1996) and Kishk et al. (2003) state this calculation does not, by itself, provide added value to the client because it is inappropriate to predict and decipher a standalone lump sum WLCC without comparing it to another alternative. They state that LCC is beneficial when it is used to compare how one built asset monetarily performs against a competing alternative design. The competing designs could be a traditional design to a more sustainable option, or refurbishment versus new construction (Gluch & Baumann, 2004).

2.5.2 Life Cycle Costing as a Measure of Sustainability

Kelly & Hunter (2009) and Gluch & Baumann (2004) ascertain that sustainable construction presumes a whole systems approach, which considers the environmental, social and economic consequences of any decision made within the construction industry. An applicable word in this definition is ‘whole’ as it accentuates the consideration of more than just the initial action. The SCI-Network (2011) maintains that clients implementing sustainable practices into their buildings should require the total cost of their investment in the building rather than just the initial CAPex. It is becoming increasingly important that clients use an investment appraisal technique that uses a whole life approach, to examine how better environmentally performing buildings could be built for a cost that can be evaluated and justified in commercial terms (Aye, Bamford, Charters, & Robinson, 2000; Kelly & Hunter, 2009; Cole & Sterner, 2000). Therefore, without a whole life consideration sustainability could not be measured. The BSI/BCIS (2008) substantiate this view by defining WLCC as a methodology for assessing the economic effects of sustainability which allows for more comprehensive decision making based on sustainable evaluation rather than initial costs alone.

Gluch & Baumann (2004) and Churcher (2008) suggest that a LCC cannot fully represent a measure of sustainability as environmental considerations cannot only be expressed in monetary terms. Gluch & Baumann (2004) and Aye et al. (2000) propose that LCC be used in tandem with Life Cycle Analysis (LCA), which is a better determinant of environmental performance as it focuses on embodied carbon rather than an exclusive monetary analysis. LCC complements LCA because many

of the calculation metrics such as maintenance and replacement profiles, for the calculation of LCC, are also necessary in LCA (Davis Langdon, 2007).

Design decisions related to the building's energy efficiency such as orientation, thermal efficiency and airtightness can influence the buildings costs in use and LCC can be used to evaluate whether additional sustainable attributes and energy efficiency measures are cost effective over a given study period (Cole & Sterner, 2000; Gluch & Baumann, 2004). Fuller & Petersen (1996) explain how LCC can be used to assess the increased value of energy conservation on projects, hence adding to the sustainability of the asset. Ashworth et al. (2013) note that this is evaluated by payback analysis carried out through LCC calculations (outlined in Section 2.9) and allows for different energy solutions to be selected based on their LCC.

The application of LCC in sustainable construction is evident in green building rating methodologies such as Building Research Establishment Environmental Assessment Methodology (BREEAM) and Leadership Energy Efficient Design (LEED). These systems provide a scaled rating based on a building's sustainability in UK and US respectively. Both LEED and BREEAM provide rating points for the application of LCC (RICS, 2015).

2.5.3 LCC and Facilities Management

LCC can also be used to determine the maintenance and replacement cost of a component or system over a study period. This information can inform design decisions on Facilities Management (FM) issues such as cleaning, maintenance, energy efficiency, durability and disposal (BS-ISO, 2008). Cost consultants can build sophisticated maintenance plans and profiles, ideally consulting with facilities managers, to devise a life cycle strategy and carry out maintenance and replacement works in accordance with the expenditure set out in the strategy (BS-ISO, 2008; Kehily, 2011). This essentially provides a budget and template for cost control during the life of the building (Churcher, 2008; Kirkham, 2005; El-Haram et al., 2002). This framework, as Kirkham (2005) suggests, can also be used to collate actual operational data during the operational phase, providing a mechanism of recording LCC as well. He recommends that information obtained from the building 'in use' should be utilised for future operational decision making. However, as will be discussed in Section 2.6.2 the applicability of recorded data for use on another

construction project and in another context is refuted by a number of eminent authors in the field (Ferry & Flanagan, 1991; Ashworth, 1996; Clift & Bourke, 1999).

BS 8544:2013 provides guidance for carrying out LCC during FM and in doing so provides a framework to collect real cost data during use (BSI, 2013a). If LCC is used to inform FM and likewise FM to inform meaningful assumptions and costs in LCC, there must be collaboration between the two disciplines early in the procurement process (McAuley et al. 2013; Eastman et al., 2011). Eastman et al. (2011) note with early stakeholder involvement a building which is end use orientated can be achieved.

2.5.4 Procurement & Tendering

Hourigan (2012) states that the majority of construction work in Ireland is procured through the traditional procurement and tender process. The traditional tender process does not lend itself to a meaningful evaluation of LCC as the design is already completed prior to the tenderer receiving the tender documents (Kehily, 2011). As stated previously in Section 2.4.6, the contractor in traditional procurement has no real influence outside the quality of construction, over the cost of the building in use, and thus a LCC by the contractor would be of no real benefit (Flanagan & Jewel, 2005). However, in design and build procurement the contractor does have an input into the design process and thus has a significant influence on how the building will perform during the occupancy stage (Chiurugwi et al., 2010; Opoku, 2013). As discussed in Section 2.4.6, under the CWMF in Ireland, tenders can be evaluated as the ‘Most Economic Advantageous Tender’ (MEAT) rather than just lowest cost. The CWMF (Dept. of Finance, 2009) state that MEAT is a tender arrangement which meets the current economic needs of the Government and also their economic needs of the future by evaluating a tender that takes into account more than just the lowest price. Kirkham (2012, p. 100) points out that MEAT is not the lowest construction cost “*but the best balance of quality and whole life cost to meet the clients brief*”. LCC is a criteria which is included in the MEAT award, thus it encourages contractors to develop, and clients to evaluate, a tender which will reduce the future maintenance and operational costs of an asset (Kirkham, 2012; Dragos & Neamtu, 2013). As previously outlined in Section 2.4.6, MEAT will become more engrained in the tender process in EU member states, due to a recent

EU directive, which will necessitate its use. This will increase the use of LCC on publically procured projects where contractors have an influence on the design.

In UK, the Government introduced the Private Finance Initiative (PFI) in 1992 as a means of privately financing public projects (Boussabaine, 2007; Swaffield & McDonald, 2008). PFIs are based on a long term contract where the company employed provides public services after construction of a project has been completed (Davis Langdon, 2007; Swaffield & McDonald, 2008). The long term nature of these investments means that there is increased client interest in operational and maintenance costs, as they have to pay the contractor staged payments over an agreed period, typically twenty-five to thirty years (Ashworth et al., 2013; Swaffield & McDonald, 2008). The contractor bidding on a PFI project must submit a tender that includes both construction costs and LCC. Kehily (2011) states without a way of accurately profiling future maintenance and replacement costs over the evaluation period, the PFI tenderer could mistakenly over-bid the tender, even if they submitted a very competitive construction cost. Conversely they could underestimate their LCC leaving them under resourced and exposed to risk during the operational phase.

LCC is viewed as the most effective method of analysing long term costs on PFI projects (Davis Langdon, 2007; OGC, 2007; Swaffield & McDonald, 2008). This is evidenced in the increased use of LCC on PFIs compared to non-PFI projects (Meng & Harshaw, 2013; Opoku, 2013). Swaffield & McDonald (2008) maintain that these projects are more likely to apply LCC effectively. However, their research found that in certain circumstances such as during exceptionally busy times or when working with tight construction budgets LCC was not considered and decisions were based on initial costs alone. This is echoed in Meng & Harshaw (2013) who conclude that the introduction of PFI increases the use of LCC on those projects, but does not help overcome the traditional barriers to LCC.

2.6 Barriers to adoption

Kirkkam (2005), Cole & Sterner (2000) and Fu et al. (2007) found that although the significance of LCC has been recognised on construction projects in UK, as early as the 1980s, together with substantial amounts of research into the field, the application has not been implemented into standard practice. Schaudé (2011), Opoku (2013), Olubodun et al. (2010) and Oduyemi, et al. (2014) found that although its

usage has increased in recent years, LCC still has some significant barriers to overcome to full implementation.

Chiurugwi et al. (2010) outline ten barriers to LCC, Oduyemi et al. (2014) outline thirteen barriers, Olubodun et al. (2010) note five barriers and Opoku (2013) presents six barriers. The reason there is a significant divergence in the amount of barriers in these publications, is that barriers are grouped together in some publications under one definition. For example, in Oduyemi et al. (2014) the ‘type of investor’, ‘lack of fiscal encouragement’, ‘the industry’s relative lack of interest’ and ‘LCC not requested by the client’, are encompassed within a common definition by Opoku (2013), i.e. that ‘there is a general lack of motivation/interest on the part of the client’. For this reason, the barriers are presented in the following sections by categorising them into barriers that relate to common themes; 1. lack of understanding by clients and professionals; 2. lack and reliability of data on operation and maintenance costs; 3. perceived complexity of the process and calculations; and 4. lack of LCC standardisation (methodology) across the construction industry. These are addressed separately in the following sections.

2.6.1 Client Requirements

Opoku et al. (2013) and Oduyemi et al. (2014) determine in their surveys that the most significant barrier in UK, is that LCC ‘is not requested by the client’. Chiurugwi et al. (2010) find that clients are unwilling to pay for an additional service, especially if they are not familiar and not convinced of its value. Oduyemi et al. (2014) and Olubodun et al. (2010) note that many clients have a limited understanding of the process and are not informed about the benefits. This is reflected in the lack of ‘contractual incentives’ or ‘fiscal encouragement’ for QSs carrying out LCC, as there is no additional fee for doing so (Chiurugwi et al., 2010; Opoku, 2013; Pelzeter, 2007).

There is also a separation between capital and running budgets on most construction projects (Oduyemi et al., 2014). Chiurugwi et al. (2010) explain that this is particularly an issue with public authorities who may be restricted in their ability to transfer funds between capital and revenue budgets. They state that one authority will often accept the lowest cost and transfer it to another department to maintain. This does not encourage the use of LCC, as the operational phase is not included in

the initial project objectives. The SCI-Network (2011) categorise this issue as a 'political barrier' and comment, that due to the limited life of public agencies and legislative programmes there is a short term emphasis on costs associated with the term of the public administration. Thus, they are less likely to accept longer term benefits at the expense of increased CAPex. Previously discussed in Section 2.4.6, with the introduction of EU Directive 2014/24/EU in 2014, public procurement agencies in EU member states will be required to develop a national methodology in LCC and utilise it in evaluating and awarding tenders on construction projects (Dragos & Neamtu, 2013). This will undoubtedly increase the prevalence of LCC on public works projects, when enacted, possibility filtering into other private non-governmental sectors.

2.6.2 Obtaining Relevant LCC Data (Using Historical Data)

Obtaining reliable, appropriate and relevant cost information to use in LCC studies is often ranked by respondents as a primary barrier to LCC (Chiurugwi et al., 2010; Cole & Sterner, 2000; Opoku, 2013). The validity of historical information has also been raised by a number of eminent authors in the field. Cole & Sterner (2000) and Ashworth (1996) found that historical LCC data may be inaccurate when used in the context of a new project. Flanagan & Jewel (2005), Kelly & Hunter (2009) and Ashworth (1996) comment that the reason historical data is inaccurate is that it is often incomplete, outdated and misunderstood, making it unreliable for third parties to analyse and apply to a new situation.

Ashworth (1996) explains that there are many dimensions and aspects in LCC data which often make it unreliable and not applicable to another asset. He notes these issues as; different maintenance policies; unplanned maintenance or failures; the use of alternative replacements; hidden costs; timing distortions and the effects of delayed work. In this context, how long a building component lasts and when it becomes obsolete is based on how the component is used or what type of traffic/wear and tear it is subjected. For example, a linoleum floor finish in the corridor of a school will need to be replaced earlier than that in a domestic kitchen, due to the extent of traffic on it. Thus, using 'expected life expectancies', without interrogation with respect to its use, would be misleading.

Ferry & Flanagan (1991) suggest that historical databases are not essential to the implementation of LCC because as technology advances, new technologies will render the material obsolete and associated costs redundant when applied to a future cost. Ashworth (1996) maintains, that similar difficulties are also encountered in evaluating the life expectancies of building components. He comments that there is difficulty in applying theoretical life expectancies to a material that may be more durable as technology advances in the future. In fact, he states, an entirely different material or technology may be used when the material is replaced.

Kirkham (2005) comments that a particular difficulty with access to LCC data is that there is a lack of any framework or mechanism for collecting LCC information in use. There have been a number of initiatives in the recent past to address this issue by proposing a means to collate LCC data (Bouachera, Kishk, & Power, 2007; El-Haram, Marenjak, & Horner, 2002; Kirkham, Alisa, Pimenta de Silva, Grindley, & Brondsted, 2004). Opoku (2013) states that efforts have been made to address this issue, but the extent of data collection, inconsistencies across data and the various levels of detail required, make collating historical data a problem. They note that few organisations collect data and thus few have reliable information. Given these difficulties in collating and utilising LCC data, there is merit to question the application of LCC as a mechanism for evaluating future expenditure. However, LCC should not be utilised as an absolute reflection of future expenditure but rather a means to make informed decisions, which in turn articulates potential risk (exposure to future costs) in the operational phase. Kelly & Hunter (2009) and Ashworth (1996) argues that due to these issues it is preferable to estimate the cost from first principles and to use historical cost information as a check.

2.6.3 Lack of a Standard Method of LCC

One of the main reasons that LCC has not gained more widespread acceptance is a lack of standardisation in carrying out and presenting LCC (Chiurugwi et al., 2010; Cole & Sterner, 2000; Olubodun et al., 2010; Opoku, 2013). However, over the last ten years there have been a number of publications addressing various barriers to adoption and presenting a standard method of measurement for LCC (similar to those that exist for construction related costs such as NRM 2 in UK and ARM in Ireland). Previously discussed in Section 2.4, these standards include; ‘*BS-ISO EN 15868-5*’ (2008) in conjunction with its supplement from the BSI/BCIS (2008);

United States' '*NIST Handbook 135*' (Fuller & Peterson, 1996) and the European Commission's '*Common methodology for LCC*' (Davis Langdon, 2007). These methodologies for LCC have been prepared and presented by various organisations, although no single standard has been accepted internationally or even at a European level (Dragos & Neamtu, 2013; Hourigan, 2012). As discussed in Section 2.4, all these standards and guidance notes have some limitations and none offer a full solution or methodology for QSs carrying out LCC and producing LCC estimates.

Although significant efforts have been made to remove this barrier, 'lack of a common methodology' is still mentioned by QSs as one of the most significant barriers to greater implementation of LCC (Chiurugwi et al., 2010; Olubodun et al., 2010; Opoku, 2013). Unfortunately there is no insight in the surveys that report this barrier, as to why it is still an issue, given the plethora of standards published in the last ten years. Thus, there is further research to be carried out to address this issue. A reasonable conclusion is that QSs realise that no one methodology offers a complete solution and further work is required to provide an adequate methodology. It could also be, as Chiurugwi et al. (2010) maintain, that this is not necessarily a reflection of the standards, but a product of other barriers, such as 'lack of understanding' and 'lack of LCC skills', where in many instances construction professionals do not know relevant standards and guidance notes exist.

2.6.4 LCC and the QS (The calculations – Time Consuming & Longwinded)

Three recent surveys investigating the use of LCC reveal that there is a lack of application by QSs in UK (Chiurugwi et al., 2010; Olubodun et al., 2010; Oduyemi et al., 2014). Chiurugwi et al. (2010) state, that just 32% of respondents had been personally involved in a project where LCC was carried out and only half rated their understanding of LCC as 'good or satisfactory'. Olubodun et al. (2010), in a survey from the same year, found that 51% of respondents applied LCC 'very frequently' or 'quite frequently', while the remainder 'rarely' or 'never' utilised LCC. Oduyemi et al's. (2014) more recent study indicates that 95% of QSs surveyed have carried out LCC. This is a considerable increase from Chiurugwi et al. (2010) and Olubodun et al's. (2010) findings in just four years, but the way the questions were phrased in the survey includes respondents, in the 95%, that carry out LCC infrequently. The same study outlines that only 3% consistently provide it as standard service.

Davis Langdon (2007) found that a few of the larger QS firms in Ireland were using LCC but medium and small QS practices rarely provided it. In 2012, Hourigan (2012) found that 62% of QS firms in Ireland have carried out LCC but 42.5% of these are using expertise from UK.

These statistics do not tell the whole story, because in the majority of cases where LCC was provided it was only applied sporadically and in many cases the QS respondents only carried it out on an isolated number of projects (Chiurugwi et al., 2010; Hourigan, 2012; Oduyemi et al., 2014). Meng & Harshaw (2013), note that there is considerably greater utilisation of LCC on PFI projects (95%) and other procurement strategies where LCC is considered and evaluated in the tender.

The accuracy of these surveys is somewhat questionable given that the majority of them are from conference publications (with the exception of Oludodun et al. 2010) and the rigor and validity in their research is not particularly evident. The sample sizes are also small. All three surveys are less than 70 respondents, as well as the questions being phrased differently from survey to survey. Thus, consistency in the results cannot be relied upon. However, the surveys present a common theme that QSs do not widely practice LCC in their standard practice other than some infrequent or isolated applications.

The barriers to adoption by QSs are in line with the industry wide issues outlined above, but there are further QS centred problems which are evident. The main issue for QSs is that they do not have the ‘understanding or skills to carry out the calculations’ (Chiurugwi et al., 2010; Fu et al., 2007; Olubodun et al., 2010; Pelzeter, 2007). Other related barriers are that QSs ‘do not have sufficient time to carry out LCC’, ‘the calculations are complex and time consuming’, and ‘there is a perceived lack of confidence in the results’ (Fu et al., 2007; Olubodun et al., 2010; Pelzeter, 2007; Opoku, 2013). These issues accentuate a time consuming process which is compounded by the barrier outlined in Section 2.6.1, where ‘QSs are not reimbursed by the client’ for the additional time to carry it out. The main difficulty for QSs is that incorporating a prolonged time frame or study period into the construction cost equation introduces unfamiliar data requirements when valuing the built asset. LCC calculations such as net present value, nominal costs and internal rate of return (explained in Section 2.8) are not traditional computations in cost management (Kehily, 2011; Pelzeter, 2007).

2.7 Representing Life Cycle Costs

This review of literature pays particular attention to LCC calculations. This is necessary because an understanding of and background to the methodology is necessary to address how utilising technology and embedding LCC calculations within cost estimating software can be used to increase the speed and efficiency of carrying out these calculations. Simplifying LCC by automating the calculations should not only address that particular barrier, but also influence other issues where an efficient process could be presented in a standard structure and also promote its use to prospective clients.

2.7.1 LCC as a Formula (*what it encompasses*)

Some publications such as Eurovent (2005, p. 2); Fuller & Petersen (1996, pp. 5-3) and El-Haram et al. (2002, p.146) express the scope of LCC in a formula. These formulas are generally outlined in Equation 1;

$$\text{Life Cycle Cost (LCC)} = \text{Initial Investment} + \text{LCC}_{\text{OMR}} + \text{LCC}_{\text{D}}$$

OMR = Operation Maintenance and Replacement

D = Disposal

Equation 1: LCC expressed as a Formula (Eurovent, 2005)

The ‘initial investment’ includes costs associated with the construction of the asset which also include other construction related costs such as design team fees, planning charges and local county council contributions (BS-ISO, 2008; BSI/BCIS, 2008). Construction costs are priced and paid for immediately at the construction stage and therefore an escalation/discount time based adjustment is not applied. Therefore, these costs can be directly applied from the cost plan or BOQ cost items. LCC_{OMR} ‘Operation, Maintenance and Replacement’ (OMR) costs represent the costs incurred over the study period of the asset (Fuller & Peterson, 1996). ‘Operational’ costs include energy and management costs and ‘Maintenance’ costs include regular maintenance carried out on the building. ‘Replacement’ costs include capital replacements calculated at different intervals over the study period. These costs can be obtained from energy providers, cost databases and manufacturers. LCC_{D} ‘Disposal’ (D) costs represent the cost incurred or sale benefitted from the disposal or sale of an asset when it has reached its end of life (BS-ISO, 2008). Eurovent (2005) states the cost/benefit is usually obtained by calculating the

usefulness of the building at the end of the study period to decide whether it would be demolished or sold on, and an estimate is made on the price of this action.

The formulae presented in Equation 1 is similar to the BS-ISO 15686-5 (2008) WBS, presented in Figure 2.1, which also includes operations, maintenance and replacement costs. However Equation 1 does not account for the ‘occupancy cost’ category in the BS-ISO definition of LCC. It is not evident where costs associated with this category such as telephone; laundry; postal services and ICT costs would be included in Equation 1. The BS-ISO 15686-5 (2008) WBS is a better determinant of LCC and a more recent articulation of its scope. The scope of LCC does not need to be expressed as a formula because it is evident that the tiered structure in BS-ISO 15686-5 (2008) encompasses operations, maintenance, replacement and occupancy costs.

Evaluating operation, maintenance, replacement and disposal costs is an exercise in predicting the future costs of these events over the study period of the project, so that an economic evaluation can be applied not just to the construction cost but to the entire scope of the life cycle. This is the essence of LCC, which is ingrained in the definitions outlined in all authoritative standards (BS-ISO, 2008; BSI/BCIS, 2008; DavisLangdon, 2007; Fuller & Peterson, 1996).

2.7.2 Representing LCC

LCC relies on predicting when elements of the building and services will deteriorate to a condition where intervention is needed, and what the cost of each intervention will be. For each cost the life cycle profile of when the cost occurs (or recurs) should be determined and recorded (BS-ISO, 2008; Kehily, 2011). When analysed over a period of time, cost items give rise to cost/time profiles that consist of a single occurrence or costs that are repeated at regular or irregular intervals (BS-ISO, 2008). LCC calculations take account of these cost/time profiles and therefore depend on numerous assumptions, all subject to a degree of uncertainty (Ashworth, 1996).

There are a number of methods of life cycle economic evaluation defined in BS-ISO 15686-5 (2008), NRM 3 (RICS, 2014) and Fuller & Petersen’s ‘*NIST Handbook*’ (1996). These are Net Present Value (NPV), Annual Equivalent Cost (AEC), Payback Period (PB), Net Savings (NS), Savings to Investment Ratio (SIR) and Internal Rate of Return (IRR). AEC converts all future expenditure to an equivalent

annual cost so that LCC can be evaluated based on a single figure that represents an average yearly cost over a given study period. The PB represents the time required for the expected annual savings to pay back the initial investment. The NS is a simple technique that represents the difference between the income generated from the investment and the initial CAPex of that investment. The IRR and SIR are traditional financial appraisal techniques, which provide a calculation in a percentage and ratio respectively, on how the initial investment performs over a certain period based on income to investment (Davis Langdon, 2007; Kishk et al., 2003). The plethora of calculations and the context in which they should be applied can lead to confusion on which one should be utilised. It also gives rise to inconsistency in applying a standard approach.

Kishk et al. (2003) opines that NPV is the most powerful method and the most obvious choice because it focuses on cash flow analysis, which is beneficial in the evaluation of design decisions, rather than a single percentage or ratio that oversimplifies the cash flow. Kishk et al. (2003) add that the other calculations are less valid for LCC because not all building investments will generate an income greater than the initial investment and in the case of PB ignores cash flows outside the payback period.

Schaude (2011) examined the advantages and disadvantages of the different methods of calculating LCC and found with Kishk et al. (2003) (outlined above) that the most suitable approach for LCC in the construction industry is the NPV method. This is consistent with other authors in the field who consider the NPV calculation as the most suitable in the industry (Churcher, 2008; Clift & Bourke, 1999; Fuller & Peterson, 1996; TG4, 2003). The RICS (2014) and the BSI/BCIS (2008) use the NPV method as one of the methods for presenting costs in their recommended template/summary page and annexes at the back of the documentation. Due to its prevalence as the most used LCC method, this research concentrated on LCC calculations based on PV. However, Fuller & Petersen (1996) note that the calculation utilised should be applicable to the circumstance of what is required. For example, NPV cash flow analysis may be suitable for WLCC, but if you require a simple calculation to evaluate the benefit of investing in a renewable technology, a PB or IRR may be more applicable.

According to the BSI/BCIS (2008), calculating the NPV starts with the representation of the life cycle costs as a cash flow over a study period. This is demonstrated in Figure 2.2 by adding together those costs that accrue in the same calendar year.

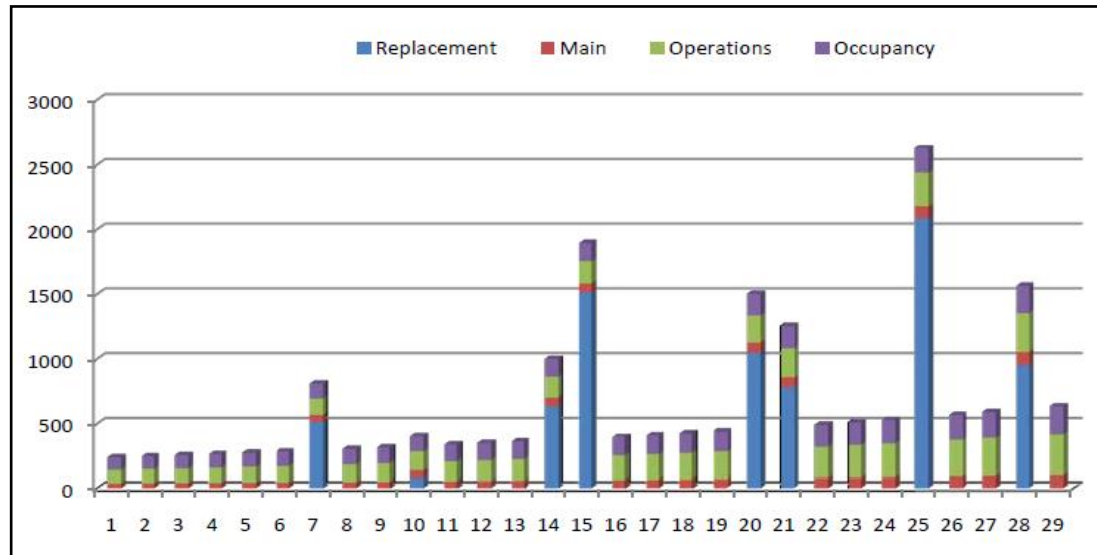


Figure 2.2: Maintenance Profile (Kehily 2011)

However, comparing different buildings or component options through cash flow forecasting is difficult as particular costs occur at different time frames (BSI/BCIS, 2008; Kehily, 2011). Thus, these costs need to be evaluated at a common time base, so that options may be evaluated in equivalent terms. The BSI/BCIS (2008, p. 19) state that the comparable time base is usually present day, noted as ‘year zero (0)’ on the LCC estimate. Fuller and Petersen (1996) describe this comparable date as the ‘base date’. The RICS (2015) notes that ‘base date’ can be set at the point where services or operations are commenced. Therefore, as illustrated in Figure 2.3, all expenditure on fees, construction and financing and all overhead charges from the ‘Date of Commencement of Analysis’ until the ‘Base Date Year’, are added together and treated as CAPex. OPex commences when the service is provided, starting at the ‘Base Date Year’ up to the ‘End of Study’ period. This encompasses an ‘LCC Analysis Period’ (25 years) which includes operations, occupancy, renewal, maintenance and end of life costs associated with BS-ISO 15686-5 LCC categories illustrated in Figure 2.1. These costs are discounted back with NPV calculations to the base date to add to the CAPex (BSI/BCIS, 2008; RICS, 2015).

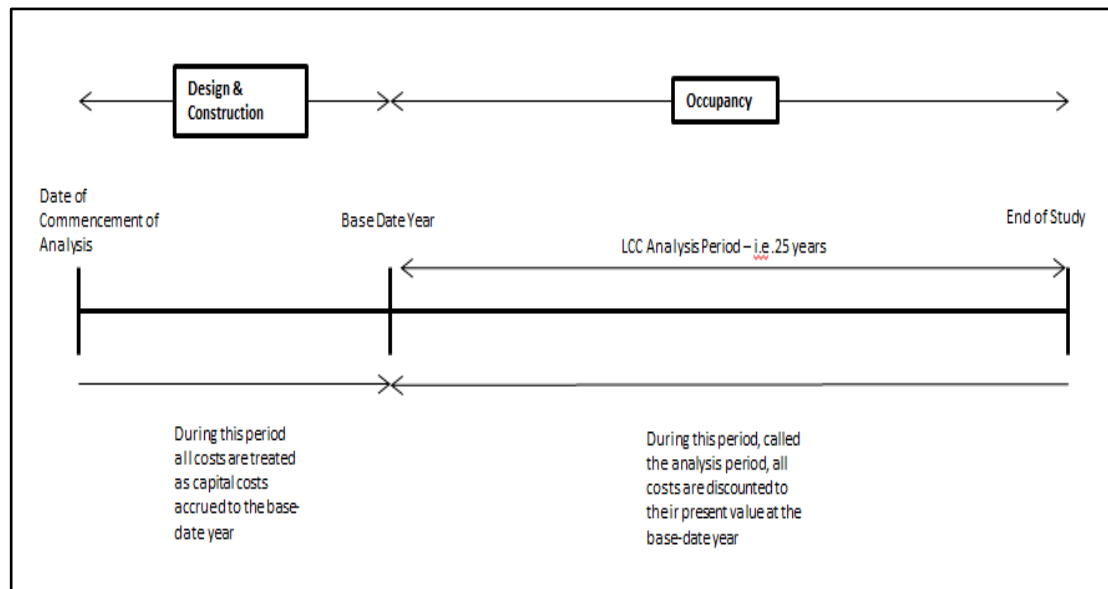


Figure 2.3: Representation of key dates in LCC (RICS, 2015)

‘Discounting’ is the process of converting ‘future money’ to ‘present money’ (RICS, 2014, p. 36). A stream of discounted future costs can be converted to a single sum Present Value (PV) by adding together the discounted costs at the equivalent time base (BSI/BCIS, 2008; Clift, 2003; Fuller & Peterson, 1996; TG4, 2003). The total discounted PV or Net Present Value (NPV) is a single figure that takes account of all relevant future incomes and expenditure over the period of analysis discounted back to present day (BSI/BCIS, 2008; RICS, 2014). Gluch & Baumann (2004) outline that the NPV of different buildings or components within buildings over a certain study period can be compared to assess the most economic effective alternative. To calculate NPV certain additional data requirements are necessary such as interest rates and study periods.

2.8 Data Requirements for LCC

2.8.1 Calculating Present Value

Fuller & Petersen (1996) and Clift, (2003) state the extent of data input required for LCC exercises is more complex than that required for assessing initial costs or short term considerations. The reason for this is that the scope of the analysis, in relation to time and economic considerations, is considerably longer. LCC is a method for condensing an almost overwhelming large quantity of information, over a long period of time, into one economic figure (Pelzeter, 2007). Costs that fall outside the scope of pure construction CAPex are also considered such as maintenance costs; replacement costs; occupancy costs, and utilities costs (BS-ISO, 2008, pp. 6-7; Fu et

al., 2007). The expansive scope of the LCC study and the additional cost and time factors employed in the calculations can make considering LCC on construction projects very time consuming (Fu et al., 2007; Hunter et al., 2005).

Certain data requirements need to be applied to carry out the NPV calculations in LCC. NPV calculations for LCC incorporate escalation and discount rates to account for different operations taking place at different times throughout the built asset's life cycle (Cole & Sterner, 2000; Fuller & Peterson, 1996; TG4, 2003). This enables the cost consultant to evaluate different systems and building options over a selected study period even though their replacement and maintenance profiles may be significantly different (Ashworth, 1996; Kelly & Hunter, 2009; Kirkham, 2005).

2.8.2 Escalation/Inflation Rates

When LCCs are expressed in 'nominal' costs, the costs are adjusted for inflation, representing the 'current costs' at the time the cost is incurred (BSI/BCIS, 2008; Charette, 2010; Churcher, 2008). To do this, LCC calculations incorporate an escalation rate to take account of the rise in the general price level of the item that is being analysed to the future date the cost will be incurred (Hunter et al., 2005). Hunter et al. (2005) describe how assessing escalation becomes harder when the rise differs across products. Different products and services escalate at different levels even though a general inflation rate in the construction sector may be reported and applied. Taking account of different escalation rates adds complexity to the calculations as a single rate cannot be applied to the entire LCC assessment (Davis Langdon, 2007). Nominal costs can be presented in an LCC estimate and represent the future costs prior to them being discounted for NPV (BS-ISO, 2008; Churcher, 2008).

2.8.3 Discount Rates

The discount rate, on the other hand, is usually a universal rate applied to the LCC analysis. Churcher (2008) and Fuller & Petersen (1996) state that a discount rate takes account of the time value of money. The principle of time value means that cash available now has a greater value than the same quantity of cash in the future (Churcher, 2008). For example, the spending power of a quantity of cash will be less in ten years' time. LCC discounts future sums with a discount rate into present day money or a comparable time base for evaluation purposes (Kelly & Hunter, 2009).

Discussed in Section 2.7.2, Fuller and Petersen (1996) outline this comparable date as the 'base date' while Kelly & Hunter (2009) describe it as 'year zero (0)'.

2.8.4 Choosing a Discount Rate

Discount rates can be expressed as 'real' and 'nominal' depending on whether escalation is included in the rate (BSI/BCIS, 2008; TG4, 2003). Real discount rates are already adjusted for inflation and assume that a standard rate of inflation applies equally to all items in the estimate (BS-ISO, 2008; BSI/BCIS, 2008; Kelly & Hunter, 2009). As inflation is already factored into the real discount rate, escalation rates are not applied when real discount rates are used in LCC calculations. Nominal discount rates do not include the escalation rate in the discount rate, thus escalation rates are applied as a separate rate in calculations that include nominal discount rates (Charette, 2010; Churcher, 2008). BSI/BCIS (2008) and Fuller & Petersen (1996) recommend the use of real discount rates. They note that using real discount rates increases the speed of calculating LCC. However, this limits LCC being expressed solely as 'present value' rather than 'nominal cost' and representing LCC as nominal costs may be a requirement by the client. The RICS (2014) acknowledge that there are various views on how to account for inflation in discount rates. The RICS (2014) state that contrasting views make it difficult to prescribe advice on which type of discount rate to apply. Given these divergent views, the most valuable way to calculate LCC would be to use a tool that can represent the costs in real costs, nominal costs and present value, thus selecting the preferred LCC representation depending on project requirements, client requirements and the methodology being used. The OGC (2007) state that whatever way the estimate is presented, it should be used consistently.

The BSI/BCIS (2008) outline that the discount rate selected for public projects is usually quoted by central government. The current edition of HM Treasury's Green Book in UK, presents the discount rate to be used for all LCC analysis periods of thirty years or less (RICS, 2015). In Ireland discount rates and inflation rates are listed on the Department of Public Expenditure and Reform's website (DPER) (Kehily, 2011). The rates are listed as nominal discount rates, which indicate a separate treatment of inflation. The website advises that on public construction projects a government technical adviser will quote a prescribed inflation rate based on the context of a particular project.

2.8.5 *Study Period (Period of Analysis)*

The 'study period' is that period of time for which the investor has an interest in the building's life (Fuller & Peterson, 1996). The ISO define this as the 'period of analysis', which they state is the length of time over which the LCC is calculated (BS-ISO, 2008). According to Fuller & Petersen (1996), there is no optimum length of study and should be selected in light of the clients specific requirements or investment time horizon. In a WLCC analysis this may be the estimated physical life of the building or alternatively the estimated period of use (BS-ISO, 2008). Clift (2003) and Swaffield & McDonald (2008) comment that in PFIs, the study period is determined by the hand over date which is usually twenty to thirty years. The study period may also be determined by the investor's expected payback period on their initial investment (Fuller & Peterson, 1996). Churcher (2008) maintains that for new construction or refurbishment projects, study periods of between fifteen and twenty-five years are used. However, on public projects periods of up to one hundred years are evident, which relates more closely to the number of years the client maintains an interest in the asset (RICS, 1999). As LCC is an analysis tool usually used for comparing project options and component options, the same study period should be applied to all options being evaluated (Churcher, 2008; Fuller & Peterson, 1996).

Various definitions exist to define the length of time during which the building satisfies specific requirements. These can be described as:

- economic life – a period of occupation which is considered to be the least cost option to satisfy a required functional objective
- functional life – the period until a building ceases to function for the same purpose as that for which it was built
- legal life – the life of a building, or an element of a building until the time when it no longer satisfies legal or statutory requirements
- physical life – life of a building or an element of a building to the time when physical collapse is possible
- social life – life of a building until the time when human desire dictates replacement for reasons other than economic consideration
- technological life – life of a building or an element until it is no longer technically superior to alternatives.

(Ashworth, 1996; BSI/BCIS, 2008)

2.9 Basis of the Calculations

2.9.1 Calculating Factors.

To calculate the NPV, financial PV factors must be calculated with the data requirements outlined previously, where 'r' represents the discount rate and 'n' the study period. The standard PV factor in Equation 2 is expressed as (BS-ISO, 2008, p. 25; Churcher, 2008, p. 21; Gluch & Baumann, 2004; TG4, 2003, p. 23):

$$\frac{1}{1+r^n} \quad r = \text{discount rate, } n = \text{study period (usually years)}$$

Equation 2: PV Factor (BS-ISO, 2008)

This formula gives rise to a factor which can be multiplied by the relevant cost to calculate its PV. This equation would be used in a situation where the future escalated cost is known and thus a nominal discount rate can be applied to discount the future cost to a PV. There is no separate treatment of inflation in this formula, thus if escalation is to be factored into the equation, a real discount factor must be used.

A number of publications such as Clift (2003), BS-ISO (2008), TG4 (2003) and RICS, (1999) explain the calculation of the real discount rate from the nominal discount rate and the escalation/inflation rate prior to applying it to calculate the discounted PV. This is a two stage process, firstly calculating the real discount rate and then secondly to use it in the PV calculation outlined in Equation 2. The stages are outlined in

Equation 3 and Equation 4 where 'i' represents the nominal discount rate and 'e' is the escalation rate:

1st Stage

$$\text{Real Discounted Rate (r)} = \left[\frac{(1+i)}{(1+e)} \right] - 1$$

Equation 3: Real Discount Rate (Churcher, 2008)

The calculated real discount rate (r) is then incorporated into the PV calculation in Equation 4 to calculate the relevant factor based on the year (n) the cost is incurred.

2nd Stage

$$\text{PV Factor} = \frac{1}{1+r^n} \quad r = \text{real discount rate}$$

Equation 4: PV Factor 2 (BS-ISO, 2008)

The factor calculated in stage two is then multiplied by the current (known) cost to calculate the PV. Ultimately, the two stage PV process outlined here represents the current cost of the item today escalated to a future date and then discounted back to present day. This calculation would be used for a one off replacement item such as replacing a door or repainting skirting.

Fuller & Petersen (1996) describe this calculation as a Single Present Value (SPV), as it is a calculation based on a one off payment in the future. They propose that this two staged calculation can also be applied in a single formula which is presented and discussed in Equation 7.

2.9.2 Recurring Costs

If the same cost is incurred in another year, such as annual electricity costs, then the calculation must be performed again and added to the previous PV cost. Churcher (2008) outlines this calculation for a recurrent cost every year over a study period, whereby the factors are calculated every year and the results are added together to calculate an accumulated factor (Equation 5). The accumulated factor is then multiplied by the recurring cost to calculate the NPV.

$$\text{PVFactor} = \frac{1}{1+r^1} + \frac{1}{1+r^2} + \frac{1}{1+r^3} + \frac{1}{1+r^4} + \frac{1}{1+r^5} + \dots$$

Equation 5: Accumulated PV Factor (Churcher, 2008)

Instead of calculating the factors every year for those costs that accrue on an annual basis, Fuller & Petersen (1996) provide a Uniform PV (UPV) (Equation 6) calculation which incorporates the cumulative calculation for the study period in one calculation rather than having to do it for every year in the life cycle.

$$\text{UPV Factor} = \frac{(1+r)^n - 1}{r(1+r)^n}$$

Equation 6: UPV Factor (Fuller & Petersen, 1996)

The resultant factor can then be multiplied by the relevant recurring cost to calculate the NPV for that time series. UPV calculations cannot be applied to costs where the intervals are greater than one unit (Fuller & Peterson, 1996). For example, once the

intervals are greater than every year (or month) the calculations will have to be performed individually for every interval in the study period.

An issue with the UPV calculation is it assumes that the payments are made at the beginning of each period, while SPV calculates its factors at the end of the year. Thus, if you were to check the factor against performing it by adding the single factors together you would get a different result. To correct the effects of this anomaly you must add one (+1) to the number of years and deduct the first payment in the UPV calculation. This issue is not mentioned by Fuller & Petersen (1996) and may cause problems if you are using the SPV and UPV formulas interchangeably.

2.9.3 *Incorporating Escalation Separately*

Fuller & Peterson (1996) also set out ‘modified*’ PV calculations, displayed in Equation 7, that take account of the escalation rate in the formulae incorporating the two stage process outlined above in a single calculation. These calculations are identified by an ‘astrix’, ie SPV* and UPV* to account for the inclusion of an escalation rate in the calculation. In this case, there would be no need to carry out a pre-calculation for a real discount rate, as it is taken into account in the formulae.

$$\text{SPV* Factor} = \left[\frac{[1+e]}{[1+i]} \right]^n$$

$$\text{UPV* Factor} = \frac{1 - \left[\frac{[1+e]}{[1+i]} \right]^n}{\left[\frac{[1+i]}{[1+e]} \right] - 1}$$

Equation 7: SPV*/UPV* Factor (Fuller & Petersen, 1996)

2.9.4 *Summary - Calculations*

This section presents the financial calculations utilised when carrying out LCC. The standard PV formulae is outlined which allows for a future cost to be discounted back to a PV. If the future cost is not known, common practice is to escalate the current known cost to the future date and subsequently discount it back to a PV. This requires a two staged process of firstly calculating the real discount rate and then apply it to the PV formula. If a cost occurs every year this calculation must be calculated every year throughout the study period, or Fuller & Petersen’s (1996) UPV factor can be used which accommodates it in one calculation.

As stated previously, one of the issues regarding the effective utilisation of LCC is that it becomes an exhaustive process when carried out manually (Fu et al., 2007; Pelzeter, 2007). This becomes even more prevalent when different escalation rates are applied to different items, because the same real discount factor cannot be applied to the entire estimate. An example of this would be where a general escalation rate is applied to construction goods and services but a higher rate may have to be applied to energy costs.

2.10 Using the formulae

2.10.1 Scientific Calculator

Kehily (2011) and Fu et al. (2007) explain that a scientific calculator can be used to carry out the PV calculations but this method is quite time consuming, as each variable must be inputted to determine the relevant factor. This calculation must be repeated for each LCC calculation to determine the cumulative present value LCC (Churcher, 2008). In fact, a QS may have to perform a number of calculations for a cost plan or BOQ item depending on how many times it may be necessary to replace an item within the study period.

2.10.2 Calculating PV factors with financial tables

Financial tables allow for PV calculations to be performed without the use of calculators. Financial tables simplify the computational requirements of LCC (Kehily, 2011; Churcher, 2008). Fuller & Petersen (1996) point out that financial tables contain pre-calculated PV factors covering a wide range of discount rates, escalation rates and time periods. Financial tables are available for UPV and SPV calculations (Churcher, 2008; Fuller & Peterson, 1996; Kehily, 2011). Even though this takes the number crunching out of the process it still remains quite time consuming as a factor has to be looked up and applied for each item in the estimate. If a cost item has a number of different intervals, separate factors need to be calculated for each time the item is replaced in the study period.

Table 2.1 presents an extract from Charette's (2005, p. 14) financial tables. The table sets out a variety of financial factors including SPV and UPV calculations for an 8% discount rate for the years between 1 and 30 and every 5 years between year 30 and 50. The financial tables although significantly quicker than by scientific calculator

have some certain limitations whereby calculating PV factors with these tables becomes problematic if the study period is not an integer of 5 between 30 and 50 years as the tables do not provide factors for those study periods.

d= 8%		DISCOUNT FACTORS					d= 8%
		Discount Rate d = 8%					
	Single Compound Amount	Single Present Value	Uniform Capital Recovery	Uniform Present Value	Uniform Sinking Fund	Uniform Compound Amount	
Year	SCA	SPV	UCR	UPV	USF	UCA	
1	1.0800	0.9259	1.0800	0.9259	1.0000	1.0000	
2	1.1664	0.8573	0.5608	1.7833	0.4808	2.0800	
3	1.2597	0.7938	0.3880	2.5771	0.3080	3.2484	
4	1.3605	0.7350	0.3019	3.3121	0.2219	4.5081	
5	1.4693	0.6806	0.2505	3.9927	0.1705	5.8666	
6	1.5869	0.6302	0.2163	4.6229	0.1363	7.3359	
7	1.7138	0.5835	0.1921	5.2064	0.1121	8.9228	
8	1.8509	0.5403	0.1740	5.7466	0.0940	10.637	
9	1.9990	0.5002	0.1601	6.2469	0.0801	12.488	
10	2.1589	0.4632	0.1490	6.7101	0.0690	14.487	
11	2.3316	0.4289	0.1401	7.1390	0.0601	16.645	
12	2.5182	0.3971	0.1327	7.5361	0.0527	18.977	
13	2.7196	0.3677	0.1265	7.9038	0.0465	21.495	
14	2.9372	0.3405	0.1213	8.2442	0.0413	24.215	
15	3.1722	0.3152	0.1168	8.5595	0.0368	27.152	
16	3.4259	0.2919	0.1130	8.8514	0.0330	30.324	
17	3.7000	0.2703	0.1096	9.1216	0.0296	33.750	
18	3.9960	0.2502	0.1067	9.3719	0.0267	37.450	
19	4.3157	0.2317	0.1041	9.6036	0.0241	41.446	
20	4.6610	0.2145	0.1019	9.8181	0.0219	45.762	
21	5.0338	0.1987	0.0998	10.017	0.0198	50.423	
22	5.4365	0.1839	0.0980	10.201	0.0180	55.457	
23	5.8715	0.1703	0.0964	10.371	0.0164	60.893	
24	6.3412	0.1577	0.0950	10.529	0.0150	66.765	
25	6.8485	0.1460	0.0937	10.675	0.0137	73.106	
26	7.3964	0.1352	0.0925	10.810	0.0125	79.954	
27	7.9881	0.1252	0.0914	10.935	0.0114	87.351	
28	8.6271	0.1159	0.0905	11.051	0.0105	95.339	
29	9.3173	0.1073	0.0896	11.158	0.0096	103.97	
30	10.063	0.0994	0.0888	11.258	0.0088	113.28	
35	14.785	0.0676	0.0858	11.655	0.0058	172.32	
40	21.725	0.0460	0.0839	11.925	0.0039	259.06	
45	31.920	0.0313	0.0826	12.108	0.0026	386.51	
50	46.902	0.0213	0.0817	12.233	0.0017	573.77	

Table 2.1: 8% Table (Charette, 2005)

In this process the user must firstly select the appropriate discount rate (8%) in Charette's Financial Tables book. A separate page of calculations applies to each interest rate. The correct SPV factor is located at the intersection between the SPV column and the relevant year. The selected factor is then multiplied by the relevant cost to establish the discounted PV. A similar process is carried out for UPV, SPV* and UPV* calculations. Churcher (2008, pp. 41-42) presents similar tables to Charette, which he separates into 'discount factors for lump sums' and 'discount factors for reoccurring costs'. The difference with Charette's is that Churcher presents discount rates for 1% to 16% on the same page and every year from 1 to 50 years is included. Charette's tables include discount rates up to 50%, but you are not likely to require a discount rate in excess of Churcher's limit of 16% and more likely to require study periods for every year up to 50 years and beyond (Charette only includes multiples of 5 after 30 years). For these reasons, Churcher produces more comprehensive tables.

However, a criticism with both Churcher's and Charette's tables is that the years stop at year 50; certain LCC exercises require study periods in excess of 50 years such as the WLCC example in the SCSI 'Guide to LCC' (Kehily, 2010). Another issue is that the rates are only expressed as a whole number. Calculating a factor based on a fraction of a percentage is not possible. Interest rates published by the Department of Public Expenditure and Reform (DPER) in Ireland are expressed as fractions (eg 5.51%) and thus this method would not be suitable with such rates without extrapolation.

2.10.3 Spreadsheet Application of Factors

A recommended approach by the OGC (2007) is to use standard software such as MS Excel and adapt it to perform the required tasks; building in a facility for key variables. PV factors can be written into a formula in a spreadsheet cell and once checked the formula can be copied and pasted as required throughout the spreadsheet for each line item in the estimate. Equation 8 presents an extract from Kehily (2011, p. 13), indicating how the data requirements for both SPV* and UPV* factors such as escalation (e), discount rate (i) and study period (n) can be calculated in spreadsheet cells. The formulae must be written into the input bar (fx) starting with an '=' to delineate that a calculation must be computed from the subsequent formulae. The user directs the sequence of the computation through the use of brackets which expresses a series of computation from the inside out.

SPV* Single Present Value Modified in Excel

$$\frac{[1 + e]^n}{[1 + i]}$$

The SPV modified formula above could be written into excel function (fx) as follows:

$$= [[1 + e]/[1 + i]]^n$$

UPV* Single Present Value Modified in Excel

$$\frac{1 - \frac{[1 + e]^n}{[1 + i]}}{\frac{[1 + i]}{[1 + e]} - 1}$$

The UPV* modified formula above could be written into excel function (fx) as follows:

$$=(1 - [[1 + e]/[1 + i]]^n)/([1 + i]/[1 + e] - 1)$$

Equation 8: Spreadsheet Calculation 1 (Kehily, 2011, p.13)

Equation 9 is an extract from Kehily (2011, p. 14) which illustrates this process for the UPV of a payment of €1,000 yearly for thirty years at a discount rate of 8% and an escalation rate of 6%. The relevant escalation rate and discount rate are linked in the spreadsheet. The advantage with this is that if common rates apply across the calculations, changing these rates once, will change every calculation that applies to those rates in the estimate.

$$f = \frac{1 - \left[\frac{[1+e]}{[1+i]} \right]^n}{\left[\frac{[1+i]}{[1+e]} \right] - 1}$$

$$= (1 - [[1 + B2]/[1 + C2]]^D) / ([1 + C2]/[1 + B2] - 1)$$

	A	B	C	D	E	F
1	Ao	e	d/i	n	f	Total
2	1000	0.06	0.08	30	22.74904	22749.04

$$\text{Total} = A2 \times E2 = F$$

Equation 9: Spreadsheet Calculation 2 (Kehily, 2011, p.14)

Once the formulae are completed and checked against financial tables or on a calculator they do not need to be entered again for each item in the estimate. Filling down the formulae throughout the estimate will perform the calculations on each line item provided the data requirements are in the same column from item to item. Changing these data requirements (escalation, discount & time) will change the calculated factors for each item thus providing the user with a quick way to carry out the calculations. Once this is completed the template can be used for other LCC estimates (Kehily, 2011). These calculations are useful as they describe and illustrate how formulae outlined in Fuller & Petersen (1996), BS-ISO 15686-5 (2008) BSI/BCIS 15686-5 (2008) and NRM 3 (RICS, 2014) could be constructed in MS Excel. However, MS Excel already has a number of PV functions that could be utilised to calculate LCC calculations without having to construct them from scratch. These are discussed in the following section.

2.10.4 Using Excel PV Functions

Churcher (2008) indicates that there are special PV functions in MS Excel which can be used to calculate the PV factors and costs in one cell. The advantage of using the PV dedicated spreadsheet function is that the same formulae can be used to calculate a discounted lump sum or the PV for a recurring cost, i.e. it can calculate both the SPV and the UPV cost depending on which is applicable. The syntax for the PV function is outlined in Equation 10 as (TechontheNet, n.d);

$$=PV(\text{interest_rate}, \text{number_payments}, \text{payment}, [\text{FV}], [\text{Type}])$$

Equation 10: PV Function MS Excel (TechontheNet, n.d)

Inputting the relevant data allows the user to apply it to a single or recurring sum. If an item in the formulae is not applicable to either SPV or the UPV it should be left as 0. As outlined in Tech on the Net (TechontheNet, n.d), the ‘interest_rate’ is the interest rate or discount rate for the investment. The ‘number_payments’ is the number of payments for the annuity or the year the payment needs to be made. ‘Payment’ is the amount of the payment made each period. If this parameter is omitted it assumes the calculation is based on a single payment. If the calculation is based on a single payment the user must enter that sum in ‘FV’. FV is the ‘Future Value’ of the payment or cost to which the discount factor is applied. If this parameter is omitted, the PV function assumes FV to be 0 and the calculation is based on the recurring cost. ‘Type’ is optional; it indicates when the payments are due, ‘0’ for the end of the period or ‘1’ for the beginning of the period. If the ‘type’ parameter is omitted, the function assumes a type value of 0 (Churcher, 2008).

Equation 11 demonstrates an example of an SPV calculation of €325 in 8 years at a discount rate of 3% in which the data would be inputted into the formulae as follows (Churcher, 2008, p. 22; TechontheNet, n.d);

$$=PV(0.03,8,0,325,0) = 256.56$$

Equation 11: PV Function Example (1) (TechontheNet,n.d)

In this case, the third number in the calculation is 0 as only one payment applies. Alternatively, (Equation 12) if the formula was used to calculate the PV of a recurring cost of €325 every year for 8 years at a 3% discount rate the following would be inputted into the function bar in MS Excel (f_x);

$$=PV(0.03,8,325,0,0) = 2281.40$$

Equation 12: PV Function Example (2) (TechontheNet,n.d)

These MS Excel functions are advantageous when calculating SPV and UPV discussed in Section 2.9, but they are not applicable in every instance of LCC calculations. They do not account for a treatment of escalation and thus an additional calculation would have to be utilised. When producing LCC estimates many calculations are utilised which could require a combination of the calculations discussed above. The QS must use their judgment and experience to apply the right calculation to the right scenario.

2.11 Risk Analysis

Computing LCC calculations based on formulae outlined above gives an indication that the resultant values are absolute. This is not the case, there are so many variables and factors in LCC calculations that the product of the calculation can only give an indication of LCC based on a number of assumptions (Pelzeter, 2007; BSI/BCIS, 2008; RICS, 2015). LCC modelling must incorporate a facility whereby a change in any of the variables can be easily accommodated (RICS, 2015). This is referred to in the majority of LCC standards as ‘Risk Analysis’ (Kirkham, 2005; BS-ISO, 2008; BSI/BCIS, 2008; RICS, 2014). Risk analysis is utilised in LCC in two ways, through ‘sensitivity analysis’ or ‘monte-carlo’ simulation (BS-ISO, 2008; BSI/BCIS, 2008).

In sensitivity analysis a calculation structure must be developed that can accommodate ‘what if’ questioning of the results by changing variables such as the unit rates, discount rate, escalation rate, life expectancy or study period. Spreadsheet software is used to carry out sensitivity analysis because it offers a medium to set up LCC variables (data requirements) and link them through formulae. Ideally models should be set up so that a change to a single entry acts across all affected calculations, providing a framework where presenting different scenarios can be easily carried out (El-Haram et al., 2002; RICS, 2015).

Monte Carlo simulation is a statistical technique which can be used in LCC to model a range of possible costs based on probability distributions. Rather than a finite whole number for LCC, this would allow the identification of a distribution of possible costs based on a range of confidence levels (BS-ISO, 2008).

The utilisation of spreadsheet software can provide a structure for either Sensitivity Analysis or Monte Carlo with simulation software (BSI/BCIS, 2008; OGC, 2007).

2.12 Utilising Technology

Churcher (2008) includes examples of LCC exercises where financial tables and PV functions are used to evaluate a number of different options. Fuller & Petersen (1996) and Kehily (2011) also demonstrate a number of LCC exercises using financial tables. While manual methods of calculations are still defined in relevant standards they are no longer being used in the production of LCC estimates. These methods are generally included to provide the methodology underpinning the calculations but most examples of LCC are now calculated and presented in tabulated spreadsheets (Hourigan, 2012).

2.12.1 LCC in Spreadsheets

The OGC (2007) recommend the use of spreadsheet software such as MS Excel, as a basis for calculating and presenting LCC by building a facility for key variables. They state that specialist software is not adaptable and cannot process variable data as efficiently as generic spreadsheets. This is an opinion of the OGC and is not supported by any applicable evidence in their document. However, the BSI/BCIS (2008) and NRM 3 (RICS, 2014) seem to support their assertion, as they attach annex spreadsheets for presenting LCC based on NPV calculations. Although the reason why the BSI/BCIS and NRM 3 present their calculations in spreadsheets maybe that spreadsheet software is the most used medium in cost management (Eastman et al. 2011) and thus they are possibly presenting their calculations in a format that QSs can easily understand. There is no reason why bespoke software cannot carryout similar calculations (Pelzeter, 2007). However, the problem with bespoke LCC software is that it is not adaptable and the calculations are not explicit and easy to change. Pelzeter (2007) argues that while standards and methodologies in LCC provide the tabulated framework to present an LCC estimate they do not explicitly outline the calculations in the model.

There are a number of spreadsheet-based LCC applications that support LCC within the jurisdictions they encompass and embed LCC calculations within their cells (Kishk et al., 2003; Pelzeter, 2007). The fact that these jurisdictions use MS Excel

rather than bespoke LCC applications adds credence to the claim that spreadsheet software is the most suitable software for LCC calculations. Examples include, Norway (Gundersen, 1998), Sweden (SEMC, 2011) and Australia/New Zealand (AS/NZS 4536 1999) whom use customised LCC spreadsheets on publically funded projects. These are supported by various guidance documents, which outline the standard methodology on which they are based. In Ireland, the SCSI suggest the use of their LCC template, which is designed and formatted in accordance with the BS-ISO 15868-5 and the BSI/BCIS supplement (Kehily, 2011). In United States the NIST developed the Building Life Cycle Cost (BLCC) MS Excel based programme to help with LCC computational requirements on publically funded programmes. Hunter et al. (2005) also published a generic spreadsheet application tailored to assist QSs on local government projects in UK. The BSRIA in UK has provided an LCC calculator in MS Excel, which supplements their '*Guide to LCC*' (Churcher, 2008). These spreadsheet applications are advantageous to QSs because they include the necessary formulae to carry out LCC calculations but they are not adaptable to other jurisdictions and/or different methodologies (Kishk et al., 2003; OGC, 2007).

2.12.2 LCC Software

Both Davis Langdon (2007) and Kishk et al. (2003) have carried out an assessment of LCC software. A number of these tools are outlined in the previous section and are based on spreadsheet programmes such as the US's NIST BLCC and Norway's LCProfit. Other LCC applications identified by Kishk et al. (2003) and Pelzter (2007) include commercial LCC software, but they are structured to the requirements of the particular jurisdiction to which they apply and in most cases are applicable to specific functions such as; energy analysis in the US (BLCC); bridge construction in the US (BridgeLCC); military projects in the US (LCCID); LCC in manufacturing (Relex LCC) and residential construction in the Neatherlands (Kostenreferentiemodel). Some applications provide a generic system for LCC analysis (Amposol, ACEIT, Bid-Builder, and LCCWare) but do not incorporate the latest capabilities in Computer Aided Design (CAD) technologies and are not sufficiently flexible to accommodate particular methodologies in different jurisdictions.

The EU has co-financed the development of a collaborative WLCC tool called ‘Construction Industry Life Cycle Cost Analysis’ (CILECCTA). This software application allows full WLCC analysis to be carried out based on a database of LCC data (CILECCTA, 2013). The software is custom built and provides an integrated link between LCC calculations and a comprehensive database of costs. It does not utilise CAD technologies and similar to LCC software outlined above requires users to carry out their measurement and pricing in a separate application to their estimating software.

‘WLC Comparator’ is software developed by the Building Research Establishment (BRE) and is a simple tool that has been designed to calculate the LCC of building components. The tool is a straightforward concept similar to the spreadsheet templates outlined above that includes discounting PV costs through future income streams (Kirkham, 2012). It is aligned to BS-ISO 15686-5 but, similar to the commercial software outlined above, does not have the flexibility of a generic spreadsheet for variable sensitivity analysis and does not have the capability to link to CAD or quantum produced by CAD.

Kishk et al. (2003) maintain the main limitation with almost all these applications is that the classification structure has to be built manually by the user and is mostly non-elemental, i.e. if applying ISO 15686-5 the user would have to build the classification structure in the system. Another disadvantage is that because some applications are bespoke systems they would require potential investment and training by the user.

BIM technologies that accommodate software capable of carrying out LCC leveraging CAD are outlined in the next chapter.

2.13 Summary

In general, literature on LCC have agreed on the principle that LCC is used to assess the costs associated with the wider implications of operation, maintenance and disposal, in addition to, the more traditional CAPEX view of the asset. This allows for a number of applications such as option appraisal; measuring sustainability; evaluation for procurement and tendering and utilisation for FM. Although these benefits are well documented, there are a number of barriers that prevent LCC being

more widely practiced by QSs in the construction industry. The principle barriers reported are; lack of client demand; availability and reliability of quality data upon which to base calculations; lack of standards or guidance notes and the perception that calculations are complex and time consuming. Standard methodologies and LCC guides are over theoretical with little in the way of practical examples and lack process implementations to guide a cost professional through the procedures calculating and presenting LCC. The achievement of greater success implementing the requirements outlined in the OGC in UK, the CWMF in Ireland and per the EU directive 2014/24/EU, depends on a process that would allow for easier calculation, preparation and analysis in a uniform method. The process must also become more adaptable to apply to different standard LCC methodologies and to apply to different projects.

In addition, QSs use a number of well recognised software applications such as Buildsoft, CostX, Vico and CATO. The majority of these applications tend to have a spreadsheet-based workbook which could embed the calculations addressed in Section 2.8 and 2.9 and in a format that is line with the relevant standards outlined in this review of literature. Furthermore, a number of these applications have the ability to utilise BIM. The next chapter explores these applications and BIM and identifies the potential for LCC to be utilised within the 5D BIM process, by embedding an LCC calculation structure within the 5D BIM work-flow.

3 BIM and its Application for QS Practice

3.1 Introduction

Fung et al. (2014) and Underwood & Isikdag (2010) claim BIM has the potential to increase efficiency in the construction industry by changing traditional 2D information exchange to a method of delivery that promotes collaboration and integration across the construction supply chain. BIM can ensure a thorough life cycle analysis, service life planning and more solid life-cycle optimisations of the design and use of the building from a shared digital resource (Eastman et al., 2011; Cheung et al., 2012). Common to the definitions of BIM, discussed in Section 3.3, are BIM's capabilities in delivering value throughout the whole building process including its operational life cycle. If this is accurate, harnessing the abilities of BIM may facilitate an LCC approach.

One of the key aspects of BIM is its ability to provide Qs with detailed 3 Dimensional (3D) project views that combine vital information from tools within the BIM model. QTO and estimating using BIM software is a comprehensive process that maps the components of a 3D building model to material, labour and equipment cost data (Matipa & Keane, 2008; Monteiro & Martins, 2013). BIM offers capabilities to generate take-offs, counts and measurements directly from a model. This provides a process where information stays consistent throughout the project and changes can be readily accommodated (Sabol, 2008). Though sophisticated, BIM is not extensively used to provide estimation software with the data requirements for LCC, such as escalation rates, discount rates and study periods (Whyte & Scott, 2010). This chapter; describes the development of BIM; outlines its benefits and challenges; and discusses its current applications. The latter part of the chapter addresses BIM use for cost management and discusses the possibility of utilising BIM for additional QS services, including LCC.

3.2 IT Development in Construction

3.2.1 Drawings

Drawings, whether hand drawn or illustrated through technology in the 2nd (2D) and 3rd (3D) Dimension, are often inconsistent as they are drawn separately on individual

sheets. This practice is susceptible to errors, as information may be changed in an elevation but the draftsman omits the change from the plans or details (Ajibade & Venkatesh, 2012). Another issue outlined by McNell et al. (2011), is that standalone drawn documents exclude design and construction information such as contractual obligations, quantities, detailed specification, schedule information and life cycle data. To provide the complete information necessary for construction, Architectural 2D drawings need to be supplemented with discipline specific information from members of the design and construction team (Azhar, Hein, & Sketo, 2008). This is the traditional tender documentation process and gives rise to a mass of construction information produced by various disciplines and organisations in many forms, such as; drawings; reports; specifications; schedule of quantities and contractual documentation (Wijayakumar & Jayasena, 2013). According to Howell & Batcheler (2005), this process leads to a traditional project delivery which is fraught by lack of cooperation; poor information sharing; inaccuracies in the information; is costly; time consuming and prone to human error.

3.2.2 Computer Aided Drawing (CAD)

Riddell (2009) notes that up until the 1980s the AEC industry was dominated by 2D information such as hand drawings and drafting tables. In the 1980s, Computer Aided Design (CAD) tools were developed and implemented to automate the process of drafting. The focus was primarily on representing 2D geometry via graphical elements such as lines and symbols (Sabol, 2008). Howell & Batcheler (2005) state that in an attempt to give more meaning to these graphical representations, the concept of 'layering' was introduced to group particular elements together based on their function. Various layers could then be turned on and off, which controlled what could be seen on the drawing, reducing the clutter and providing clarity in the detail, if required. Howell & Batcheler (2005) claim that this merely hid information, while more complex information such as the relationship between the elements could not be represented.

In the 1970's the introduction of 3D CAD primarily focused on creating geometry in support of visualisation in isometric view, so that realistic renderings could be created (Forgues, Iordanova, Valdivesio, & Staub-French, 2012). However, these drawings were illustrative and did not include any data within the design objects. In the 1990s, Underwood & Isikdag (2010) describe the move to Object-Oriented CAD

(OOCAD) as a revolutionary step. In this technology 2D symbols were replaced with building elements (objects) which could be displayed in multiple views and have non-graphic attributes assigned to them (Olatunji, Sher, & Gu, 2010).

PAS 1192-2:2013 (BSI, 2013b) notes that the basic problems that exist for over one hundred years, regarding the procurement of built assets, are not addressed sufficiently by CAD solutions. CAD still facilitates fragmented information exchange where information is inaccurate, incomplete, ambiguous and results in unnecessary capital delivery costs amounting 20-25% (BSI, 2013b). However, blaming 2D information exchange and CAD technology alone for productivity issues in the construction industry does not account for many of the problems outlined in reports such as Latham (1994) and Egan (1997). These reports outline that it is the prevalence of cultural and procedural inefficiencies such as the 'adversarial', 'ineffective' and 'fragmented' practices that are to blame in an industry that is incapable of delivering value to its client. Recognising this, Wijayakumar & Jayasena (2013) states that traditional information exchange perpetuates the inadequacies in the industry where increasing complexity, fast track project delivery and a growing awareness of environmental responsibility has made it even more challenging. Eastman et al. (2011) also argue that these 2D practices can no longer provide adequate assistance in a modern construction industry and a new way of delivering information is required.

3.3 Building Information Modelling (BIM)

3.3.1 Concept of BIM

There is no universally accepted definition of BIM, but most sources reveal a similar theme (Sawhney, 2014), which is evident in the definitions presented hereafter.

A widely cited definition for BIM as defined by the US National Institute of Building Sciences (NIBS-BuildingSMART alliance, 2012) is:

a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle.

Even though most BIM definitions make reference to a digital or technological process, Eastman et al (2011, p. 13) points out that:

BIM is not just a modelling technology, but an associated set of procedures which have communication and information management at its core.

Underwood & Isikag (2010, p. xxxii) differentiate between the ‘Building Information Model’ which represents “*a rich shared digital model*” and ‘Building Information Modell-*ing*’, which defines the process of “*information management*” through the digital model. Wu et al. (2014, p. 13) note this is why BIM is sometimes defined as “*Building Information Management*”...*in order to encompass the bigger picture of BIM*”. In this context, Smith (2014) and Taylor & Bailey (2011) argue that BIM does not simply involve technology/software but rather a different way of thinking, a cultural change and a new approach to project delivery. BIM brings together participants in a collaborative, cooperative and proactive manner around a common source of information (Eastman et al., 2011; Fung et al., 2014; Outreach, 2012). The focus on the model and modelling technology provide the means whereby there is a smooth flow of information throughout the design and construction life cycle, facilitating simultaneous work by multiple design disciplines on common platforms (where participants can share work seamlessly) (Ajibade & Venkatesh, 2012; Goucher & Thurairajah, 2012; Smith, 2014).

These different definitions and terminology are somewhat confusing as no clear definition seems to be widely accepted and there is nothing in the ‘BIM’ acronym that suggests it is more than just a technology. However, Underwoord & Isikdag (2010) provide a good summation of BIM, describing it both as a process focused on information management among participants of the project and a technology representing a digital model, where information about the project can be stored and transferred.

Crotty (2012, p. 82) presents an even more useful approach that does not try to articulate an all-encompassing definition, but rather breaks down BIM into three layers. He defines BIM as an approach to building design and construction in which:

- *A reference model of the building is created using one or more parametric component-based, 3D modelling systems.*
- *These systems exchange information about the building in one or more agreed standard file formats, with each other and with other systems which conform to the agreed formats.*

- *These exchanges are regulated by a set of protocols which establish the particular types of information to be exchanged between different members of the team, at different points in the project life-cycle.*

Crotty (2012) accentuates BIM as the creation of the model; a standard format for data exchange and the associated information exchange protocols for that exchange. This describes a more technological driven process but is generally consistent with Eastman et al. (2011, p. 13), who define a BIM approach as “*a modelling technology and associated set of processes to produce, communicate and analyse building models*”.

3.3.2 BIM and IPD

As discussed in Section 3.2.1, utilising BIM without integrating it into the procurement and management process will not affect change in the construction industry, because stakeholders will continue with their current work practices utilising the latest technologies which can perpetuate inconsistent information (Arayici et al., 2011; Wijayakumar & Jayasena 2013). This does not align with the view that BIM is a complete solution to the inefficiencies in the construction industry, but rather an aid that could facilitate a new approach. To achieve this, Hannele et al. (2012) notes that BIM should not be seen purely in technical terms but rather as a catalyst for a deeper process. Eastman et al. (2011) propose that the industry requires a new approach that can align interests, objectives and practices, through a collaborative-based BIM facilitated process. They outline ‘Integrated Project Delivery’ (IPD) as a relatively new procurement method that can facilitate the use of BIM through a contractual environment that promotes collaboration and integrated teams (Eastman et al., 2011; Sawhney, 2014). To facilitate this process, Hannele et al. (2012) claim that IPD requires a different contractual relationship between stakeholders. IPD and BIM can promote an approach of early stakeholder involvement in the project supply chain, where decisions made early in the design process can have a greater effect on the ability to impact cost (Ashworth et al., 2013; Eastman et al., 2011).

To achieve a successful project outcome, a commercial framework of risk allocation and associated compensation must be agreed. This requires improved alignment of

stakeholder's commercial interests with a collaborative based approach (Mathews & Howell, 2005).

3.3.3 *BIM Technology*

From a technological perspective, BIM is the latest generation of OOCAD and as a term represents a computerised process of development to generate a model in which to simulate the planning, design, construction and operation of a facility (Forgues et al., 2012; Sabol, 2008). Olatunji, Sher, & Gu. (2010) and Eastman et al. (2011) agree that it is the information attached to objects that makes BIM more than a visual representation or a 3D drawing. In this context, Matipa et al. (2010) state that models are made of “*smart objects*”, which digitally represent the physical elements and encapsulate their intelligence. These objects represent the different elements of the building and contain digital information on that object (Forgues et al., 2012). These are the ‘object properties’ which allow for storage of useful information about the object in the model; for example, wall thickness, wall material and thermal conductance of the wall. Object properties or attributes are needed to interface with analyses, cost estimations and other applications (Matipa et al., 2010; Olatunji et al., 2010; Sawhney, 2014). This will be addressed in more detail in Section 3.3.5.

BIM-enabled software uses parameters to determine the geometry and non-geometric properties of the objects (Sawhney, 2014). Eastman et al. (2011, p. 40) note this as “*object-based parametric modelling*”, where the rules set out in parameters define the context in which the object exists. For example, Lovegrove (2014) describes that a door in a BIM knows it is a door and when it is placed into a wall, the wall knows it has to have an opening to suit a particular door. This allows an object in a BIM environment to update itself as its context changes (Crotty, 2012; Sawhney, 2014).

Figure 3.1 illustrates the link between parametric properties (dimensions, alignment & location) and the context of its use in a wall, i.e. its offset and opening size in the wall. The arrows represent relations with adjoining objects and these define how the wall interacts in different locations and varied parameters (Eastman et al. 2011, p.41).

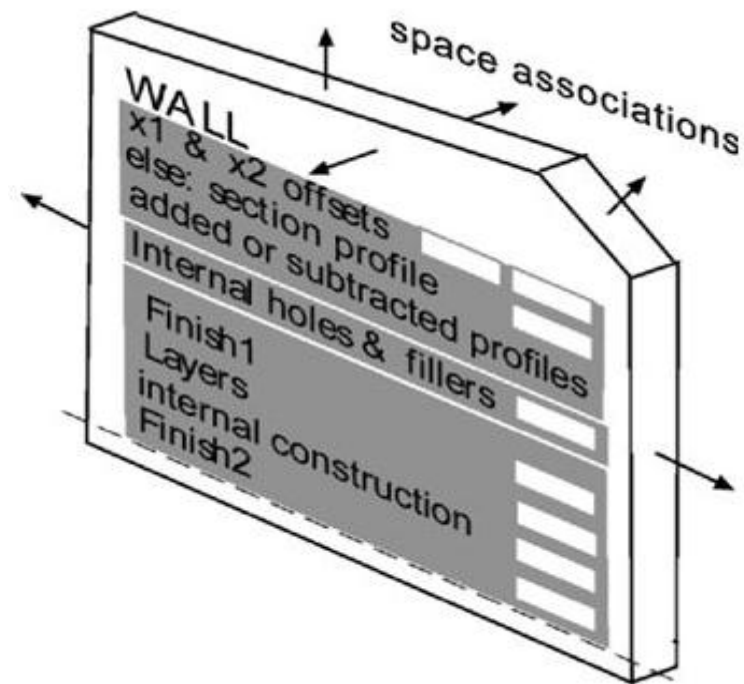


Figure 3.1: Parametric Modelling (Eastman et al., 2011, p.41)

Theoretically the BIM process efficiently generates and manages information from a single application and in a single model, and opens opportunities for multiple disciplines to share and exchange data (Goucher & Thurairajah, 2012; Olatunji et al., 2010; Underwood & Isikdag, 2010). The BIM is usually designed in a BIM authoring application, which is also known as a BIM design application. Commonly used BIM design application are Autodesk Revit, Graphisoft Archicad, and Bentley Microstation. The BIM contains the design and specification parameters and other discipline specific information such as structural properties, energy, schedule and cost (Underwood & Isikdag, 2010). Howell & Batcheler (2005, p. 2) note that all the parametric objects of a BIM combine to make up an intelligent building design that can coexist in a single “*project database or virtual building*”. They contend that the virtual building captures everything known about the building to provide a consistent source of information associated with the building. However, a number of authors dispute the use of a single model utilised for all construction disciplines and suggest in practice design team members currently rely on their own purpose built models (Howell & Batcheler, 2005; Sabol, 2008; Smith, 2014). This will be discussed in further detail in Section 3.4.

3.3.4 Benefits of BIM

As evidenced from the definitions described above, BIM expounds a new way of working, leveraging technology. The technology to create the building information model is at the heart of this new process, where models can be created in 3D, which can provide more clarity on the design for the client (Crowley, 2013; Fung et al., 2014). Underwood & Isikdag (2010) and Azhar et al. (2008) agree this has benefits by providing more accurate visualisation facilitating constructive feedback from the client earlier in the design process.

Another design benefit explicated by Eastman et al. (2011) and Wu et al. (2014) is that BIM can facilitate simultaneous work by multiple design disciplines. The metrics to facilitate this process are in the data embedded in the objects (Fung et al., 2014). According to Fung et al. (2014), Cheung et al. (2012) and Forgues et al. (2012), BIM is an object-oriented, intelligent, parametric digital representation and data repository that contains design, construction and maintenance information combined in one convenient model. These objects provide a mechanism where information can be uploaded or downloaded providing a repository of data on the project. Thus, information can be filtered and/or extracted to generate a multitude of reports on different design disciplines (Eastman et al., 2011; Nagalingam, Jayasena, & Ranadewa, 2013).

The parametric properties of the model give rise to a number of benefits predominantly in design (Eastman et al., 2011). The primary benefit of a parametric entity, according to Fu et al. (2007), is that where changes are made in any plan, elevation or 3D view within the drawing application, the change is automatically made to all other documentation, drawings and outputs. This means that accurate and consistent drawings can be printed in any number of views at any stage of design; thus design errors caused by inconsistent 2D drawings are eliminated (Azhar et al., 2008; Eastman et al., 2011). In addition, because systems from all disciplines can be brought together in the same software, clashes can be detected between multi-system interfaces in a shared model (Underwood & Isikdag, 2010). Hardin (2009) explains that a shared project model, is a model that is collectively merged from BIM models of different design disciplines, to form one 'federated model' (Figure 3.2).

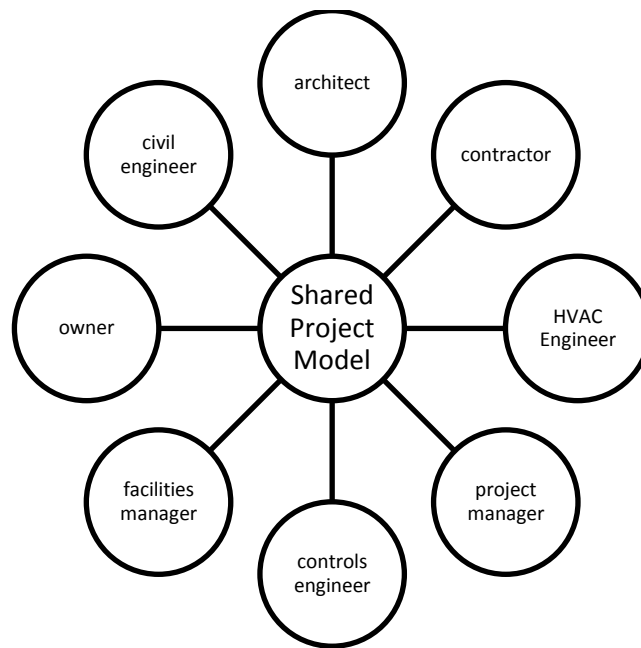


Figure 3.2: Shared Project Model (Underwood & Isikdag, 2010, p.9)

Conflicts can be identified from the federated model in design before they materialise in the field and this can negate costly variations during construction (Eastman et al., 2011; Fung et al., 2014; Goucher & Thurairajah, 2012). Figure 3.3 illustrates an example of a clash between ductwork and a structural beam, which is identified in the federated model (Autodesk, n.d). Kirkham (2012) claims the cost of making changes from design errors increases as the project progresses, so earlier clash detection increases the cost efficiency of the project and reduces the risk of running behind schedule. If changes do occur during construction the consequences of this change can be easily established possibly leading to more clarity around any subsequent claim by the contractor (Eastman et al., 2011; Nagalingam et al., 2013).

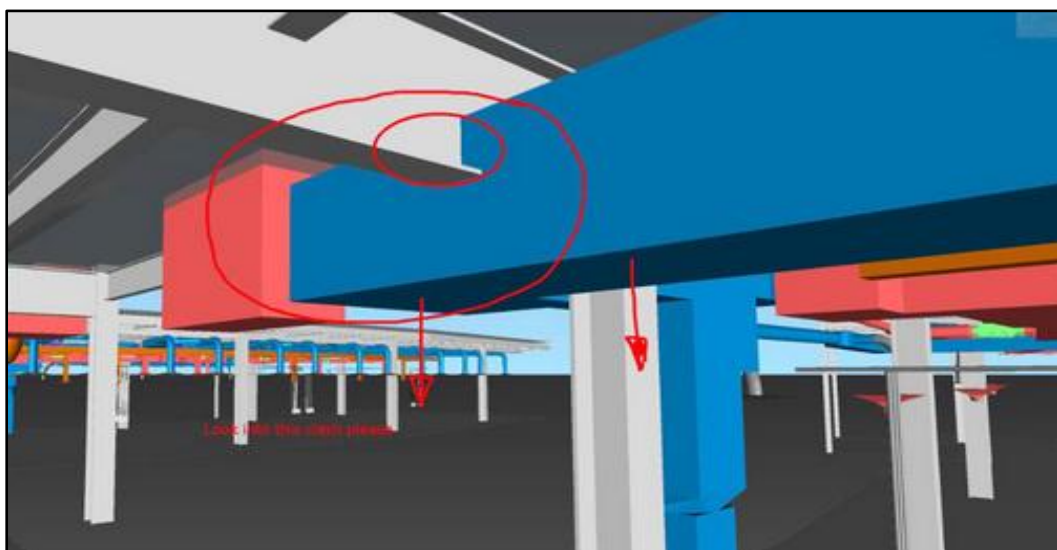


Figure 3.3: Clash Detection (Autodesk, n.d)

Eastman et al. (2011, p. 18) designates clash detection as a “*construction benefit*” and outlines a number of other construction and fabrication related benefits. Eastman et al. (2011), Azhar et al. (2008) and Wu et al. (2014) state that with increased pre-construction knowledge there is a greater capacity for off-site construction and the production of prefabricated elements. Contractors who have the capability to exchange accurate BIM information with fabricators will save time because the model can contain information needed by the fabricator to geometrically set out the prefabricated components (Azhar et al., 2008; Eastman et al., 2011). Further to this, factory conditions increase the quality of production, reduce errors and can allow economy of scale (Azhar et al., 2008; Eastman et al., 2011; NBS, 2014).

The benefits of BIM are not just related to design and construction efficiency. BIM can be utilised to improve the reliability and accuracy of cost estimation and scheduling (Azhar et al., 2008; Goucher & Thurairajah, 2012; Matipa et al., 2010; Smith, 2014; Wu et al., 2014). Matipa et al. (2008) and Wu et al. (2014) claim one of the most favourable aspects of BIM is the ability to generate QTO for estimating purposes by running extraction algorithms on the objects of the model. The benefits of BIM for cost estimating and scheduling are presented in additional dimensions of BIM, which are propagated from linking additional information to the design attributes of the model (Matipa, Kelliher, & Keane, 2008; Smith, 2014; Wu et al., 2014). These dimensions and the way in which quantities can be extracted are addressed in further detail in Section 3.4, as this is where the research topic (LCC) resides in the context of BIM dimensions.

3.3.5 Dimensions in BIM

The BIM authoring application produces a 3D visualisation of the building and is used by Architects to produce the design (Eastman et al., 2011). However, this application alone does not represent BIM because 3D visualisation can be represented with CAD without any representation of what data is contained in the drawing. As discussed in Section 3.3.1, it is the ‘information’ that is contained in the model that is of importance, such as its u-value, fire rating and specification. In this context, Ajibade & Venkatesh (2012) and Boon (2009) determine that by adding time and cost information to the model a 4D time model and 5D cost model can be produced, respectively. The 4D process links the 3D objects to a time frame which can be used to produce a schedule of works (Fu et al., 2007; Wu et al., 2014). The

5D application recognises materials used within the model and where available, assigns the associated cost to these components (Fung et al., 2014; Smith, 2014; Wu et al., 2014). Smith (2014) states that this is cost and time attributing and is parametric and dynamic, so that any change to the model will result in a change to the project cost estimate or schedule. Fu et al. (2007) and Azhar et al. (2008) claim that 4D and 5D BIM has improved communications in the construction process and reduced the duration and cost of a building project. However, there is little empirical evidence available in relevant literature to support these assertions and such claims need to be taken with care.

Aouad et al. (2005) and Fu et al. (2007) outline that ‘Infinite dimensions’ (nD) is a term in BIM to describe the expanding application to include the broader aspects of the built environment; these attributes include sustainability, acoustics, maintenance, lighting and buildability. Fu et al. (2007) outline that these considerations are primarily used in ‘what if’ analysis throughout the whole life cycle of a building, rather than just focusing primarily on 3, 4 and 5D. After the 5th BIM dimension for cost, there is ambiguity on what constitutes nD modelling (Sawhney, 2014). For example, a number of publications discuss a 6th BIM dimension (6D) and 7th BIM dimension (7D). 6D BIM relates to FM and provides a rich database of operational data, such as maintenance, replacement, specifications and warranty data (Smith, 2014; Bryde et al., 2013; Abbasnejad & Moud, 2013; O’Keeffe, 2012). 7D focuses on utilising BIM for energy analysis, sustainability and LCA (Smith, 2014; Barnes & Davis, 2014). An 8th dimension is even discussed by Smith (2014), which he notes incorporates the safety aspects of design and construction.

Bakis et al. (2003), Aouad et al. (2005) and Fu et al. (2007) did not recognise additional dimensions beyond 5D and as noted previously assigned the expanding applications of BIM under the definition of nD. However, since the publication of Fu’s work on the application of nD modelling for LCC, the terms 6D and 7D modelling has become more evident in recent publications (Barnes & Davis, 2014; Smith, 2014; O’Keeffe, 2012; Sawhney, 2014). In this context, the focus of LCC falls within the 5th cost dimension of BIM and if carried out during the operational phase crosses over into 6D modelling. However, according to Barnes & Smith (2014) LCC and WLCC is mainly provided for in 5D and thus in this research it is referred to as an extension to the 5D process.

Mitchell (2012) and Wu et al. (2013) ascertain that most of the development in BIM has occurred in the design sphere of 3D modelling, while very little development has happened in the fields of 4D and 5D. Mitchell (2012) states that for BIM to be truly successful then all the ‘dimensions’ need to be embraced.

3.3.6 BIM Adoption Trends

Considering the benefits articulated above, Wu et al. (2014) note that BIM has the potential to transform the industry and provide the tools to address the inefficiencies outlined in reports such as Latham (1994) and Egan (1998). BIM use within the construction industry is by no means common place, but awareness of BIM and an increase in its implementation has gained momentum globally over the last five years (Smith, 2014).

The National Building Specification (NBS) in UK has published an industry wide survey of BIM usage and awareness every year since 2010. These reports indicate a rapid increase in BIM usage and awareness. For example, in 2010 BIM usage was at 13%, indicating that it was very much isolated on a small number of projects; in 2013, 54% of respondents had used BIM on at least one project (NBS, 2014). The 2014 statistics indicate a slight drop to 48%, but the NBS contend that this represents a temporary plateauing of BIM use and does not constitute a reversal in the trend (NBS, 2015). This statement is speculative, it remains to be determined based on the future publication of the 2015 findings (to be published in 2016) if this is a temporary plateauing, stagnation, or even a reversal of the upward trend. A number of authors comment that the rapid recent increase in BIM use in UK, is a result of a UK mandate for level 2 BIM maturity on publically funded projects from 2016 (Crowley, 2013; Smith, 2014). This will be discussed in more detail in Section 3.3.9. In light of the UK mandate, if the soon to be published 2015 NBS findings indicate that BIM use has decreased in the previous two years (2014 & 2015), it could pose a significant problem for the success of the UK’s government focus on BIM.

A similar trend is demonstrated in the McGraw Hill (2014) report entitled ‘The Business Value of BIM for Construction in Major Global Markets’. As demonstrated in Figure 3.4, the McGraw Hill report illustrates, that BIM adoption in UK was 28% in 2013. This starkly contrasts with the NBS survey in the same year, which states that BIM use was 54%. However, these findings are possibly representative of what

constitutes ‘BIM use’ in these studies. In the NBS survey it included BIM use on only ‘one or more projects’, while the requirement of BIM use in the McGraw Hill report was ‘at least 30% of the company’s projects’. As illustrated in Figure 3.4, the McGraw Hill report also predicts BIM use will be 66% in UK in 2015, which accentuates further ambiguity between these two surveys. As stated previously, based on the NBS findings in 2015, BIM use decreased to 48% in 2014 and if this trend continues or even remains the same, BIM use will fall considerably short of McGraw Hill’s 2015 prediction of 66%.

BIM adoption by the construction industry in North America has increased from 28% in 2007 to 55% in 2013 with a predicted increase to 79% in 2015 (McGraw-Hill, 2014). This indicates that this region is leading the way globally, driven by public procurement agencies such as the General Services Administration (GSA) and US Army Corps of Engineers adopting BIM within their procurement strategies (McGraw-Hill, 2014; Smith, 2014).

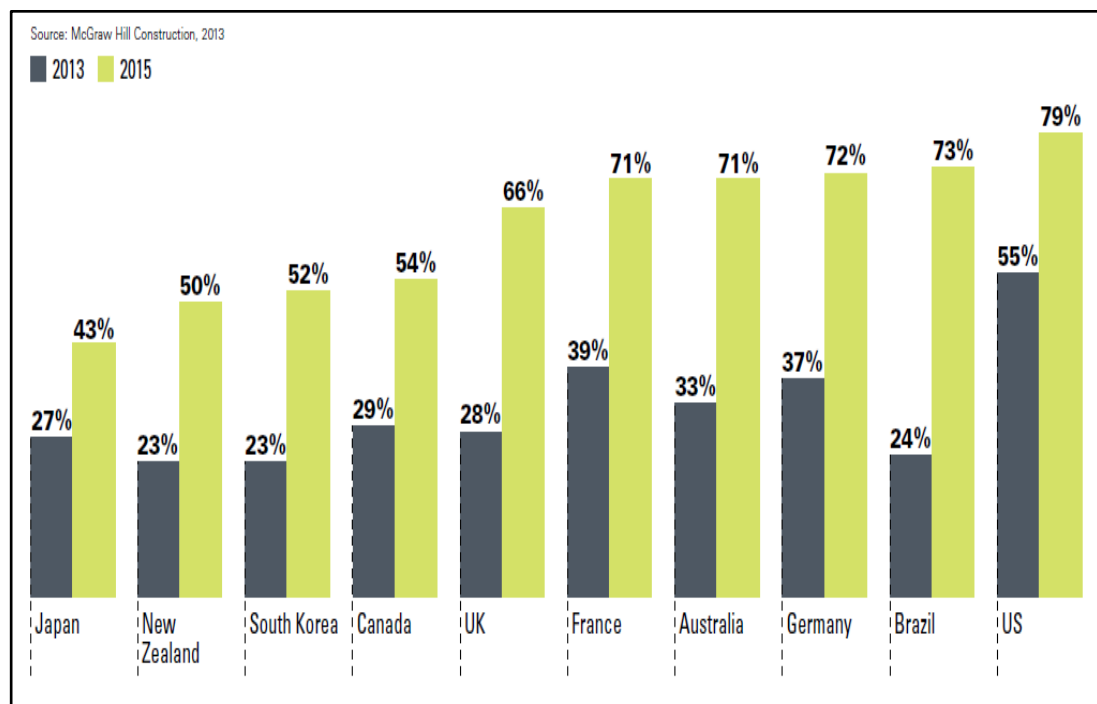


Figure 3.4: Percentage of BIM implementation (McGraw Hill, 2014)

In Europe, Scandinavian countries have a strong BIM development and implementation record. Denmark and Finland have implemented government initiatives requiring BIM to be used on all public sector projects since 2007 (Smith, 2014; Wu et al., 2014). Sawhney (2014) states that BIM maturity is more advanced in Finland than any other part of the world. Norway implemented similar initiatives

with the Statsbygg Agency requiring BIM on government work from 2010 (Wu et al., 2014). Also reported in the McGraw Hill (2014) survey is the level of BIM implementation in France and Germany with 37% and 39%, respectively in 2013.

A similar increase in adoption is evident worldwide especially in developed economies, albeit not at the same levels as UK and US markets (McGraw-Hill, 2014). In Australia, BIM adoption was at 32% in 2013 but it is expected to increase significantly to 71%, as evidenced in the McGraw Hill (2014) report. Smith (2014) adds that the rapid increase in BIM in recent years in Australia is not a direct product of a government mandate, but rather a drive from industry stakeholders who advocate a BIM approach. Sawhney (2014) notes that there is a road-map outlined by the Australian government over the next two years to develop national BIM standards, protocols and contracts, that will ultimately provide the framework for BIM on government projects by July 2016.

In Asia-Pacific regions, the Singapore Building and Construction Authority has also mandated BIM implementation by 2015 on all new building projects over 5000m² (Sawhney, 2014; Smith, 2014; Wu et al., 2014). Smith (2014) also states that the Singapore government have invested substantially with strategic initiatives to help transform the construction industry and facilitate the change required for their 2015 mandate. The Hong-Kong Housing Authority has set a target to apply BIM on all new projects by 2014 (Sawhney, 2014). South Korea and Japan are also embracing BIM adoption as evidenced in the McGraw Hill report, where BIM use in 2013 was 23% and 27%, respectively.

As stated previously the McGraw Hill report is predicting a 100% increase between 2013 and 2015 for the majority of countries in Figure 3.4. This is difficult to reconcile given that UK (which has a BIM mandate in 2016) will not reach this level based on the NBS survey. It calls into question the accuracy of the 2015 predictions for all countries in the McGraw Hill report.

The most recent adoption statistics available for Ireland are from the Royal Institute of Architects Ireland (RIAI) BIM Survey (RIAI, 2011). This survey maintained that BIM use amongst construction professionals in Ireland was 17%. This statistic corresponds with a similar level of BIM adoption in UK at the time (13% in 2010). Although no recent figures are available in Ireland, given the exponential rise in

recent years in UK, a similar upward trend could be expected. However, McAuley et al. (2012a) maintain there is lack of engagement from the Irish government in BIM and there are currently no plans to integrate BIM standards or procedures in the public procurement process. Thus, they note that a similar level of increase in Ireland may not be achieved.

3.3.7 BIM Implementation Issues (Barriers)

There are some significant challenges and disadvantages to implementing BIM in construction work practices, which are still prevalent even in light of recent global developments and trends in BIM adoption (Arayici et al., 2011; Arensman & Ozbek, 2012; Eastman et al., 2011). Eastman et al. (2011) and Arensman & Ozbek (2012) divide these issues into a number of themes such as changes in work practices; challenges regarding running BIM applications (hardware, software and training); legal concerns with respect to who owns the multi-disciplined model and challenges with increased collaboration, integration and interoperability across the construction supply chain.

Focusing firstly on changing work practices, Smith (2014) and NBS (2014) emphasise that BIM requires a new way of working, a new mind-set and change of culture. The reason for this, Fung et al. (2014) claim, is that BIM presents a very different approach to traditional work practices, where a collaborative environment under a common framework is a necessity from the outset. Arayici et al. (2011) stress for this to be achieved every aspect of a company's business requires significant changes. Smith (2014) suggests that this may require changing the mind-set of the staff that are accustomed to 2D work practices and traditional procurement systems. Bylund & Magnusson (2011) elaborate that this should be facilitated from a top down approach, where a move to BIM in a construction organisation is driven from strategic implementation at a management level. Other changing work practices can occur on the roles of members of the design and construction team working under new conditions (Sawhney, 2014). For example, Redmond et al. (2012) outline that questions may arise relating to who is in charge of the total quality of design on a collaborative model.

Another issue is working in a collaborative environment and on a collaborative model, which causes various complications in terms of legal impediments (Arayici et

al., 2011; Arensman & Ozbek, 2012; Eastman et al., 2011). Azhar et al. (2008) indicate that the main legal issue is to establish who owns the model and how to protect it through copyright laws. Redmond et al. (2011) note that the major problem is that no one can really take responsibility for a model that is essentially collective. Another legal problem is that BIM blurs the level of responsibility between parties leaving it unclear who is responsible for any inaccuracies (Arensman & Ozbek, 2012). This permeates by creating problems for insurers in relation to establishing responsibility and insuring the stakeholders (Eastman et al., 2011; Smith, 2014). Smith (2014) and Azhar et al. (2008) agree that these issues have yet to be resolved effectively and what is required is a unique response to every project, depending on the owner's needs. Eastman et al. (2011) and Forgues et al. (2012) contend that a new approach is necessary where professional groups and state organisations must develop new guidelines for contractual language to cover copyright issues raised in using a BIM approach. As discussed previously, this can be facilitated through IPD promoting a collaborative framework and contractual environment (Eastman et al., 2011; LCI, 2013). It is yet to be determined whether this can be achieved or how quickly. Redmond et al. (2012, p.5) note *“particular contract terms should be considered as additional clauses; establishing partnering and legal entity of enterprise; for roles & responsibilities; agreement of payment features, and dispute resolution using BIM”*.

BIM applications and BIM files require higher-end hardware resources than traditional 2D applications. BIM technologies, in contrast to office applications and traditional CAD technologies, require more memory, a larger hard drive, a better graphics card and often a larger screen. (Azhar et al., 2008; Eastman et al., 2011; Howell & Batcheler, 2005). Smith (2014) and McGraw Hill (2014) note that whilst there is an acknowledgement that companies will benefit in the longer term from investing in BIM, the costs associated with upgrading their software and purchasing BIM tools are significant. Zhou et al. (2012) adds that this is even more problematic for Small to Medium-sized Enterprises (SMEs) especially during an economic recession where just keeping their business going is difficult. Even if organisations spend the required resources on software and hardware they may not have the skills necessary amongst their staff to utilise these applications and realise the benefits from BIM (Azhar et al., 2008; Cheung, Rihan, Tah, Duce, & Kurul, 2012). Training

staff to use BIM software adds additional expense to hardware and software upgrades (Azhar et al., 2008; Forgues et al., 2012).

Working in a collaborative environment may give rise to further issues other than the legal problems regarding copyright. Eastman et al. (2011) provide an example where designers use traditional 2D practices and thus downstream other consultants and contractors will not be supplied with the necessary outputs to utilise BIM. However, Eastman et al. (2011) clarifies, that in many instances other members of the supply chain may utilise their own models to increase efficiencies in their work practices, even if a BIM is not available.

Presuming that all of the parties in the construction supply chain have committed to working on a collaborative BIM, 'interoperability' problems regarding software applications can arise (Cheung et al., 2012). A number of authors have raised this as one of the most significant issues in effective BIM implementation (Cheung et al., 2012; Goucher & Thurairajah, 2012; Taylor & Bailey, 2011). NIST (2004) reported that 15.8 billion is lost annually by interoperability problems in the construction industry in US. Furthermore, McGraw-Hill outline that interoperability is deemed an important consideration by contractors considering investing in BIM (McGraw-Hill, 2014).

3.3.8 Exchanging BIM data

As design team members rely on their own discipline specific software to build and manage their models, it is necessary that there is movement of information from one BIM application to another (Cheung et al., 2012; Matipa et al., 2008). The smooth sharing of information across all BIM applications and disciplines (where different software can recognise the product of another) is described by Arayici et al. (2011) as 'interoperability'. Cheung et al. (2012) view interoperability as the key underpinning of BIM, because it allows various stakeholders to work together by exchanging information, even if they are working with different applications. Taylor & Bailey (2011) note that interoperability's importance in BIM is based on how information can be exchanged for the beneficial reuse for another. If this process is lacking or data is lost in that exchange full collaboration cannot be realised (Smith, 2014). Eastman et al. (2011) explain that in order for collaboration to be efficient and effective, the object based data exchange needs to include geometric shape,

specification, parametric properties, a classification structure, assembly data and the overall design intent - so that this information can be extracted and utilised by other stakeholders in the supply chain. Goucher & Thurairajah (2012, p. 3) found that interoperability is currently underdeveloped and is a major issue “*that BIM adoption has got to deal with*”. Crotty (2012) outlines the need for agreed exchange formats to be used in all key applications.

Bylund and Magnusson (2011) claim that there are two approaches to interoperability and data exchange. They state that users can either stay in one software vendor’s product range and use their specific file formats or use software from various vendors that can exchange information in a common language. Matipa et al. (2010) clarify an example of this first approach would be the exchange of proprietary DXF (Data eXchange Format) files between the Autodesk product range, such as ‘Revit’, ‘Navisworks’ and ‘Autodesk QTO’. Howell & Batcheler (2005) emphasise that this type of collaboration can be difficult to achieve because it is rare that all the design and construction team will be using one application or one vendor’s product range.

Bylund and Magnusson’s (2011) second approach describes a more flexible process where open-proprietary file formats can be exchanged between different applications. An example of an open proprietary file format is a Portable Document Format (PDF). However, this is a vector format, which only contains geometry rather than data, thus it would not constitute a BIM data exchange under the definitions of BIM outlined above (Crotty, 2012; Eastman et al., 2011; NIBS-BuildingSMART alliance, 2012).

Goucher & Thurairajah (2012) say that open-proprietary data exchange has been improved through the establishment of Industry Foundation Class (IFC), which is a common data ‘schema’ that makes it possible to exchange data between different proprietary BIM software applications. Sawhney (2014, p.15) defines a ‘schema’ “*as a formal structure of a defined set of information*”. IFC is developed by BuildingSMART International (BSI) (formerly the International Alliance of Interoperability), an international not-for-profit organisation which constructs and supports what they describe as ‘Open BIM’ (BuildingSmart; Dhillon, Jethwa, & Rai, 2014; Wijayakumar & Jayasena, 2013). As an open format, IFC does not belong to a single software vendor, it is neutral and independent of a particular vendor’s native

format and plans for software development (BuildingSmart, n.d). The IFC language is specified using the EXPRESS data definition, as defined by ISO103-11:1994 (Dhillon et al., 2014; Eastman et al., 2011). Sabol (2008) states that IFC is now recognised as an internationally accepted framework to facilitate information exchange among participants throughout the built asset's entire lifecycle. IFC has gone through a number of evolutions, with the newest version IFC4 published in 2013 as ISO 16739:2013 (BuildingSmart; Dhillon et al., 2014). At present, many BIM software vendors have integrated IFC importers/exporters within their applications. This enables models to be imported and exported from BIM authoring applications, such as Autodesk Revit into 5D estimating applications such as Exactal CostX, Autodesk QTO and Nomitech CostOS (Dhillon et al., 2014; Fu et al., 2007).

However, IFC is not without issues. A number of authors comment that IFC does not completely solve the problem of interoperability as there is a degree of data loss through the exchange of information between heterogeneous software (Eastman et al., 2011; Redmond et al., 2011). Cheung et al. (2012) explain that this can happen due to the lack of uniformity between object schemas adopted between individual BIM tools and the IFC objects and properties. Redmond et al. (2011) claim that true interoperability will only be achieved when every software being used on a project can read and write to and from a centralised web hosted database by standardising the process of passing information between stakeholders and representing the latest information on the project.

Open-proprietary file formats such as IFC are a 'collaboration benefit' from a technological perspective, but they do not fully address all the implementation issues when adopting a BIM approach (Moore, 2015). Moore (2015) and Eastman et al. (2011) agree that a 'collaborative working environment' needs to be promoted to help teams produce information in a consistent format and at certain designated stages throughout the lifecycle of the built asset. A collaborative working environment is achieved through the production of co-ordinated design and construction information, providing order to the information flow for all those involved. This is achieved through 'collaboration exchange standards', where teams agree to produce information using standard processes and agreed standards and methods to ensure a consistent form and quality of information in a timely manner (BSI, 2013b). Collaboration exchange standards can take the form of a bespoke

agreed protocol; a BIM execution plan or the adherence to published jurisdictional standards or guidance documentation (Moore, 2015).

3.3.9 UK Government Level 2 BIM

The UK public construction sector is moving towards the legal implementation of BIM by 2016 (Crowley, 2013; Smith, 2014; Barns & Davies, 2014). Known as the ‘UK BIM mandate’, it is part of a phased BIM development programme where public projects will be required to be delivered, in line with that defined by BIM Level 2, from 2016 (Cabinet Office, 2011; Crowley, 2013; Goucher & Thurairajah, 2012). Smith (2014) and Crowley (2013) state that the UK mandate is considered the most ambitious and advanced government driven BIM framework in the world. The objective is to transform the UK construction industry into a global BIM leader by significantly reducing CAPEX, OPEX and carbon emissions from built assets under the ward of the UK public sector (Cabinet Office, 2011; NBS, 2014).

For this to be achieved, the UK construction industry needs to move from Level 0, which is based on 2D work practices, to a Level 2 BIM implementation standard, which is BIM – File Based Collaboration and Library Management (Figure 3.5) (BSI, 2013b; Underwood & Isikdag, 2010; Barns & Davies, 2014). Sawhney (2014, p.7) explains that BIM Level 2 “*is a common method of producing, exchanging, publishing and archiving information*”. Sawhney (2014, p.7) adds that Level 2 can be described as pre BIM (pBIM) as full integration is yet to be achieved, because models are still “*discipline centric*’ and “*proprietary*”. This is in line with authors that suggest disciplines are managing their own models rather than collaborating on a fully integrated model and would suggest that this level is attainable based on current practice. The overall goal, on the other hand, is to achieve a Level 3 BIM standard which requires further integration through an Integrated Web Service BIM Hub and full open process managed by a collaborative model server (BSI, 2013b; Barns & Davies, 2014). The ‘Strategic Plan’ for attaining Level 3 has recently been set out in ‘Digital Built Britain’ (HM Government, 2015; Barns & Davies, 2014). Attaining BIM Level 3 requires further integration and collaboration through change in the industry’s management processes and procurement systems, leading to a collaborative computerised construction industry by 2025 (HM Government, 2015). One of the emphasis of BIM Level 3 is ‘asset life cycle management’ which focuses on the management of the built asset throughout its operational phase (Sawhney,

2014). This is in the realm of 6D BIM modelling where LCC can be used to calculate possible future expenditure.

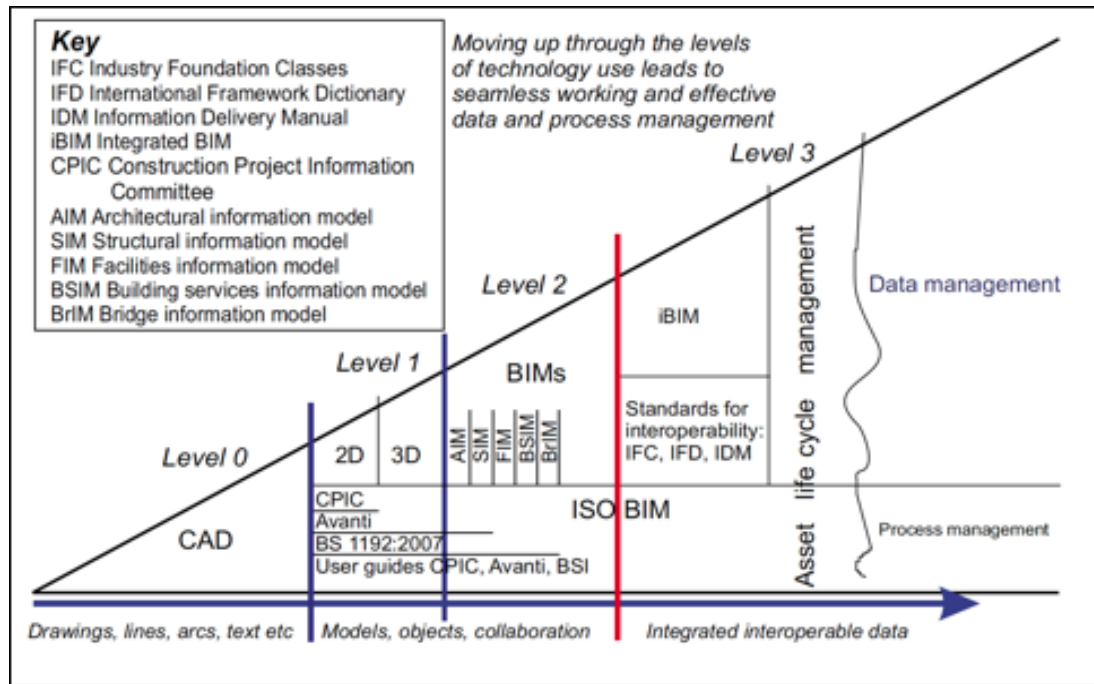


Figure 3.5: Bew Richards BIM maturity wedge: (BSI, 2013)

As part of the 2016 strategy there has been a suite of documents, protocols and standards, published by UK public agencies and stakeholders in the last five years, to provide assistance to design and construction teams developing their BIM capabilities (McAuley, Hore, West, & Rowland, 2013; Barns & Davies, 2014). Public Assessable Standard (PAS) 1192-2:2013 (BSI, 2013b) is one of the most important documents from this suite, in that it presents a protocol for BIM usage that focuses on collaboration information standards for the CAPex phase of a construction project (Moore, 2015; Barns & Davies, 2014). PAS 1192-2:2013 provides specific guidance for the information management requirements associated with projects delivered using BIM. It also describes the context of other important deliverables and documents in the suite for delivering BIM Level 2 by 2016 (BSI, 2013b; McAuley et al., 2013). The key documents referenced in PAS1192-2:2013 are the Construction Industry Council's (CIC) 'BIM protocol', Royal Institute of British Architect's (RIBA) 'Digital Plan of Work', 'Uniclass 2', 'Government Soft Landings (GSL)' and 'COBie UK' (BS 1192-4:2014).

The CIC BIM protocol provides a legal agreement which can be incorporated into professional service appointments and construction contracts by means of an amendment to address legal issues involved in working in a collaborative BIM

environment (Sawhney, 2014). The RIBA Digital Plan of Works and the Uniclass classification provide clarity and structure to the digital deliverables on a BIM project. The UK Government's GSL, is a document which is designed to link all the stages of the life cycle to ensure value is achieved throughout the operational lifecycle of an asset (BSI, 2013b; McAuley et al., 2013; NBS, 2014).

Most of the documents in the 2016 Level 2 Suite are information standards, whereas the last document listed above, COBie UK, is an information exchange format. COBie stands for Construction Operations Building Information Exchange (COBIE) and it is an information exchange format that obtains useful information which is put into the model during both the design and construction phases of the project (McAuley et al., 2013; NBS, 2014). COBie is outlined in BS 1192-4:2014 (BSI, 2014) which defines expectations throughout the life cycle of a facility by specifying a COBie schema for information exchange per the UK Level 2 BIM mandate. The captured information can then be passed to the building owner in a structured format free of charge and utilised in their FM program during the occupation of the building (BSI, 2014). COBie is formally defined as a subset of IFC whereby additional COBie parameters are added to IFC properties of BIM library objects (Nisbet, 2012). COBie information can also be exported from modelling software to spreadsheet form. COBie parameters are important in the context of this research as they provide useful information on LCC such as 'Replacement Cost' and 'Service Life Duration'. McNell et al. (2011) claim in terms of efficiency, the applications of this robust database appear to provide endless advantages for not only the owner and facilities manager but also information that can be utilised by the design team. Many parties can use COBie information including engineers whom can use it for detailed energy modelling and QSs for LCC analysis (McNell et al., 2011).

As discussed in Section 3.3.6, the NBS (2014) survey indicates that BIM use in the UK was at 48% in 2013. If this statistic remains the same through 2015, it could call into question whether the industry is ready for this mandate.

3.3.10 Irish Perspective

McAuley et al. (2012b) state that BIM developments in UK are encouraging to an Irish perspective, as Ireland's current contracting arrangements are not considerably different to UKs. The Forfás Report (2013) echoes this sentiment and proposes to

work with industry organisations to promote the use of BIM and develop the appropriate technical skills amongst Irish construction firms, so that they can successfully compete in markets where BIM is widely adopted or a requirement. The report further acknowledges that within the Irish construction sector there is a continued low take-up of ICT and an emerging competitive disadvantage in project delivery due to slow adoption of process improvement and productivity enhancing BIM systems. Maguire (2015) stresses that “*if our closest neighbours UK are going to mandate BIM, it looks like it’s going to be an option for other European members to mandate it in the EU. There’s an inevitability that Ireland will have to follow*”. Crowley (2013) is in agreement and feels that BIM will eventually permeate across all levels and all stages of the supply chain and it is important that the public sector in Ireland recognises the importance that BIM can bring. The role of the Irish Government will be important if BIM is to be implemented in Ireland. McAuley et al. (2012b) maintain the Irish Government, similarly to the UK Government, must be a major driver in this process for transformation and change in the industry, as well as, review current BIM initiatives and barriers within internationally public sector procurement.

3.4 BIM and Cost Management

3.4.1 Utilising BIM for Cost Management

Traditionally, QSs and estimators take off manually from the Architect’s paper drawings or import 2D CAD drawings into an estimating software package and carry out onscreen QTO (Ajibade & Venkatesh, 2012; Drogemuller & Tucker, 2003). This process is described by Sabol (2008) and Ajibade & Venkatesh (2012) as a time consuming and a costly process, which is prone to human errors that often lead to inaccuracies in the estimates. Monteiro & Martins (2013) explain that issues can arise in this process because measurement is essentially open to interpretation. For example, a QS measuring from 2D drawings may not have the same vision as the designer or make assumptions that are not in line with the designer’s intent.

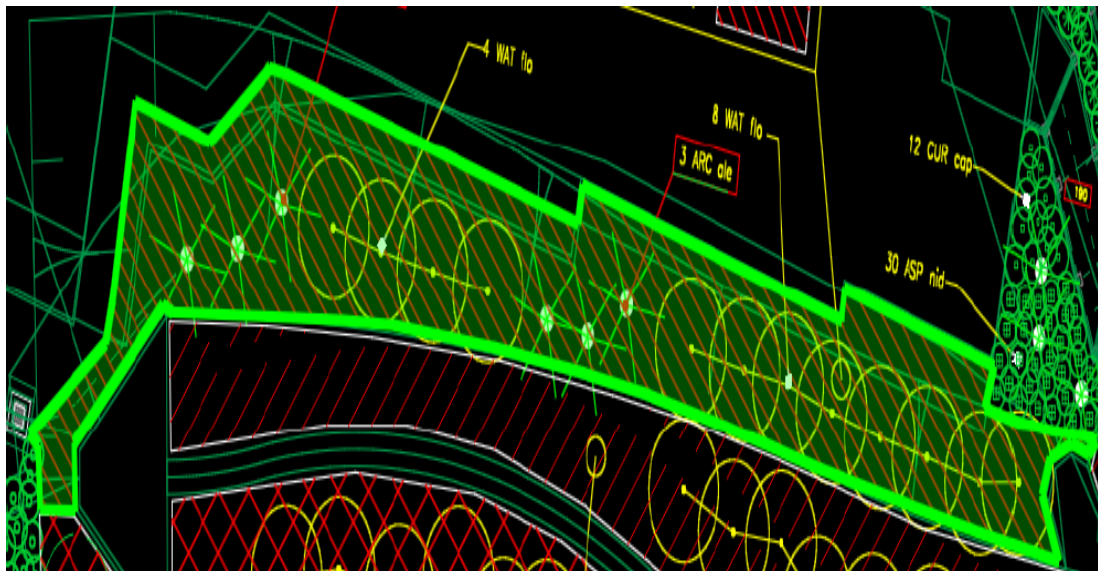


Figure 3.6: 2D On-Screen Take Off (Lovegrove, 2010)

As demonstrated in Figure 3.6, the development of QTO software from 2D CAD has made it easier for QSs measuring quantities from 2D drawings by automating the computation of areas, lengths and volumes (Wijayakumar & Jayasena, 2013). Wijayakumar & Jayasena (2013) ascertain that automation has greatly improved QSs working efficiency but the manual process is still prevalent in 2D QTO. They explain that QSs still have to manually extract information from the drawing data files using digital pointers rather than scale rulers. This automates the QTO process and reduces mistakes, but it is still prone to human error and is time consuming (Sabol, 2008; Matipa et al. 2008; Wijayakumar & Jayasena, 2013).

BIM has the potential to help QS practices and construction companies estimate the cost of a project with more detail and accuracy, while reducing time and expenses (Eastman et al., 2011; Goucher & Thurairajah, 2012). Figure 3.7, illustrated by Eastman et al. (2011. p.279), presents the difference between the traditional estimating process and the 3D/BIM estimating process. The top half of the figure illustrates the 2D QTO process, where you can either manually take off the quantities from dimensions on the drawings or digitize quantities by using onscreen QTO applications. In the 'BIM based estimating process' (bottom half), Eastman et al. (2011) accentuate that there is a digital link between the quantities extracted from the 3D model and the assembly of the estimate. The quantities from the model can be automatically generated within the BIM authoring tool or can be imported into specialised BIM estimating software and manually or automatically extracted. This is discussed in greater detail in Section 3.4.2.

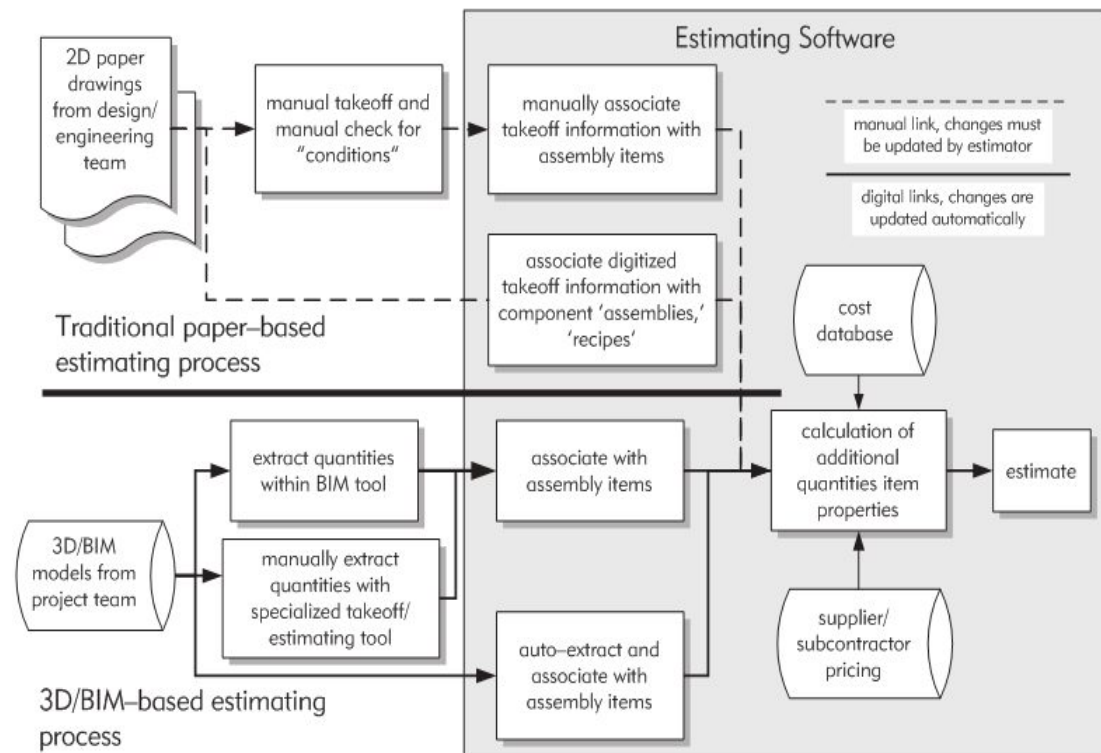


Figure 3.7: Estimating Processes (Eastman et al., 2011, p.279).

The benefit of cost planning through BIM, as discussed by Sabol (2008), is that it quantifies exactly what is in the model, so there should be no variations between what has been measured and what is required. It is also much simpler and faster to quantify and cost a variation or an extension to the works as the quantities will automatically be updated when the model is changed (Eastman et al., 2011). Monteiro & Martins (2013) determine that QTO in BIM is carried out by routines that can perform calculations on the geometry of the model to extract measurement data. These are provided as an output through schedules within the software, which can also be exported to MS Excel (Fung et al., 2014).

One of the issues with extracting quantities within the BIM authoring tool is that it is primarily a design tool and is not robust enough for the QS carrying out cost estimating (Forgues et al., 2012; Olatunji et al., 2010; Sabol, 2008). A QS may not find the Architect's BIM tool sufficient for cost plan modelling because architectural BIM schema are not compatible with the elemental or trade code structure required under QS classifications and Standard Method of Measurements (SMMs) (Lovegrove, 2014; Sabol, 2008; Sawhney, 2014). Figure 3.8 illustrates an example of the hierarchical structure of the Revit model schema (on the left). Quantities automatically extracted from that schema will output in the Revit structure

(Category, Family & Type) and thus will need to be mapped to the applicable QS building elemental schema (on the right). This will be outlined in further detail in Section 3.4.3.

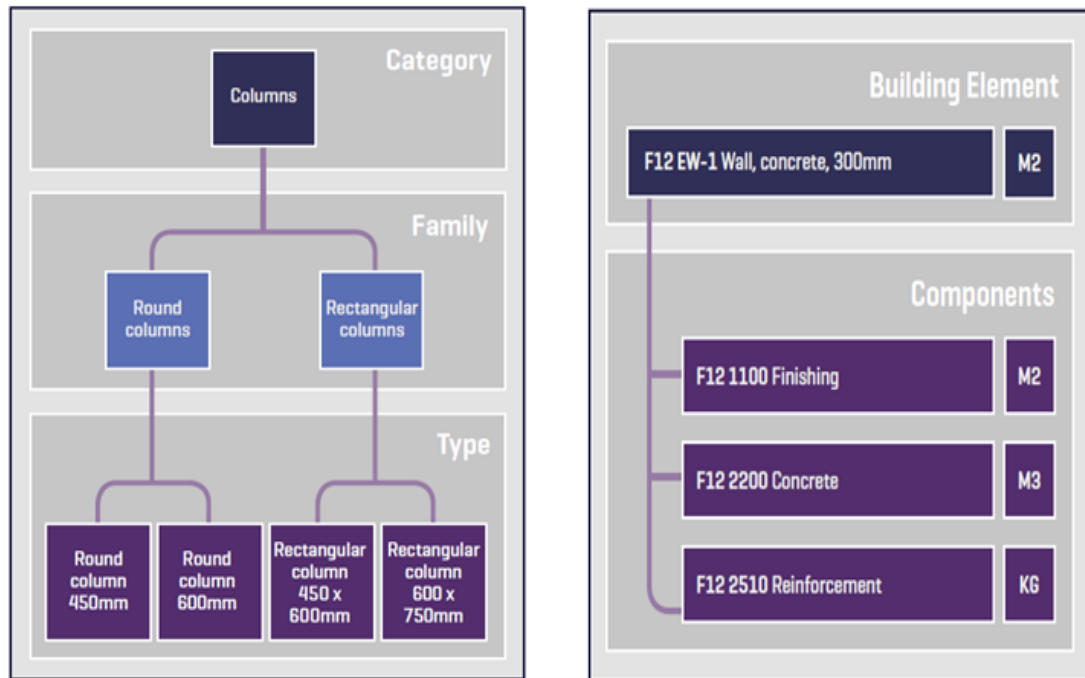


Figure 3.8: Classification of Building Elements (Wu et al. 2014)

This means that QTO outputs from the model are limited to the classification structure of the model, which is further compounded as these output schedules cannot be manipulated within the application (Monteiro & Martins, 2013). Ultimately, there is no magic button in the BIM authoring tool that will generate a BOQ in Ireland's Agreed Rules of Measurement 4 (ARM 4) or UK's NRM 2.

Different jurisdictions have different SMMs. Discussed in Section 2.3, In UK, the SMM 7 has been replaced by the NRM 2 and in Ireland the current standard is the ARM 4. Australia, the Middle East and Canada also have different SMMs. Olatunji et al. (2010) state that multiple SMMs mean that the financial returns to software developers to develop country specific BIM/SMM filters are limited. Olatunji et al. (2010) note that there is a major issue in developing country specific estimates if the support of such filters is modest and the investment required to develop robust filters is considerable. The development of such filters has so far been restricted to research projects. Arguably there is a case for re-engineering measurement procedures so that they are comparable with BIM schema (Monteiro & Martins, 2013). There are precedents for more extreme approaches, which disregard SMMs altogether in favour of BIM-related cost code structures (Goucher & Thurairajah, 2012; Monteiro

& Martins, 2013; Olatunji et al., 2010). These issues will be discussed further in Section 3.4.3.

Despite agreement among a number of authors that the advantages of BIM revolve around a single model, Howell & Batcheler (2005), Taylor & Bailey (2011) and Smith (2014) dispute this in practice. Sabol (2008, p. 11) maintains that “*a monolithic, do everything system*” is yet to be developed. In practice these authors have found that design team members rely on purpose built models including separate models for 3D design, structural steel fabrication, energy analysis and the 4th and 5th dimensions of sequencing and construction cost planning (Howell & Batcheler, 2005; Sabol, 2008; Smith, 2014). This view poses a weakness to the idealistic BIM process outlined above, as it appears to go against the fundamental principle of using a single model for the purpose of consistency, collaboration, and reliability. The primary driver of these discipline specific purpose-built models, is that individuals who have greater expertise in their own fields prefer to build their own model in the way that suits them with discipline dedicated technology (Mitchell, 2012).

Mitchel (2012) states that from a QS perspective, practitioners are currently utilising their own traditional software to extract BIM quantities into familiar programmes. This has been facilitated by existing QS and estimating software adding BIM capability (Wu et al., 2014). Goucher & Thurairajah (2012) state that this process has seen the emergence of 5D BIM specialists whom can utilise 5D BIM technology, rather than rely on the BIM authoring tool to carry out QS activities. Sylvester & Dietrich (2010) and Crowley (2013) agree that with the 5D process, practitioners can move from spending time on generating quantity and cost information, to validating the quantities and costs contained within their estimates. However, this does not mean that the BIM authoring tool is not sufficient as a QTO application. It can produce a useful schedule of quantities and also through the use of open BIM (giving users the ability to programme/add additional functionality) provide users with the ability to add QS functionality. Further developments in this field will bring greater integration between disciplines possibly eliminating the need for a plethora of discipline specific software, but currently, this is not yet common practice (Mitchel, 2012; Eastman et al, 2011; Smith 2014; Howell & Batchelor).

3.4.2 5D BIM Estimating

QSs have traditionally relied on the functionality and computation capabilities of the spreadsheet. Most QSs produce their estimates and cost reports in spreadsheet applications such as MS Excel and Open Office, while many others use estimating applications that contain workbooks similar to standard spreadsheet applications (Matipa et al., 2008). The spreadsheet provides an automated tool that can carry out the number crunching, while providing an adaptable format to present cost information (OGC, 2007). Variations of the spreadsheet are embedded in many estimating applications where QTO, cost databases and the spreadsheet workbook exist in the same product and are harnessed and linked to help produce formatted cost plans.

According to Eastman et al. (2011, p. 220), “*No BIM tool (BIM design tool) provides the full capabilities of a spreadsheet or estimating package, so estimators must identify a method of BIM QTO that works best for their specific estimating processes*”. Sylvester & Dietrich (2010) recommend that the BIM 5D process requires third party software to conduct specialised activities related to detailed cost estimating. Eastman et al. (2011, p. 220) present three primary options for QSs working with BIM, based on Figure 3.7 presented previously in Section 3.4.1:

1. Export BIM object quantities to estimating software
2. Use a BIM quantity take-off tool
3. Link the BIM tool directly to the estimating software

Option 1 entails QSs exporting quantities from the BIM authoring tool, such as Revit Architecture, to the QSs estimating tool. Eastman et al. (2011) explain that even though there are over one hundred commercial estimating packages, MS Excel is the most commonly used. They maintain the reason for this is spreadsheet programmes provide the computational and formatting capabilities necessary for BOQ production at a price that is considerably less than bespoke estimating software. BIM quantities can be exported to MS Excel, where the QS can validate and utilise this data in their cost reports (Eastman et al., 2011; Wu et al., 2014). However, Hardin (2009) contends that this process is ineffective because there is no automatic link between the model and the quantities exported to MS Excel. Option 1 may also require QSs to buy both the design tool as well as the estimating software; firstly to generate and

export the quantities from the design tool and then to use the quantities to produce an estimate in the estimating tool. It would also require Qs to have knowledge of both systems (Monteiro & Martins, 2013).

The second alternative proposed by Eastman et al. (2011) is to use an estimating/QS tool that is capable of linking directly to a BIM tool, via a plug-in, such as VICO, Innovaya and Tocoman iLink. Matipa et al. (2008) describe this system as an integrated environment, where two software vendors have solved their interoperability problems through collaboration in an integrated system. This is a move to a more holistic BIM process where the design and cost management functions are housed in the same application. This process enables users to link objects in the BIM to assemblies and items in the QS's estimating database (Aouad et al., 2005; Eastman et al., 2011; Monteiro & Martins, 2013). This method is not possible if the Architect's authoring tool is not compatible with the QS's plug-in, or if the QS is using software that does not have this capability. Another practical issue, is that in this option (similar to option 1) the QS may be required to buy BIM design software that they are not familiar with and which will not give them the capabilities to carry out 2D onscreen measurement, which at the moment is still the most prevalent method in producing quantities (Forgues et al., 2012).

Traditional estimating applications have generally not been designed specifically for BIM. However, many of the leading software estimating vendors have added a BIM interface to their existing application as an updated extra (Eastman et al., 2011; Lovegrove, 2014). Outlined by Eastman et al. (2011) as their third option for Qs working with BIM, it integrates the outputs of the model with the cost database and workbook functions of the existing software (Matipa et al., 2008; Sabol, 2008). This is different than option 2, in that the 5D process happens in the QS's software rather than the BIM design tool. For this process to be facilitated, information needs to be exchanged between the authoring tool and the 5D BIM tool (Monteiro & Martins, 2013). As discussed in Section 3.3.8, this is carried out with the use of interoperable data, exported from the BIM application and imported subsequently into the 5D application (Monteiro & Martins, 2013; Wijayakumar & Jayasena, 2013). Once the model is in the 5D tool, Sattineni & Bradford, (2011) state that the 5D application has the potential to leverage the model by culling QTO and through a database management interface, price the components necessary for cost estimating. The

primary advantage of option 3 is that there is no need to purchase or get trained in new BIM software (Eastman et al., 2011) other than a possible upgrade to the existing estimating application. Another advantage is that the product still has the functionality for 2D take off, which is still prevalent in QS practice. Monteiro & Martins (2013) state that most 5D applications fall into this category such as Exactal's 'CostX', Nomitech's 'CostOS', Buildsoft's 'Cubit', CATO and Autodesk's 'QTO'. Matipa et al. (2008) propose that the skill in this process is the ability to navigate the model to extract the relevant quantities, and to do this, the QS must be familiar with the structure of the model. Forgues et al. (2012) maintain that a choice has to be made between adopting an application compatible with the company legacy and utilising BIM software that can integrate with their existing cost database. It is for this reason that many companies choose option 3, as they can continue with their legacy programmes. These three options indicate that this choice is absolute. As discussed in the previous section currently QSs are utilising their own discipline specific software to extract quantum from the 3D authored model (Smith, 2014; Matipa et al., 2010; Wu et al., 2014). However, if the quantities were already somewhat mapped to the QSs schema prior to the QS importing it into their software, it would help the QS post-processing the quantities for use in their estimates. This is discussed in further detail in the following section.

3.4.3 Mapping BIM Quantities to QS processes (Post-Processing)

Wu et al. (2014) contend that the efficiency and accuracy of QS functions can be significantly improved by aligning the BIM-based cost estimation process to QS classification systems such as the NRM schema.

Wijayakumar & Jayasena (2013) note that to do this effectively BIM quantities must be generated to suit QS requirements and measurements rules. The three options outlined by Eastman et al. (2011) above provide the mechanism to carry out this process through 5D BIM technologies. Drogmuller & Tucker (2003) describe a 'post-processing' system for generating and then validating the quantities from the model, where users can define and edit rules or codes by which the quantities can be extracted. Noted previously, if some of the processing was carried out by the Architect in their design software even to just identify what objects are below ground or above ground this would be beneficial to the QS. However, Drogmuller & Tucker (2003) state the most common method of carrying this out is in a 5D tool, which has

an integrated application of an estimating tool and a drawing viewer. This approach is in line with Eastman et al. (2011) option 3, where the model is imported into the 5D estimating application. Matipa et al. (2010) and Wijayakumar & Jayasena (2013) define this process as ‘model mapping’, where the objects in the model are attributed to a QS WBS or elemental code, so that when the quantities are extracted they are aligned to that code (Figure 3.9).

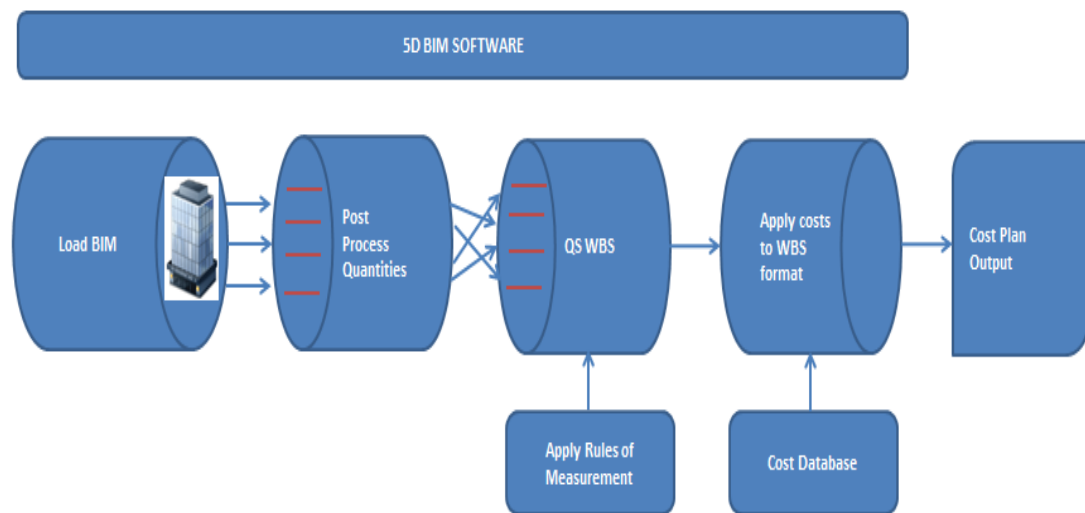


Figure 3.9: Mapping quantities

As stated previously, there are many different WBSs depending on the country or jurisdiction they encompass. Monteiro & Martins (2013) argue it would be near to impossible for IFC developers to add all the elemental codes and WBS structures into the objects for every global standard due to the amount of standards that exist. However, Matipa et al (2010) and Wu et al. (2014) say there is an opportunity in UK to consolidate the BIM schema with the information from the NRM 1. This is currently underway through the NBS digital toolkit where the NRM 1 codified framework is being mapped to the IFC objects in the NBS BIM library (Burrows, 2015). Although this will not eliminate post-processing it will, as explained previously, reduce the QSs workload in this regard. Matipa et al. (2010) claim this would have a positive impact on the cost planning process in UK as it would improve the speed as well as create a consistent approach to the allocation of cost resources, but they note it would not be applicable to other jurisdictions.

Given that cost mapping is not engrained yet in IFC objects, current practice is that QSs add these codes in the authoring application or append them in the estimating tool to suit the WBS they require (Crowley, 2013; Monteiro & Martins, 2013). If

there has not been any pre-processing in the design software, this is the first stage of post-processing the model. Generating quantities that are in a classification and unit that makes it easier for the QS to populate their cost plan (Drogemuller & Tucker, 2003). However, even after quantities are extracted in this manner, there is still considerable post-processing to include them in a cost plan or BOQ (Crowley, 2013; Drogemuller & Tucker, 2003; Monteiro & Martins, 2013). Mitchell (2012, p. 1200) states that the modern QS is carrying out post-processing by utilising models within the 5D environment to provide detailed and accurate estimates for what he deems “*living cost plans*”. The living cost plan would be categorised per Eastman’s option 3 above and means that there is what Lovegrove (2014) deems a “*live link*” between the 3D quantities generated from the model and the cost plan. For example, a BIM quantity could populate a number of different cost items in the estimate through the live link.

One of the cornerstones of BIM from a measurement and costing perspective is the dynamic population of the cost plan from the model (Barker, 2011). Updating the model will update those quantities generated from the model and in turn change all those dimensions and quantities in the cost plans, which are linked to the model quantity. The living cost plan becomes the basis for providing quick updated estimates every time the model information is changed (Mitchell, 2012; Sylvester & Dietrich, 2010).

Wu et al. (2014) reviewed the four most well-known 5D BIM applications in the UK market, i.e. Solibri Model checker, Autodesk QTO, Exactal CostX and Causeway’s BIM Measure, in order to comment on their ability to map to the NRM 1 schema. Wu et al. (2014) commented that all these systems provide different capabilities to map the model properties to an elemental classification (WBS) at various level of success. They noted that Exactal CostX, in particular, greatly supports manual intervention by providing the capability to extract quantities in a way that can be defined by the user.

3.4.4 Benefits of 5D

Wong et al. (2014) point out that clients are dissatisfied with the output of the QS as 50%-80% of their time is spent on the manual process of quantification, which can be prone to human error. Mitchell (2012) also notes that QSs spend 90% of their

time generating BOQs of which quantification is the most time intensive part. These figures are very high and there is no evidence of a survey or academic rigor to generate these figures in either paper, so their accuracy is somewhat questionable. However, it is widely reported that Qs spend a significant amount of time generating quantities (Ashworth et al., 2013; Cartlidge, 2011; Sabol, 2008; Ajibade & Venkatesh; Monterio & Martins 2013). As outlined in Section 3.4.2, BIM has the potential to automate the process of quantification, reducing the time needed in the cost planning and management process (Eastman et al., 2011; Goucher & Thurairajah, 2012). Monteiro & Martins (2013) claim that this provides a more accurate take-off, where margins of error are often below 1% compared with the same quantities using traditional methods. Monterio & Martins (2013) also ascertain that there is a possibility, due to the rich nature of data within BIM objects, to extract and differentiate information from the model beyond traditional measurements, such as the number of beams within a particular material characteristic.

Wong et al. (2014) note that 5D estimating is particularly advantageous at early stages of the design. Geometry from BIM at early stages of design comprises few quantities, thus information can be easily culled from the model to perform order of magnitude and elemental estimates (Cheung et al., 2012; Fung et al., 2014; Mitchell, 2012). Fung et al. (2014) explain that because there are less formality and measurement rules to preliminary estimating, it is easier to map BIM quantities to a relevant SMM structure. As outlined in the previous Section, this is evidenced where the NBS and the RICS are mapping the NRM 1 schema (cost planning rules) to the NBS digital BIM library schema rather than the NRM 2, which governs more detailed BOQ production.

Shen & Issa (2010) claim that BIM tools can address the significant limitations of 2D drawings that lack the rich three-dimensional (3D) context which estimators need in order to identify important cost-sensitive design features. Sylvester & Dietrich (2010) agree by stating that BIM has further helped estimators visualise real world conditions through a virtual 3D construction, which is of particular benefit in complex designs that are not easily represented in floor plans. Wong et al. (2014) say this is of particular benefit where the QS can carry out a 3D virtual walk-through and make sure everything in the model is factored in the QTO.

Wong et al. (2014) note that problems with the 2D process are that sometimes design changes are not reflected consistently in all views simultaneously. Due to the parametric capabilities of BIM, changes are automatically depicted in the model and propagated through all drawing views (Fung et al., 2014). Quantification is enhanced in this regard where drawing revisions and quantity changes per those revisions can be updated and identified quickly (Lovegrove, 2014). In the traditional process this would have been carried out manually where the QS would check and identify what has changed and make the changes to the estimate accordingly (Sabol, 2008). This can lead to serious consequences if the changes were not identified, possibly leading to claims on site (Fung et al., 2014).

Another benefit of the parametric capability of BIM is that QSs can quickly generate estimates for various design alternatives (Cheung et al., 2012; Mitchell, 2012). Mitchell (2012) maintains that multiple design options can be easily proposed at early stages of design through the capability of BIM software. They add that once live links are set up between the quantities and the estimate, any alternative can be investigated in real-time. Crowley (2013, p.2) describes this as “*optioneering*” and notes that this is beneficial to the client because early cost feedback and design alternatives provide an improved understanding of the likely implications of design decisions.

One of the overall benefits of BIM outlined in Section 3.3.4 is its capability to interrogate and merge multiple design disciplines in the same system to identify clashes and analyse interference (Wong et al., 2014). From the QS perspective, if clashes can be addressed in the design stage, there is a better chance a variation will not occur on site (Fung et al., 2014; Wong et al., 2014).

Eastman et al. (2011) outline that BIM offers capabilities for cost management during the construction phase of the project. They state that this is even more important than those benefits offered in the planning stage. Hardin (2009) explains that when linked to a 4D sequencing model accurate and informed payments can be made on the staged completion of works. Hardin (2009) argues that this provides transparency on staged payments and eliminates arguments on what sum the contractor is entitled to. Another advantage outlined by Hardin, is that due to the federated nature of the model, packages of work can be easily subdivided by the contractor and assigned to individual sub-contractors. This means that the

Contractor's Quantity Surveyor (CQS) can readily know exactly what elements, systems, and materials each subcontractor is responsible for and the associated cost.

BIM has the capabilities to increase efficiencies in QS practices especially in the area related to quantification and the associated utilisation of this quantification in cost reporting (Wong et al., 2014). Crowley (2013) and Sabol (2008) maintain that by adopting and utilising BIM the base skills of the QS can translate into enhanced skills providing more cost advice at the early stages of design and on alternative solutions (Crowley, 2013; Fung et al., 2014). Fung et al. (2014) and Mitchell (2012) envisage, through the implementation of BIM, that QSs will shift from simply BOQ producers to cost advisors, by having more time to concentrate on value enhancing activities.

3.4.5 QS BIM Implementation

Wong et al. (2014) and Wu et al. (2014) say that despite all the advantages of BIM for QS practice, QSs are lagging behind other professions in the implementation of BIM. RICS (2013) found that 49% of their QS membership were using BIM in 2013 compared to 10% (BCIS, 2011) in 2011. This is a significant increase, which Smith (2014) and Crowley (2013) agree is a likely product of the 2016 BIM government initiative in UK. Goucher & Thurairajah (2012) also carried out a survey of cost consultants in UK and found that 20% used BIM for cost management. Goucher & Thurairajah's (2012) survey compliments the RICS reports in 2011 and 2013 as it demonstrates a statistic in 2012 that was continuing in a rapid upward trajectory. There is no new data from the RICS on BIM uptake by QSs in the last number of years. Outlined in Section 3.3.6, overall BIM use in the construction industry increased from 2012 to 2014 (albeit with a slight decrease in 2014). There is reason to conclude that this trend is also continuing within the QS profession. However, even though BIM use by QSs has considerably increased from 2011 to 2013 it is still slightly less (49%) than other construction professionals at 54% in 2013, evidenced in the NBS (2014) report. Crowley (2013) also speculates that many QSs when answering surveys do not differentiate between 2D measurement and 3D measurement, which she states, indicates BIM use is considerably less than what is reported.

Wong et al. (2014) found that the major benefit of BIM for QS practice is that it automates the measurement process providing quicker more accurate estimates. This is an interesting statement given that the RICS report (BCIS, 2011) found that the most frequent application of BIM use by QSs was for construction scheduling (14%), with only 8% using it for quantification. However, 100% of the members' surveyed are considering adopting BIM and a further 51% have already invested in training. Crowley (2013) carried out a survey of Irish QSs and that found that 24% are currently utilising BIM technologies for QS practices. Crowley (2013) also found that a further 60% of respondents state that they will be using BIM within the next two years.

Several authors stressed that for BIM to become more main stream it is crucial to create greater awareness of the potential and benefits of BIM in surveying practice and to address the challenges that impede its general use in the QS profession (Matipa et al., 2008; Nagalingam et al., 2013; Wong et al., 2014).

3.4.6 Challenges with 5D BIM

Crowley (2013) and Fung et al. (2014) outline that QSs are slow to adopt BIM due to a lack of understanding of its capabilities and that there are some significant obstacles yet to be fully addressed. The general implementation issues of BIM are outlined in Section 3.3.7, however, there are a number of issues that are particularly applicable to generating quantities from the model and using BIM for QS practice (Ajibade & Venkatesh, 2012).

Forgues et al. (2012) explain that QSs may have an issue with buying BIM software that is first and foremost an architectural tool. Generally, QSs will already be spending a significant sum on estimating and cost management software and another application, which is primarily an architectural tool, maybe seen as an additional expense that is not necessarily applicable to day to day practice (BCIS, 2011; Zhou et al., 2012). Current practice is that the 5D QS carries out BIM measurement in an QS/estimating tool that is capable of extracting quantities from the model and sanitises these quantities so that they can be used in their cost reports (Ajibade & Venkatesh, 2012; Goucher & Thurairajah, 2012). Using software that is capable of this process may require additional expense; buying the software; upgrading the hardware to run the applications, and training staff to utilise the software (Ajibade &

Venkatesh, 2012). Goucher & Thurairajah (2012) note that there is a strong tendency for QSs to maintain their existing ways of working in the 2D environment; thus they are more likely to look for software that can post-process 3D model quantities in a familiar programme.

Ajibade & Venkatesh (2012) outline a number of issues with the model that is problematic for QSs when utilising it for QTO and costing. These include (which are also outlined as general issues) that the model has incomplete and/or inaccurate information; the file format cannot be utilised in the QS's software, and fundamentally that there is no model available for the QS (Crowley, 2013; Matipa et al., 2008; Smith, 2014). Forgues et al. (2012) warns that using the BIM without question could be misleading. Mitchell (2012) and Barker (2011) clarify that the model can be inaccurate as elements could be missing or there could be anomalies in the model that will alter the quality of the estimate. Sylvester & Dietrich (2010) maintain that these models are not constructed from the viewpoint of the QS, or the constructor, but from the perspective of the authors of the model which are usually Architects and/or Engineers. For example, Forgues et al. (2012) outline that temporary structures and equipment are not taken into account in the 3D model, so they will not be accounted for in the QTO. The content of the model not unlike traditional drawings can especially be limited in the early design stages. The 5D QS must ensure that all work is estimated by utilising their experience and supplementing the quantities generated from the model with 2D measurement (Barker, 2011; CostX, 2012; Eastman et al., 2011).

Goucher & Thurairajah (2012) add, that even if quantities can be accurately extracted from the BIM, there is a lack of trust among many QSs in something that was for so long a manual process. Shen et al. (2007) suggest that the manual process of measurement develops an aptitude and understanding of construction drawings and construction techniques that could be lost if quantities are automatically generated. Smith (2014) explains that in an electronic environment far less time is spent in absorbing and understanding the project, which is prevalent in the 2D process. Smith (2014) is worried that BIM could lead to a new breed of QSs without this aptitude and experience and thus they might not have the skill and intuition to identify problems in the model or recognise what is not in the model. On the other hand, Ajibade & Venkatesh (2012) argue that there may be a scarcity of skilled 5D

BIM users to work with 5D BIM tools, because organisations are reluctant to train their staff and upgrade their ICT. Crowley (2012) and Monteiro & Martins (2012) note that the time savings of automated quantification may not be realised because the QS spends more time checking the correctness and accuracy of the model so that resources saved from automation are not fully realised.

Sabol (2008) comments that in current practice the QS culls component information from the model to generate an estimate, but costing applications have not yet been developed to feedback cost information into the original model. This is a case of model information extraction, rather than information integration and as yet is still problematic in practice (Matipa et al., 2008). Matipa et al. (2008) ascertain that there is no way, based on current building product model schema including IFC, that the QS could feedback cost data back into the model because the object properties could not accommodate the cost data. This leads to a one way flow of information, which is not contiguous with a BIM ideology (Matipa et al., 2010).

Mitchell (2012) describes a process at the moment, whereby parties are confidently managing construction projects through independent software, collaborating on the outputs of technology, but not integrating the software in a beneficial way. Smith (2014) notes as the 5D BIM process develops and becomes more effective, the QS will need to adapt accordingly to provide more sophisticated cost management services that incorporate sharing cost information through the model rather than in a report. He adds that this will need to be addressed as sharing cost data within the model may be an issue for QSs that do not want to share their databases.

3.4.7 BIM and Additional QS Services

Wu et al. (2014) state that major QS firms in UK are changing their work practices from the traditional disciplines of quantity surveying. They outline that these companies are rebranding as consultative and managerial organisations, offering more intelligent holistic services, which focus on value rather than cost. For example, they explain that EC Harris and Turner & Townsend are working on providing new strategic services including advising clients on investment, energy use, carbon emissions, and running costs.

Sabol (2008) points out that BIM makes it possible for QSs to provide alternative professional services by leveraging BIM technology and freeing up time that would

have been spent on labour intensive activities in traditional QS processes. Goucher & Thurairajah, (2012) contend that clients are demanding life cycle services through the calculation of embodied carbon and/or the analysis of a buildings life cycle cost. For example, 'IES Virtual Environment' software have developed a BIM tool (IMPACT) to complement their existing applications in energy modelling that allow users to quantify the embodied environmental and cost implications on a whole-building basis (IES, n.d).

In addition, cost consultancy firms have reported several alternative service provisions that are possible through BIM, including Risk Management, Value Management and Capital allowances (Goucher & Thurairajah, 2012; Sawhney, 2014). Traditionally, LCC puts QSs out of their comfort zone (Boon, 2009), which is demonstrated by the low levels of the service provided by QSs in UK and Ireland (Chiurugwi et al., 2010; Opoku, 2013; Oduyemi et al., 2014). Smith (2014) and Sabol (2008) state that the use of technology and software brings with it efficiencies and speed of process, that enables practitioners to carry out activities that were once time consuming and complicated. The BIM Industry Working Group (2011) in UK outlines BIM as a key government driver to "*derive significant improvements to cost, value and carbon performance*". Leveraging the most recent developments in technology and the 'know how' skills through the production of standard methodologies in LCC has helped provide the tools necessary to extend the construction cost estimate to include costs over a longer duration, even within existing fee structures (Whyte & Scott, 2010).

However, Goucher & Thurairajah (2012) indicate that whilst cost consultants generally seem positive towards BIM for assisting in their current practices, there is an overall lack of enthusiasm to use it for expanding services such as LCC and embodied carbon assessments. Boon (2009) clarifies that this is not necessarily a product of their lack of experience with BIM but their lack of knowledge of LCC and LCA and how BIM could be utilised in this regard. Hourigan (2012) and Crowley (2013) state that in Ireland and UK these services are being requested by clients and therefore, Goucher & Thurairajah (2012) adds the most successful cost consultancy companies in the future will likely be those that leverage BIM to offer such services. The inclusion and integration of life-cycle cost analysis is described

by Whyte and Scott (2010) as a major, essential step to extend historical 2D and 3D towards 4D and alongside the construction CAPex in 5D.

3.5 BIM and Life Cycle Costing

Whyte & Scott (2010) assert that construction clients will increasingly demand buildings with low operating costs, driving demand for ICT that can quickly account for operational performance and then budget accordingly. Although most BIM authoring applications have well developed scheduling and pricing functions, there are significant limitations within current BIM design tools that restrict the estimator gaining a LCC perspective (Whyte & Scott, 2010). One of the major limitations, as explained by Shen et al. (2007), is that the current IFC model is not semantically rich enough, to cover all the construction process data and job conditions. With many of the properties on a construction project dependant on very specific job conditions, static default object properties in the model may not be applicable to variable LCC analysis. Sylvester & Dietrich (2010) state that the BIM LCC process may require several software packages to create viable and usable results, firstly to generate quantities, to cost them and then to carry out the calculations.

Sylvester & Dietrich (2010) state that there are restrictions in interacting within the BIM interface to produce LCC within the BIM authoring application. In this context, it can be seen from IFC and Cobie parameters that there are few LCC properties other than 'replacement cost' and 'service life duration' related to the data requirements needed to carry out LCC (Nisbet, 2012). To carry out LCC calculations, an escalation rate, a discount rate and a study period would need to be added to the parametric components of the objects as well as the calculations necessary to represent nominal costs and present values. BIM authoring applications such as 'Autodesk Revit Architecture' and 'Graphisoft Archicad' do provide the user with the ability to add user defined parameters to the library objects, however, in most cases, LCC attributes are job specific and are subject to variation depending on the location, market conditions and client requirements of the project (Matipa et al., 2008). Applying default LCC criteria to BIM object definitions by focusing on the data model itself could mislead Qs to use those criteria and not take account of the broader economic conditions in which the project may apply. As noted above, Eastman et al. (2011, p. 220) states that "*no BIM tool (BIM design tool) provides the*

full capabilities of a spreadsheet or estimating package". This is even more evident from an LCC perspective as there are a multitude of additional variables to be incorporated in LCC and financial calculations to be performed (BSI/BCIS, 2008; RICS, 2011).

Currently, Qs can use their existing estimating applications (that are updated with a BIM plugin or interface) for automated QTO and 'live link' those quantities to their spreadsheets and workbooks (Barker, 2011; Mitchell, 2012, p. 1200). This process allows estimators to apply their own domain-specific judgments to the design features with the assistance of 3D visualization and quantity data from BIM models (Shen & Issa, 2010). However, whilst there is a host of digital technologies available in BIM 5D, Whyte & Scott (2010) and Kirkham et al. (2004) call for further research in the area of 5D and LCC. They argue that there is much to be done in the development, promotion and utilisation of digital models that address appropriate life cycles, if productivity and environmental gains are to be realised. Redmond et al. (2011) also state that this is a field that needs attention and proposes a more integrated approach through open operability.

As will be discussed in further detail in Section 5.5, there is a case for developing and creating model definitions for LCC within design/authoring software. In BIM research many studies focus on this route by expanding capabilities within an integrated structure. However, as discussed in the previous paragraphs, a number of publications report that BIM authoring tools do not currently have the probabilistic capabilities to accommodate LCC. Focusing on developing LCC model definitions for the BIM authored model may cause problems in variable LCC analysis (Eastman et al., 2011; Sylvester & Dietrich 2010; Whyte & Scott, 2010; Shen et al. 2007). Advocates in this regard, propose utilising QS discipline specific 5D BIM, which provides a suitable stochastic cost medium for LCC. The 5D environment provides a facility to firstly post-process the quantities (similar to CAPex estimating) and then subsequently map them to the LCC calculation structure and schema. However, developing LCC model definitions for the BIM model itself is a worthwhile endeavour and maybe more applicable to a research project in the future as technology and federated models become more advanced to accommodate the complexities of LCC.

3.5.1 BIM LCC Tools

As described in Section 3.4.2, most LCC tools are in MS Excel which as Whyte & Scott (2010) maintain can provide the probabilistic support to perform LCC calculations. Whyte & Scott (2010) also note for BIM to be utilised effectively for LCC, the BIM LCC tool needs the probabilistic support of an application that can perform stochastic calculations to create assumptions and forecast outputs that are contingent on many variables. Eastman et al. (2011) state that BIM authoring tools do not have this capability, thus this process should be carried out in 5D and 6D BIM tools.

Kirkham et al. (2004) developed an application for predicting LCC performance applicable to new and existing construction. The application is an integrated tool between a repository of LCC data (LCC logbook) and an integrated LCC calculation model, which performs the calculations based on the logbook data and presents the LCC report. The application could not be defined as a BIM tool, based on the definitions outlined in Section 3.3.1, because the data contained in the LCC repository is not physically represented through geometric objects. However, the process did demonstrate an integrated environment between a database and an LCC modelling application, which exposed the possibilities to develop an integrated system that could link LCC modelling to a 3D digital environment.

Integrated Environmental Solutions (IES) have added what they describe as 'IMPACT', to their 'Virtual Environment' software in the last number of years. Impact adds LCC and LCA onto IES's existing engine, which was originally energy analysis software, predominantly used by Building Services Engineers. This system is bespoke software with a formulated approach to LCC. The software focuses on early design and cost planning and does not have the capabilities to carry out more detailed LCC. There is very little scope for the user to change or manipulate reporting functions. IES cannot be used by QSs for their primary estimating duties and would present a significant additional investment to carry out LCC. However, the system does demonstrate the latest integrated developments in 5D, 6D and 7D analysis and links to BRE databases on LCC and embodied carbon.

An nD modelling project was carried out by the University of Salford between 1999 and 2007, which demonstrated the possibilities of utilising BIM for LCC. A number of participants worked on this project at various junctures from 1999 to 2007,

including Aouad et al. (2002; 2001; 2005), Bakis et al. (2003) & Fu et al. (2006; 2007). Fu et al. (2006; 2007) built on the work of previous participants by developing an IFC integrated virtual environment viewer and an LCC calculation sub-tool. This tool has similarities to Kirkham's LCC logbook system, as there is an integrated environment between a LCC database and the system which performs the LCC calculations. The nD tool and its LCC sub-tool are a bespoke integrated system where the users input data sequentially through a number of input screens, ultimately generating LCC information in graphs and cash flows within the system (Fu et al., 2006; Fu et al., 2007). The nD tool is innovative for its time, but there has been a significant period since its development, which is compounded by the rapid development in BIM and 5D BIM in recent years. A more prevalent issue is that since 2007 there has been a plethora of LCC methodologies outlining WBS's and methods of calculating LCC, which could not have been taken into consideration in the nD tool. Redmond et al. (2011) outline the potential to build on this research by developing a 5D based LCC system founded on open BIM such as IFC.

The nD tool's virtual environment, where users can visually browse the building components and their attributes is typical of the model tree viewers that are evident in most 4D and 5D BIM tools available today. If current 4D or 5D applications provide the users with the capability to add LCC functionality, there is potential to extend these systems to provide LCC calculations rather than purchase a bespoke BIM LCC tool similar to the nD and IES tools.

This research builds on the nD tool discussed in the previous section by utilising an existing 5D application (which already has the integrated viewer) and adds an LCC application which has similarities to the LCC sub-tool in the nD project. The difference in this approach is that in this research the LCC tool is built as an add-on to an existing system having much of the same functionality as a spreadsheet. It is envisaged that this will give the user more flexibility in the format and presentation of the LCC estimate.

3.5.2 Adding LCC to 5D BIM

A feature which is inherent in some of the leading 5D estimating applications such as CostX, and CostOS is a customisation feature, which provides users with the ability to add columns and functions to the application's default workbooks and settings.

Hypothetically, users could customise cost data via spreadsheet functions to include adjustments for the additional variables of LCC that cannot be extracted from the model. This process could theoretically accommodate the probabilistic LCC calculations within a BIM 5D system, while also providing a mechanism where BIM quantum output can be aligned to cost management SMMs (CostX, 2014; Lovegrove, 2014). Outlining a calculation methodology within a spreadsheet format that could be incorporated in 5D BIM would ground the system within current methodologies that suggest calculations and algorithms should be in a spreadsheet framework (BCIS, 2011; RICS, 2011).

3.6 Summary

This Chapter has described the development of CAD, outlined recent developments in construction informatics and presented the emergence of BIM in recent years. The general benefits, barriers and levels of adoption in BIM are explored through relevant literature, narrowing the focus to BIM and cost management. 5D BIM is defined and the benefits, challenges and its current practice in the QS profession are addressed. BIM is now being used in cost management to automate QTO and measurement functions which were traditionally time consuming. This enables QSs to concentrate on other value creating activities such as risk management, value management and LCC. However, while BIM is currently being utilised for cost management, it is not extensively used to provide estimation software with the data requirements for LCC, such as the necessary escalation rates, discount rates, life expectancies and study periods (Whyte & Scott, 2010). Without incorporating LCC functionality within the BIM model or in an external application with a BIM interface a complete picture of the WLCC cannot be generated from the outputs of the model. There is an opportunity to leverage the capabilities of 5D BIM so that there is a direct link between the quantum, the CAPEX and the LCC calculations. The 5D environment could provide a means where the outputs of the model are mapped to the LCC schema outlined in the previous chapter. This could provide the QS with the financial tools required to select the most economical advantageous solution and provide an effective way to address the barriers that prevent its widespread adoption. Chapter 5 provides the detail of a process of embedding LCC within 5D BIM, but prior to articulating this development, it is necessary to describe the research design employed in this research and methods used to collect data.

4 Research Methodology

4.1 Introduction

In order to outline the research design, one must consider the fundamental elements of what constitutes knowledge. This chapter will initially frame the historical and contemporary debate on ontological and epistemological assumptions in the context of built environment research and practice. The traditional epistemological approaches do not fit with the research aim and objectives because they do not take account of the researcher's participation in the research. Alternative approaches are explored and an advocacy/participatory worldview is expounded in the context of this research. This chapter evolves by providing a tread of reasoning and a lens of focus linking the hierarchical structure of research philosophy, research design, research methods and data analysis. An action research and design science strategy is proposed for this research. These strategies are applicable to this research as the researcher's involvement and collaboration with a software vendor indicates a participatory and pragmatic research approach. The different stages of action research and design science are outlined with the two main stages of development and evaluation addressed.

4.2 Research Philosophy

4.2.1 *Discovering the nature of reality and how it shapes research*

“People have sought to come to grips with their environment and to understand the nature of the phenomena it represents to their senses” (Cohen, Manion, & Morrison, 2011, p. 3). Those that carry out these endeavours in a reasoned and methodological manner, such as scientists, philosophers and explorers, have generally tried to comprehend and make explicit the world around them. They do this through experience, reasoning and research. Most of us go through life experiencing the world around us and reacting to those experiences on an unconscious level. According to Dispenza (2007), much of our reasoning is ingrained over time into our unconscious and subconscious minds through repetitive conscious thought. Many of our haunches and feelings were originally recorded in our minds through explicit conscious experience. Mann (1998) describes this process

as tacit knowledge, which he describes as the knowledge of the body, the knowledge of know-how and the knowledge of learning while doing. Over time the web of conscious knowledge we accumulate and lessons learned percolates into our deeper mind providing us with our hunches, feelings and opinions.

Decisions based on unconscious thought are not rational to the knower, but are felt emotionally through feelings and hunches rather than logical reasoning (Dispenza, 2007). Cohen et al. (2011) argue that scientists strive to make implicit feelings and hunches explicit, by giving more reason than the layperson to the links and casual relationships between the external world and our perception of it. They state that scientists do this by developing their hypothesis empirically, so that their experiences have a firm basis in fact. Scientists are also “*conscious of the multiplicity of factors and implement procedures and processes that test their hypothesis by manipulating and analysing the effect of their results by changing the factors*” (Cohen et al., 2011, p. 3). Research, as described by Borg (1963, cited in Cohen et al., 2011, p.4), is a combination of experience and research and must be “*regarded as the most successful approach to the discovery of truth especially in the natural sciences*”. However, the process the researcher enacts of discovering this truth is based on how they view the world around them and their assumptions about human knowledge (Saunders & Tosey, 2012). Saunders & Tosey (2012) outline this as the researcher’s philosophy and state that this can lead to a plethora of research approaches as there are a number of differing philosophies and a number of different methodologies under each philosophy.

4.2.2 Ontology

How scientists reason and how they research has been the form of much debate since the ‘original thinkers’ of Greek philosophy (Robson, 2011). The basis of these debates, which have been argued through different forms and with different terminology over the centuries, are rooted in ontological assumptions of what reality is (Knight & Ruddock, 2008). These ontological arguments have revolved around whether reality is external to individual influence and thought and is not dependent on the views or actions of the observer (‘realism’), or whether the cognitive process is part of the knowledge equation, (‘nominalism’) (Cohen et al., 2011). It may seem strange to discuss the essence of ontological assumptions when researching a specific discipline such as construction management or the built environment, but

these assumptions shape how knowledge is perceived and thus how it is obtained in that discipline (Saunders & Tosey, 2012). Dawood & Underwood (2010) state, the failure of a great deal of research arises from the researcher not fully understanding their own philosophical assumptions. Cohen et al. (2011) note one of the reasons for this is that researchers automatically orientate themselves to a realist view of the world. This view was central to research from the beginning of the scientific revolution and dominates the natural sciences, which were the initial focus of scientific research (Cohen et al., 2011). Many researchers still start from a realist ontological perspective because of this historical tradition, even if their research may be better served by a nominalist approach (Chynoweth, 2009; Clough & Nutbrown, 2002). This issue can be observed in the construction management research community where quantitative research has been the dominant methodology (Knight & Ruddock, 2008).

Cohen et al., (2011, p.8) describe paradigms in research as “*a shared belief or set of principles, consensus on what and should be investigated in an academic area*”. Realigning or readdressing paradigms is difficult as they become embedded in the research community over time (Clough & Nutbrown, 2002; Knight & Ruddock, 2008). According to Grix (2010, p. 10), one’s ontological and epistemological assumptions end up being a “*skin and not a sweater*” where Clough and Nutbrown (2002) describe a conscious choice between a positivist or interpretivist paradigm as ‘extraordinary’, implying that researchers are tied to the prevailing paradigms within their field. One of the ways researchers can break the norm is by starting their research analysing ontological and epistemological arguments and understanding the research trends in different subject matter (Dawood & Underwood, 2010; Saunders & Tosey, 2012).

4.2.3 Epistemology, Worldviews

Grix (2010) argues that ontology and epistemology are to research what footings are to a house. Ontology may be the foundations but epistemology may very well be the rising walls, as the researcher can only construct how knowledge is acquired (epistemology) if they build on what is out there to know (ontology). Once the researcher understands the deeper discussion of reality, they can go about discovering the nature of it (Saunders & Tosey, 2012). Many researchers focus on epistemology without ever asking about the nature of their assumptions and many

more do not even analyse their epistemological foundations to shape their research methods (Dawood & Underwood, 2010; Saunders & Tosey, 2012).

Any student undertaking research will need to convincingly argue how their research contributes to knowledge in a given field (Creswell, 2009; Knight & Ruddock, 2008; Saunders & Tosey, 2012). Epistemology deals with the nature of this knowledge and a firm understanding of how others in your field acquired their knowledge is necessary if you are to build upon it (Grix, 2010). Creswell's (2007; 2009) uses the term 'worldview' in outlining the different research philosophies. His definition of a worldview is similar to the terminology discussed above for epistemology - espousing a general orientation about how to obtain knowledge that guides the researcher's action from the outset (Creswell, 2007, 2009). Fellows & Liu (2008) and Grix (2010) describe the researchers worldview as the their 'paradigm', which they state forms a theoretical framework to guide their research. The terminology in research philosophies may differ but authors in the field agree that researcher's worldviews are shaped by their topic, the researcher's advisors worldviews and the researcher's past experiences (Creswell, 2007; Grix, 2010; Knight & Ruddock, 2008; Robson, 2011).

Before undertaking this research the author would have described his worldview or epistemological position as 'positivist'. Positivism as outlined in Fellows & Liu (2008) and Saunders & Tosey (2012) recognise only objects and patterns which can be observed and measured by an observer who remains uninfluenced by the observation and measurement. This position was not framed from a reflection on an ontological position but possibly an uneducated understanding that research must be positivist if it is to be relevant. However, after reading relevant literature on research design, the author has reoriented to one that is more in line to an interpretivist paradigm. Interpretivism is based on the premise that truth and reality are social constructs rather than existing independently to the observer (Fellows & Liu, 2008).

Chynoweth (2009) describes built environment research as an 'academic interdiscipline' where practices are based on 'relationships', 'multidisciplinary processes' and 'artificial constructs'. He stresses that reality within this field cannot be revealed without knowledge and understanding of the social constructs and processes that make up the industry. Fellows & Liu (2008, p. 13) state that this type of understanding is better facilitated through an interpretative approach, which

“reveals truth and reality through determining the perspectives of the participants in the process”.

It must be noted that positivism is not entirely discounted in this research as elements of both approaches are leveraged to formulate the most appropriate research design for the research problem. This idea aligns with a post-positivist paradigm which bridges the gap between the two traditions (Grix, 2010). Post-positivism, although still very much derived from a realist ontological position, acknowledges that a reality does exist, but that it can only be known *“imperfectly and probabilistically”*, in part because of the researcher’s limitations (Robson, 2011, p. 22). This shift towards post-positivism and interpretivism was facilitated simply by becoming aware that other worldviews were relevant in built environment research.

Defining research paradigms as positivism, post-positivism and interpretivism is over simplistic; there are a number of other paradigms that expand the methodological base in favour of alternative approaches (Voordijk, 2009). Notable worldviews in the context of this research are outlined by Creswell (2009; 2007) and Savin–Baden (2013) as ‘advocacy/participatory’ and ‘pragmatism’. Creswell proposes that researchers who hold these worldviews feel that pure post-positivism and interpretivism do not entirely fit with the goals of their research. He further maintains that an advocacy/participation worldview should contain an action agenda for reform that may change the lives of the participants. Robson (2011, p.28) states that pragmatism (similar to post-positivism) focuses on *“what works”*, combining elements of different methods from philosophical positions. However, in pragmatism the researcher is not aligned to one system of philosophy but rather uses multiple methods to best answer the research question (Creswell, 2007). Advocacy/participatory and pragmatism worldviews resonated with the author as he wishes to produce research that he can participate in to effect change. Participation occurs where an LCC BIM solution is developed with a company and whether it can affect change in the environment to which it is introduced is subsequently evaluated. A methodological choice was necessary that aligns with this philosophy and the aims and objectives of the research.

4.3 Research Design

4.3.1 *Methodological Choice*

The choice of methodologies is influenced by the worldviews the researcher holds or establishes prior to undertaking their research (Creswell, 2009; Robson, 2011). As a consequence, their research approach can be established through a more focused lens on the methodologies and strategies within those trends (Dawood & Underwood, 2010; Saunders & Tosey, 2012). Saunders & Tosey (2012) maintain that researchers have the choice of three distinct types of methodologies: whether they use a qualitative method, a quantitative method or a mixture of the two. Amaratunga et al. (2002) note that quantitative research grows out of a strong academic tradition based on positivist and post-positivist paradigms, where considerable trust is put in numbers that represent opinions or concepts of an observed phenomenon. Creswell (2007) states when researchers conduct qualitative research they are embracing the idea of multiple realities focusing on words and observations to express reality through the views of the participants. A mixed-method methodology combines both qualitative and quantitative data collection techniques (Saunders & Tosey, 2012). In light of the interpretative worldview discussed above and the research aim and objectives (which includes an action agenda), the research strategy is in line with a qualitative methodology. This is driven by the phenomena of the study which is based on introducing a change in current QS work practices through a technological development in the 5D BIM process. The qualitative views and observations of participants in this process are necessary to determine its effectiveness and give rise to feedback that may effect change in current work practices.

4.3.2 *Traditional Research Strategies*

Creswell (2007; 2009) proposes five qualitative research strategies that are underpinned by an interpretative worldview. These are ‘narrative research’, ‘phenomenological research’, ‘grounded theory’, ‘ethnography’ and ‘case study’ research. Differing slightly from the normal explanation of research strategies being quantitative or qualitative, Robson (2011, p. 131) determines that research strategies can be divided into “*fixed*” and “*flexible*” design. Robson (2011, p.131) states that fixed design strategies follow a post-positivist worldview and are typically “*off the shelf*”, while flexible strategies follow a more interpretative paradigm, “*where research strategies maybe outlined early on, but predominantly evolve throughout*

the course of the research". Robson (2011) accounts three influential flexible research design traditions which he outlines as 'case studies', 'ethnographic studies' and 'grounded theories'. It is evident through the strategies that Robson lists (similar to Creswell), that he is giving an alternative name (flexible) to what Creswell describes as qualitative research strategies. These are traditional qualitative research strategies and are utilised by many researchers carrying out social research (Bryman, 2008).

The 'narrative', 'ethnography' and 'phenomenological' approaches outlined by Creswell (2007; 2009) and Robson (2011) do not entirely fit with the research problem. The reason is that, although elements of the research may express what Creswell (2007, p.54) describes as the "*lived experiences*" of the participants, the nature of this research is not purely on the revelation of patterns and relationships of the participants involved in the study (which is a theme in ethnography, narrative and phenomenological research). Thus, the focus is not on one or more of the participants, but rather the process (LCC/BIM) they are engaging in, and their views of it. Observations and reflections on using a BIM solution for LCC and engaging in this process can then be used to improve the solution and ultimately affect change. This strategy is more in line with what Creswell (2009) proposes as 'grounded theory', which is a research methodology where the researcher derives a general abstract theory of the process, action or interaction, grounded in the views of the participants. However, grounded theory cannot be aligned with the research intent as it does not accommodate the active role of the researcher in generating the theory (Azhar et al. 2010). The process developed in this research (leveraging 5D BIM for LCC) is not just grounded in the views of the participants but is derived from past experiences, relevant literature and action learning, thus this strategy is not applied.

One of Creswell's (2007; 2009) 'qualitative strategies' which could be applied as a strategy in this research is 'case study research'. The case study focuses on understanding the dynamics present within a single setting (Amaratunga et al., 2002) and usually refers to relatively intensive analysis of a single instance of a phenomenon being investigated (Yin, 2009). Naoum (2013) claims that with such an interpretative approach the researcher tends not to affect or interfere with what is being studied, thus, the researcher is a passive observer in this type of approach. In this regard, a case study research strategy does not entirely meet the researcher's

needs, as primarily focusing on observing the phenomenon will not take stock of the active role in engaging in the phenomenon.

4.3.3 Action Research

An advocacy/participatory research paradigm which is included in a number of research methodology texts such as Bell (1993) Yin (2009), Fellows & Liu (2008) and Savin-Baden & Howell Major (2013) is action research. In these publications action research is defined as a qualitative research strategy based on an interpretative paradigm and more specifically an advocacy/participatory and pragmatism worldview. The term ‘action research’ was coined by Kurt Lewin (1943) who developed the method in wake of social changes that happened after World War II. Lewin articulated the method as “*a way of generating knowledge about a social system while, at the same time attempting to change it*” (Lewin 1946, cited in Azhar, Ahmad, & Sein, 2010, p. 88).

Azhar et al. (2010) present action research as a research approach that aims at building and/or testing theory within the context of solving an immediate ‘practical problem’. Savin-Baden (2013) notes that the practical problem is solved through a cyclical process of action and reflection, theory and practice, in participation with others. Iivari & Venbale (2009) elaborate that action research should; be carried out through a cyclical process of problem solving, change and action; contribute to both practice and research at the same time; explicitly outline what learning is achieved through reflection and should include joint collaboration with an external party. Susman & Evered (1978) (Figure 4.1) present a staged process to action research, starting with diagnosing a practical problem; planning an action to propose a solution; evaluating the action and subsequently specifying the learning from the solution in action.



Figure 4.1: Action Research (Susman & Evered, 1978)

The focus of action research as outlined by Jarvinen (2007) and Azhar et al. (2010) encompasses Iivari & Venbale (2009) latter principle, where the researcher is an

active participant rather than a passive observer. By including the researcher in the research equation, Robson (2011, p.188) proposes that action research adds the “*promotion of change to the traditional research purposes of description, understanding and explanation*”. In the context of this research adding LCC to the 5D BIM process by post-processing BIM data is the subject matter or phenomenon of the evaluation research and its development is achieved through what Savin-Baden (2013) outlines as a cyclical process of thinking, acting, data gathering and reflection. Including LCC in the BIM process instigates a change in the 5D BIM work-flow and as Sagor (2005) states, this change needs to be evaluated to determine whether it can be accomplished.

Considering the research aim and objectives, which contains an action agenda to develop an integrated 5D BIM - LCC process, an action research approach emerged as a relevant methodology to use in this research. The premise being that action research complements research in a practical setting by enabling collaboration with an external body to solve a work related issue (Azhar et al. 2010). However, Aram & Salipante (2003) and Azhar et al., (2010) claim one of the shortfalls of action research is its emphasis on context and action, leaving action research without an understanding of what knowledge can result from the action process and how this may be applied in a different context. From the perspective of this research, another issue that could impede it being categorised purely as action research is that the researcher is not directly acting on behalf or involved with a practitioner or professional organisation (Azhar et al., 2010). However, there are a number of different variants of action research prescribed on their level of interaction with a company. Cohen et al. (2011) note what is important is that the action approach has a form of collaboration at some stage in the research process. Moreover, Savin-Baden (2013) describes an action research approach where the researcher designs the action plan for the practitioners (rather than with them) and validation happens in the latter stages to address whether it solves their practical problem.

In this study, the research question and the initial construct of the solution is framed from experience, reflection and secondary research. Collaboration happens later in two forms, the first with Exactal technologies when developing the 5D BIM LCC process and later with QS practitioners who will potentially use the solution. Both sets of collaborators provide feedback and suggestions to improve the process. Thus,

the practitioner's involvement in the early stages of this research is less formal than what is described in Azhar et al. (2010), Savin-Baden (2013) and Yin (2009). However, the action research cycle of reflection and action, which is the cornerstone of action research, is very evident throughout the research processes.

At this stage, action research emerged as the most appropriate methodology, but this was based predominantly on a review of traditional research approaches from authors such as Creswell (2007; 2009), Bell (1993), Yin (2009), Savin-Baden (2013) and Robson (2011). There has been much debate on the relevance of academic research and the knowledge transfer between academics and practitioners in the last number of decades, and many viewpoints, which are discussed in the next section, have been put forward that describe a gap between traditional academic research and the practitioner (Aram & Salipante Jr., 2003; Gibbons et al., 1994; Kuechler & Vaishnavi, 2008; Voordijk, 2009). Given that the research focuses on a practical solution, it was necessary to investigate whether an alternative methodology could be utilised or supplemented to support a practice based approach.

4.3.4 Relevance of Academic Research in Practice

Azhar et al. (2010) points out that one reason why there is a gap between academic research and its practical application is that research methodologies and methods used by academics have mostly studied phenomena that have already occurred rather than a focus on an approach that creates a new reality to affect change in a practical setting.

van Aken (2005) agrees with Susman and Evered's (1978) view that the disconnections between academic research and practical application is rooted in the widening gap between sophisticated and complicated research methods in academia and their practical application. Barrett & Barrett (2003) explain that academics spend much of their time paying homage to research methodology, carrying out protracted research and writing up detailed and extensive reports. They further argue that industry is impatient with this type of lengthy research and there is a desire for short solution orientated guides that are easily implemented into practice. In the AEC industry practitioners cannot afford to wait for answers from academia. The issue may have already been resolved as lengthy research is being carried out or when the

solution is generated it is too late or no longer relevant to have a bearing in a professional context (Azhar et al., 2010; Barrett & Barrett, 2003; van Aken, 2005).

van Aken (2005) outlines an approach to improve the relevance of academic management research. She advocates the use of Gibbons et al. (1994) 'mode 2 research products', which she states provides a solution to the problem in academic research outlined by Aram & Salipante (2003) and Azhar et al. (2010) above. Gibbons et al. (1994) concept of two modes of research is orientated around their usefulness in a practical context, where they are applicable research approaches for action orientated management research (Kelemen & Bansal, 2002; van Aken, 2005). The difference between mode 1 and mode 2 research products outlined by Kelemen & Bansal (2005) and Voordijk (2009) is that mode 1 follows traditional research practices in universities, where problems are defined by the intellectual interests and preoccupations of academics. In contrast, they argue that mode 2 research is driven by the practical applicability of knowledge which is determined by issues that emerge in industry, in research centres, think-tanks, consultancies, government agencies, laboratories and companies (Kelemen & Bansal, 2002; Voordijk, 2009). Voordijk (2009, p. 335) states that mode 2 knowledge "*is less concerned with discipline base but crucially concerned with knowledge as it works in practice in the context of application*". Research carried out by solution orientated institutions outside the traditional domain of universities, indicates a widening boundary and increased diversity to research that may not be accommodated by traditional academic approaches (Eraut, 1985; van Aken, 2005; Voordijk, 2009).

Aram & Salipante, Jr. (2003, p.192) state that mode 2 knowledge production "*results from a convergence of specialised disciplines often working in different institutions in the context of a defined problem*". If this statement is true, mode 2 knowledge production may work well in finding solutions to issues in the built environment inter-discipline through a more integrated approach between disciplines.

4.3.5 Design Science

van Aken (2005, p.20) proposes a mode 2 research product, viz the "*field tested grounded technological rule*" which she describes is a "*solution concept*" that includes the problem solving activity in the research process. Voordijk (2009, p.716) explains that a solution concept is "*field tested*" to determine the success of its

application in a real world setting and “*grounded*” which means that the reason why the intervention gives the desired result or performance is known. Voordijk (2009) notes that this type of strategy should focus on a solution concept developed through testing in practical contexts but should be conscious of the rigor required for academic research - thus it should also be ‘grounded’ in the sciences. Holmström et al. (2009) state this concept is similar to what Creswell (2007; 2009) outlines as grounded theory. The difference being that the theory must be created before it can be evaluated. In grounded theory the phenomena are observed in the field to reveal a theory based on grounded field evaluation (Creswell, 2007). Pure grounded theory is not constructed prior to the evaluation as is in the case in mode 2 research (Holmstrom et al., 2009).

van Aken (2005, p.20) maintains that the “*field tested grounded technological rule*” differs from pure mode 2 knowledge production in that she states it can produce reflective knowledge that can be transferred to contexts other than the one which is produced. In this context Voordijk (2010) describes the ‘technological rule’ as a ‘general’ rule that is not a specific solution for a specific problem but a general solution for a type of problem.

An applicable use of this concept is the approach of design science, which van Aken (2005, p.22) outlines as a core mission “*to develop knowledge that can be used by professionals in the field in question to design solutions to their field problems*”. Kuechler & Vaishnavi (2008) state that alternative names such as ‘improvement’ and ‘constructivist’ research have been used in the past but design science is the most common name for the last decade. Voordijk (2009) maintains that design science is gaining prominence as an appropriate research method which can improve the relevance of academic research for practical use. van Aken (2005) and Hevner et al. (2004) define design science as solution orientated research strategy with a focus on developing knowledge that can be used by professionals in practical contexts. Voordijk (2009) and Iivari & Venable (2009) also propose that design science is a knowledge creating activity that corresponds to prescriptive research which he states has a focus on improving aspects of the built environment rather than a descriptive strategy which just explains phenomena in the built environment.

Johannesson & Perjons (2012, p. 3) state in design science the ‘technological rule’ outlined by van Aken (2005) must take the form of what is known as an ‘artifact’,

“which they describe as an artificial object made by humans to solve practical problems”. Johannesson & Perjons (2012) explain that artifacts are either physical entities (such as a hammer, a car or a hip-replacement) or they can be drawings, a set of guidelines or an ICT solution. Kuechler & Vaishnavi (2008) broadly defines an artifact as “those bundles of cultural properties packaged in some socially recognisable form such as hardware and software”. Hevner et al. (2004) cautions that an artifact is more likely to be an idea, practice or partial product rather than a fully realised ready for business ICT solution and thus this is where the difference lies between an artifact and a piece of software.

Johannesson & Perjons (2012) and March & Smith (1995) state that the research output in design science is not just the artifact, but also the affect the artifact has on the environment to which it has been introduced. In this context, the output of this research is an evaluation of the artifact (which is post-processing BIM data by leveraging 5D BIM for utilisation in LCC) to aid Qs in the production and presentation of LCC estimates: but also the artifact’s ability to affect change in the environment to which it has been introduced (Hevner et al., 2004). Theoretically this represents an LCC add-on to the 5D BIM process to provide more efficient and effective LCC. This process constitutes Hevner al. (2004) emphasis that the artifact is not software or an interface but an idea, practice or partial solution which is presented through an articulation of the process in the research. Hevner et al. (2004) state by evaluating the artifact ‘in use’, the researcher can clarify the feasibility of their approach to the solution (i.e to determine if the solution is working!). Vaishnavi & Kuechler (2007) propose a staged research process in design science, illustrated in Figure 4.2, where the artifact is developed from a field problem and evaluated to address if it is successful in its intended environment. This is discussed in further detail later in the chapter.

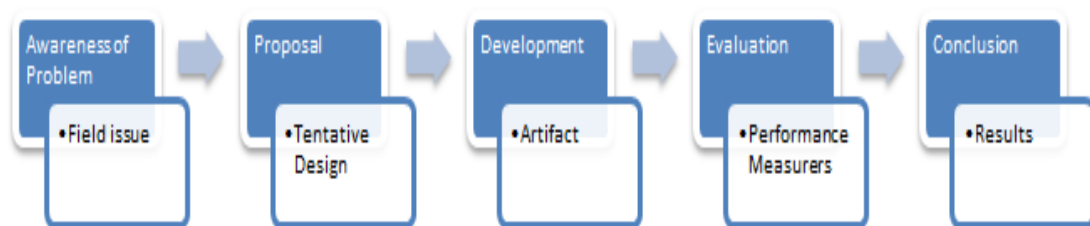


Figure 4.2: Design Science research process (Vaishnavi & Kuechler, 2007)

4.3.6 Design Science and Action Research

Earlier in this section, action research was outlined as an appropriate methodology based on the aim of the research and the author's research philosophy. van Aken (2005) points out that design science is similar to researcher/practitioner collaboration in action research. In Jarvinen's (2007) opinion the process of action research and design science research may have different names but the contents of the processes are identical. Jarvinen (2007) contends that they should be seen as similar approaches where action research focuses on the evaluation of social constructs, whereas design science focuses on the evaluation of artificial constructs. Holmstrom et al. (2009) agrees with Jarvinen's assertion, stating that design science is conducted under many different rubrics including: action research, action science, action innovation research, participatory action, participatory case study and academe-industry partnerships. Holmstrom et al. (2009) explains that methodological arguments can be ambiguous due to the philosophical nature of the subject matter thus cases can be made for a number of practice based approaches for the same study. Hevner et al. (2004) argues what is important in an action research project is that the strategy is well defined and articulated, so that if the researcher is interested in developing a means to an end, 'an artifact', that there is an explicit development and evaluation process.

In relation to this research an argument is made for the research approach being carried out under both the banner of action research and design science. The principle of this argument is based on Jarvinen (2007) and Holmstrom et al. (2009) accentuation that action research focuses on the process element of the research (i.e. evaluating an addition and change to the 5D BIM process to accommodate LCC) and design science emphasises the technological aspect of the research, which highlights the innovative artifact being produced in this process. Iivari & Venable (2009) illustrate this concept in Figure 4.3. They emphasise that the solution intervention is evaluated on the right side of their action research/design science model based on an artificial evaluation in design science and on the left side per a naturalistic evaluation based on the impact of the solution in a human context. They note that combining both methodologies can evaluate the creation of a method, product, system, practice or technique from social interaction and technical interaction with the proposed solution.

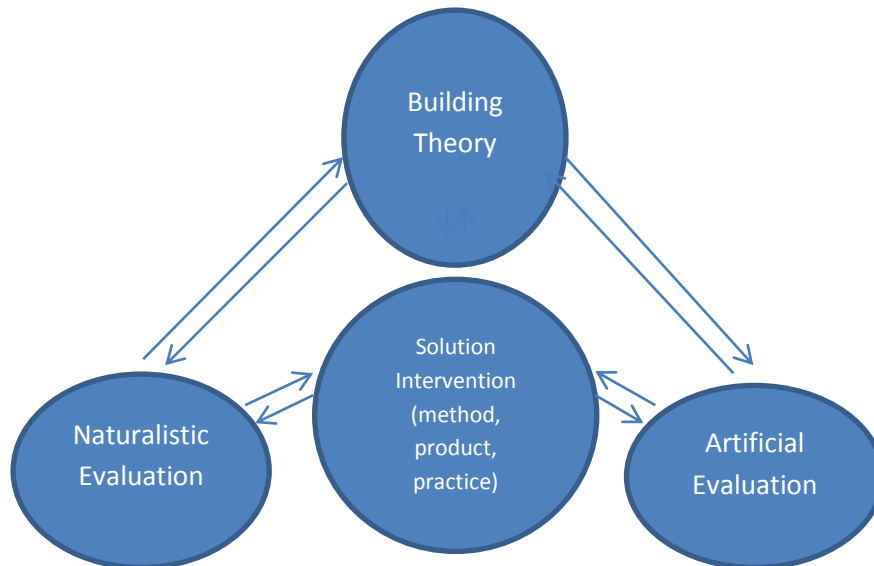


Figure 4.3: Framework for AR/DSR (Iivari & Venable, 2009)

Conveying a dual methodological approach complements the possible inadequacies of articulating a single strategy. This research would traditionally have been solely presented as action research because of its focus on reflection and action in the circumstance of solving a practical problem. However, the emergence of design science as a methodology in this context is valuable because it focuses on technological change, which complements the process change of action research. Design science also addresses another issue in action research, in that it does not require a practical problem from a specific organisation as the starting point, while this is a prerequisite for most forms of action research (Johannesson & Perjons, 2012).

Hevner et al. (2004) states that no matter what type of banner the action orientated research strategy is proposed under, what is important is that the strategy is well defined and articulated, so that if the researcher is interested in developing a means to an end, ‘a solution’, that there is an explicit development and evaluation process.

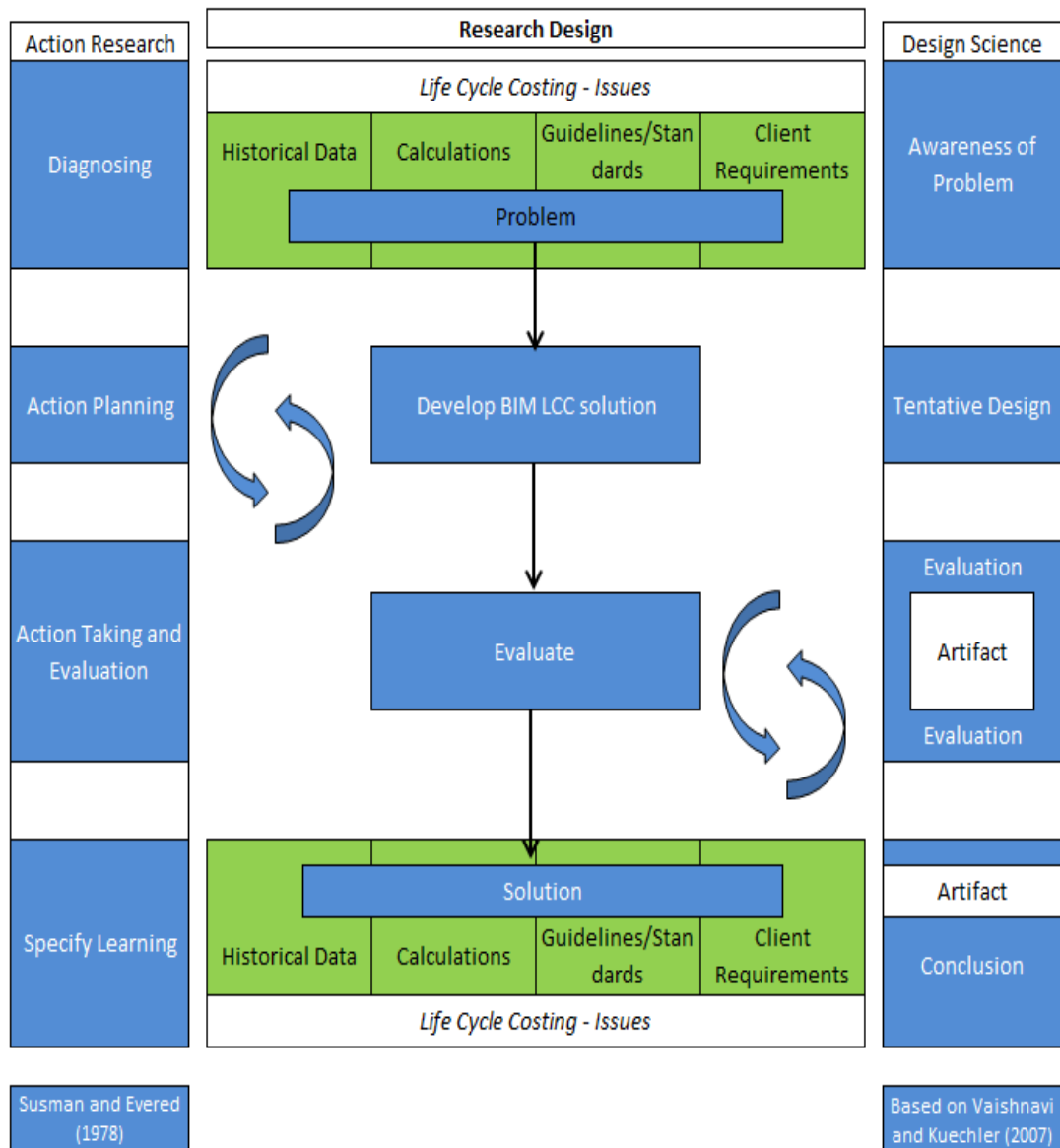


Figure 4.4: Research Strategy

Figure 4.4 frames the research strategy alongside both action research (left ladder), as extrapolated from Susman and Evered (1978) and design science (right ladder) based on the concepts illustrated in Vaishnavi & Kuechler (2007). The centre of the figure demonstrates the research process which starts with outlining the practical problem; then developing a solution to that problem (outlined in Chapter 5); subsequently evaluating the solution and finally outlining how that solution affects the issues from which it was framed. The circular arrows beside the development and evaluation phase highlight the cyclical nature of both stages and are discussed in greater detail in Section 4.4 and Section 4.5. This illustration is based on Jarvinen’s (2007) opinion that there is little difference between action research and design science methodologies. Thus, once the process is well defined, action-orientated

research can be carried out under the rubrics of both research strategies. The reason for adopting both is that one can address issues with the other and that a focus on both social change (action research) and technological change (design science) can be attended in the same study (Iivari & Venable, 2009).

The similarities in action research and design science are highlighted in Figure 4.4 where the processes and stages outlined on the left and right ladders, albeit using different terminology, pronounce very similar themes and processes. Both research strategies outline [1] diagnosing a problem; [2] proposing (developing) a solution; [3] implementing the solution & evaluating the process in action; and [4] specifying learning. Holmstrom et al. (2009), Hervner et al. (2004), March & Smith (1995), Johannesson & Perjons (2012) and Azhar et al. (2010) all articulate similar frameworks, again using different terminology, with a ‘development’ [2] and ‘evaluation’ [3] process at the core of the procedure. The following headings address in more detail the stages presented in Figure 4.4 and identify the similarities outlined by publications in the field.

1. Diagnosing (awareness of) the problem

Johannesson & Perjons (2012, p.34) state that the starting point for the design science researcher is that “*something is not quite right with the world and it has to be changed*”. Holmstrom et al. (2009, p. 88) outline the first phase of design science is to address what is wrong, by “*diagnosing the primary research problem*”. Similarly, Savin-Baden (2013) proposes that in action research, the research problem must be addressed through an ‘identity phase’. As can also be see in Figure 4.4, Susman & Evered (1978) outline this stage in action research as ‘diagnosing’ the problem.

Johannesson & Perjons (2012) suggest that there may be a need to carry out primary research at this phase to investigate and determine the nature and prevalence of the problem. Alternatively, Azhar et al. (2010) state that the research issue could involve self-interpretation through reflection or an initial review of literature. Hevner et al. (2004) also explains that diagnosing the problem can be achieved through the existing knowledge base by reviewing literature in the field such as academic papers, practice based publications and industry reports. It may be the case, as with this research, that the problem has been well reported and published, but that a solution has not been addressed.

Figure 4.4 illustrates, at the top centre, the four main issues when carrying out LCC (Historical Data, LCC Calculations, Guidelines/Standards & Client Requirements). This is the research problem and it is diagnosed through relevant literature outlining LCCs limited application as a consequence of these barriers. Chapter 2 provides a detailed review of literature on LCC, outlining the barriers that prevent its widespread adoption, thus this phase of the methodology is represented in that chapter. Voordijk (2011), March & Smith (1995) and Kuechler & Vaishnavi (2008) agree that once the problem is outlined the following two steps of ‘building the solution’ and ‘evaluating the solution’ are the crux of the process.

2. Proposing (develop tentative design – ‘the artifact’) a solution

Voordijk (2009) and Hevner et al. (2004) propose the second step is to develop the technological rule (artifact) which is proposed to address the practical problem. In action research this is the ‘action planning’ phase (Susman & Evered, 1978). Sagor (2005) notes that in this stage researchers engage in planning out a solution which they believe is theoretically sound and will be a successful change to the current norm.

March & Smith (1995) claim that this stage has two basic activities: to design and to build the artifact. Hevner et al. (2004) state that building the artifact is the process of constructing a solution concept (method or system) for a specific purpose. Constructing a technological rule in design science demonstrates that the process can be automated (Hevner et al., 2004) and enables a change in current work practices, which is the basis of action research (Sagor, 2005).

The circular arrows in Figure 4.4 demonstrate that the artifact is developed through an iterative process of action and reflection (Johannesson & Perjons, 2012). Voordijk (2009) states that reflective practice can be supplemented with best practices through the review of high quality publications, which is addressed through the review of literature in Chapter 2 and 3. The action planning and reflective processes are outlined in more detail in Section 4.4. The development of the artifact and proposed change in the 5D BIM process by post-processing BIM data is discussed in Chapter 5.

3. Implementing the solution and evaluating in action.

Susman & Evered (1978) advise that the intended action is implemented and evaluated in this stage of action research. Sagor (2005) stresses that this is where it must be determined what is accomplished by the change and to carry this out a mechanism for evaluation must be proposed. The utility, quality and efficiency of an artifact must be rigorously demonstrated via well executed evaluation methods (Hevner et al., 2004). Evaluation requires some way of determining how successful the proposed change is in its environment or simulated environment (Hevner et al., 2004; Johannesson & Perjons, 2012).

Savin-Baden (2013) describes that the researcher should seek the views of participants on the new process or artifact that has been developed. Voordijk (2011) and March & Smith (1995) outline this stage as the 'evaluation phase' and maintain that it is possibly the most important stage in design science. It is also important in action research to incorporate a mechanism that can evaluate the social interactions and subjective attitudes of potential participants when engaging with the technological solution and then assess the resultant change in their work process (Sagor, 2005). Holmstrom et al. (2009) note that there could be a number of evaluation phases providing iterative feedback and cyclical development through a number of cycles and this is why this stage is also illustrated in Figure 4.4 with cyclical arrows.

Voordijk (2011) states that evaluation should start with the development of measurers and criteria which represent the goals of the process: the artifact's performance is subsequently evaluated against these criteria. Voordijk (2011) asserts that the criteria are based on the ability to perform the intended task, the ability of actors and organisations to effectively use the method, its efficiency, its effectiveness, its ease of use and its impact on the environment and its users. Nielsen (1993) and Faulkner (2000) advise these criteria as the 'goals' of the process which are determined by the system's usability. Voordijk (2009) proposes that methods used to carry out evaluation can be interviews, surveys, case studies and simulation (through empirical evaluation) with the intended users. Holmstrom et al. (2009) and Johannesson & Perjons (2012) note that one of the best evaluation methods is empirical evaluation. Through empirical evaluation the artifact can be tested to validate that it actually works for its intended users and in its intended environment.

Nielsen (1993) states that empirical evaluation can be carried out by simulating the process in a lab environment or evaluating the artifact 'in-use', in the workplace. Evaluation procedures are addressed in further detail in Section 4.5 and their application to this research are discussed in detail in Chapter 6.

4. Specify Learning/ Conclusion.

Johannenson & Perjons (2010) and March & Smith (1995) state that the research output in design science is not just the artifact, but also the affect the artifact has on the environment to which it has been introduced. This is also the focus of action research where there is attention on the implemented action and the attitudes of the users or practitioners when engaged in that action (Iivari & Venable, 2009; Sagor, 2005). In this context the output of this research is an evaluation of the artifact but also its ability to affect change, particularly its ability to have an effect on the barriers of LCC. Hevner et al. (2004) notes that design science research should contribute to knowledge by applying knowledge in a new or innovative way. They state that this can be achieved on a number of fronts; the artifact itself is demonstrated as a new and innovative product, practice, system or technique; an existing product is used to solve a practical problem in a different context to which it was designed; the research process can be defined as a 'general rule' that could be applied to a different problem and another situation and that the process and the artifact can affect change in its environment.

This research has the potential to satisfy a number of these criteria, on the basis that the research utilises an existing technology to carry out a process that it was not originally designed to do (5D for LCC) and that the practice can have an effect on some of the barriers that prevent its widespread application. Thus, it can potentially affect change within the environment in which it has been implemented and the same process, if successful, could be applied with different software, demonstrating it as a 'general rule'.

4.4 Development through Reflection and Action

Johannenson & Perjons (2012) propose that the requirements to develop an artifact are evidenced from the initial activity of diagnosing a problem. Johannenson & Perjons (2012) and Hevner et al. (2004) propose that the development must be carried out in a cyclical process of generation, reflection and change. The theoretical

context of this process is discussed in the following sections so that the development process of the artifact is rooted in a formulated approach which is conscious of this grounding. As demonstrated above through publications such as Holmstrom et al. (2009), Hevner et al. (2004), Voordijk (2009) and van-Aken (2005), a cyclical process of reflection and action is embedded in both action research and design science. This cyclical process is particularly required at the front end of the research where the artifact needs to be developed through what Azhar et al. (2010) calls self-interpretation. This is a speculative process, proposing a solution that the researcher believes will work prior to any validation by the users (Johannesson & Perjons, 2012; Voordijk, 2009). The process discussed below is not a methodology in itself but a practice that is utilised through the development phase of the research.

4.4.1 Reflective Practice

Dewey (1933) outlines the importance of thought in the pursuit of action and doing. He states that using our conscious thought process for judgement and reflection on our action, provides us with a tool which can override the reactive and instinctive thought process. According to Hinett (2002, p. 2) with the aid of a simple prompt question such as “*what might I do better next time?*” or “*what I could do differently?*”, researchers have the potential to draw on the past and present and direct themselves into a better future. Asking questions such as these stimulates students and practitioners to reflect on past experiences.

Biggs (1999) provides a metaphor for reflection when he compares the difference between the reflection in a mirror, which he describes is “*an exact replica of what is in front of it*” and reflection in practice “*which gives back not what it is, but what might be, an improvement on the original*”. Moon (1999, p. 4) seems to agree with Biggs’s simile as she states that “*reflection seems to suggest more processing than would occur when simply recalling something*”, *the insinuation of considering something other than accepting what is ‘just in front of you!’*.

Kolb’s (1976) learning model demonstrates a four staged process of how reflection can assist in improving the learning process and how issues are reflected upon to form new concepts and theories, which are in turn used to provide solutions. The success of Kolb’s learning model is rooted in its recognition that reflective learning requires abilities that are polar opposites.

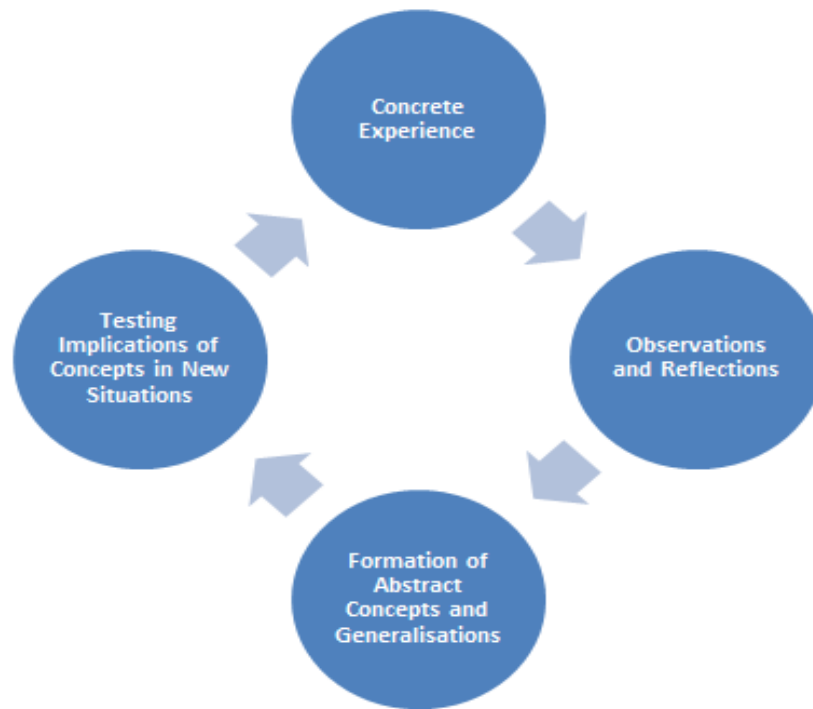


Figure 4.5: Kolb's Experiential Learning Model, (Kolb, 1976, p.22).

As illustrated in Figure 4.5, the model moves from experience to observation and reflection, to abstract conceptualisation and then to active experimentation. No matter what background you come from or what learning style or strengths you possess – the model, according to Kolb (1976) encourages a set of learning abilities that provide practitioners with the tools to adapt and master the changing demands of their job and career. Reflection in this research is cognisant of Kolb's model and the standards and processes described by Schon (1991), Dewey (1933) and Moon (1999), because the development of the 5D BIM - LCC solution was not achieved in one instantiation but through a laborious process of work, reflection, change and work again. It is evident that Kolb's model is similar to the action orientated methodologies outlined above, demonstrating a comparable process of reflection and action. However, the action (testing) that Kolb proposes is 'action learning', which is a self-evaluation rather than an action orientated research process, which must be validated through primary research (McGill, 1995). McGill (1995) states that action learning is a key ingredient of the reflective process where reflection must be bound with action to be applicable.

4.4.2 Reflection and Action

Schön (1991) argues that reflection is a key element of professional thinking, as it provides professionals with a tool to improve their practice rather than rely on some

readily available predetermined course of action. Schön (1991) refers to this process as “*reflection on action and reflection in action*”. Both terms suggest that reflection is closely bound with action and is described by a McGill (1995) as ‘action learning’

McGill (1995, p. 11) describes action learning as “*a continuous process of learning and reflection, supported by colleagues with an intention of getting things done.....action learning is based on a relationship between reflection and learning*”. McGill (1995) proposes reflection as the essential ingredient linking past action and more effective future action. McGill proposes an ‘action learning cycle’ similar to Kolb’s ‘experiential learning model’, where the action learning process moves from reflection on a certain experience or experiences, to identifying patterns in those experiences and formulating plans for improvement through action. McGill (1995) describes the action phase as the most important phase, as failure to act on reflections and thoughts will lead to a situation where a practitioner will never quite know whether their ideas have worked.

4.4.3 Action Learning and Action Research

McGill (1995) states that there is a difference between action learning and action research. The action researcher is committed to learning from investigation, making decisions about necessary change, applying these and then evaluating the consequences. In action learning, research may not be the primary aim and the project may not involve any formal research at all (McGill, 1995). The circular arrows in Figure 4.4 emphasise the cyclical process of action and reflection in this research. Reflection and action learning are utilised as practices within the development process and the overarching action research/design science methodology, thus they are not presented as the actual methodology but a part of a practice utilised within it. Firstly, reflective practice and action learning are utilised to develop the 5D BIM – LCC solution in the ‘action planning’ stage and subsequently there is an element of reflection and action in the cyclical ‘evaluation’ of that solution in a practical simulation.

Chapter 5 describes the development process (action planning) in this research. It outlines a process of reflection and action in order to develop an artifact that could have an effect on the barriers that prevent LCC being carried out effectively. The nature of this process was cyclical and thus the process is presented as a

chronological progression of reflection, action and change in line with the practices suggested by authors above.

4.5 Evaluation

Once the artifact is developed through reflection and action it should be judged based on its value or utility to a community of users based on performance evaluation (Voordijk, 2011). Ultimately a design artifact is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve (Hevner et al., 2004). van Aken (2005) states the most powerful technological solution is field tested and grounded by user participation. Voordijk (2011) asserts that evaluation should start with the development of measurers and criteria which represent the goals of the process; he outlines these measurers as the artifact's ability to perform the intended task in terms of its efficiency, effectiveness, generality, ease of use, and its impact on the environment and its users. Hevner et al. (2004) outline similar metrics such as functionality; completeness; consistency; accuracy; performance reliability and usability of the artifact. These metrics are similar to the usability characteristics of software development, which are discussed by Nielsen (1993) and Faulkner (2000) and provide measureable objectives for the system. Voordijk (2011) warns that failure to measure the artifact's performance according to established criteria will result in an inability to effectively judge research efforts.

Hevner et al. (2004) explain that rich phenomena will emerge from the interaction of people and technology, thus a method or methods to adequately capture this rich data is necessary, where participants engage in the new technological process. There are a number of different methods utilised by design science practitioners to carry out this process, such as user interviews, surveys, case studies and user testing simulations (Johannesson & Perjons, 2012; Voordijk, 2009). Voordijk (2009) and Van-Aken (2005) recommend that evaluation should involve a protocol which evaluates the participants using the system, whether in their actual work setting or a simulated environment, yet there is very little detail outlined in design science publications on this process. Hevner et al. (2004) requires that rigorous methods must be applied in the evaluation of the artifact, thus a data collection and analysis technique was required where evaluation could be performed in a consistent and formulated manner. As recommended by Voordijk (2011) and van Aken (2005), a process

described by Nielsen (1993) and Faulkner (2000) as usability evaluation (which is a method used in software engineering) was used to evaluate the artifact. However, there are a range of evaluation tools in usability evaluation and one that complemented an evaluation of social/human interaction as well as an evaluation of the artifact was necessary to fit with the methodological choice. The next sections articulate the process of selecting the most applicable evaluation technique for this research. Chapter 6 then outlines in more detail the procedures adhered to in the context of this research evaluation.

4.5.1 Usability

Before outlining usability evaluation it is necessary to establish what usability means in terms of systems development and how usability evaluation is carried out under the process of usability engineering.

Design science pays attention to the affect human factors have on computer systems and the affect computer systems have on the user (Shneiderman & Plaisant, 2005). Schneiderman & Plaisant (2005) describe an interdisciplinary design science of ‘human computer interaction’ where human performance and computer information systems intersect. According to Davis (1993), users overall attitude towards a given application will determine whether or not they actually use the system and thus whether it will be successful in carrying out a task. Davis (1993, p. 476) state whether or not a user uses a given system is a function of two criteria: “*usefulness of the system and its ease of use*”. Schneidnerman & Plaisant (2005) state that these criteria do not come from flamboyant systems with a stylish interface but from practical features derived from “*usability, universality and usefulness*”. Wahl (2000) states that the developer must keep these goals at the forefront of their mind when producing quality systems and advises that the system must also be easy to remember. Holzinger (2005, p. 71) and Dumas & Redish (1999, p. 4) describe these attributes as “*usability*” and outlines that it is most often dependent on the usefulness of the system to a given set of users in a specific environment.

An eminent piece of work on usability is Nielsen’s (1993) book on ‘Usability Engineering’ (UE), which brings together a number of journal papers he published in the preceding years (Nielsen, 1992, 1995). In line with design science recommendations by Voordijk (2010) and Hevner et al. (2004), Nielsen (1993) states

that practical and social acceptance criteria should provide the metrics whereby usability can be measured and evaluated. Schneiderman & Plaisant (2005) note that these metrics can provide precise measurable objectives that can guide the designer in proposing a functional system and a basis for measuring that system. Nielsen (1993, p.27) proposes that the following five essential ‘characteristics’ should be considered when developing software; [1] ‘learnability’, so the user can rapidly begin working with the system; [2] ‘efficiency’, enabling a user which has learned the system to attain a high level of productivity; [3] ‘memorability’, allowing the casual user to return to the system after a period of non-use; [4] ‘low error rate’, so users make fewer and easily rectifiable errors while using the system and [5] ‘satisfaction’, making the system pleasant to use.

The International Standard Organisation (ISO) (ISO 9241-11, 1998) also define the basis of usability as ‘effectiveness’, ‘efficiency’ and ‘satisfaction’ with which the specified users can achieve specified goals in particular environments. Faulkner (2000) states that the ISO characteristics are not enough by themselves for judging usability, she presents a further three attributes: ‘learnability’; ‘flexibility’ and ‘attitude’. Schneiderman & Plaisant (2005) commend the ISO goals but also propose more definite characteristics which are very similar to Nielsen’s metrics. In response to the critiques from publications such as Faulkner (2000) and Schneiderman & Plaisant (2005), the ISO (ISO 9126, 2001) added a number of sub-attributes to usability characteristics namely understandability, learnability, operability, attractiveness and usability compliance.

Although the terminology defined in the publications above may differ, the meanings behind the definitions are consistent. For the purposes of this research and to maintain consistency, usability characteristics will be addressed per Nielsen’s (1993) original metrics discussed above.

4.5.2 Usability Engineering (UE)

The concept of UE endeavours to address the usability of a system by proposing a systematic process which ensures that the system is fit for the purpose for which it was designed (Faulkner, 2000; Nielsen, 1993). ‘Usability evaluation’ is the fulcrum of the UE process, supported by steps in a ‘UE - life cycle’, which has multiple stages (Faulkner, 2000; Nielsen, 1993; Shneiderman & Plaisant, 2005; Wahl, 2000).

Nielsen (1992; 1993) and Faulkner (2000) state that there is a need to have multiple usability stages to be cognisant of the iterative process of design and redesign based on user input. Nielsen (1993) and Faulkner (2000) note that the 'UE life cycle' starts with the evaluation of the user and the task that the user will be carrying out. The stages of UE life cycle are discussed hereafter and are presented based on the staged processes outlined by Faulkner (2000), Nielsen (1993), Schneiderman & Plaisant (2005) and Dumas & Redish (1999).

The User

The first stage of the process outlined in many of these publications is to establish who the users are, and what tasks are to be addressed. Faulkner (2000) and Hall (2001) advise that we should have a firm understanding of who the users of a product are, what level of expertise they have, what they are likely to assume and the environment in which they are operating. Wahl (2000), Dumas & Redish (1999) and Schneiderman & Plaisant (2005) propose building up a realistic profile of the user such as their computer experience, their work experience and educational level. Faulkner (2000) states that based on the users level of experience there may be a number of different user profiles using the system, from novice, intermediate to expert. Establishing these attributes and considering which of these factors matter most is significant in deciding who the participants should be (Dumas & Redish, 1999). Dumas & Redish (1999) and Schneiderman & Plaisant (2005) agree that you should plan to include a broad range of participants in the evaluation in terms of their user profile.

The Task

Nielsen (1993) outlines that it is also important to carry out a task analysis. This can be carried out in conjunction with the user study, gaining information on what the user currently does, why they do it, their issues with the current process and what might improve the process (Faulkner, 2000; Nielsen, 1993). The result of a task analysis can be what Wahl (2000) describes as a 'problem statement' from which a specification for the proposed system can be envisaged. The weaknesses in the current system and the subjective feedback from its existing users, present an opportunity to design a system that can help the user achieve their goals effectively and efficiently. Dumas & Redish (1999) describe a process where general 'usability

concerns' are established prior to moving on to more specific goals and finally to what it is the system will do. Dumas & Redish's 'usability concerns' are similar to the 'problem statement' outlined by Nielsen. Ultimately the aim is to convert that understanding of the task and the problem statement into an appropriate human computer system (Faulkner, 2000).

Goal Setting

After the user characteristics and task analysis are carried out there are a number of stages before design work is started. Nielsen and Faulkner both outline a process of goal setting. Schneiderman & Plaisant (2005) state that getting beyond the vague quest for a user friendly system, designers must specify exactly what the goals of the system will be. The goals of the system can be framed within the usability characteristics outlined previously, such as ease of use; easy to learn; low error rate; effectiveness and satisfaction. Faulkner (2000) maintains that in order to achieve a goal the user has to carry out a specific action that leads to a desired outcome. Faulkner (2000) describes that usability goals are translated into an intention to perform some action, this is then translated into an action sequence, which when performed will lead to the achievement of the goal. The message here is that a successful action cannot be achieved without a specific goal.

Design

Following task analysis and goal setting the design process should start. Nielsen (1993) advocates a parallel and participatory design process whereby the developer may start with a number of different alternatives before they settle on a single approach. Participatory design accentuates the role of the user during the design process. Nielsen (1993) states that it is important to include users in the development process by getting early input on the parallel designs. Nielsen (1993) and Hall (2001) state that prototyping is a good way of getting input from the prospective users as prototyping can be presented in a manner that the user can understand.

Guidelines and Heuristic Evaluation

At this stage of the UE life cycle, both Faulkner (2000) and Nielsen (1993) propose that heuristic evaluation should be employed. Holzinger (2005) differentiates heuristics as an inspection method rather than a evaluation method, noting that

inspection methods do not involve the end user. Schneiderman & Plaisant (2005) compares heuristic evaluation to the critique that a theatrical preview is subject to. They suggest that systems should be critiqued by expert reviewers with experience in such a process. Heuristic evaluation involves checking the design against established guidelines and well known standards in user interface design (Holzinger, 2005; Jain, Dubey, & Rana, 2012; Nielsen, 1993). Bevan & Macleod (1994) claim that heuristic evaluation has the advantage that it can be applied early in the design process and adherence can be merely assessed by inspection by an expert without the resources applicable to user evaluation.

Prototyping

Nielsen (1993) states that one should not start full scale evaluation on early designs. Prototyping provides a medium for participatory user centred design, where early usability evaluation can be based on a scaled down version of the full system (Dumas & Redish, 1999). The advantage with producing a mock up or scaled down version of the system, is that feedback from the user can be achieved without designing the full system and realising it does not meet the user needs after considerable expenses are incurred (Faulkner, 2000; Nielsen, 1993). Hall (2001), Monk et al. (1993) and Dumas & Redish (1999) state that prototypes can take a number of forms. Examples of prototypes begin with verbal or written forms and visual representations on paper or screens. More detailed forms are a physical representation; a screen based interactive version and finally a fully working prototype (Dumas & Redish, 1999; Faulkner, 2000; Monk, Wright, Harber, & Davenport, 1993; Nielsen, 1993).

Faulkner (2000) states that paper mock-ups, storyboards and diagrams can take the form of early prototypes in the concept and design stage. Dumas & Redish (1999) note that these initial mock-ups are sometimes called screenplays. Faulkner and Nielsen outline a number of prototype forms including paper mock ups, storyboards, simulations, scenarios and state transition diagrams. Faulkner (2000) maintains that there is a lot to be said for the paper and pencil mock-up, while Nielsen (1993) advocates scenario prototyping which is described later in the cycle.

Prototype design is driven by a number of factors including the stage of the process, the resources available and the information required from the evaluation. It may be

sufficient to design a paper mock-up due to the fact the product has a simple interface and resources are limited. If the level of information required is concerned with the functionality of the system and whether the system can carry out the task without any errors, then a more detailed prototype could be required. Hall (2001) states that the later in the design process the evaluation is carried out, the more appropriate it is to have a more functional product. Nielsen (1992) establishes that it is useful to have an interface similar or as close to the finished product as possible, but not carried out too late in the development stage where significant changes might be harder to accommodate. Schneiderman & Plaisant (2005) outline that printed versions of the proposed systems are helpful but an onscreen display with an active keyboard and mouse is more realistic.

Microsoft Visual Basic (the programming language behind MS Excel) can provide a means whereby a proposed system can be built in an accessible application such as Excel and tested before it is developed in a bespoke system. Dumas & Redish (1999) emphasise that higher level prototyping is becoming more common as there are a number of different prototyping tools that can simulate the look and feel of a proposed application based on the possible full scale version. These products as well as spreadsheet applications such as MS Excel enable designers to try out design concepts quickly.

Once you have the list of tasks for the evaluation you have to decide how to present those tasks to the participants. In the complete system there maybe thousands of tasks, in prototyping Schneiderman & Plaisant (2005) propose reducing the proposed system down into a prototype that considers a handful of active pathways to perform the most important or most used tasks. This may take the form of a table of task sequence, indicating which tasks follow other tasks. Dumas & Redish (1999) ascertain one way of getting participants to carry out tasks is to present a ‘scenario’ or ‘situation’ in which the tasks are embedded. The advantage of scenarios is that the user can clearly see the meaning and benefit behind doing a particular task.

Scenarios

Scenarios may pose a question, or present a problem. Schneiderman & Plaisant (2005) state that scenarios should focus on the fundamentals of the system and the common tasks that the system will need to perform. There may be one task per

scenario or a number of tasks per scenario. Ultimately the scenarios should be short, direct and easy to understand (Dumas & Redish, 1999). Nielsen (1993) states that scenarios are utilised in prototypes to demonstrate the system and provide the users with a number of tasks. Faulkner (2000) determines that scenarios are possible interactions with the system, where designers can actually communicate to the user what can actually be done with the system. The advantage of this is that the users can actually see the usefulness of the system and give the designer feedback to be incorporated in the next iteration. The user follows the scenario descriptions and interacts with the system to perform a pre-planned set of procedures.

User Evaluation

Once the prototype evaluation is carried out and feedback is incorporated into the design, more detailed evaluation with a larger sample of users can be carried out. Holzinger (2005) and Nielsen (1993) agree that usability evaluation is the most fundamental stage in the usability life cycle. User evaluation by measuring user performance is almost always performed by having a group of users perform a set of predefined tasks, while observing them and collecting data (Nielsen, 1993). Usability evaluation provides direct information about how people use the system and their exact problems relating to using the system (Holzinger, 2005). Dumas & Redish (1999) address user evaluation within categories of performance measurement and subjective measurement. Performance evaluation counts actions and behaviours and is quantitative while subjective measurement evaluates people's perceptions, opinions and judgements and is qualitative. The specific types of evaluation techniques are addressed in the next section.

4.5.3 Usability Evaluation Methods

User evaluation is at the heart of most usability formulated processes and it is seen as the most important step in the UE life cycle (Nielsen, 1993). There are many ways to conduct usability evaluation and the method used has a direct result on the findings of the study (Olmsted-Hawala, Murphy, Hawala, & Ashenfelter, 2010). The most common forms of usability evaluation are experimental testing, thinking aloud, field observations, data logging and qualitative inquiry such as interviews and focus groups (Faulkner, 2000; Holzinger, 2005; Nielsen, 1993). Hall (2001) outlines that the most appropriate method depends on the type and complexity of the proposed

system, the purpose of the evaluation, the stage in the life cycle the evaluation will be carried out and the resources at your disposal in terms of equipment, money and time. A number of usability evaluation procedures were investigated in order to select the most appropriate one for this study.

Performance Measurement (Experimental Testing)

Nielsen (1993) outlines a user evaluation method that is based on performance evaluation of the user in a controlled environment, this method could be carried out in a user testing laboratory or in the work place. Many usability test laboratories use software programs for collecting (logging) data on participants performance (Dumas & Redish, 1999). Schneiderman & Plaisant (2005) describe the typical usability laboratory consisting of two ten by ten foot areas, divided by a silvered screen mirror including computers and recording equipment. Nielsen (1993) maintains that specially equipped usability laboratories are a convenience but not an absolute necessity. Wahl (2000) adds that it is possible to convert an existing office for usability testing or to use a university computer lab with no other specialty equipment.

Faulkner (2000) proposes a similar process but describes it as experimental testing. Performance measurement is used to obtain quantitative data on the tasks carried out by the participants where there is little or no interaction between the participant and the tester (Dumas & Redish, 1999). Schneiderman & Plaisant (2005) note that the tasks should be assigned possible response times or error rates from which the product can be evaluated. The system can then be benchmarked against these acceptable measures to evaluate whether it is working effectively. Faulkner (2000) describes a number of disadvantages to performance evaluation outlining that emulating the hard sciences by carrying out user evaluation in a controlled environment such as a computer testing laboratory does not provide data which is representative of the social interactions at play in a real work setting.

Performance measurement was not pursued in this research because it is not the intention to investigate the usability of a software programme, but to determine how post-processing data through 5D BIM could have an effect on the successful application of LCC on construction projects. Performance measurement does not take into account how this process could change existing work practices and thus an

evaluation method that could gauge the subjective attitudes of the participants engaging in a 5D BIM - LCC process was necessary.

Thinking Aloud (TA)

A method that is conscious of the user/system interaction is the 'Thinking Aloud' (TA) method, which provides a closer approximation to how the users actually use the system in practice (Faulkner, 2000; Monk et al., 1993; Nielsen, 1993). Holzinger (2005) asserts that the TA may be the single most valuable usability evaluation method, as it not only addresses user performance but it also generates qualitative data by probing what the user is thinking while using the system. Nielsen (1993) and Olmsted-Hawala et al. (2010) state that by verbalising their thoughts, participants can give an insight into how they use the system, which makes it easier to identify those parts of the process that cause the most issues. Nielsen (1993) believes the strength of TA is that it can find most of the usability problems from the qualitative data it can collect from a number of fairly small evaluation participants (4 participants, +or- 1). The traditional TA approach is outlined by Olmsted-Hawala et al. (2010) as 'concurrent TA', which is an approach where the participant is encouraged to think aloud while working on tasks set by the evaluator. There is little or no intervention in the process from the evaluator.

Monk et al. (1993) state that a TA variant known as 'cooperative evaluation' overcomes some of the problems with the traditional TA method by encouraging the user to explain their behaviour while using the system. This is similar to the 'coaching method' outlined by Nielsen (1993), where the evaluator may ask questions to stimulate the user to explain their behaviour. Dumas & Redish (1999) describe a similar process of 'active intervention'. They outline that the advantage of this method is that you gain insights into the participants evolving mental model of the product while they use the system. Rather than just silently observing the participant, this method provides a better understanding of the problems participants encounter while using the system (Monk et al., 1993; Nielsen, 1993). These methods may take the form of coaching the user through some aspect of the system they are having problems with (Dumas & Redish, 1999). Nielsen (1993) maintains that this method is more natural than traditional TA because the users are not under pressure to verbalise their thoughts and they feel that they are helping rather than being evaluated themselves.

Faulkner (2000) advises that the TA cooperative evaluation method is not conducive to quantitative measurement but provides hard evidence of user interaction with the system and can be carried out a lot quicker and easier than performance evaluation. The main disadvantage with TA in general, according to Nielsen (1992), is that performance evaluation metrics such as time taken to complete tasks and error rates are distorted by the presence and interference of the evaluator. Another issue outlined by Dumas & Redish (1999) is that participants may vary in their ability to tell you what they are thinking while they work. Some participants may forget to verbalise their thoughts, so it is important that the evaluator reminds these participants with helpful prompts (Monk et al., 1993). The level of participation applied in the evaluation depends on the level of interaction permissible, which should be explicit to both parties prior to the evaluation. However, specific questions can be a powerful tool, both to remind the participant to keep talking and to get valuable information on the reasons why they followed a course of action (Dumas & Redish, 1999). Olmsted-Hawala et al. (2010) and Boren & Ramey (2000) agree that TA protocols vary widely in terms of the methods employed as researchers often ignore protocols for TA and employ different or non-standard methodologies in an ad-hoc manner. It is important that the procedures are explicit in the study so that the research may be open to academic rigor and peer review. TA cooperative evaluation was utilised in this research and is discussed in further detail, on how it was applied, in Section 4.6.3 and Chapter 6.

Field Studies and Field Observation

Holzinger (2005) claims that field methods are the simplest of all methods. Field methods are carried out in the users own working environment. In this method the observer should be virtually invisible to ensure participants are operating under normal working conditions (Faulkner, 2000). Field observation may take numerous forms, such as data logging of the system in use and video analysis (Holzinger, 2005; Shneiderman & Plaisant, 2005). Nielsen (1993) ascertains that field observation is best suited to the evaluation of the final product in the work place. Portable usability laboratories can be used on site to support more thorough field evaluation (Shneiderman & Plaisant, 2005). Development in field evaluation has led to remote usability testing which can be carried out off site by online data logging. Schneiderman & Plaisant (2005) note that the downside is that there is less control

over user behaviour and less chance to observe the participants subjective reactions to using the system. Data generated from logging actual use and video recording usually gives rise to statistical information which can be supplemented with questionnaires to gain the users subjective satisfaction when using the system. Field observation was not carried out in this research. This was because, similar to performance evaluation, the artifact being evaluated was not a finished piece of software and the author did not have the capability or the resources at his disposal to implement and carry out a field study.

Other Indirect Methods

The usability evaluation methods outlined above are described by Nielsen (1993) as 'direct evaluation methods' as they generate data that is a direct result of the user using the system, for example the time it takes them to perform a task and the number of errors they make while performing the task. Traditional research methods such as interviews, focus groups and questionnaires can be used to gather supplementary data on user beliefs (Nielsen, 1993; Shneiderman & Plaisant, 2005). Schneiderman & Plaisant (2005) outline that interviews and focus groups can be a time consuming and costly process so it is usually only carried out on a handful of the user community. These traditional research strategies can be valuable in UE as they can uncover hidden issues that are of a more subjective nature. Holzinger (2005) states that these methods are deemed indirect evaluation methods since they do not study the actual user interface but only user opinions about the user interface.

As will be discussed in further detail in Section 4.6.3 and Chapter 6, elements of traditional research approaches, such as open-ended questions in the TA cooperative evaluation have been included in this research. However, indirect evaluation methods were not selected as the main evaluation tool because an evaluation procedure was necessary which could demonstrate the process through direct contact with the artifact.

4.5.4 Discount Usability Engineering

The previous sections outlined the detailed usability engineering cycle to software development and is a fairly lengthy time consuming process with many stages. It is often not practical to follow the detailed UE process for software development (Monk et al., 1993). An organisation or an individual with limited resources and time

would find it difficult to carry out all the stages in the UE life cycle due to time and monetary constraints (Monk et al. 1993). A number of authors in the field advocate a reduced or discounted approach to the formal UE process (Faulkner, 2000; Monk et al., 1993; Nielsen, 1993). Nielsen (1995) coined the phrase ‘discount usability engineering’ to describe a process that cuts down the UE cycle to a small set of broader stages. The advantage of a reduced approach in UE is that evaluation can be carried out in a fraction of the time and cost of more formal approaches (Nielsen, 1993).

Nielsen (1993) describes a four stage process to discount usability engineering, including [1] user and task observation, [2] creating scenarios, [3] evaluating by simplified thinking aloud and [4] heuristic evaluation. Hall (2001) notes that Nielsen’s discount stages can be representative of what can be achieved at a discount, but are not necessarily a definitive list. Hall (2001) explains that it is up to a prospective developer to use Nielsen’s approach to discount usability or employ their own reduced version, once it is grounded in reason.

Wahl (2000) describes an economic usability evaluation process that can be run by students that do not have access to usability laboratories, expensive equipment and other resources at the disposal of large organisations. Wahl’s approach consists of three phases [1] preparing for the evaluation [2] carrying out the actual evaluation and [3] analysing the results. Wahl (2000) notes that student run usability evaluation can be run in a university computer lab with no other equipment other than the computers. Wahl’s process does not include a prototype evaluation, but she does state that her proposed framework can be run on any number of iterations of the system.

4.6 Discount Usability Engineering (Approach in this Research)

In this research a reduced approach, similar to Nielsen’s, Monk et al. and Wahl’s methods was adopted. As outlined by Monk et al. (1993) and Nielsen (1995), an individual would find it difficult due to limited resources and time to carry out detailed UE. Monk et al. (1993) and Wahl (2000) specifically propose a formulated reduced approach for students addressing the main stages of the UE cycle. Even with the reduced approach, outlined below, most elements of the detailed UE cycle

articulated in Section 4.5.2 are taken into account in this research with the exception of heuristic evaluation. Heuristic evaluation was not considered because it is not included in Monk's and Wahl's frameworks and the focus of the research is not purely on the usability of the product but rather the dynamic relationships between the users, the process and the utilisation of the technology.

Figure 4.6 and subsequent sections present this research's discount usability engineering process. This staged process served as the evaluation stage and data collection measurers under the design science and action research methodology presented previously. This approach proposes the development of a prototype concept which was evaluated by six QS participants in a first stage of TA cooperative evaluation. Feedback and recommendations for improvement were included in a redesigned more developed version and a second TA cooperative evaluation, with a further ten participants, was carried out. The application of this process to this research is discussed in further detail in Chapter 6.

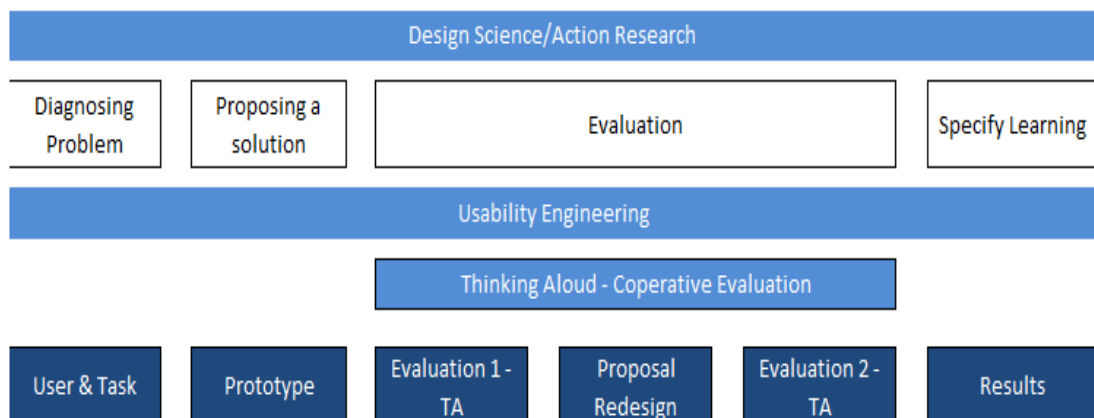


Figure 4.6: Usability Engineering

4.6.1 Define the User and Identify the Task

The users selected for this study were sixteen QSs (six for model development and ten subsequently for model evaluation) working in Ireland from various backgrounds and experience. The user is defined based on a user profile which is discussed in further detail in Section 6.2.1. At this stage, the evaluator must be conscious of the problems that need to be addressed, which were presented and outlined through the review of literature in Chapter 2 and 3. The tasks must be constructed to demonstrate how 5D BIM can be leveraged by post-processing BIM data for LCC and how this process can effectively address this problem. The tasks should encompass most aspects of what the solution can achieve. There is further detail presented in Chapter

6, providing evidence of the procedures and support documentation when carrying out these tasks on this study.

The review of literature has established how LCC is under-utilised as a service in the QS profession due to a number of barriers. The overall task itself is identified through the development of the solution, which is essentially leveraging BIM for more efficient LCC. This overall task is broken down per a number of scenarios (per the ideology outlined above), which demonstrate this process, by asking the user to perform a number of tasks. The evaluation measures, discussed in further detail in Chapter 6, describe how the tasks of the evaluation were identified and the step by step process carried out as part of the evaluation process. The tasks are representative of the work that the product and process will support.

4.6.2 Prototype in Excel

Hall (2001) notes that at the heart of the iterative design process is prototyping, where evaluation takes place early with representative users performing tasks appropriate to what they would be doing in a real world situation. A prototype was developed that replicates the functionality of the finished system by presenting the LCC calculations in 'MS Excel', while incorporating many of the functions and features of the proposed CostX system. The prototype development is outlined in Chapter 5 and was developed in conjunction with Exactal's CostX 5D estimating software. The premise of using MS Excel is that CostX's costing function is similar to a spreadsheet application, with all the basic functionality of a spreadsheet such as cells, sheets, formatting and formulae. The advantage of using Excel as a prototype medium is that most QSs are proficient with spreadsheet applications and thus the evaluation can be carried out quickly, without having to explain how the software works. It is also easier to construct the calculations in a generic application to simulate what the user may face in the proposed CostX system. Incorporating the calculations into the software is a time intensive process so gaining feedback and debugging the spreadsheet part of the system before full development is undertaken should lead to a better final system with many of the possible issues already addressed (Faulkner, 2000; Nielsen, 1993; Shneiderman & Plaisant, 2005).

By using MS Excel as a prototype tool some of the functionality of the final system will not be on show, this includes CostX's BIM toolkit which generates the QTO

used in the cost plan and LCC exercises. However, the main focus at this stage is on leveraging the cost plan and developing an effective LCC calculation structure to be incorporated into the BIM process. The prototype will provide a vehicle for feedback on these matters.

4.6.3 Evaluation – Thinking Aloud cooperative evaluation (1&2)

The evaluation method that was employed in this research was the TA cooperative evaluation method. As discussed in Section 4.5.3, the TA method has a number of variants prescribed on the basis of the designer's interaction with the user. An evaluation method that is conducive to a design science methodology and action research approach, which requires more than just the functionality of the system, was necessary. A TA process that involves greater interaction between the researcher and the user is cooperative evaluation (Holzinger, 2005; Olmsted-Hawala et al., 2010).

Monk et al. (1993) maintain that cooperative evaluation can be applied to prototypes and simulations, and is envisaged to be used in the early stages of the design process. TA cooperative evaluation combines empirical usability evaluation with a qualitative research design, by integrating interview type questions into the traditional TA method (Dumas & Redish, 1999). This method involves interaction and collaboration, where the user and the designer can both ask questions, but it also involves the evaluator steering the participant in the right direction while using the system (Monk et al., 1993). This is specifically suitable for this research, as some of the participants using the system will not have carried out LCC calculations to any great extent and thus will need to be guided in relation to what to do. It is also applicable based on qualitative data that is generated from engaging with the 5D BIM process and the views of the participants in relation to adding on LCC functionality to this work-flow. The level of interaction between the participant and the evaluator depends on some extent to the goals of the evaluation (Dumas & Redish, 1999). The objectives regarding the evaluation do not just specifically relate to the product but also include general questions on the overarching process of LCC and BIM, which are primarily addressed in the post-evaluation (debriefing) questions. Thus the method is both a usability evaluation and a research interview. This also complements an action research strategy because of the social interactions and the qualitative nature of the data.

Monk et al. (1993) claim that TA cooperative evaluation requires very little training and can quite simply identify and rectify problems with model development. In this research, two TA evaluations were carried out, one on the prototype (where feedback is included in a more developed version) and a second evaluation on a more developed version. Monk et al. (1993) outline the procedure to cooperative evaluation as follows:

- **Recruiting users** – Define the target population and recruit users.
- **Preparing & establishing the tasks** – Tasks should be specific. Tasks should explicitly outline what is required by the user.
- **Interacting with the user and the system and recording what happens** – It is important to record what the users say and do. Recording can be carried out by video, tape recorder or note taking. The session also includes a post-evaluation interview (debriefing session).
- **Summarising the observation** – When analysing the data from the evaluation, two broad categories of information should be examined: behaviour and user comments.

Faulkner (2000) maintains that participants enjoy TA cooperative evaluation more than the other formal techniques, as they have a sense of helping to find and fix the problems rather than feeling they are under investigation. Scheiderman & Plaisant (2005) and Monk et al (1993) agree the informal nature of TA puts the participants at ease and often leads to spontaneous interaction and comments that were not envisaged. These methods also have advantages in cases where the user population is small, specialised and the participants may not have the time nor interest in participating in lengthy performance evaluation (Nielsen, 1993). Faulkner (2000) suggests this method is as close a usability evaluation to simulating the users actual environment other than observing them in the field.

Henderson et al. (1995, cited in van Velsen, van der Geest, & Klaassen, 2007) state that TA identifies more usability issues than interviews, questionnaires and field observation. The TA process includes interview type questions in the debriefing stage of the TA exercise (post-evaluation questions) to generate subjective feedback on the topic addressed in the system rather than just the usability of the system itself (van Velsen et al., 2007). In the debriefing stage more general questions on the topic

of LCC are asked to gather opinions and attitudes on the issue of LCC and BIM, rather than just the usability of the LCC tool. This enables qualitative data to also be generated on the process the participants are engaged in and the relationship between the actions being taken and the results being obtained. The debriefing process is important in this context because it focuses on the human interactions at play which is necessary in action research. This broadens the data being generated and enables links and observations between the system and the theoretical grounding from which it emanates.

As illustrated in Figure 4.6, there were two TA cooperative evaluations carried out - firstly with six participants on model development (prototype) and subsequently with ten participants to evaluate the developed version/process. The procedures adhered to in this research followed the formulated structure evident in Nielsen (1993), Faulkner (2000) and Wahl (2000) for TA cooperative evaluation but are particularly applicable to the steps outlined by Monk et al. (1993) which are presented above. The procedures outlined by Monk et al. (1993) were the same for both evaluations. Further detail related to this process is discussed in Chapter 6.

4.6.4 Ethical Considerations

Ethical considerations are engrained in the procedures to be adhered to when carrying out the TA cooperative evaluation. As noted in the previous section the procedures of TA cooperative evaluation outlined by Monk et al. (1993) were specifically applied to this research and these are discussed in more detail in Chapter 6. These considerations extend from selecting the users, establishing the tasks and the administration of consistent instructions and check sheets on the day the evaluation takes place. Wahl (2000) and Monk et al. (1993) propose that each evaluation participant sign a consent form, which states that they are a volunteer in the process and that they may terminate the investigation at any stage. Faulkner (2000) and Schneiderman & Plaisant (2005) recommend, it is important the participant knows it is the process that is under evaluation and not the user. The consent form, as evidenced in Appendix 1h, explained the procedures of the evaluation; the possible risks to the participant; the opportunity to ask questions and that the participant could withdraw at any time (Dumas & Redish, 1999; Shneiderman & Plaisant, 2005). Ethical approval, evidenced in Appendix 5, was

gained from University of Salford based on the procedures outlined in this chapter and the information included in Appendix 1a-i.

4.7 Usability Engineering and Design Science

An important characteristic of a legitimate research method is that it is grounded in a firm theoretical framework. Often in published research on usability, no source is cited as a theoretical basis (Faulkner, 2000; Shneiderman & Plaisant, 2005). The only evidence of UE as a research approach is where Shneiderman & Plaisant (2005) describe UE as an “*interdisciplinary design science of human computer interaction*”. The UE life cycle outlined in Section 4.5.2 is a protocol for organisations carrying out system development and is too detailed and lengthy a process for an individual to be carrying out as part of a research project (Monk et al., 1993; Wahl, 2000). Wahl (2000) and Monk et al. (1993) mention that their proposed reduced approaches to UE could be used by students carrying out usability evaluation, but again there is no mention of the process being an academic research methodology.

Usability engineering and design science have many similarities, they both outline a development and evaluation framework and it could be argued that UE is a design science methodology - which is what Schenierman and Plaisant (2005) eluded too. However, the firm difference when examining the approaches is that UE only addresses the functionality of the system being developed. In this case, UE would only satisfy one criteria of design science knowledge production, and that is that the artifact is an innovative application in terms of addressing a certain task. It is for this reason that UE was not presented as the full framework for carrying out this research but rather the metrics of the latter part of the research, which is the evaluation of the artifact. In this context, UE is presented as the framework for evaluation under the design science methodology.

Another issue is the data produced by usability evaluation. To specify learning in design science and action research a technique is required that would generate the emotions and feelings of the user while using the system. This is what is required in a science that is interested in people and their interaction with a technological phenomenon (Hevner et al., 2004; Johannesson & Perjons, 2012). Performance

measurement of the artifact, per UE, would not give rise to the necessary data to determine the artifacts effect on the environment to which it was introduced. Other indirect methods such as interviews or focus groups would not facilitate a participant using the artifact thus participants views in indirect methods are not rooted in direct experience and would not be applicable to the learning required in design science. It was necessary to find an interactive method of data collection that could enable the researcher to guide the user through the software, while collecting data during use and comments and observations after use. Dumas & Redish (1999) state that measured active intervention in the TA process can gather this type of valuable data.

4.8 Positioning of the Research within a Traditional Framework

The research methodology is previously presented as action research focusing on the social process involved in carrying out LCC and design science focusing on the proposed artificial construct (leveraging 5D BIM for LCC) and its evaluation. By focussing on both the social and technological processes the research complements both action and design science research as discussed previously.

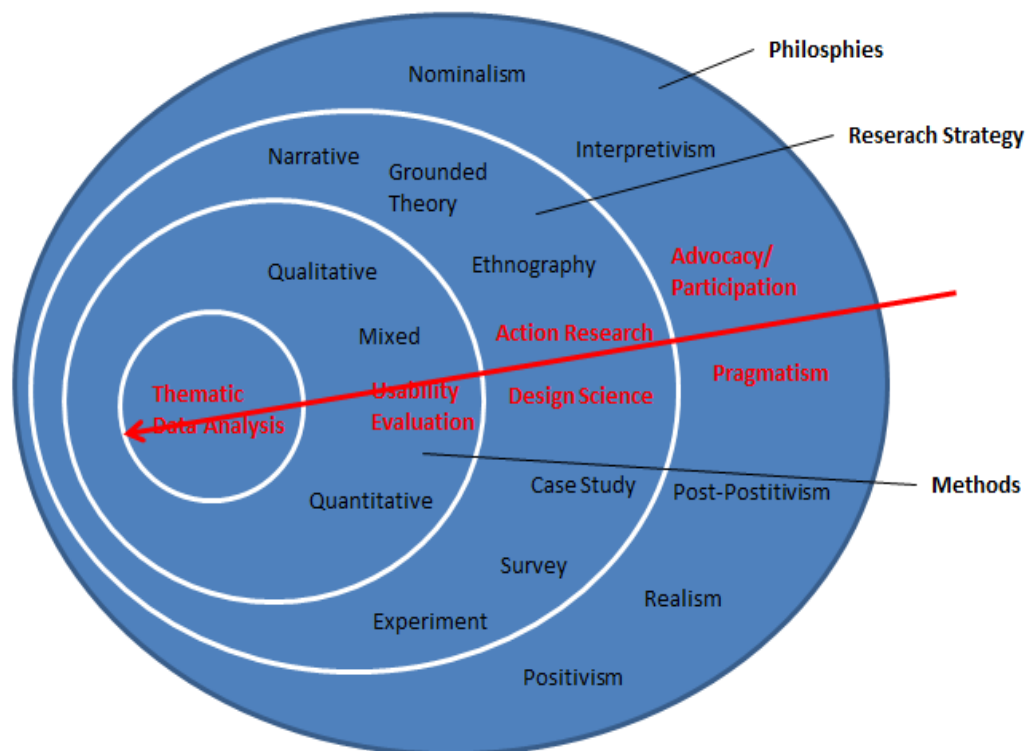


Figure 4.7: Research Onion (Saunders et al. 2009)

Figure 4.7 illustrates the research design within Saunders et al. (2009) research onion. The arrow crosses from pragmatic and participatory philosophies through an action research/design science strategy. Due to the similarities between action research and design science the latter is inserted in a similar position in the research onion. Usability evaluation and particularly TA cooperative evaluation is positioned in the context of traditional research methods and crosses the mono/multi method divide. This is due to usability evaluation's different stages, focusing on different types of data collection from performance evaluation and usability to the more subjective collection measures of emotions and feelings.

The rationale for utilising usability and particularly TA cooperative evaluation and the general data collection measures employed per the TA procedure are presented in Sections 4.5 and 4.6. The evaluation measures in the context of how they are applied in this research are not presented in full in this chapter. The development process leading to the solution needs to be articulated in the next chapter before the evaluation procedures relating to that solution can be fully digested. Once the development process is articulated in Chapter 5; Chapter 6 describes in detail the evaluation procedures that are applied in the context of the developed solution.

As noted previously, TA cooperative evaluation does not lend itself to performance measurement, thus the data that is generated from this evaluation is qualitative, based on information from the comments and observations of the participants and a number of post-evaluation questions (Monk et al. 1993). The comments generated during the evaluation and in the post-evaluation debriefing session are very important sources of data because they reflect the users experiences when using the system and engaged in the process (Monk et al., 1993).

Other than Wahl's (2000) contention that the data collected during the TA must be summarised and tabulated, there are no data analysis techniques addressed or proposed in the UE publications outlined above. The data generated from the TA cooperative evaluation are similar to data generated in an interview and thus data analysis techniques associated with qualitative research were investigated and employed. Maykut & Morehouse (1994) outline, that without a transparent process it would not be possible to verify the data and ensure credibility.

The data analysis method used in this research was ‘thematic analysis’. This approach has similarities to constant comparison and the open and axial coding process in grounded theory but because the focus is on themes, the process is more aligned with the formulated process of thematic analysis outlined by Braun & Clarke (2006). One ultimate central theme (grounded theory) is not what is required from the data, but a number of themes and categories which can offer feedback on the goals of the process such as ease of use, satisfaction, learnability, low error rate and effectiveness. The data analysis techniques and rationale for their selection are discussed in Chapter 6.

4.9 Summary

The aim of this research is to address a solution intervention in 5D BIM, specifically with a BIM 5D cost estimating application and whether the utilisation of this system and process could have an effect on the barriers to LCC. The researcher’s involvement in this process constitutes advocacy/participatory and pragmatism epistemologies. This chapter discusses two similar research strategies, action research and design science, within the boundaries of these research philosophies. Traditional methods of data collection such as questionnaires, interviews and focus groups do not suit this research, because they do not encompass interaction with the artifact in design science. It was necessary to find an interactive method of evaluation that could enable the user to be guided through the 5D BIM - LCC process, while collecting data during use and comments and observations after use.

Theoretical methods of evaluation in software engineering embody the concept of usability and provide a framework for collection within a formulated research design. The UE life cycle process outlined by Faulkner (2000) and Nielsen (1993) is cognisant of the theoretical grounding in design science methodology, where the process is iterative and includes adherence to a design, evaluation and a redesign cycle. This process is also in line with Kolb’s (1976) experiential learning model, where the model moves from experience to observation and reflection; to abstract conceptualisation; and then to active experimentation.

A usability evaluation method described as TA cooperative evaluation is proposed, as it enables an evaluation while collecting data based on the subjective attitudes of the participants on the process they are engaged in. The next two chapters outline the

main two stages of the proposed methodology of development and evaluation. Chapter 5 deals with the development of a design science artifact in an existing 5D BIM technology, which enables (through post-processing of BIM data) the extension of the BIM work-flow for LCC. Chapter 6 articulates in more detail the evaluation process applied specifically to the development outlined in Chapter 5.

5 Leveraging 5D BIM for LCC

5.1 Introduction

This chapter presents the staged process to the development of the technological solution (artifact), which is at the centre of a design science methodology (Vaishnavi & Kuechler, 2007) and Kolb's (1973) experiential model. It also outlines the iterative process of reflection and action (which is inherent in action research) by focusing on a process that will eventually be presented to the participants of the research. This represents the second step in the research strategy, which deals with developing a solution concept to the problem outlined in the review of literature.

The development process discussed in this chapter was carried out over five years, starting in 2010 and concluding in 2015. The initial focus was on constructing LCC spreadsheet templates and calculations within these templates to aid Qs carrying out LCC. Subsequently these calculations were imported into 5D BIM estimating software to provide an integrated environment for the calculation of both CAPex and LCCs. Each of the development stages are illustrated in Figure 5.1 and discussed in the sections below, including a brief summary at each stage of the reflective process, which informed the next cycle.

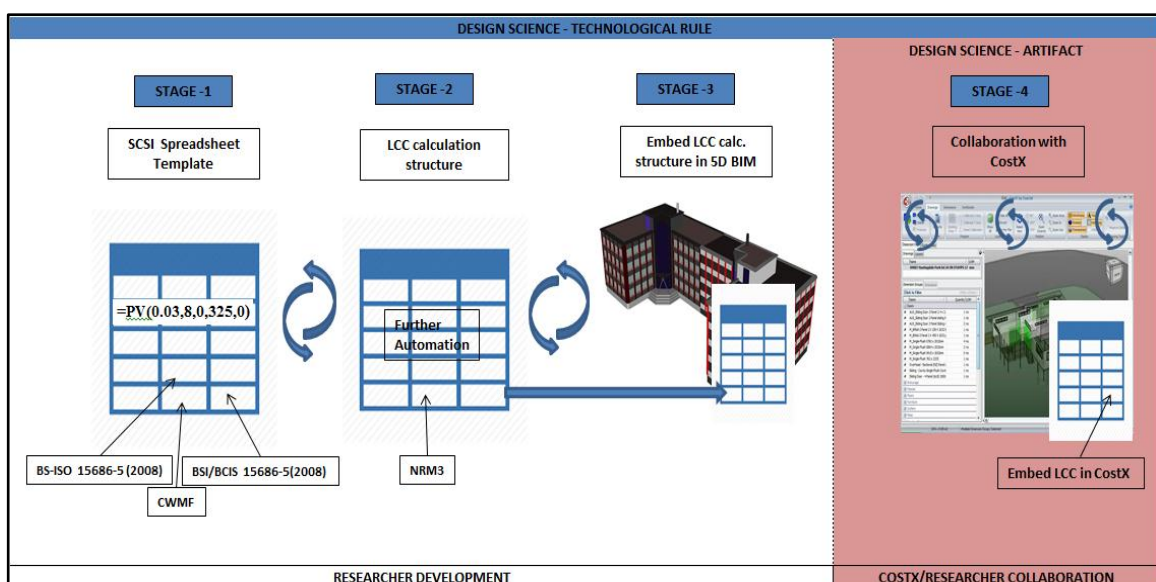


Figure 5.1: Staged Development Process

The developments discussed in this chapter represent post-processing BIM data for effective utilisation in LCC. This process is enabled with the use of a 5D BIM

technology by appending an LCC calculation structure into 5D BIM. The LCC calculation structure proposed in this research is positioned within the BIM workflow outlined in Chapter 3 and a conceptual map is presented illustrating the uniqueness and originality of this research within those parameters.

5.2 Initiating the Development Process

The Society of Chartered Surveyors Ireland (SCSI) is the professional body for construction, land and property professionals in Ireland and is the Irish body of the RICS (SCSI, 2015). As discussed in the review of literature, LCC is not in widespread practice by QSs offering cost services to their clients (Hourigan, 2012; Oduyemi et al., 2014; Opoku, 2013; Schaude, 2011). In May 2010 the SCSI and Dublin Institute of Technology (DIT) jointly invited Dr. Robert Charette from Concordia University in Montreal, Canada, to carry out a seminar and workshop for SCSI members and DIT staff. Charette guided the participants through the calculation methodology and practical application of LCC exercises. The attendees gained knowledge through a number of exercises and presentations in carrying out LCC option appraisal of building components. Charette (2005) recommended the use of financial tables to calculate the relevant formulae and calculations for LCC.

As discussed in the review of literature, the perception in the QS profession is that the formulae used in LCC are complex and time consuming (Fu et al., 2007; Hunter et al., 2005). Engaging in reflection during Charette's workshop and thereafter, it was considered that the calculations are not necessarily complex but time consuming, as each variable must be inputted to determine the relevant result and each result must be accumulated to determine the total LCC. In response, the use of spreadsheets were considered to calculate these factors and thus to calculate the LCC.

Subsequent to Charette's workshop, the LCC formulae presented in the workshop were written into functions in MS Excel and validated against the financial tables handed out in the workshop (Charette, 2005). These calculations revolved around building a facility for LCC data requirements such as the escalation rate, discount rate and the study period. This represented a basic first attempt to automate the calculations in a form that the QS could use effectively.

The first step in this research, (discussed in the next section) commenced when the SCSI requested that an LCC spreadsheet template be developed, which could aid their members carrying out LCC. To support this process a working group in ‘LCC and Sustainability’ was established by the SCSI from participants whom attended Charette’s workshop. While the group’s work did not necessarily constitute a novel approach (because it is similar to other jurisdictional LCC spreadsheets evidenced in the review of literature), it provided a starting point for this research; evidence of the cyclical nature of the development process and grounded further developments in relevant literature and methodologies.

5.3 SCSI Working Group in LCC – 1st Development Stage

The SCSI has a number of working groups researching best practise and procedures within the Institute’s professional groups (SCSI, 2015). The SCSI “*Working Group in Life Cycle Costing and Sustainability*”, has as its aim: *to provide practical guidance and assistance for QSs and the Irish government in carrying out LCC*” (Kehily, 2011). The group’s research was carried out by Dermot Kehily (the author), which is articulated through a number of practice and academic papers (Kehily, 2011; Kehily & Hore, 2012). The group outlined the different mathematical constructs of LCC and proposed a structure and methodology for presenting LCC through a standard spreadsheet template. The proposed spreadsheet was based on similar LCC functions to those outlined in the review of literature and Charrette’s workshop (Kehily, 2011).

As discussed in the review of literature, the requirement for LCC in Ireland was heightened by the introduction of the CWMF in May 2010 by the Irish government. The CWMF advises that LCC should be implemented by QSs providing cost management services on public projects in Ireland (Dept. of Finance, 2009). The SCSI ‘LCC and Sustainability working group’ commenced work in 2010 and completed in December 2011 with the publication of the ‘*SCSI’s Guide to Life Cycle Costing*’ (Kehily, 2011). A LCC calculation structure in MS Excel was developed, in conjunction with the guide, to provide a common approach within a recommended spreadsheet template. LCC functions similar to what were discussed in the review of literature were embedded in the template to automate the calculations. The LCC template is discussed in the next section and proposes a response to the requirements outlined in the CWMF. It provides QSs working on public projects in Ireland with a

template to quickly and accurately present a LCC estimate, grounded in the international standards at the time.

5.3.1 SCSI Life Cycle Cost Template

The SCSI template is designed and formatted per the ‘classification categories’ of BS-ISO 15686-5 (2008) and BSI/BCIS, ISO 15686-5 supplement (2008), which were discussed in Section 2.2 & 2.4.3 and illustrated in Figure 2.1. The template provides a suggested WLCC calculation structure and estimate layout which includes descriptions and formulae that can be changed and manipulated to suit the building type, client requirements and the stage of the project the WLCC is carried out. The template provides a step by step process to carrying out a WLCC estimate, supported through a series of spreadsheets, which are constructed in line with the appendices of BSI/BCIS (2008). The key benefits for SCSI members are the ability to complete a WLCC exercise without having to do any of the LCC calculations; the format is standardised in accordance with BSI/BCIS (2008) and the document can be saved to record data that may be used on estimates in the future. In total there are seven sheets in the template, representing the LCC classifications in BSI/BCIS (2008), including worksheets for project details, parameters, areas and scope. These sheets follow the recommendations for structure and layout in BSI/BCIS (2008) but include formulae and links through the worksheets to automate the LCC calculations. The worksheets of this template are addressed below to outline the content and rationale to their structure.

The first sheet is a blank sheet, which provides for the company preparing the WLCC to include their company details or ‘cover page’; the second sheet is an index page which presents the ‘table of contents’ and subsequent detail to follow; the third sheet includes input cells for relevant project details and ‘parameters’ and the fourth sheet outlines the ‘basis of the estimate’, which includes information on overall areas, exclusions, inclusions and the documents used in the preparation of the WLCC. These sheets encompass the ‘information’ sheets of the WLCC and are constructed in accordance with recommendations in the appendices of BSI/BCIS (2008).

The next sheets illustrated in Figure 5.2 and Figure 5.3 provides a summary of the information included in the WLCC estimate. There is no data to be entered in these sheets, as all the succeeding input sheets are linked and formulated to roll the

costings forward to populate these summaries, within BSI/BCIS coded classification categories. The overall summary, shown in Figure 5.2, provides a breakdown of the cost classification categories from BSI/BCIS 15686-5 (2008), which were previously discussed in in Section 2.2 & 2.4.3 and illustrated in Figure 2.1. These categories are; 2.0 maintenance Costs; 3.0 Operations Costs; 4.0 Occupancy Costs; 5.0 End of Life Costs and relevant mark-ups. Each classification category is represented in ‘Life Cycle Cost’ (real costs) ‘Present Value’ costs and Annual Net Expenditure (equivalent annual cost).

WLCC Life Cycle Cost Summary		Years 60			
WLCC	Whole Life Cycle Cost	Life Cycle Cost	€/m2	Total Present Value	€/m2
CC	Construction Costs	0	0.00	0	0.00
	2.0 Maintenance Costs	17,004	0.00	9,550	0.00
	3.0 Operations Costs	1,800,000	0.00	1,057,691	0.00
	4.0 Occupancy Costs	0	0.00	0	0.00
	5.0 End of Life Costs	0	0.00	0	0.00
LLC	Life Cycle Cost (2.0 - 5.0)	1,817,004	0.00	1,067,241	0.00
TLLC	Total Life Cycle Cost (Incl Construction)	1,817,004	0.00	1,067,241	0.00
	6.0 Non Construction Costs	0	0.00	0	0.00
	7.0 Income	0	0.00	0	0.00
	8.0 Externalities	0	0.00	0	0.00
WLC	Whole Life Cycle Cost (ex VAT)	1,817,004	0.00	1,067,241	0.00
VAT	Vat	245,296	0.00	144,078	0.00
WLC VAT	Whole Life Cycle Cost (Inc. VAT)	2,062,300	0.00	1,211,319	0.00
NAE	Net Annual Expenditure	Annual Costs	€/m2	%	
	2.0 Maintenance Costs	283	0.00	1%	
	3.0 Operations Costs	30,000	0.00	99%	
	4.0 Occupancy Costs	0	0.00	0%	
NAE	Net Annual Expenditure	30,283	0.00	100%	
	7.0 Annual Income	0	0.00		
WNAE	Whole Net Annual Expenditure	30,283	0.00		

Figure 5.2: LCC Template Summary 1 (Kehily 2011)

The next sheet is a more detailed summary (Figure 5.3), which provides further breakdown within each of the BSI/BCIS classification sub-categories. For example, ‘2.0 Maintenance Costs’ is broken down into seven sub-categories, providing more detail on the type of maintenance category.

LLC		Life Cycle Costs Analysis - BCIS			60 Years		
	Ref	BCIS	Annual Amount	Life Cycle Cost	Escalated Life Cycle Cost	Total Present Value	
Construction Costs	1.0	Construction Costs					
	1.1	Construction works costs					
	1.2	Other construction related costs					
		Total Construction Costs		0	0	0	
Maintenance, Operations and Occupancy Costs	2.0	Maintenance Costs					
	2.1	Major replacement	283	17,004	41,273	9,550	
	2.3	Redecoration - internal / external					
	2.4	Minor replacement, repairs and PPM maintenance costs					
	2.5	Unscheduled repairs, replacement and maintenance					
	2.6	Grounds maintenance					
	2.7	Client definable costs					
			Total Maintenance Costs	283	17,004	41,273	9,550
	3.0	Operations Costs					
	3.1	Cleaning costs					
3.1.1	Windows and external surfaces						
3.1.2	Internal cleaning						
3.1.3	Specialist cleaning						
3.1.4	External works cleaning						
3.2	Utilities costs gas and electric						
3.2.1	Fuel Costs	30,000	1,800,000	5,038,351	1,057,691		
3.2.2	Water and Drainage						
3.3	Administration Costs						
3.3.1	Property management						
3.3.2	Staff engaged with servicing the building						
3.3.3	Waste management disposal						
		Total Operations Costs	30,000	1,800,000	5,038,351	1,057,691	
4.0	Occupancy Costs						
4.3	Security						
4.5	Switchboard / telephones						
4.6	Postroom - mail services						
4.7	ICT and IT services						
4.12	Occupiers furniture, fittings and equipment						
4.14	Stationary and reprographics						
		Total Occupancy Costs	0	0	0	0	

Figure 5.3: LCC Template Summary 2 (Kehily, 2011)

The subsequent sheets provide for data input per the BSI/BCIS (2008) classification categories in ‘construction costs’, ‘maintenance costs’, ‘replacement costs’, ‘operations costs’, ‘occupancy costs’, ‘end of life costs’, ‘income costs’ and costs related to ‘externalities’.

An example of one of these sheets (Operations and Maintenance) is illustrated in Figure 5.4. This sheet provides a formatted spreadsheet, which includes the coded cost holding categories and sub-categories, and also the embedded formulae to automatically calculate the LCC. The template provides an example of electricity costs (ESB costs) which can be traced from the input sheet in Figure 5.4, to the level 2 summary in Figure 5.3 and ultimately to the overall summary page shown in Figure 5.2. The automatic LCC formulae and calculations are outside the print area demonstrated here, but will be discussed in the example presented in the next section.

O&M Operations and Maintenance							Years	60			
Ref	BCIS	Description	Qty	Unit	Rate	Annual Cost	Life Cycle Cost (e)	Escalated Life Cycle Cost (i)	Present Value		
2.0	Maintenance Costs										
2.1	Major replacement										
2.1	AP3 - Replacement Costs					283	17,004	41,273	9,550		
2.2	Subsequent refurbishment and adaptation costs										
2.2	State client requirements, standards required, working restrictions and procurement context										
2.3	Redecoration - internal / external										
2.3	State client requirements, standards required, working restrictions and procurement context										
2.4	Minor replacement, repairs and PPM maintenance costs										
2.4	State client requirements, standards required, working restrictions and procurement context										
2.5	Unscheduled repairs, replacement and maintenance										
2.5	State client requirements, standards required, working restrictions and procurement context										
2.6	Grounds maintenance										
2.6	State client requirements, standards required, working restrictions and procurement context										
2.7	Client definable costs										
						Total Maintenance Costs	283	17,004	41,273	9,550	
3.0	Operations Costs										
3.1	Cleaning costs										
3.1	3.1.1 <u>Windows and external surfaces</u>										
3.1	3.1.1.1 State client requirements, standards required, working restrictions and procurement context										
3.1	3.1.2 <u>Internal cleaning</u>										
3.1	3.1.2.1 State client requirements, standards required, working restrictions and procurement context										
3.1	3.1.3 <u>Specialist cleaning</u>										
3.1	3.1.3.1 State client requirements, standards required, working restrictions and procurement context										
3.1	3.1.4 <u>External works cleaning</u>										
3.1	3.1.4.1 State client requirements, standards required, working restrictions and procurement context										
3.2	Utilities costs gas and electric										
3.2	3.2.1 <u>Fuel Costs</u>										
3.2	3.2.1	ESB	1	LS	30,000.00	30,000	1,800,000	3.00%	5,038,351	5.00%	1,057,691
3.2	3.2.2 <u>Water and Drainage</u>										
3.2	3.2.2.1 State client requirements, standards required, working restrictions and procurement context										

Figure 5.4: Operations and Maintenance (Kehily, 2011)

5.3.2 Life Cycle Cost Example – Using Embedded Formulae

Kehily (2011) prepared an example WLCC for Colasite Bhride, Secondary School in Clondalkin, Dublin, as part of the SCSi working group’s project. The WLCC analysis was prepared with the recommended template, utilising cost information provided by Kerrigan Sheanon Newman (KSN) QS consultancy. The WLCC was presented by the working group to provide an example of how a WLCC estimate could be carried out and presented on a school project, using the SCSi template. Figure 5.5 represents a screen-shot of the WLCC summary page.

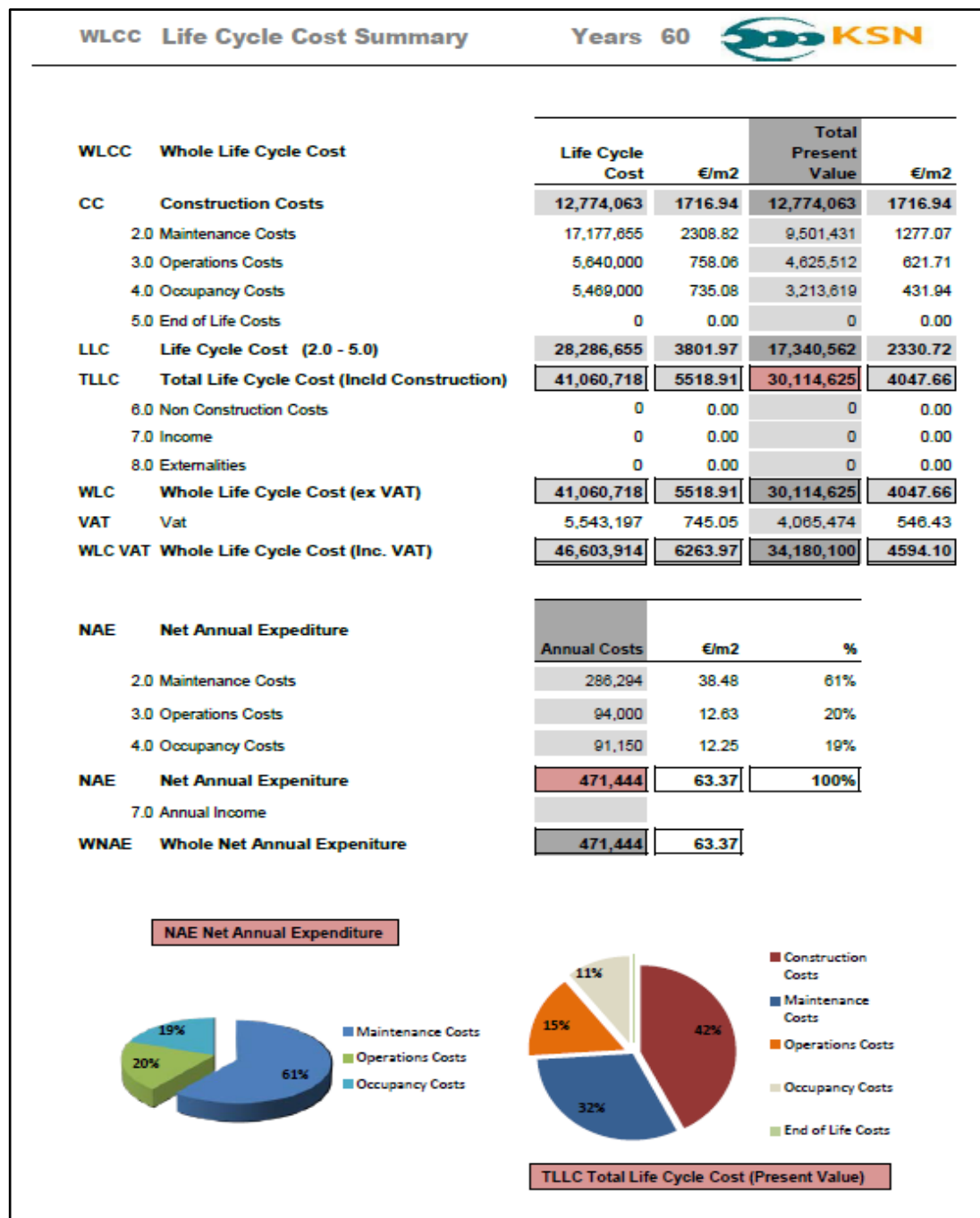


Figure 5.5: Example WLCC Summary (Kehily, 2011)

The total PV WLCC of the school building over a sixty year study is €34,180,100. This figure is broken down into eight coded classification categories from the BSI/BCIS (2008). The WLCC summary in Figure 5.5 also presents the proportional breakdowns of the WLCC estimate through the pie charts at the end of the summary page. Given that non-construction costs, including wages and salaries, income and externalities are not included in the estimate, the ‘construction costs’ account for 42% of the ‘Total Present Value’ costs. Maintenance costs accounts for 32%, operations costs 15% and occupancy costs 11%. Once the model is complete it can be used to run sensitivity analysis on the effects of different escalation and discount rates, additional costs and alternative replacement profiles.

Figure 5.6 provides an example of the input involved in the operations and maintenance sheet. The LCC calculations are carried out outside the print area where the factors are calculated from formulae which extract the escalation (e), discount rate (i) and study period (n) from the relevant cells to include them in the calculation.

BCIS	Description	Qty	Unit	Rate	Annual Cost	Life Cycle Cost	Escalated Life Cycle Cost	Present Value	f	f1	f2	(n)	Annual Amount		
Utilities costs gas and electric															
3.2.1 Fuel Costs															
3.2.1	Heating	1	LS	23,000.00	23,000	1,380,000	5.00%	8,539,047	5.00%	1,380,000	0.0000	0.0000	60,000	60,000	23000
3.2.1	ESB	1	LS	30,000.00	30,000	1,800,000	5.00%	11,137,887	5.00%	1,800,000	0.0000	0.0000	60,000	60,000	30000
3.2.2 Water and Drainage															
3.2.2	Water	1	LS	6,000.00	6,000	360,000	3.00%	1,007,670	5.00%	211,538	0.6846	0.0194	56,2564	50,000	6000

Figure 5.6: Example of PV calculation (Kehily, 2011)

These formulae are based on LCC calculations for Single Compound Amount (SCA), SPV and UPV formulae, discussed in the review of literature. If any of the variables are changed the result would proliferate through the estimate because the formulae are linked throughout each sheet in the workbook. The ‘utilities gas and electric costs’ are one of the costs associated with the ISO 15686-5 classification category, ‘operations costs’. Changing variables in this sheet, through the inherent

linkages will have an effect on the Total Present Value WLCC on the summary pages.

Figure 5.6 illustrates an example of a UPV* formulae used in the sheet which is typical to the other sheets used in the template. The UPV factor (column f2/row 3.2.2) which is calculated outside the print area is constructed with the relevant escalation rate (e), discount rate (i) and study period (n) through a number of calculations in the cells of row 3.2.2, columns f, f1 and f2. The formulae in f accounts for the top half of the UPV* formulae, f1 accounts for the bottom half and f2 is a result of dividing f1 into f to achieve the UPV factor in f2. The resultant UPV* factor in f2 is multiplied by the annual amount to determine the PV cost ($35.2564 \times 6000 = 211,538$). The text boxes above the screen capture show the formulae in the cells outside the print area. The formulae are illustrated here to demonstrate how the UPV* factor is broken up into three calculations. As can be seen in subsequent iterations, these formulae can be made more efficient by combining them within one cell.

5.3.3 Reflection & Summary of 1st Stage

Kehily (2011) developed a template that can be used to aid Qs producing LCCs under the CWMF. The template puts forward a standard response to the CWMF and is produced in consultation with ISO 15686-5 (BS-ISO, 2008) and BSI/BCIS supplement (2008). The template includes the relevant factors and formulae required to carry out LCC calculations automatically and were developed based on content from Charette's workshop.

The template, although applicable to carrying out detailed LCC estimates on public projects in Ireland, is too rigid to apply as a fixed LCC template on all LCC scenarios. It does not constitute a technological rule, which is necessary in design science, because it was a complete solution built specifically for the construction industry in Ireland, rather than a method or a process that could be followed in a different context.

After carrying out a number of LCC estimates based on this template, it was considered that the structure of an LCC estimate is a result of the specific scope and parameters of that project, rather than a fixed template that might not meet all scenarios. It is important that a template can be changed/manipulated to reflect the

context of the study, i.e. whether it is a LCC component evaluation or a full WLCC. In the context of a design science ‘technological rule’ it is important that it can be applied to a different circumstance.

In the next stage in the development process, the focus was on presenting a calculation structure that could be applied universally to any given LCC study, utilising existing technologies. The next cycle in this development, incorporates standards and information from NRM 3 (RICS, 2014), as well as BSI/BCIS (2008) and BS-ISO (2008). Rules of measurement pertaining to NRM 3 (RICS, 2014) were not included in the template presented above, because it was published subsequent to its development.

5.4 LCC Template for QS software – 2nd Development Stage

This work builds on the 1st Stage of development by producing a template to aid QSs carrying out LCC estimates in line with the standard methodologies in LCC and the calculations demonstrated in the review of literature (Kehily, McAuley, & Hore, 2012). At this stage in the development process expertise with LCC formulae and financial functions were more advanced and thus this template presented an even more efficient calculation methodology than what was contained in the SCSI template discussed above.

The template articulated in this section provides a suggested column layout in spreadsheet form, (Figure 5.7) to be used on its own when completing LCC estimates, or imported into estimating software through the software’s column customisation functions; i.e. replicating it in estimating software that has spreadsheet functionality. The calculations do not represent a complete LCC template but rather a calculation structure/methodology that can be used in conjunction with estimating/QS software. The LCC mathematical constructs and calculation structures are based on guidelines outlined in NRM 3 (RICS, 2014) and again on BSI/BCIS (2008) and BS-ISO (2008). The LCC calculations are constructed in such a way that they carry out the necessary calculations for study periods up to 100 years.

The LCC calculations discussed in this section focus on two main factors applied in LCC; the SPV and the UPV (Rows 1 & 2 – Figure 5.7). These calculations follow the methodology of Charette’s workshop (2010), albeit in a spreadsheet formulae

rather than contained in financial tables. The example calculations outlined in Figure 5.7 present an LCC calculation for painting (row 1) and energy costs (row 2). The study period considered for both calculations is 25 years, with painting occurring/recurring every 6 years (design life) and energy costs recurring every year.

The calculations are not framed within classification categories from any particular methodology but could be applied to any of the prevalent international or national standards. Once one row is imported into applicable QS software, it could be copied throughout the estimate or BOQ to provide LCC calculations to each line item in the estimate. This structure represents what van Aken (2005) outlines as a 'technological rule' in design science, because it does not constitute a complete software or interface but what Hevner (2004) outlines as an 'idea' or 'practice' that can be used as a guide to implementation in different contexts.

The template is demonstrated in a spreadsheet as many QS estimating applications simulate typical spreadsheet form in their workbooks. If the process can be carried out in a spreadsheet application, logically it could be transferred into estimating software through the customisation function; adding LCC criteria and data requirements to the existing quantity/cost functions. Alternatively, the primary quantity and cost data generated in an estimating application can be exported to the LCC spreadsheet template to generate a LCC estimate.

In this section the template is demonstrated and the calculations described. How the template can be incorporated into the 5D BIM process will be presented later in the chapter.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Ref	Description	Qty	Unit	Rate	Cost	Replacement Action	Scale of Replacement %	Rep Qty	Unit	Uplift Factor	Replace Rate	Factored Replace Cost	Interval	Design Life	Lifting Factor	Real LCC (base)	(e)	(i)	SPV factor	SCA factor	Nominal (Escalated) LCC	Present Value (Discounted) LCC	
				CUR																			
	Cost Plan Items																						
x.xx	Painting	184	m2	8.50	1,564	Remove make good and replace	100%	184	m2	1.10	9.35	1,720	4.00	6.00	1.00	6,882	2.00%	6.65%	2.14	5.43	9,344	3,686	
x.xx	Energy	1	LS	25,000.00	25,000	Yearly Energy Cost	100%	1	LS	1.00	25,000.00	25,000	25.00	1.00	1.00	625,000	2.00%	6.65%	4.74	32.67	816,773	368,471	

Figure 5.7: LCC Template Spreadsheet (Kehily, 2012)

For the purposes of explaining the calculations and linkages between the calculations, Figure 5.7 is broken down into more detailed sections, which are outlined below in Figure 5.8, Figure 5.9 and Figure 5.10. The columns are also coloured and numerated 1 through 24, to explain the process involved in the calculations and the content in each column.

The content of the spreadsheet in this example only includes two items. This is to illustrate the two calculations (SPV and UPV) applicable to most LCC calculations. An LCC estimate will have many more items but one of these two calculations can be applied to most LCC scenarios. The first row in Figure 5.7 outlines the calculations required for payments that occur at regular intervals throughout the evaluation period. The second row includes a calculation for a payment that occurs on a uniform basis (yearly or monthly). The calculations are identical in each row and thus annual recurring costs or costs at regular intervals can be applied in any row. The calculations are included throughout every relevant row and column in the workbook sheet so any number of cost plan or BOQ items can be added and calculated.

5.4.1 Utilising the Construction Cost Plan

The first number of columns (filled in blue, 1-6), illustrated in Figure 5.8, represent the typical data included in a cost plan or a BOQ, including a reference number (code); item description; quantity; unit; rate and total cost. These items can be copied or imported from the itemised CAPex cost plan and should represent all those items that will be replaced within the total life (years) of the building or the study period. Cost plan items that will not be replaced or maintained within the study period of the analysis can be omitted from the estimate. The advantage of using the cost plan as a basis of evaluating LCC is that the items provide a real cost basis for estimating replacement costs. This logic assumes that what will be replaced will be the same as the original item installed. If this is not envisaged to be the case the 'replacement action' (7) can be changed to a different item. In the example outlined in Figure 5.8, 184m² of painting is included at a rate of €8.50/m².

← Cost Plan Items →												
1	2	3	4	5	6	7	8	9	10	11	12	13
Ref	Description	Qty	Unit	Rate	Cost	Replacement Action	Scale of Replacement	Qty Replac.	Unit	Uplift Factor	Replace Rate	Factored Replace Cost
				CUR			%					
	Cost Plan Items											
x.xx	Painting	184	m ²	8.50	1,564	Remove make good and replace	100%	184	m ²	1.10	9.35	1,720
x.xx	Energy	1	LS	25,000.00	25,000	Yearly Energy Cost	100%	1	LS	1.00	25,000.00	25,000

Figure 5.8: Utilising the Cost Plan (Kehily, 2012)

← Replacement Items →

The spreadsheet is applicable to LCC for elemental and detailed cost planning. For example, the cost plan item may be at an elemental cost level, whereby the user allocates a replacement profile to the entire elemental cost. This is obviously not as accurate as a detailed component analysis but if performed on an early design, an elemental breakdown maybe all that is available or required. When more information is available at the latter stages of design a component level analysis will be able to be carried out. Ultimately the level of detail in the LCC estimate will correspond with the level of detail in the cost plan.

5.4.2 Replacement Action on Cost Plan Items

The subsequent columns filled in orange (7-13), in Figure 5.9, represent the replacement action to take place on the cost plan item. These columns follow the guidelines for calculating replacement costs in NRM 3 (RICS, 2014). The ‘quantity’ of the item to be replaced (9) is calculated from the ‘scale of the replacement’ (8) of the cost plan ‘quantity’ (3). In this example, the scale is 100% of the cost plan quantity, thus the replacement quantity is the same as the cost plan quantity (184m²). The user can also input a new quantity in this column (9) not based on the cost plan quantity.

An ‘uplift factor’ (11) can be applied to the cost plan rate to calculate the ‘replacement rate’ for the item (12). The majority of cost plan items will need an

uplift factor applied to them for preparation, demolition and making good to receive new work over and above the original cost (Ashworth, 1996; BSI/BCIS, 2008; RICS, 2014). The ‘replacement rate’ (12) multiplied by the ‘replacement quantity’ (9) generates the ‘factored replacement cost’ (13) for replacing this item in real costs (RICS, 2014).

7	8	9	10	11	12	13	14	15	16	17
Replacement Action	Scale of Replacement	Qty Replac.	Unit	Uplift Factor	Replace Rate	Factored Replace Cost	Interval	Design Life	Lifting Factor	Factored Life
	%									
Remove make good and replace	100%	184	m2	1.10	9.35	1,720	4.00	6.00	1.00	6.00
Yearly Energy Cost	100%	1	LS	1.00	25,000.00	25,000	25.00	1.00	1.00	1.00

Figure 5.9: LCC Characteristics (Kehily, 2012)

To carry out a more detailed analysis the user may breakdown the replacement item into a number of different components. One cost plan item and quantity may have a number of different components of the item being replaced at different times. These new items can still be linked to the original cost plan item and quantity (RICS, 2014). The spreadsheet allows for applicable replacement components to be added below the full replacement item. For example, in the case of a door, the door maybe painted, ironmongery replaced and seals replaced before the entire item itself is replaced. With these additional items a new replacement rate may be inputted not based on the original unit rate but specific to the component replacement; this cost will be inputted directly into the ‘replacement rate’ (12).

5.4.3 Adding LCC Characteristics

The green columns (14-17), in Figure 5.9, provide the inputs for calculating the subsequent LCC. The ‘interval’ (14) outlines the number of times the item will be replaced in the cycle. The ‘design life’ (15) is the published reference life for the item being replaced (Ashworth, 1996; BSI/BCIS, 2008; RICS, 2014). An uplift factor can be applied to the design life to take account of the conditions of the item in a project specific context. The methodology for calculating the uplift factor is

outlined in Ashworth (1996) and the NRM 3 (RICS, 2014). Multiplying the ‘uplifting factor’ (16) by the notional ‘design life’ (15) gives rise to the ‘factored life’ (17) applied in the estimate (Ashworth, 1996; BSI/BCIS, 2008). The study period considered in both calculations is 25 years. In the case of painting there are 4 intervals (14) with a design life of 6 years (15). Thus, painting recurs in year 6, 12, 18 & 24, within the 25 year life cycle. Energy is a yearly commitment over 25 years.

5.4.4 Representing Life Cycle Costs

The total real LCC represented in column 18, in Figure 5.10, is a result of the ‘factored replacement cost’ (13) multiplied by the number of times the item will be replaced (interval) (14). Real costs do not include inflation or discounting and are included here as publications such as BSI/BCIS (2008) and TG4 (2003) recommend LCC should be represented in real (current) costs.

However, as stated in the review of literature the predominant representation of LCC is ‘present value’. Present value discounts the future cost of a cost plan item (TG4, 2003). Accounting for future costs are difficult given the variables that exist between the date of the estimate and the date the cost is incurred. OGC (2007) and Ashworth (1996) recommend calculating future replacement costs from first principles. This is to calculate the costs of the replacement today (13) and escalate the costs with an ‘escalation rate’ (e) (19) to a future value based on the ‘design life’ (15) of the item. The future value of a series of payments over a study period are outlined here as the ‘nominal LCC’ (23), illustrated below in Figure 5.10. These costs can be discounted with an applicable discount rate to establish the ‘present value’ LCC (24).

13	14	15	16	17	18	19	20	21	22	23	24
Factored Replace Cost	Interval	Design Life	Lifting Factor	Factored Life	Real (base) LCC	(e)	(i)	SPV factor	SCA factor	Nominal (Escalated) LCC	Present Value (Discounted) LCC
1,720	4.00	6.00	1.00	6.00	6,882	2.00%	6.65%	2.14	3.43	9,344	3,686
25,000	25.00	1.00	1.00	1.00	625,000	2.00%	6.65%	14.74	32.67	816,773	368,471

Figure 5.10: Representing LCC (Kehily, 2012)

5.4.5 Life Cycle Cost Formulae and Factors

Similar to the method employed in the SCSI template, SCA and SPV factors are used to calculate the total ‘nominal’ cost (23) and the total ‘present value’ (24). These factors are generated from the data inputted in the green columns (14-17) and the escalation and discount rate inputted in column 19 and 20. The calculations and formulae in columns 21 and 22 are constructed with MS Excel functions based on the LCC calculations discussed in review of literature. The factors represent the accumulated factor for each time the item needs to be replaced based on the escalation and discount rates. If there are a number of replacements (intervals) (14), the SCA and SPV factors will be calculated for each interval in the study period based on the design life of the component and added together. For example, if there are 3 intervals and the item has a design life of 7 years, an SPV factor will be calculated at year 7, year 14 and year 21 and added together. The same methodology applies to the SCA factor. The resultant factors are then multiplied by the ‘factored replacement cost’ to outline the ‘nominal LCC’ (23) and ‘present value LCC’ (24), respectively.

The escalation and discount rates can be linked to a project rate inputted elsewhere or it can be manually inputted in the (e) column for an item specific rate. The SCA and SPV formulae are hidden and locked in the spreadsheet but are presented in Figure 5.10 per the yellow columns for illustrative purposes. In fact, these columns may be hidden from view completely as they are not input data or contain information required in any presentations of the LCC. They are calculations that are static and once embedded in the template there is no need to change them or manipulate them for different variables. They can be hidden from view as they represent the calculations occurring in the background. The SCA and SPV formulae contained in these cells will calculate factors for any inputted design life and interval, based on the escalation rate and discount rate. These formulae were checked with a scientific calculator and with Charrette’s (2005) financial tables, to make sure they were accurate. The formulae include the links, which extract the variables from the relevant preceding cells to include them in the calculation. They are constructed in such a way that they carry out the necessary LCC calculations for study periods up to 100 years. If any of the variables are changed the result would proliferate through the estimate without the need to reformulate the factors. This provides a means of

carrying out sensitivity analysis on any of the variables such as the rates, design life and intervals.

The second row of Figure 5.7 shows a cost for energy. These costs will not necessarily be linked to a cost plan item because they do not represent or are determined from a quantity from the drawings. The 'Energy Costs' [Row 2] are one of the costs associated with the BS-ISO15868-5 (2008) classification category, 'operations costs'. Energy costs differ from the examples presented above as they are costs that recur on a uniform basis (UPV) rather than at certain intervals. These uniform costs can occur weekly, monthly or annually. Uniform costs are usually calculated as costs for the year and replicated over the relevant study period. As stated previously, each row has the same inherent calculations. If an annually recurring cost such as energy is to be calculated over a certain time period, the user will insert the study period into the interval column (14). The design life will be '1' unit or in this case '1' year, thus calculating a cost in every year. Although the SCA and SPV factors are based on one off costs, they accumulate all the costs inputted for each one of the intervals and with a uniform cost they can calculate SCA and SPV factors for every year of occurrence; thus there is no need for a separate UPV calculation which was the case in the 1st Stage.

5.4.6 Reflection & Summary of 2nd Stage

The calculation structure outlined above is presented in a format that can be used on an elemental estimate, or a more detailed cost plan. Although the calculations are more automated than other LCC spreadsheets, in comparison with the LCC templates mentioned in the review of literature, it does not represent a significant departure in methodology, as it ultimately uses MS Excel to carry out the calculations. It is also based on a spreadsheet application that does not leverage any Computer Aided Design (CAD) technology. Carrying out measurement must be done separately or in an alternative application and then manually inputted into the spreadsheet. There is also no database function in MS Excel that can capture cost information to be reused in another exercise or on another project.

On reflection, it was also considered that there was too much detail in this structure, i.e. 24 columns. Thus, a QS looking to carry out LCC quickly and efficiently could be confused by the amount of information and be put off by the process. A summary

sheet similar to the original SCSI template outlined in Section 5.3.1 would also need to be developed to collate the calculations and present the LCC in a standard format because this is a requirement per all the LCC methodologies outlined in the review of literature.

In order to successfully generate an accurate LCC, the next sections outline the process of incorporating the calculation structure outlined above, within 5D BIM estimating software (with the ability to customise columns and add formulae). Leveraging BIM's 5D capabilities for LCC and incorporating an LCC calculation structure into the 5D BIM work-flow should provide the client with the financial tools to select the most economical advantageous solution and eliminate the need for investing in new estimating software to carry out WLCC. As outlined in Chapter 3, this is a field in the BIM process that requires attention (Goucher & Thurairajah, 2012; Redmond et al., 2011; Whyte & Scott, 2010) and it is the integration between LCC and BIM that drives the novelty in this.

5.5 Integrating LCC with BIM – 3rd Development Stage

The development process which is an integral part of design science started with the construction of a spreadsheet LCC template for the SCSI and continued through further development which proposed a calculation structure for potential use in QS's estimating software. This 3rd Stage describes how the LCC calculation structure outlined in the previous section can be incorporated into the 5D BIM process, to include LCC in the QSs 5D estimating platform.

This process, discussed briefly in Section 3.5, constitutes post-processing the quantities in the 5D BIM environment for LCC integration rather than focusing on incorporating LCC in an integrated design model. The reason for this, as discussed in the review of literature, is that BIM authoring software does not currently have the capabilities to accommodate the variable conditions and probabilistic calculations necessary for LCC (Eastman et al., 2011; Sylvester & Dietrich 2010; Whyte & Scott, 2010; Shen et al. 2007). Estimating software and 5D BIM tools were investigated to determine an application which could potentially accommodate the LCC process. The products explored were previously discussed in Section 3.4.

To demonstrate how the LCC calculation structure can be incorporated into the 5D BIM work-flow, the research adopted CostX. CostX is a 5D BIM estimating software by Exactal Technologies. CostX was selected because it has a workbook that is similar to the functionality and capabilities of a spreadsheet. Thus, it was seen as a good medium to incorporate the calculations described above. Other QS software has this functionality and any of these could have been used, but due to DIT having a good relationship with Exactal Technologies and CostX being one of the most prevalent 5D BIM systems in UK and Ireland, it was selected as the most appropriate choice.

Once the LCC calculation structure is embedded in the CostX system, it is possible to leverage the 5D BIM tool to create links between the model quantities, the original cost plan and the LCC calculations (Wu et al., 2014). The next sections present the initial development process of incorporating LCC calculations into the CostX 5D BIM platform and subsequent further development in this regard, consulting with Exactal Technologies.

5.5.1 Extracting Quantities by Utilising CostX

CostX enables you to quickly and accurately take off quantities from 2D drawings and 3D/BIM models using on-screen electronic measurement (CostX, 2014; Lovegrove, 2014; Wu et al., 2014). CostX comprises of a spreadsheet-based workbook and an electronic measurement tool/drawing viewer (Lovegrove, 2014). The workbook function in CostX is similar to a standard spreadsheet but is optimised by the use of a hierarchy structure, where work in one spreadsheet will return quantities, rates and totals to the spreadsheet above (Wu et al., 2014). CostX also provides the user with the ability to add ‘user defined columns’ to the workbook, to adjoin further columns and calculations to the traditional quantity, unit rate and cost columns of a cost estimate.

As illustrated in Figure 5.11, Wu et al. (2014) note that the CostX drawing viewer provides an excellent visualisation of the model similar to the functionality in Revit, where the navigation features enable you to rotate, pan, zoom and spin the 3D drawing. CostX also enables the user to filter, hide and invert model properties and layers to emphasise model information which is applicable to what is being measured (CostX, 2014). This functionality is similar to the integrated IFC viewer

developed by Fu et al. (2007), in their nD tool, which enables users to visually navigate the model, isolating building components and their attributes.

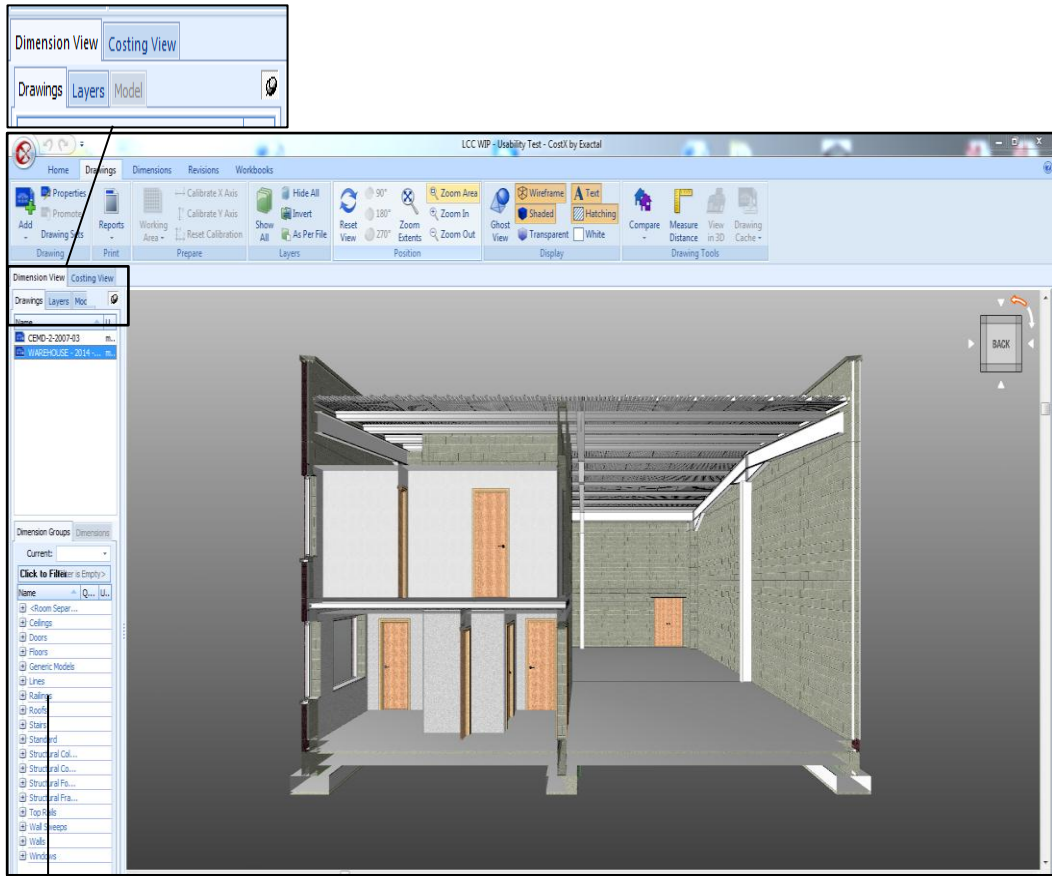


Figure 5.11: CostX model visualisation

A:Code	B:Description	C:Quantity	D:Unit	E:Rate	F:Subtotal	G:Factor	H:Total
1	SB Substructure	0	m2	0.00	0	0	0
2	CL Columns	0	m2	0.00	0	0	0
3	UF Upper Floors	0	m2	0.00	0	0	0
4	SC Staircase	0	m2	0.00	0	0	0
5	RF Roof	0	m2	0.00	0	0	0
6	EW External Walls	0	m2	0.00	0	0	0
7	WW Windows	0	m2	0.00	0	0	0
8	ED External Doors	0	m2	0.00	0	0	0
9	NW Internal Walls	0	m2	0.00	0	0	0
10	NS Internal Screens & Borrowed Lights	0	m2	0.00	0	0	0
11	ND Internal Doors	0	m2	0.00	0	0	0
12	WF Wall Finishes	0	m2	0.00	0	0	0
13	FF Floor Finishes	0	m2	0.00	0	0	0
14	CF Ceiling Finishes	0	m2	0.00	0	0	0
15	FT Fitments	0	m2	0.00	0	0	0
16	SE Special Equipment	0	m2	0.00	0	0	0
17	PD Sanitary Fixtures, Plumbing & Gas	0	m2	0.00	0	0	0
18	AC Air Conditioning	0	m2	0.00	0	0	0
19	FP Fire Protection	0	m2	0.00	0	0	0
20	LP Electric Light, Power & Communications	0	m2	0.00	0	0	0
21	TS Transportation Systems	0	m2	0.00	0	0	0
22	SS Special Services	0	m2	0.00	0	0	0
23	Element Sub-Total				0.00		0.00
24	<i>Delete following options not applicable</i>						
25	PR Preliminaries (Rate based)	#VALUE!	%		0	0	0
26	YY Contingency Provisions (Rate based)	#VALUE!	%		0	0	0
27	PR Preliminaries (Insert %age)	0.00	%		0	0	0
28	YY Contingency Provisions (Insert %age)	0.00	%		0	0	0
29	BM Builders Margin (Insert %age)	0.00	%		0	0	0
30	ET Escalation To Tender (Insert %age)	0.00	%		0	0	0
31	Building Total				0.00		0
32							
33	Professional Fees (Insert %age)	10.00	%		0	0	0
34	Fees - Other (Insert %age)	0.00	%		0	0	0
35	Construction Total				0.00		0

Figure 5.12: CostX workbook

The power of CostX revolves around the integration between the electronic measurement tool and the workbook module of the software, as demonstrated in Figure 5.11 and Figure 5.12. Mitchell (2012) describes that the user can take off quantities from either 2D or 3D/BIM drawings in the electronic measurement tool and create automated 'live links' between their take off and their workbooks. CostX can view and read information in 2D file formats such as JPEG, BMP, PDF & DWG (Wu et al., 2014). If the CostX user has a 3D model, in either a DWF or DWFx format, they can import the file into the CostX viewer and extract the quantities based on the Revit model structure, by applying pre-coded BIM templates (which ships with CostX) (CostX, 2014b). These BIM templates have been pre-coded specifically to extract data from the DWF object properties of the model, producing quantities in accordance with the Revit object hierarchy of 'Element Category', 'Family Name' and 'Family Type' (CostX, 2014b; Wu et al., 2014).

CostX also has a model definition tool which enables the user to configure a 'model map' to extract data and quantities from a BIM using any combination of object properties. According to CostX (2014a), this means that instead of generating quantities using the standard CostX BIM templates, users have the option to define model maps to customise quantities to user selected object properties. There are no specific BIM templates for the IFC structure; so a 5D QS using an IFC file, would use the model map to write code to extract quantities from models produced from authoring applications such as Archicad & Bentley. Using this function a 5D QS can map to the cost related object parameters of the model, such as the naming and dimension properties, in order to prepare a QS specific dimension structure from any authoring application. This represents a period of post-processing the quantities, as explained in the review of literature, where the measurement extracted from the BIM is mapped to the classification structure utilised in the cost plan.

Mitchell (2012) maintains it is helpful in post-processing if the BIM author/designer has included elemental codes such as UniFormat II (USA), UniClass (UK) or ACMM (AUS) in the model information to provide dimension classification. However, as outlined in the review of literature, this is rarely the case as they are not default properties in the DWF or IFC model structure. Mitchell (2012) notes it is often much quicker and more accurate if the 5D QS adds the preferred codes in the 5D programme themselves.

The goal of the dimension output from the model, using model maps, is to get the dimension structure (post-processed quantities) as close as possible to classification structure used in the project template in the workbook. This makes it easier to ‘live link’ dimensions to applicable descriptions in the CostX workbook. Subsequently changing any of the dimensions in the measurement tool will, in turn, change those dimensions in the workbook where the dimensions are linked. The live links keep the workbook updated with relevant quantities and leads to easy revisioning and real-time estimating (Lovegrove, 2014).

5.5.2 Importing LCC Calculation Structure into CostX

As discussed previously, the workbook function in CostX is similar to a standard spreadsheet but is optimised by the use of a hierarchy structure (Figure 5.13), where work in one spreadsheet will return quantities, rates and totals to the spreadsheet above (Wu et al., 2014).

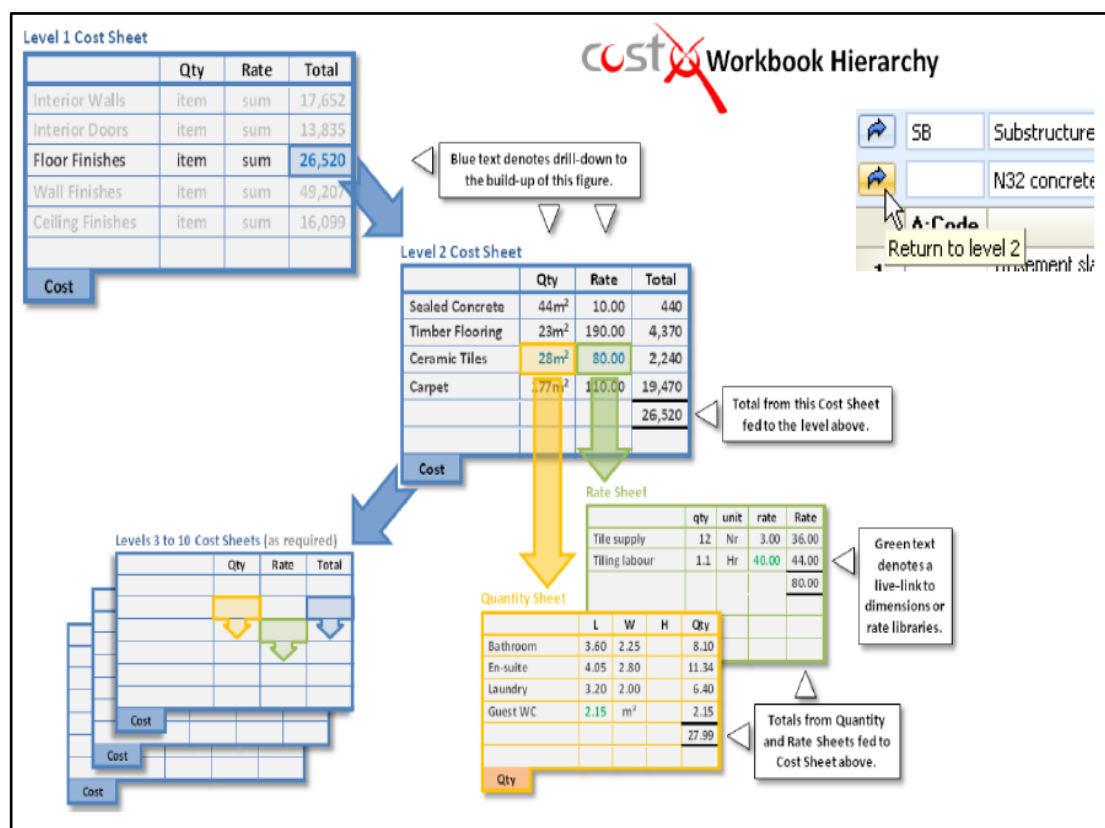


Figure 5.13: CostX workbook hierarchy (CostXa, 2014)

This is common in many estimating applications as it provides a structure whereby rates and quantities can be constructed in the background sheets and the total figures returned to the summary sheets. As illustrated in Figure 5.14, CostX provides the user with the ability to add user defined columns to the workbook (right columns of

workbook), thereby enabling the user to add additional columns to the existing 'quantity' 'unit' 'rate' and 'total' columns. This is carried out in the same way that you might add columns and create formulae embedded in those columns in MS Excel. In this way, you can add additional user defined information such as LCC calculations and data to the cost items in your BOQ or cost plan.

Figure 5.14 illustrates the LCC spreadsheet template outlined in Section 5.4, having been imported into CostX's workbook, by adding user defined columns and embedding formulae in those columns. This creates a customised LCC CostX workbook based on the BSI/BCIS (2008) and NRM 3 (2014) WBSs. The workbook is live linked both to the original construction cost plan and to the dimension group quantities in the measurement tool. This enables automation where changes in the model quantities will in turn change any item in the LCC workbook where those quantities are used.

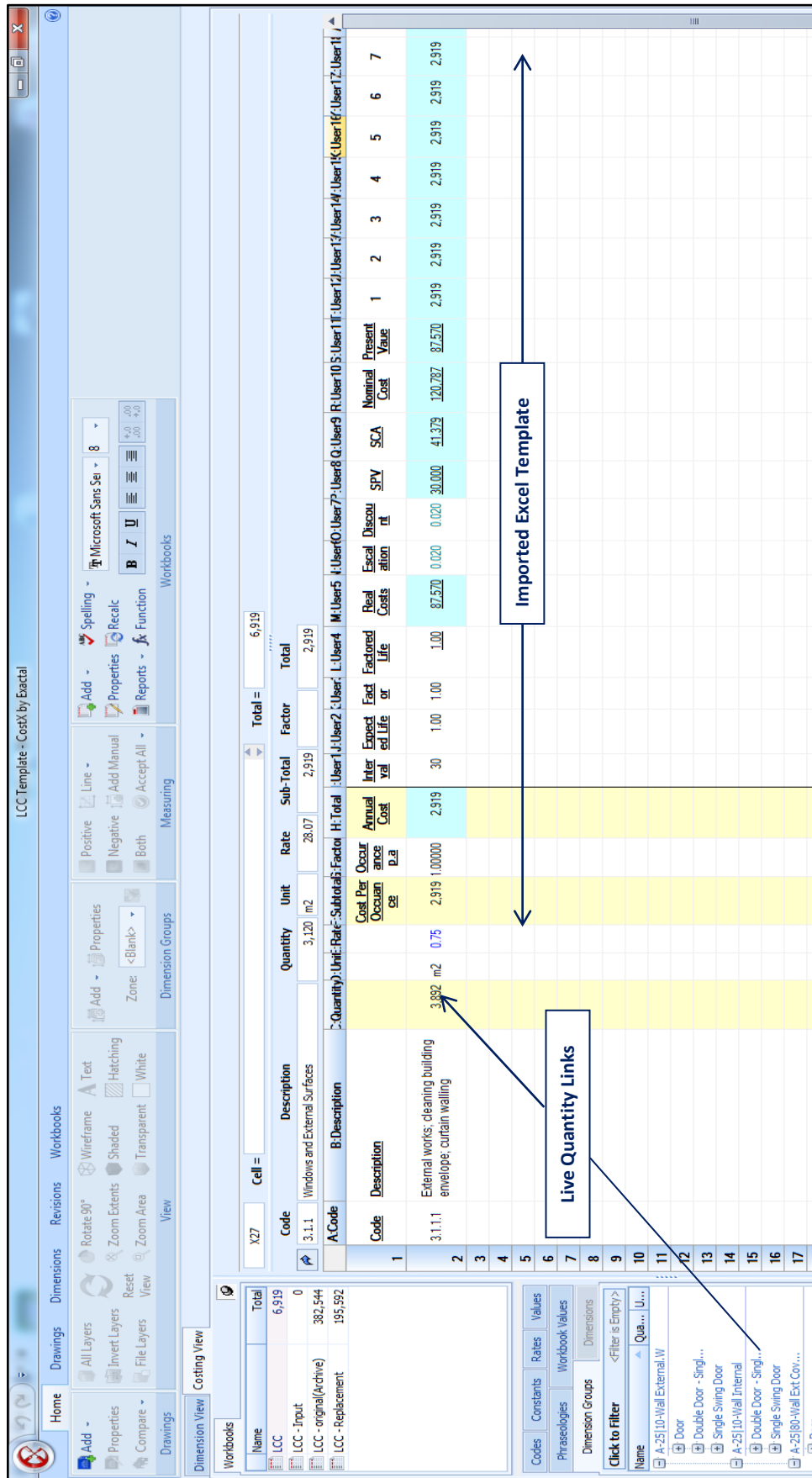


Figure 5.14: Imported Excel Template

The power of the LCC template utilised in CostX is embedded in the formulae of the cells. The cell calculations and formulae in the LCC CostX workbook are built in the template format using CostX functions (similar to spreadsheet functions) to create the formulae necessary to carry out the calculations. Thus, all the automation demonstrated in Section 5.4 is replicated in the CostX workbook. When the user returns from this spreadsheet level to the level above, LCC information such as real costs, nominal costs and present value are returned into the relevant coded breakdown structure and overall hierarchy of the BSI/BCIS (2008).

The coded WBS applicable to a WLCC item(s) can be selected from the 'Phraseology' tab in CostX, which contains a user imported CSV file of the BSI/BCIS (2008) WBS. In this manner, WLCC estimates can be constructed from the information in the workbook depending on the information required (real costs, nominal costs or present value) and the detail in the original cost plan and drawings in line with eminent standards and WBS. The calculations in the workbook provide for a detailed LCC but any level of detail can be catered for including early cost planning and conceptual life cycle costing.

The multidimensional links between the dimensions, the cost plan and the LCC workbook harnesses the power of CostX to produce a LCC calculation medium that can effectively create speedier and more accurate real-time LCC analysis, within a 5D BIM environment. Maintenance, operations and occupancy costs can be quantified and linked to the outputs of the parametric model in a similar way to the cost plan quantities.

5.5.3 Reflection & Summary of 3rd Stage

The process outlined above, where the LCC calculation structure described in Section 5.4 is incorporated into CostX, represents an attempt to embed an LCC calculation structure into a 5D BIM estimating application. The LCC calculation structure can be facilitated in the programme by replicating the LCC MS Excel template in the workbook feature of the CostX system. This embeds the automated LCC calculations in the 5D platform, extending its functionality into LCC.

Initiated through the close relationship between DIT and CostX, the following section outlines collaboration with CostX to develop this process further, with their help and expertise. Accessing CostX's expertise in the CostX workbook provided a

more efficient means of including an LCC calculation methodology within the software. It also addresses validating, with a software vendor, whether the design science technological rule could be achieved with an existing 5D BIM tool. The following sections discuss this work and describe the steps taken over a number of iterations with CostX.

5.6 Collaboration with CostX – 4th Development Stage

Initial discussions with CostX started with presenting them the work outlined in the previous section. Exactal stated that they were interested in further developing the LCC template in their CostX 5D BIM system and testing the theory discussed in the previous section. In particular, a senior product specialist with Exactal stated that he had worked on something similar and would like to collaborate on the developing the LCC calculation structure within the CostX workbook. The senior product specialist is an expert in the functions and formulae of the system, his command in programming the software complemented what was already achieved to date.

It must be noted that the collaborative development process articulated in the following sections is predominantly the author's own work. Collaborating with CostX offered an opportunity to fine-tune the artifact (idea/solution) proposed in the previous section; a means to validate if it could be effectively carried out (by getting an external expert to also carry it out) and also to gain the first cycle of feedback on whether it is operating effectively (further evaluation by potential QS users is discussed in Chapter 6). Essentially the CostX product specialist offered some additional advice on the LCC formulae in the calculation structure.

LCC methodologies and guidance notes were discussed and it was agreed that embedding a LCC workbook in CostX would need to reflect relevant international standards and WBSs. This started a process of collaboration over a number of months which included the exchange of CostX files (.exf), discussions, reflection on those files and cyclical changes. The collaboration gave rise to a number of iterations leading to a working prototype. These iterations are presented in the following sections and represent the action/reflection cycle necessary in action research and design science research. In recognition of maintaining Exactal's senior product specialist anonymity, collaboration with this individual will be referred to as collaboration with CostX.

5.6.1 *The CostX Workbook*

It must be noted that the CostX spreadsheet workbook is not specifically built to carry out the level of detail in a LCC estimate, as it does not have the same level of functionality as MS Excel. However, the workbook does give similar functionality to Excel, in relation to new columns, rows and functions that can link calculations between them. This is an advantage over other estimating applications and was a reason why CostX was selected. CostX's spreadsheet functionality can be utilised to replicate the spreadsheet LCC calculation structure, embedding it within the software. However, there are limitations to the CostX workbook that needed to be worked around, which included that the first number of columns had fixed headings and content that could not be manipulated or changed, thus it was only in subsequent columns that LCC calculations could be added.

5.6.2 *Iteration 1*

Active consultation started with CostX generating an interpretation of incorporating LCC calculations in the CostX workbook. CostX's work encompassed a slightly different approach to the structure outlined in Section 5.5. It was evident that CostX understood LCC calculations and that they could develop more applicable and complex CostX functions (with the necessary links and formulae within the cells) than what was previously attempted. Key discussions at this stage revolved around how best to present LCC calculations within the CostX workbook, leveraging the workbooks capabilities.

The first CostX iteration consisted of a one level/one sheet estimate, which did not leverage the hierarchical structure of the CostX workbook. Their first version was a similar concept to the LCC template in Section 5.5 but lacked hierarchical structure, thus it could not provide the framework to present an LCC estimate within relevant standards such as the ISO 15685-5 (BS-ISO, 2008) and NRM 3 (RICS, 2014).

As illustrated in Figure 5.15, CostX presented a structure that provided for a percentage breakdown of a cost plan item into LCC headings. As can be seen in the column headings (Figure 5.15), CostX divided the LCC calculations into 'Light Maintenance', 'Full Maintenance', 'Replacement' and 'Other Costs'; applying a factor to state what proportion of the cost plan item will be applied to the LCC

calculation for each of the LCC breakdowns and the period that it will be replaced (period & factor).

A:Code	B:Description	Quanti	D:Unit	E:Rate	F:Subtotal	G:FacH:Total	I:User1	J:User2	K:User3	L:User4	M:User5	N:User6	O:User7	P:User8	UseA:User1	B:User2	C:User2	User2	User3	User4	User5	User6	User7	User8	
								Light Mainten ance Period	Light Mainten ance Factor	Full Maintai nance Period	Full Maintai nance Factor	Replac e Period	Replac e Factor	Statutory /Other Inspecti ons / Testing Period	Statutory /Other Inspectio ns / Testing Factor	Years >>									
1																									
2	1 Item	123	m2	4.56	561	561	1	0.00	0	1.00	0	1.00	1	1.00											
3	1 Item	123	m2	4.56	561	561	1	0.24	3	0.48	6	1.20	1	0.11											
4	1 Item	123	m2	4.56	561	561	1	0.24	3	0.48	6	1.20	1	0.11											
5	1 Item	123	m2	4.56	561	561	1	0.24	3	0.48	6	1.20	1	0.11											

Figure 5.15: Iteration 1a

This idea of combining multiple LCC items on the same row was something that had not been investigated, primarily because each of these costs need to be identified as separate costs under most of the eminent methodologies in LCC (BSI/BCIS, 2008; RICS, 2014; Fuller & Petersen, 1996). A cash flow of present values was included to the right based on the number of years in the study period. These were automatically calculated and populated from the cost plan items, LCC factors and periods inputted in the preceding columns in that row.

From discussions with CostX it was noted that this draft could be used in some context which could be further explored, but it would need to be aligned with the applicable LCC methodologies, as terminology such as ‘Light Maintenance’ and ‘Full Maintenance’ were not in line with recent LCC standards. It was also noted that the different LCC items such as ‘Light Maintenance’, ‘Full Maintenance’ and ‘Replace’ would need to be broken out into separate cost items rather than included as an accrued cost on one line. The calculations did not include a total cost for the NPV cash flows (i.e a total Present Value) and it did not represent cash flows or total costs in Real and Nominal costs.

It was agreed at this stage that the terminology of the headings be changed (demonstrated in Figure 5.16) to align with BSI/BCIS (2008) and NRM 3 (RICS, 2014). A summary sheet was also developed, illustrated in Figure 5.17, that included

the coded WBS summary headings for the BSI/BCIS (2008) and the NRM 3 (RICS, 2014) before being sent back to CostX for consultation.

A:Code	B:Description	Quantit	Unit	E:Rate	H:Total	I:User1	J:User2	K:User3	L:User4	M:User5	N:User6	O:User7	P:User8	Q:User9	R:User10	S:User11	T:User12	U:User13	V:User14	W:User15
						Maintenanc	Minor Mainten ance Period	Minor Mainten ance Factor	Major Maintai nance Period	Major Maintai nance Factor	Repla ce Period	Repla ce Factor	Reactive (Unplann ed) Maintena nce Period	Reactive (Unplann ed) Mainten ance Factor	Years >> NPV Values			1	2	3
1																				
2	1	Single Doors	25	nr	1,000.00	25,000	-Replace Seals, +Replace Ironmongery, (D) Repair, (C) Clean	2	0.07	10	0.30	20	0.60	1	0.05	60,930	1,295	2,892	1,213	
3	1	Item	100	m2	4.56	456		1	0.24	3	0.48	6	1.20	1	0.11		154	150	343	
4	1	Item	100	m2	4.56	456		1	0.24	3	0.48	6	1.20	1	0.11		154	150	343	
5	1	Item	100	m2	4.56	456		1	0.24	3	0.48	6	1.20	1	0.11		154	150	343	

Figure 5.16: Iteration 1b - Heading changed

A:Code	B:Description	H:Total	I:User1	J:User2	K:User3	AA:User19	BB:User20	CC:User21	DD:User22	EE:User23
1	2.0 Maintenance	Annual Real Costs	Real Costs	Escalated Costs	Present Value	Years >> Present Value	Year 1	Year 2	Year 3	Year 4
2	2.1 Major Maintenance & Replacement (full replacement items) on elements below									
3	Element	2,244								
4	Element	26,368								
5	Element	78,903.20								
6	31 Internal Wall Completions	1,411.67	42,350	69,395	22,050		0	0	0	0
7	Element									
8	Element									
16									
17	2.2 Subsequent Refurbishment and Adaption Costs (Not in 2.1 or 2.4)									
18	2.3 Redecoration (Not in 2.1 or 2.4)									
20	2.4 Minor Replacement Repairs and PPM Maintenance Costs (Routine) on Elements below									
21	Element									
22	31 Internal Wall Completions	36,708	313,750	481,286	191,066		7,501	7,260	7,027	6,802
23	Element									
24	Element									
25	Element									
26									
27	2.5 Unscheduled Replacement Repairs and Maintenance (Reactive)									
28	2.6 Grounds Maintenance									
29										
30	3.0 Operation costs (Annual)									
31	3.1 Cleaning Costs (not in above)									
32	3.1.1 Windows and external surfaces									
33	3.1.2 Internal cleaning									
34	3.1.3 Specialist cleaning									
35	3.1.4 External works cleaning									
36	3.2 Utilities costs gas and electric									
37	3.2.1 Fuel Costs									
38	3.2.1 Fuel Costs (electricity)	3,330	99,900	212,295	81,820		3,286	3,243	3,200	3,157
39	3.2.2 Water and Drainage									

Figure 5.17: Summary

5.6.3 Iteration 2

It was agreed with CostX that the next iteration would encompass a scenario which leveraged the hierarchical levels of the CostX workbook. Iteration 2 in the collaborative process was somewhat of a departure from the first, as it did not calculate costs on one line or as a proportional percentage allocation of the cost plan item. At this stage, two separate sub-sheets for the breakdown items on the summary page were proposed. One was based on costs for cyclical replacement and maintenance items (items having intervals other than every year) and the second sub-sheet was for LCC costs that occur on an annual basis. This ideology was based on the two calculations originally outlined in Section 5.5, but included more efficient formulae based on a greater command of the programme by CostX. The LCC sheet for the calculations of cyclical replacement and maintenance costs included two proposed examples of how these calculations could be carried out; one based (Figure 5.18) on doing all the calculations on the 2nd level sheet (behind the summary page) and the other utilising a further 3rd level (Figure 5.19). This proposed two different options leveraging the hierarchical nature of the workbook and provided a means to discuss the best approach.

A:Code	B:Description	Quantit:Unil	E:Rate	F:SubtotalG:Factor	H:Total	J:User2	K:User3	L:User4	M:User5	N:User6	Use	P:User8	A:User13:User20	User20:User2E:User2F:User2G:User2H:User2I:User2J:User2K:User2L:User2M:User2N:User2O:User2P:User2Q:User2R:User2S:User2T:User2U:User2V:User2W:User2X:User2Y:User2Z							
8	EXAMPLE USING SECOND LEVEL SHEET Maintenance Actions		Real Cost Per Occurrence Per Unit	Real Cost Per Occurrence	Nr of Occurrences	Real Cost	Mainten ance Period	Mainten ance Factor	Real Cost	Escalated Cost	Present Value		Years >> — Year 1 Year 2 Year 3 Year 4 Year 5 Year 6 Year 7 Year 8 Present Value								
9	820 x 2040 Internal door, flush, veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery																				
10	1 Replace seals	25 nr	52.88	1,322.00	5.00000	6,610.00	6	1.10	7,271	11,591	4,198		0	0	0	0	0	1,196	0	0	
11	1 Replace Ironmongery	25 nr	129.00	3,225.00	3.00000	9,675.00	10	1.10	10,643	17,795	5,740		0	0	0	0	0	0	0	0	0
12	1640 x 2040 Internal double door, flush, veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery																				
13	1 Replace seals	5 nr	105.76	528.80	7.00000	3,701.60	4	1.10	4,072	6,163	2,499		0	0	0	511	0	0	0	448	
14	1 Replace Ironmongery	5 nr	518.00	2,590.00	3.00000	7,770.00	10	1.10	8,547	14,291	4,609		0	0	0	0	0	0	0	0	
15																					

Figure 5.18: 2nd level estimate

As can be seen in Figure 5.19 returning from the 3rd level will populate the relevant total costs on the 2nd level. It was agreed that some of the terminology in the columns be changed to align with standard LCC terminology. It was discussed that the 3rd level estimate was too complicated with too many levels and thus we focused on the 2nd level approach as outlined in Figure 5.18; the first level being the summary and the next level encompassing the detail.

A:Code	B:Description	Quant	Unit	E:Rate	F:Subtotal	L:User4	M:User5	N:User6	UseA:User13	UserZ:User20	User2E:User2F	User2G:User2H	User2I:User2J	User2K:User2L
EXAMPLE USING A THIRD LEVEL SHEET										Years >> Present Value Year 1 Year 2 Year 3 Year 4 Year 5 Year 6 Year 7 Year 8 Year 9 Year 10				
1				Average Real Cost Per Unit Over Specified Period	Real Costs	Real Cost	Escalated Cost	Present Value						
1	820 x 2040 Internal door, flush, veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery	25	no	1,587.00	39,675	43,643	71,871	22,922						2,560
3	1640 x 2040 Internal double door, flush, veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery	5	no	2,294.32	11,472	12,619	20,455	7,108			582		582	2,849

C:Code	B:Description	Quant	Unit	E:Rate	F:Subtotal	G:Factor	H:Total	UseJ:User2K	User3	L:User4	M:User5	N:User6	UseA:User13	User18:User2C	User2D:User2E	User2F
Maintenance Actions										Years >> Present Value Year 1 Year 2 Year 3 Year 4						
					Real Cost Per Occurrence	Number of Occurrences	Replacement Cost	Mainten ance Period	Mainten ance Factor	Real Cost	Escalated Cost	Present Value				
2	1 Full door replacement	25	nr	1,200.00	30,000.00	1.00000	30,000.00	20	1.10	33,000	54,074	17,182			0	0
3	1 Replace Ironmongery	25	nr	129.00	3,225.00	3.00000	9,675.00	10	1.10	10,643	17,799	5,740			0	0

Figure 5.19: 3rd level estimate

Based on what was identified in the previous iteration, total costs and cash flows for Real Costs, Escalated costs and Present Value, (which were not included in the original template and not included in the first iteration) were added at this stage.

In summation at the end of this iteration the prototype had a summary page and two calculation sheets. The first calculation sheet illustrated in Figure 5.18 and a second sheet outlined in Figure 5.20 that calculates LCC on a yearly basis.

C:Code	B:Description	Quant	Unit	E:Rate	F:Subtotal	G:Factor	H:Total	UseJ:User2K	User3	L:User4	M:User5	N:User6	UseA:User13	User18:User2C	User2D:User2E	User2F	User2G:User2H	User2I:User2J
Description										Years >> Present Value Year 1 Year 2 Year 3 Year 4 Year 5 Year 6 Year 7								
		QTY		Rate	Real Cost Per Occurrence	Nr of Occurrences / In year	Annual Cost	Factor	Real Cost	Escalated Cost	Present Value							
2	Electricity																	
3	1 Elec	2,220	kwh	1.50	3,330.00	1.00000	3,330.00	1.00	99,900	149,951	62,674	3,223	3,120	3,019	2,923	2,829	2,738	2,650

Figure 5.20: Annual costs

It was also agreed that CostX’s original concept of proportional LCC, described in iteration 1, could be used for routine planned preventative maintenance and repairs items, which would speed up the calculation of these items. This would include maintenance and repair items other than the full replacement. CostX also suggested that the sheet could be used either way for a proportional breakdown or on a line by

line detailed breakdown. Therefore it was agreed that this would be added back and further developed in the next iteration

5.6.4 Iteration 3

This iteration included the 2nd level approach to full replacement items and the original CostX LCC sheet for proportional breakdown of planned preventative maintenance with a change in some of the terminology. The annual costs were kept per the last iteration, which was based on the original template in iteration 1. It was suggested that a cost plan specific escalation and discount rate be included in the cost plan rows to allow for an item specific escalation rate. This is important because not all cost items will be applied at the same escalation rate and thus a standard escalation rate could not be applicable across the entire LCC estimate. As demonstrated in Figure 5.21, CostX included an override escalation space on each sheet, which included a formulae whereby if a rate was inserted it would override the project specific escalation rate inputted in the project details. For example, if the escalation rate for energy needs to applied at a different rate than the construction cost items, this can be facilitated. In the example in Figure 5.21 electricity is applied at 4.5% (0.045), overriding the standard rate of 2% applied to other items.

Code	Description	Quantity	Unit	Rate	F:Subtotal	G:Factor	H:Total	I:User1	L:User4	M:User5	N:User6	P:User8	A:User13	User2	User3	User4	User5	User6	User7	User8
1					Real Cost Per Occurrence	Nr of Occurrences / In year	Annual Cost	Factor	Real Cost	Escalated Cost	Present Value	Override Inflation Rate (e.g. Enter 0.025 for 2.5%) or leave blank.	Years >>	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
2	Electricity												Present Value							
3	1 Elec	2,220	kwh	1.50	3,330.00	1.00000	3,330.00	1.00	99,900	212,295	81,820	0.045	3,286	3,243	3,200	3,157	3,116	3,074	3,034	
4																				

Figure 5.21: Annual costs with specific escalation

5.7 Prototype

The 3rd iteration resulted in a working prototype based on a summary page and three sub-sheets; (1) full replacement items (i.e. one off replacements) (2) minor replacement & repairs (cyclical routine maintenance) and (3) costs that occur on a yearly basis (occupancy and operations costs). Figure 5.22 represents the summary page and the three relevant sub-sheet calculations. These three sub-sheets form the basis for any LCC calculations in a WLCC estimate.

A:Code	B:Description	F:Subtotal	I:User1	J:User2	K:User3	L:User4	AA:User19	B:User2C:User2D:User2E:User2F:User2G:User2H:User2I:User2J:User2K:User2	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
2.0	Maintenance	Annual Real Costs	Real Costs	Escalated Costs	Present Value		Years >>	Present Value										
1																		
2.1	Major Maintenance & Replacement (full replacement items) on elements below																	
3	Element																	
4	Element																	
5	Element																	
6	32 Internal Wall Completions	1,980.00	59,400	95,076	34,105				0	0	0	0	0	8,954	0	0	0	1,191
7	Element																	
8	Element																	
9																	
2.2	Subsequent Refurbishment and Adaption Costs (Not in 2.1 or 2.4)																	
2.3	Redecoration (Not in 2.1 or 2.4)																	
2.4	Minor Replacement Repairs and PPM Costs (Routine)																	
13	Element																	
15	32 Internal Wall Completions	1,165	34,947	57,112	19,450				0	0	0	0	967	0	2,245	0	0	3,679
16	Element																	
17	Element																	
18	Element																	
19																	
2.5	Unscheduled Replacement Repairs and Maintenance (Reactive)																	
2.6	Grounds Maintenance																	
22																		
3.0	Operation costs (Annual)																	
3.1	Cleaning Costs (not in above)																	
3.1.1	Windows and external surfaces																	
3.1.2	Internal cleaning																	
3.1.3	Specialist cleaning																	
3.1.4	External works cleaning																	
3.2	Utilities costs gas and electric																	
3.2.1	Fuel Costs																	
3.2.1	Fuel Costs (electricity)	1,887.00	56,610	120,301	46,365				1,862	1,837	1,813	1,789	1,766	1,742	1,719	1,696	1,674	1,652
3.2.2	Water and Drainage																	

Figure 5.22: Summary sheet prototype

5.7.1 Calculation Sub-Sheet [1]

As illustrated in Figure 5.23, in the first sub-sheet [1] the cash flows and total cost items are being populated from the cost plan items in the traditional columns and the replacement period and uplift factor. Inputting LCC information in this sheet includes a replacement period of 6 years and an uplift factor of ‘1.10’. The same sub-sheet can be used to represent the relevant ‘major maintenance and replacement costs’ for every applicable elemental category in the WLCC estimate, e.g. in this case ‘Element-32 Internal Wall Completions’ which encompasses Internal Doors and Windows. These LCC totals and cash flows carry forward to the relevant element on the summary sheet, Figure 5.22.

5.7.3 Calculation Sub-Sheet [3]

LCC calculation subsheet [3] is outlined in Figure 5.21 above and presents the yearly costs calculation methodology for LCC items which recur on a yearly basis. This would include all items based on BSI/BCIS (2008) standard for 3.0 operations costs and 4.0 occupancy costs. In the example in Figure 5.21, electricity costs estimated on the cost per floor area is automatically populated throughout the cash flows and totaled.

5.7.4 Reflection and Summary of 4th Stage.

Section 5.6 and 5.7 present the collaborative stage in the development process. This outlined further integration of the LCC calculation structure in CostX 5D BIM software, collaborating with the software vendor. However, the methodology discussed was based on the model developed by the author in Section 5.5 with the vendor adding some expertise and advice on the validity of the process. The development process in the 4th Stage was presented in three iterations, outlining the decisions made leading to the prototype demonstrated in Section 5.7. This stage and the earlier stages demonstrate a technological rule for extending 5D BIM into LCC analysis. As BIM is not just modelling technologies but the process it facilitates; it is necessary to present how this artifact builds on the existing 5D BIM work-flow and its innovativeness in this regard.

5.8 Contribution to the BIM Work-flow (Post-processing BIM for LCC)

There are significant similarities between the process proposed in this research and the nD modelling tool developed by Aouad et al. (2002; 2001; 2005) and Fu al. (2006; 2007), whereby there is an integrated virtual environment viewer which can be utilised to perform LCC analysis. The nD tool and its LCC sub-tool was built from the ground up and is a bespoke system where the users input data sequentially through a number of screens, ultimately generating LCC information in graphs and cash flows within the system (Fu et al., 2007). The nD tool is innovative for its time, but there has been a significant period since its development in 2007, which is compounded by the rapid growth in BIM and 5D BIM in recent years. A more prevalent issue is that since 2007 there has been a plethora of LCC methodologies,

discussed in the review of literature, which could not have been taken into consideration in Fu's and Aouad's nD tool.

While this research builds on the nD tool, due to CostX's BIM functionality being very similar, the difference in this approach is that this 5D BIM-LCC tool (extended for LCC) is built as an add-on to an existing 5D BIM application (CostX), which also incorporates similar functionality to a spreadsheet. From a technological perspective it highlights an innovative design science artifact, but from a process perspective it can take account of information that currently resides outside the 5D BIM work-flow by post-processing BIM data, such as LCC methodologies; LCC cost and design life data and the capital cost plan estimate. Figure 5.25 illustrates the information links to the LCC calculation structure. These are facilitated in CostX through the 'live link' functionality, which is described previously. Figure 5.25 indicates that the LCC calculation structure provides a medium which can pull the information necessary to carry out LCC calculations into the BIM work-flow including post-processed BIM quantities that are extracted from the model.

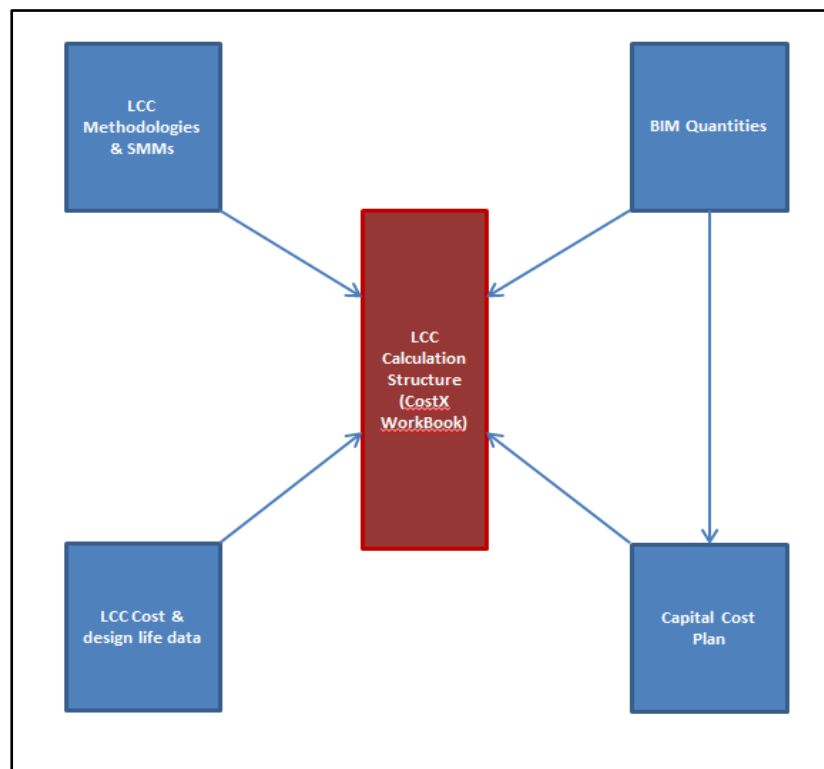


Figure 5.25: LCC calculation structure

The calculations and the templates discussed in the sections above, present the staged development process to a 'technological rule' (per a design science methodology) that incorporates an LCC calculation structure into 5D BIM software.

This section articulates this rule from a BIM process point of view and highlights the LCC add-on (Figure 5.25) to the 5D BIM work-flow. In design science this technological development is expressed as an innovative idea or practice, presented amongst the theoretical content discussed in the review of literature; notably as an extension to Eastman et al.'s (2011) BIM work-flow illustration in Figure 3.7.

Figure 5.26 illustrates the 5D LCC process that is enabled through the use of incorporating the LCC calculation structure, outlined above, in the CostX 5D BIM platform. This figure conceptualises the 5D BIM work-flow outlined in Chapter 3 and the integrated LCC process facilitated through the development of the artifact discussed in this chapter.

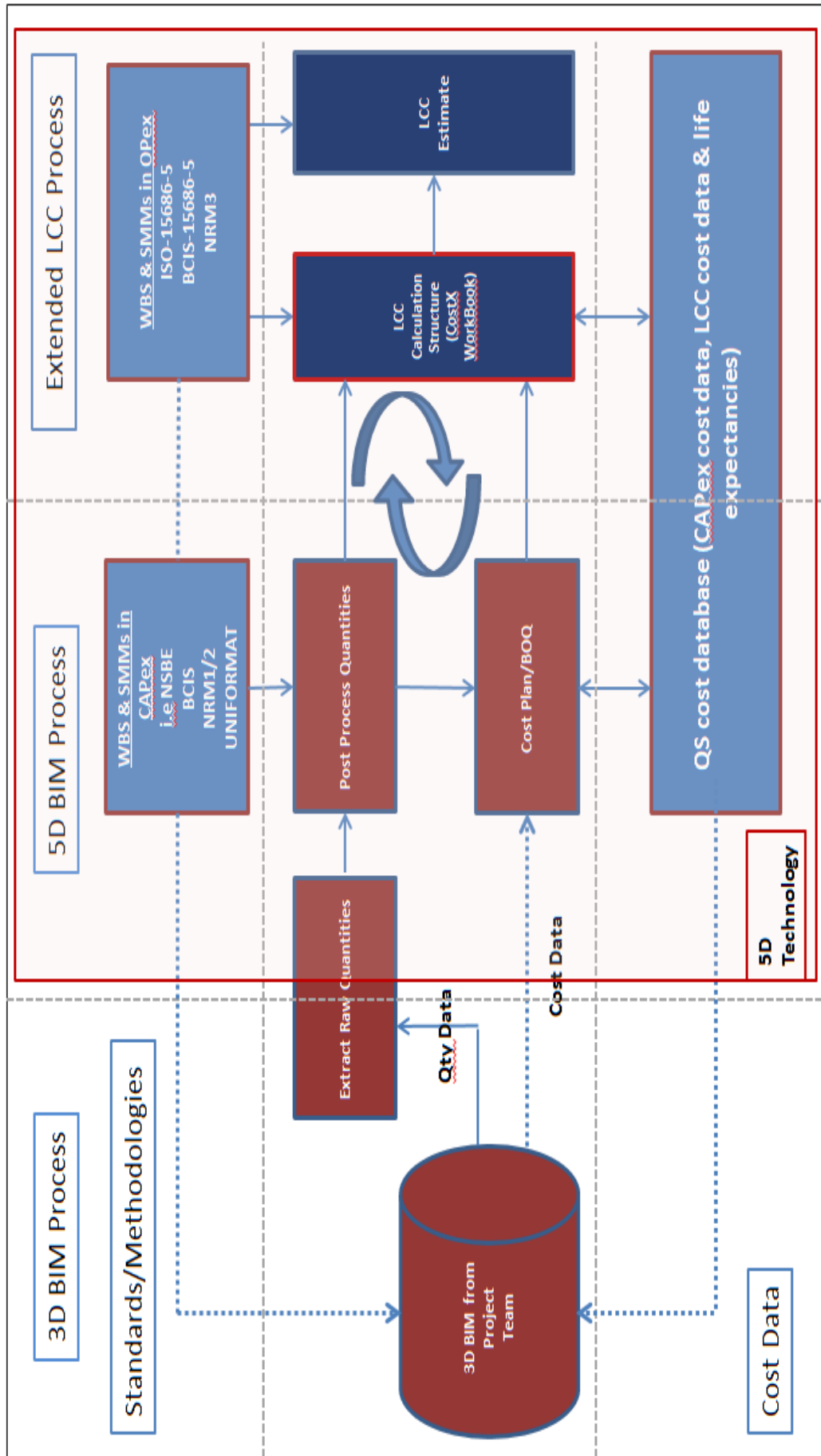


Figure 5.26: 5D LCC Extension

The diagram is divided into nine sections through the intersection of three columns and three rows. The 3D, 5D and extended LCC processes are represented by three columns, while the central row outlines the 5D BIM work-flow which embodies Eastman et al. (2011) 'main stages of the BIM estimating process', outlined in Chapter 3. The peripheral rows signify the information (such as QS cost data, LCC data and SMMs) that needs to be added by the QS to produce the CAPex and LCC reports and indicates, as discussed in the review of literature, that this process is presently outside current work practices in 5D BIM. The extended 5D LCC solution developed as part of this research is represented by the outer red box which encompasses the 5D and LCC work-flows and provides an interface which facilitates appending LCC.

The 5D BIM process illustrated in the central column of the diagram outlines the process of extracting raw quantities from the authored BIM and post-processing the quantities so that they align with WBSs such as the BCIS in UK or the National Standard Building Elements (NBSE) in Ireland. Further breakdown maybe required in accordance with the SMM of the jurisdiction in which the estimate is being carried out, such as the NRM1/2 or the ARM4 (Matipa et al., 2010; Wu et al., 2014). As described in the review of literature, post-processing BIM quantities sanitises them per a standard format and presents the quantities in a structure that makes it easier for the QS to utilise in their cost reports and BOQs (Drogemuller & Tucker, 2003; Matipa et al., 2008; Mitchell, 2012; Monteiro & Martins, 2013). These structures and methodologies are illustrated in the top row and inform the format and classification of both the CAPex and LCC outputs. The database utilised for cost and life cycle information is illustrated on the bottom row and represents the QS's in-house or external databases, such as RS Means in US or BCIS in UK. The QS utilises these databases to populate cost information in their CAPex estimates and LCC estimates, such as design life expectancies and maintenance cost data. As discussed in the review of literature, both the standard methodological structure and the QS database are represented outside the central work-flow, as they are currently outside the 5D BIM process, i.e. they are not contained in the object properties of the model and thus need to be manually processed and attached through 5D programmes such as CostX (Wu et al., 2014). Current practice in the 5D BIM work-flow is that this information is 'pushed' into the 5D process at the reporting end rather than 'pulled' from the BIM (i.e. this information is not embedded in the authored model because it

is not usually in the domain of the designers and thus needs to be added by the QS). The other issue, discussed in Section 3.5, is that the 3D BIM environment is not semantically rich enough to accommodate the extent of LCC data and variable conditions for probabilistic calculations; thus, creating LCC definitions in the authored BIM would be of no value. This is a significant impediment to model integration, as the information is not pushed into the model but rather into the interface that creates the reports (Matipa et al., 2010). This does not represent any real change in current work practices, other than generating 3D quantities, as the 2D process is carried out in much the same way where quantities are generated from drawings and processed so they align with WBSs and SMMs. This will be addressed in the 'limitations to the research' in Chapter 8.

However, the originality in this research is effectively post-processing BIM data to aid in the production of LCCs by adding on the LCC calculation structure, outlined above, to the 5D work-flow. This is illustrated on the right column of Figure 5.26 and bordered with a red box to represent its inclusion and place in the 5D/LCC process. This column represents an LCC add-on to the existing 5D work-flow outlined by Eastman et al (2011). The CostX 5D BIM software assists this process by providing an integrated platform where the LCC estimate can be prepared in a standard structure leveraging the processed BIM quantities and the construction cost plan. The LCC calculation structure provides an interface that can accommodate information from the post-processed quantities, the construction cost plan, SMMs and the QS cost database. Information from these sources are linked or attached to the LCC calculation structure and automatic LCC calculations are carried out to produce the LCC estimate.

The dashed line between the 5D and LCC work-flows represent the prevailing separation between the two processes. The process described in this section and illustrated in Figure 5.26 is facilitated through the technological solution outlined above. This proposes an integrated interface leveraging the capabilities of existing 5D BIM technology. The cyclical symbols represent the integrated links between the quantities, the CAPEX cost plan, the relevant standards and the cost data. These links promote a BIM post-process where changes in different variables of the cost plan or LCC estimate will automatically recalculate the reports.

The broken line feeding back from the QS database and SMMs to the BIM on the top and bottom row represents the current 5D work-flow which does not effectively feedback CAPEX and LCC information into the federated BIM model (Sabol, 2008). As outlined by Matipa et al. (2008) and Sabol (2008), this promotes a one way information flow of model extraction rather than model integration. However, if this data was contained in the authored BIM it could be utilised (dragged and dropped) into the LCC calculations structure.

5.9 Summary

Bringing complex LCC calculations into the 5D BIM process provides the user with the tools to generate quantities, cost them and calculate the WLCC in real costs, nominal costs and present value costs. This chapter outlines how an LCC calculation structure can be incorporated into the 5D BIM process by developing a LCC calculation structure add-on to the 5D estimating software CostX. Stage 1 initially presents automating LCC calculations within a standard structure in MS Excel, outlining an LCC spreadsheet template that is used to present a WLCC estimate under Ireland's CWMF. This calculation methodology is developed in the next stage, where further automation is programmed into the spreadsheet and recommendations from the NRM 3 (RICS, 2014) are included on presentation and structure. The next stage described how this LCC calculation structure could be imported into the CostX 5D BIM platform. This initial work with the CostX interface lead to further development of the LCC operability in their 5D BIM estimating interface through collaborating with the software vendor. This work was presented through a number of iterations that ultimately lead to the development of a working prototype.

Finally, the developed (working prototype) solution was conceptualised through a process map whereby the technological solution is positioned in the context of innovating the 5D BIM work-flow by adding on an LCC interface within the same system and process. The next stage was to gain feedback on the developed (working prototype) solution from the QS community. The following chapter presents the evaluation procedures in determining the effectiveness and efficiency of the process together with addressing whether it would provide added value and therefore its potential implications on LCC.

6 Evaluation Procedures and Data Analysis

6.1 Introduction

This chapter presents the procedures of the evaluation phase of the research design. As noted in the research methodology, along with the development stage, the evaluation phase of action-orientated research is an integral part of the methodological process. Chapter 5 outlined the development of a 5D BIM solution for LCC by post-processing BIM data; this chapter articulates the procedures employed to evaluate this proposed solution, through two stages of fieldwork. Fieldwork Stage 1 evaluated and collected data from six participants on the model development (prototype) discussed in the last chapter. Fieldwork Stage 2, which collected data from a further ten participants, evaluated a more developed version informed from data collected and analysed in Stage 1.

In the latter half of this chapter data analysis methods are discussed. The rationale for conducting thematic analysis is presented and adheres to Braun & Clarke's (2006) formulated process in two stages; thereby mirroring the two stages of evaluation.

Figure 6.1 illustrates a process map of the staged evaluation and analysis framework discussed in this chapter. This figure was constructed to encapsulate the two different stages of evaluation and data analysis, and the relationship between them; culminating with the findings outlined in the next chapter. This chapter is broken down into sections that outline this process in the order it is presented in Figure 6.1.

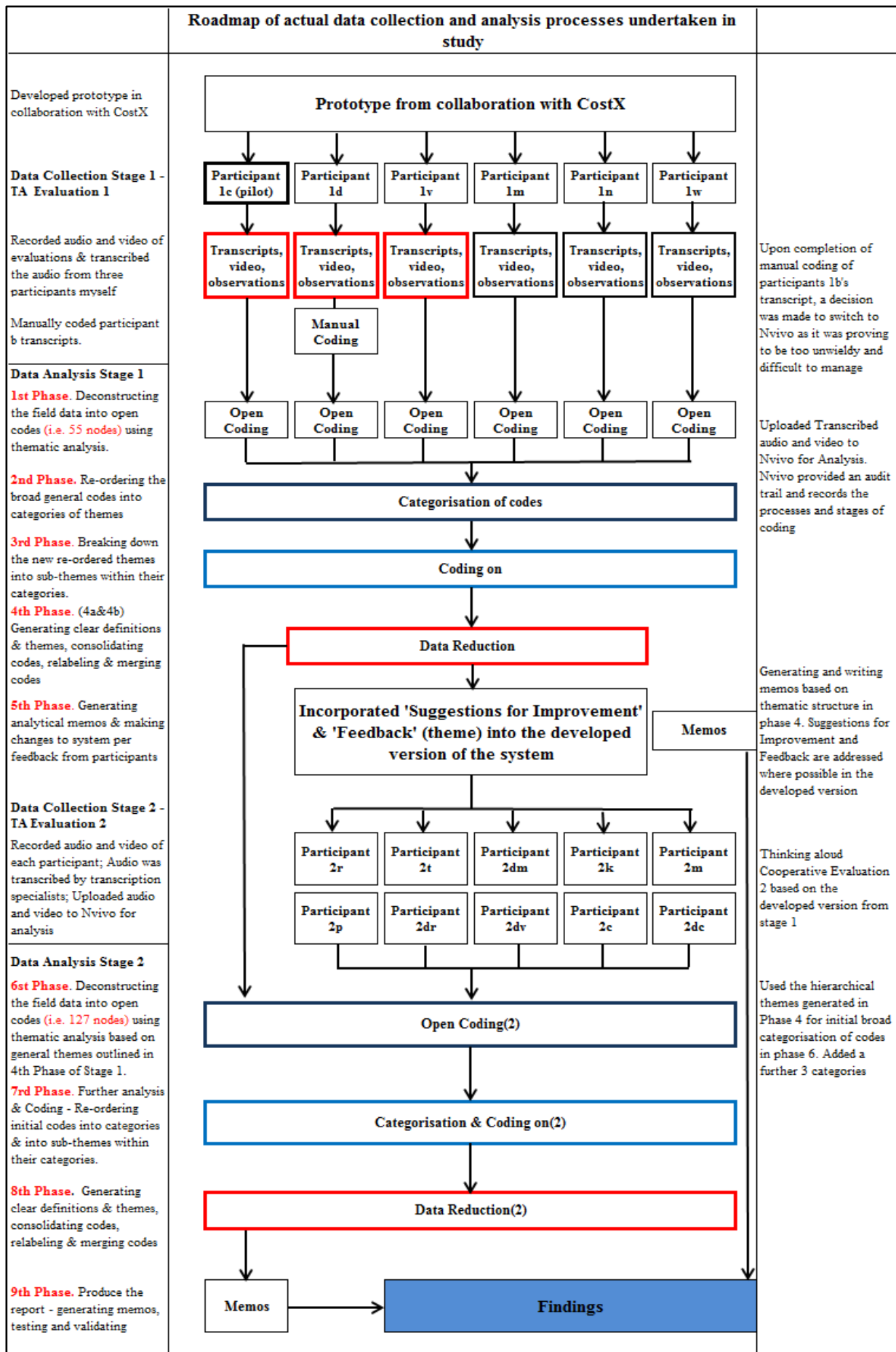


Figure 6.1: Evaluation and Analysis Framework

6.2 Evaluation Procedures

It is important that the evaluation is carried out and data collected in a consistent manner and format to ensure validity and reliability (Monk et al., 1993; Nielsen, 1993). Carrying out evaluation in an ad-hoc manner could lead to ambiguous results or recommendations and eventually a poor solution. It also opens up the process to criticism from the research community and potential users. Nielsen (1993), Faulkner (2000), Wahl (2000) and Monk et al. (1993) all outline a comparable formulated step by step structure to TA cooperative evaluation, which were consulted for the procedures presented in this chapter. These procedures elaborate on the TA protocols initially articulated in the research methodology in Section 4.6.3, but provide more detail by applying the procedures to the model development discussed in the previous chapter. The following sections 6.2.1-6.2.4, describe the procedures applied in both the model development evaluation (prototype) and the evaluation of the more developed process.

6.2.1 *Recruit the Users*

The first stage in all approaches of usability evaluation is to recruit the evaluation participants. Nielsen (1993) and Monk et al. (1993) maintain the main rule is to recruit participants that will be representative of the intended users of the new solution. Overall, sixteen QSs were recruited in Ireland, whom were in a position to evaluate whether the proposed 5D BIM LCC process might provide a means to carry out LCC quickly and efficiently. As demonstrated in Figure 6.1, six participants were selected for the prototype evaluation (Fieldwork Stage 1) and a further ten participants for the developed version (Fieldwork Stage 2). Nielsen (1993) and Monk et al. (1993) agree the strength of TA cooperative evaluation is that it can collect effective qualitative data from a fairly small set of participants ('4 participants, +or- 1'). More participants than is recommended by Monk et al. (1993) were selected in each stage, due to this research being more than just a software evaluation. The subjective attitudes of the participants on the extended 5D LCC process were also gathered. This was carried out to evaluate their feedback engaging in a process that facilitates an integrated 5D LCC work-flow.

Hourigan (2012) notes that many QSs in Ireland do not know how to carry out LCC calculations; therefore requiring all the participants to have experience in this field

was considered to be too restrictive. Furthermore, having prior experience in calculating LCCs is not fundamental to the research, because it is necessary to have a sample of participants that are representative of the QS profession (many of whom do not carry out LCC) and thus a number of participants whom can evaluate whether it is an effective solution from a novice perspective is beneficial. The evaluator, in accordance with TA cooperative evaluation protocols, was able to coach the participants through the 5D BIM-LCC process gaining their thoughts and feedback on whether it might add benefit to them providing cost services for their clients.

There were a broad range of participants, from different companies and educational backgrounds, with diverse experience in carrying out LCC calculations; ranging from 'very little experience' to being 'proficient' in doing the calculations. What was necessary is that the participants had some experience of preparing cost plans and BOQs. These are the documents that are leveraged to carry out LCC, so without prior experience in the preparation of these documents, the participants would not be in a position to comment on whether the proposed process can be used effectively.

It was also necessary that the participants were proficient with MS Excel (or other spreadsheet software), entering data and creating basic formulae. This was required so that they could input LCC information in the prototype and the developed version and understand the relationship to what they are entering and the calculations that are taking place through the formulae. It was important the participants had used a QS cost estimating application to take off quantities and formulate their estimates; so that they could understand how these systems work and where possible how other information could be added. Some of the participants had different levels of experience with BIM and some were CostX users, but the majority of participants were 'novice' users of CostX, with varying levels of expertise in using BIM quantum and 5D estimating software.

Encompassing the QS user characteristics, a detailed 'user profile' was developed, as evidenced in Appendix 1a. The user profile was based on the process outlined by Dumas & Redish (1999) and Monk et al. (1993), where the characteristics of the users are clearly defined prior to selecting them for the evaluation. The user profile forms the basis of the 'pre-evaluation questionnaire' (Appendix 1f) which checked these characteristics prior to administering the evaluation. The pre-evaluation

questionnaire was also used during data analysis to examine the participants responses based on their user profile, i.e. to address their comments based on their professional experience, educational background, IT capabilities and LCC expertise. The questions administered in the pre-evaluation were not designed to provide quantitative results, but rather a means to frame the data from the participants within the context of their work experience, computer proficiency and their level of LCC knowledge. Table 6.1 presents a tabulated collation of the participant profiles in each stage of the evaluation; outlining the credentials they filled out in each category of the pre-evaluation questionnaire in Appendix 1f.

Participant	Job Description	Level of Education	What do you do in your Job	How long have you been doing this work	Experience in Excel	QS software are you proficient	BIM Experience	LCC Experience	CostX Proficiency
Stage - 1 data collection									
Participant - 1d	Professional QS	Hons Degree	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	12months - 2 Years	Advanced	Buildsoft Cost X	Advanced	Proficient	Advanced
Participant - 1m	Professional QS	Hons Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	10 - 20 years	Advanced	Buildsoft BT2 CostX	Intermediate	Very little	Advanced
Participant - 1n	Contractors QS	Hons Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	5 - 10 years	Advanced	Buildsoft BT2	Intermediate	Very little	Novice
Participant - 1w	Professional QS	Hons Degree	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	12months - 2 Years	Intermediate	Buildsoft Cato CostX	Novice	Some Knowledge	Novice
Participant - 1v	Contractors QS	Hons Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans Life Cycle Costing	10 - 20 years	Advanced	Other: Estimation	Novice	Some Knowledge	Novice
Participant - 1c	Professional QS	Hons Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	10 - 20 years	Intermediate	Buildsoft BT2 CostX Other: Estimate	Novice	Very little	Intermediate
Stage - 2 data collection									
Participant - 2dc	Contractors QS	Hons. Degree	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	20 - 30 years	Intermediate	Buildsoft BT2	Novice	Some Knowledge	Novice
Participant - 2dv	Contractors QS	P.Grad	Measurement for BOQ's Cost & Prepare Cost Plans	10 - 20 years	Intermediate	Other: Estimate	Intermediate	Very little	Novice
Participant - 2t	Professional QS	Hons. Degree	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	20 - 30 years	Advanced	CostX Autodesk QTO	Advanced	Some Knowledge	Advanced
Participant - 2c	Professional QS	Hons. Degree & MRICS	Measurement for Cost Plans Cost & Prepare Cost Plans	5 - 10 years	Intermediate	Buildsoft BT2 CostX	Advanced	Very little	Intermediate
Participant - 2k	Contractors QS	Hons. Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans Life Cycle Costing	10 - 20 years	Advanced	Buildsoft BT2	Novice	Proficient	Novice
Participant - 2m	Professional QS	Hons Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	20 - 30 years	Intermediate	Buildsoft BT2	Intermediate	Some Knowledge	Novice
Participant - 2dm	Professional QS	Hons. Degree & MRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans Life Cycle Costing	10 - 20 years	Advanced	Buildsoft BT2	Intermediate	Some Knowledge	Novice
Participant - 2r	Contractors QS	Hons Degree & MRICS	Measurement for Cost Plans Cost & Prepare Cost Plans	20 - 30 years	Intermediate	Buildsoft CostX Other: Vector	Novice	Some Knowledge	Intermediate
Participant - 2p	Professional QS	Hons Degree & FRICS	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans	30 - 40 years	Intermediate	Buildsoft	Novice	Very little	Novice
Participant - 2dr	Professional QS	Hons Degree	Measurement for Cost Plans Measurement for BOQ's Cost & Prepare Cost Plans Life Cycle Costing	2 - 5 years	Advanced	Archicad	Intermediate	Some Knowledge	Novice

Table 6.1: User Profile

Participants are described in Table 6.1 based on the relevant fieldwork stage and the first letter of their first name. As demonstrated in Table 6.1, the participants are practicing professional or contractor QSs. Ten participants are registered as a chartered Member with the RICS (MRICS). They have a wide range of professional experience, varying from twelve months to forty years' experience. Their level of proficiency in MS Excel and QS software are indicated, as well as their experience in LCC and BIM.

Initially participants were informally contacted by phone to discuss whether they would be interested in taking part in the research. The nature of the evaluation was explained and the potential participant's experience was discussed to establish if they were representative of the user profile. To provide them with further information they were sent a 'participant information sheet', which is evidenced in Appendix 1b. This document set out in detail; the background and aim of the research; why they have been invited to participate; instructions for the cooperative evaluation; as well as data protection & confidentiality protocols. Once they indicated that they were willing to take part, an interview time was scheduled. This proved difficult in some cases as the participants had to attend the computer lab that was set up in DIT, but ultimately all the participants who said they would participate eventually took part.

6.2.2 Establishing the Task

In accordance with the recommendations of Faulkner (2000), Schneiderman & Plaisant (2005) and Monk et al. (1993), a written task list was produced so that the participants could follow exactly what the evaluator wanted them to do, in the order in which the users would do them in a real working environment. The scenarios and tasks were designed so that the evaluation provided reasonable coverage of most parts of the 5D BIM-LCC process articulated in Chapter 5 and were short enough to be completed within the time limits of the evaluation (Nielsen, 1993). As per the recommendations of Dumas & Redish (1999), the tasks were put in the order in which the users would do them in a real working environment. Nielsen (1993) advises that the evaluation tasks should specify exactly what type of result the user is being asked to produce. Dumas & Redish (1999) note that it is important that there is a clear beginning and end to each task. Monk et al. (1993) stress that the tasks should be reasonably specific, so as not to lend to any confusion and keep the user focused. Monk et al. (1993) emphasise that the participants should be made aware or make

the administrator aware when the task is complete. As demonstrated in the task list, appended in Appendix 1c, the tasks are logically sequenced, explicit and the result of the calculations specified below each task. The content of the tasks are discussed in Section 6.3.

6.2.3 Preparing and Administering the Evaluation

Faulkner (2000) recommends that before the actual evaluation is administered further preparation should take place on the day of the evaluation. The first element of this was to make sure that the evaluation room was ready, comfortable for the participants and that the equipment and software were in working order (Dumas & Redish, 1999; Monk et al., 1993; Nielsen, 1993). A method of recording the users carrying out the tasks was necessary (Monk et al., 1993). A video recorder was pointing at the screen, which captured the participant's movements for later analysis and a dictaphone was used to record the audio of the entire evaluation, including the post-evaluation questions. Video and audio capture allowed the evaluator to concentrate on interacting with the user during the evaluation (Monk et al., 1993). As will be discussed further in Section 6.6.2, the video recordings were not used as coded data and were only considered when clarification was needed regarding the transcribed audio recordings.

Nielsen (1993), Faulkner (2000) and Monk et al. (1993) advise that an introduction should be carried out where the evaluator welcomes the participants and explains exactly how the evaluation will be conducted. Faulkner (2000) and Monk et al. (1993) suggest that this information should be written down so that nothing is missed and that consistent information is given to each participant. The formulated process outlining the procedure adhered to for every participant, for both model development (prototype) and the developed version, is presented in Appendix 1d.

As in all other TA formats, continuous dialogue must be maintained by asking questions. Therefore, before the evaluation was administered the participant was made aware of the type and level of interaction envisaged between the evaluator and the participant. This is carried out so that the participants understand what is meant by 'cooperative evaluation' and they are put at ease from the outset (Monk et al., 1993). The type of questions the participants could be asked during the evaluation was briefly outlined. They were also told that they could direct questions to the

evaluator at any time during the evaluation. Instructions regarding the nature of the dialogue that was administered as part of this research are included in Appendix 1e.

As recommended by Nielsen (1993) the participants were also given the opportunity to read the tasks prior to the start of the official evaluation and ask any questions if they needed further clarification. No participants had any questions and indicated that they were ready to proceed.

6.2.4 The Evaluation Procedure

Once the participant had signed the relevant documents and filled out the pre-evaluation questionnaire, the evaluation commenced and the recording equipment was turned on. The participant worked their way through the scenarios and evaluation tasks. Monk et al. (1993) note data is generated when the users make mistakes, find problems, ask the evaluator questions and when the evaluator asks the participant questions.

Once the tasks were complete, the participants were asked to engage in a ‘debriefing’ process which encompassed completing a ‘post-test interview’ (Dumas & Redish, 1999; Faulkner, 2000; Nielsen, 1993). Dumas & Redish (1999) maintain the post-test interview provides a vehicle to assess the participant’s subjective attitudes to the process they are engaged in (leveraging 5D BIM for LCC), facilitated by the 5D technology. Dumas & Redish (1999) note the debriefing process complements the data from the TA part of the evaluation with more subjective information. This is particularly important, in the context of this research, as the participants are not only engaging with an interface (and its usability) but also the process of leveraging 5D BIM by post-processing BIM data for LCC, which is enabled by the CostX interface. Their attitudes in respect to this process are relevant to the aim of the research, which is to determine if this process can have an effect on the reported barriers to implementing LCC.

The post-evaluation questions (debriefing process) took the form of a discussion, based on open-ended interview type questions (Monk et al., 1993). The questions are outlined in Appendix 1g for both stages of evaluation and included questions such as; what the participants liked/not liked about the process? do they have any recommendations/suggestions that might improve the process? their experience with

LCC and BIM? and whether the process has addressed any of the barriers to the utilisation of LCC? Not all questions asked on the day were prescribed, some questions materialised based on the participant's responses to the prescribed questions, particularly surrounding their own experience with LCC and BIM.

As recommended by Monk et al. (1993), questions were also asked on the evaluation itself; how the participants felt about the TA cooperative evaluation process? and did they find the tasks clear? The debriefing process was also used to give the participants an opportunity to ask retrospective questions that they may not have had a chance to ask prior to the evaluation or during the evaluation.

The debriefing process ended up being a very valuable source of qualitative data, because it gave rise to data on the more subjective nature of the users experience engaging in the 5D BIM-LCC work-flow. This enabled relevant information to be compared to the theoretical content in the review of literature. Once the debriefing stage was complete, the participants were thanked for their time and effort and made aware that the results of the evaluation would be available at their request.

6.3 Fieldwork

As illustrated in Figure 6.1, the fieldwork was conducted in two stages, Fieldwork Stage 1 evaluated the prototype developed in Chapter 5 and garnered data based on six participants working through the task list. Fieldwork Stage 2 evaluated a more developed version, which also collected data from ten participants working through a similar task list.

Figure 5.26 in Chapter 5 represents the 5D BIM-LCC work-flow which the participants engaged in when utilising this process. Facilitated by the scenarios and tasks of the evaluation, the participants moved through the BIM work-flow represented through the centre row of Figure 5.26. Data was generated not only from utilising the CostX LCC add-on (highlighted by the cloud) but also from engaging in the overarching process of leveraging 5D BIM by post-processing BIM data for LCC and how this process could have an effect on LCC.

6.3.1 *Thinking Aloud cooperative evaluation 1 (Fieldwork Stage 1)*

The first TA cooperative evaluation (Fieldwork Stage 1) was based on the prototype articulated in Chapter 5. There were three scenarios and eight tasks in this evaluation, as demonstrated in the tasks outlined in Appendix 1c. The first two scenarios revolved around the LCC of an internal single door, in terms of its [1] full replacement and its [2] minor replacement, repairs and maintenance costs. The third scenario dealt with [3] annual recurring costs (in this case electricity), which was evaluated on a yearly basis. These scenarios and tasks follow the calculations described in ISO 15686-5 (BS-ISO, 2008) and BSI/BCIS (2008) LCC methodologies.

The prototype that was developed is what Hall (2001) describes as a ‘high fidelity, analytical concept’, that replicates the functionality of the CostX workbook by presenting the calculations in MS Excel. This is a detailed level of prototyping which can provide a medium incorporating many of the functions and features of the CostX system because of their similar functionality. Incorporating the calculations into the CostX 5D software is a time intensive process, so gaining feedback on the LCC calculation structure before full development in 5D BIM should lead to a better final solution with many of the possible issues already addressed (Faulkner, 2000; Nielsen, 1993).

Figure 6.2 illustrates one of three MS Excel sheets that were used in the prototype evaluation to represent the LCC calculation methodology of the prototype. Each sheet represents the calculation structure outlined in the prototype in Chapter 5. The participant was requested per the scenarios and tasks to carry out a number of LCC inputs and calculations. Scenario 1 had two tasks. Task 1 dealt with opening the document and inputting the project details such as the escalation rate, the discount rate and the study period. Task 2 (presented in Figure 6.3) addressed the full replacement of an internal single door in 25 years where the user inputted the information given in the task into the required yellow cells shown in the example in Figure 6.2.

Major Replacement																			
Code	Description	Qty	Unit Rate	Cost	Period	Annual Real Cost	Replace. Period	Maint. Factor	e	d	Real Costs	Escalated Costs	Present Value	Real ->	1	2	3	4	5
1					0.00	30.00	0.00		2.50%	5.00%	0	0	0		0	0	0	0	0
2	Double Doors including frame, ironmongery & decoration	10	1100.00	11000.00	30.00	403.33	20	1.10	2.50%	5.00%	12,100	19,827	6,300		0	0	0	0	0
											0	0	0		0	0	0	0	0
											0	0	0		0	0	0	0	0
											0	0	0		0	0	0	0	0
											0	0	0		0	0	0	0	0
Total Element											12,100	19,827	6,300		0	0	0	0	0

Figure 6.2: Prototype in excel

Task 2 – Approx Time (4min)
 Click on the next sheet 'Replacement', enter the description for the cost plan item in the relevant description cell for the item.

'Internal single door, flush veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery, painting'

- Enter a **Qty of 25nr** and a **Rate of 1100**.
- Enter a **Replacement period of 20 years** and a **Maintenance Factor of 1.10** in the relevant cells.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
30,250	49,568	15,750

Complete -- Yes/No

Figure 6.3: Task 2

Scenario 2 had four tasks outlined on the task list as Task 3, Task 4, Task 5 and Task 6. Task 3 and 4 dealt with minor replacement, repairs and maintenance costs of the internal single door on a percentage basis of the total cost of the cost plan item (in this case, replacing the seals of the door, replacing the ironmongery and repainting the door and frame), which is demonstrated per an extract from the task list in Figure 6.4.

Task 3 – Approx Time (1min)
Click on the next sheet 'Minor Repairs PPM'. Enter the following maintenance actions in the maintenance action description cell

(1) Replace Seals, (2) Replace Ironmongery, (3) Repaint.

Complete -- Yes/No

Task 4 - Approx Time (1min)
Enter in the following maintenance periods and maintenance factors in their appropriate cells.

Replace seals = Maintenance Period 1 '**5' years** & Maintenance Factor **0.05** (5%)
Replace Ironmongery = Maintenance Period 2 '**15' years** and Maintenance Factor **0.35** (35%)
Repaint = Maintenance Period 3 = '**7' years** and Maintenance Factor **0.20** (20%)

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
49,500	81,650	27,196

Complete -- Yes/No

Figure 6.4: Test tasks 3&4

Task 5 demonstrated that changing the study period and maintenance factor in the calculation will in turn change the results. Task 6 and 7 addressed how the workbook could be used to calculate the actual minor replacement, repairs and maintenance costs for the internal single door instead of a percentage estimate based on the cost plan item. Scenario 3 included Task 7 and Task 8. Task 7 required the participant to enter an annual electricity cost for the year which, in turn, calculated the LCC for the study period inputted in Task 1. Task 8 asked the participant to override the project escalation rate to an item specific electricity escalation rate.

6.3.2 Pilot Evaluation

No usability evaluation should be performed without first trying out the proposed evaluation on a pilot subject (Nielsen, 1993). A pilot evaluation is a dry run or rehearsal for the usability evaluation to follow. Monk et al. (1993) state that the pilot participant can be selected based on convenience, by selecting a participant who is easily accessible to the evaluator, even if they are not necessarily representative of the users. As recommended by Dumas & Redish (1999), the evaluator should follow the exact same procedures in the pilot evaluation that they will follow in the actual

evaluation. The pilot evaluation offers a means to address problems with the process prior to administering the full evaluation (Nielsen, 1993). The aim of a pilot evaluation should not be to get feedback from the user but rather to check the instructions and tasks are easily understood and the evaluation can be completed within the time outlined (Monk et al., 1993). Dumas & Redish (1999) maintain that the pilot evaluation can unearth problems with the evaluation methods; the evaluation materials and the system or documentation. Nielsen (1993) points out that one of the most common issues with evaluation is that there is a mismatch between the tasks and the time allocated to the evaluation session. He suggests the issues raised in the pilot evaluation can give the evaluator an opportunity to tweak the tasks or procedures in the full evaluation.

A pilot evaluation was carried out in a computer laboratory in the School of Surveying and Construction Management in DIT. The purpose of the pilot evaluation was to make sure that the evaluation ran smoothly, that the tasks were clear and that everything was working effectively and efficiently. Monk et al. (1993) also note that the pilot evaluation should be used so that the evaluator can estimate the time it takes to carry out each task. The evaluator also got an opportunity to familiarise himself with the process and to do a dry run before carrying out the prototype evaluations. The computer laboratory was booked for two hours, the video equipment was set up and the prototype file was loaded on the desktop of one of the computers. The documentation such as the scenarios, instructions and participant's agreement were printed and placed in front of the evaluators chair so that they could be administered in accordance with the guidelines of the evaluation.

The pilot evaluation went smoothly. There were no fundamental problems in administering the evaluation and the pilot participant was satisfied with the process and found the tasks were easy to follow and the prototype was easy to use. A number of minor issues were identified from the analysis of the pilot evaluation data. Task 6 required that the participant enter details from Task 4 again and this confused the participant. The pilot participant felt that it would be easier if these details were explicit in Task 6 again, rather than referring back to a previous sheet and a previous task. The participant was also confused which cells to enter the maintenance period and maintenance factor for Task 6, due to having to enter different details in the same columns as Task 4. He maintained this could mislead the user. It was suggested

that the columns for the maintenance period and maintenance factor should be particular for that task rather than using the same column heads as Task 4.

The focus of the pilot evaluation was on the procedures of the evaluation, whether it ran smoothly and any feedback regarding the test tasks themselves. Feedback regarding the prototype and evaluation in terms of what the participant thought of the system was analysed with the data collected from the other participants in the full prototype evaluation. Minor changes were made to Task 6 based on the feedback from the pilot participant. An adjustment was also made to the approximate times for carrying out the tasks, as it was noted that the times by the pilot participant to complete each task were distorted by the ‘thinking aloud’ process of talking during the action. Time was added to each task to reflect this and noted that future participants should be made aware that the task times are not a test requirement but a guide. The evaluation from start to finish took approximately fifty three minutes, so future participants could be made aware of the approximate duration of the evaluation.

In addition to the pilot evaluation, five more participants took part in the first evaluation stage. These interviews were transcribed, but this was taking a considerable amount of time and after the third interview a professional transcription service was procured to transcribe the remaining audio files from the interviews. Each transcript from the transcription service was checked to verify that the contents accurately represented the audio files. The transcripts were then forwarded to their respective participants for checking and verification. No participants indicated that they wanted any changes/modifications made to their transcripts.

6.3.3 Think Aloud cooperative evaluation 2 (Fieldwork Stage 2)

The data generated from Fieldwork Stage 1 evaluation was analysed and the findings are presented in the next Chapter 7. Based on the data analysed from Fieldwork Stage 1, the prototype was updated to incorporate, where applicable, feedback and recommendations for improvement from the users on the LCC calculation structure. The user informed version was evaluated in a Fieldwork Stage 2. The scenarios and tasks were the same as those administered in Fieldwork Stage 1 with the addition of a further scenario and task (Appendix 1i). Figure 6.5 highlights the additional task that dealt with extracting BIM quantities from the model, which is illustrated in

Figure 6.6. This task was not in the Fieldwork Stage 1 because the MS Excel prototype presented did not have the BIM element on show. The purpose of this was to firstly validate the LCC calculation structure prior to fully incorporating it into 5D process.

SCENARIO AND TASKS LIST – Total Test Time <u>Approx</u> (8min 45sec)
<p>SCENARIO 1 – Total <u>Approx</u> Time (2min)</p> <p>This scenario extracts quantities from the model using quantities defined from the Revit families in the Revit model.</p>
<p>Task 1 – <u>Approx</u> Time (1min)</p> <p>Click 'Drawings' tab and click on 'Add' icon and select 'Warehouse 2014'; 'Open' and 'Insert'.</p> <p>Click 'Dimensions' tab and click on 'Import' icon and select 'Import Dimensions using BIM Template' select 'BIM Import Revit General' and 'Open'.</p> <p>Un-collapse the 'Doors' dimension group folder to see the 9no Internal Doors</p> <p>Complete -- Yes/No</p>

Figure 6.5: BIM Scenario

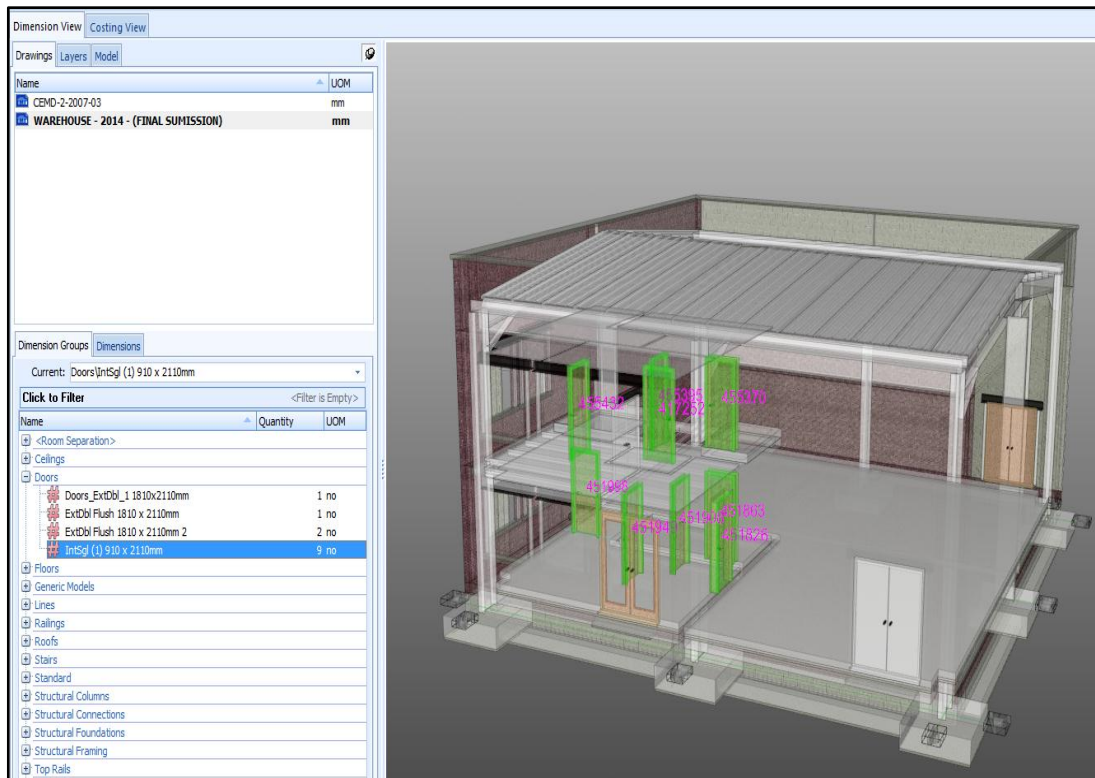


Figure 6.6: Extracting quantities

Rather than just inputting the quantity of doors into the workbook (which is carried out in the prototype evaluation) the extracted quantity in Task 3 is directly linked to the LCC workbook by ‘dragging and dropping’ the quantity from the dimension group into the workbook, forming a ‘live link’ between the BIM quantum and the LCC model. This is illustrated in Figure 6.7. The calculations in the model automatically calculate the LCC costs in Real, Nominal and Present Value (highlighted by cloud), which are checked by the participant against the answer in the task sheet.

Task 3 – Approx Time (4min)

Click back to the ‘Cost’ sheet and double click on the ‘Subtotal’ column for ‘2.1 Major Maintenance and Replacement; (32) Internal Wall Completions’.

Drag and drop the dimension group ‘IntSgl (1) 910 x 2110mm’ into the quantity cell for the internal door description in the LCC workbook and select ‘update’.

- Enter a Rate of 1100.
- Enter a Replacement period of 20 years and a Uplift Factor of 1.10 in the relevant cells.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
10,890	17,845	5,670

Return to the summary page by clicking by return arrow in left corner.

Complete -- Yes/No

Figure 6.7: Task 3 Fieldwork 2

The other scenarios and tasks are identical to Fieldwork Stage 1 to maintain consistency and to also provide a framework where data from both evaluations can be assimilated. Appendix 1i demonstrates the scenarios and tasks associated with Fieldwork Stage 2. As displayed in the user profile in Table 6.1 and the process map in Figure 6.1, ten participants were interviewed in Fieldwork Stage 2. More participants engaged in the Fieldwork Stage 2 (six in model development – ten in developed model) because it represented the developed process that incorporated 5D BIM. This is representative of the integration between LCC and BIM, which is the scope of the research.

6.4 Summary – Evaluation

The first part of this chapter outlined the specific evaluation procedures adhered to when collecting data for the prototype evaluation and subsequently the developed system. The procedures are based on usability engineering evaluation protocols, specifically the TA cooperative evaluation method outlined by Monk et al. (1993) and as discussed in Chapter 4.

Dumas & Redish (1999) state that a usability evaluation generates a substantial amount of data. TA cooperative evaluation does not lend itself to pure performance measurement, thus the data that is generated from this evaluation is mostly qualitative; based on information from the comments and observations of the participants during the TA part of evaluation and subsequent debriefing session.

There are no explicit data analysis recommendations on TA cooperative evaluation other than Wahl (2000) who states that the data collected during the TA must be summarised and tabulated. The data generated from TA is similar to the qualitative nature of data generated in an interview and thus data analysis techniques associated with qualitative analysis have been investigated and employed.

6.5 Data Analysis

This section and subsequent sub-sections discuss data analysis methods to address the most appropriate choice of analysis in the context of this research. The rationale for conducting thematic analysis is presented and adheres to Braun & Clarke's (2006) formulated process in two stages, mirroring the two stages of evaluation. As

discussed in the previous sections, data was generated from six participants evaluating the initial prototype presented in Chapter 5 and a further ten participants in a 2nd Stage engaging in a developed process informed from model development of the 1st Stage. The following sections are broken down into sections in accordance with the steps carried out in the data analysis and the order it is presented in Figure 6.1.

Data analysis is of critical importance to the qualitative research process, as improper analysis and even the analysis method chosen can have an effect on the results or themes discovered (Savin-Baden & Howell Major, 2013). Robson (2011) maintains that unlike quantitative analysis there are no strict approaches and universally accepted set of conventions in qualitative data analysis. He also adds that many qualitative researchers resist strict structures viewing qualitative analysis as an art rather than a science. Savin-Baden & Howell Major (2013) state that resisting strict structures and formulated analysis techniques should not come at the expense of academic rigor, where demonstrating how the themes and ultimately the findings emerged from the data is of utmost importance. Maykut & Morehouse (1994) and Braun & Clarke (2006) contend that without a transparent process it would not be possible to verify the data and ensure credibility/research rigour. Thus, there are a number of recommended common traits and steps to the many forms of qualitative data analysis which can be found in eminent texts in the field (Bryman, 2008; Creswell, 2009; Denscombe, 2010; Maykut & Morehouse, 1994; Miles & Huberman, 1994; Robson, 2011; Savin-Baden & Howell Major, 2013). The common traits of data analysis are discussed first, followed by the particular data analysis technique selected for this research.

6.5.1 Steps to Qualitative Data Analysis

Savin-Baden & Howell Major (2013) note that in order to analyse the data, the data must be broken down into meaningful parts, with the ultimate goal to make sense of the data by building it back together in emerging themes, which may answer the research question. Miles & Huberman (1994) comment that the foundations of qualitative data analysis are built on sorting through the raw data to identify similar phrases, variables, patterns, themes and common sequences – gradually elaborating on the consistencies in the data. Maykut & Morehouse (1994, p. 128) outline that the researcher can separate the data into meaningful segments by a process of “*unitising*

the data". A 'unit of meaning' can be a word, a sentence and a paragraph, which Maykut & Morehouse stress, should stand by itself, that it is understandable without the context of its surrounding material. Savin-Baden & Howell Major (2013, p. 451) describe this process as "*cutting*" because it involves or previously involved (prior to word processing) physically cutting out segments from the raw data. Word processing software or Computer Assisted Qualitative Data Analysis Software (CAQDAS) now automates this process by highlighting meaningful chunks or marking chunks in the software for closer examination (Denscombe, 2010; Maykut & Morehouse, 1994; Savin-Baden & Howell Major, 2013).

Savin-Baden & Howel Major (2013) and Miles & Humberman (1994) agree that each unit of meaning can be assigned a data 'label' or 'tag' to capture it's meaning and to distinguish it. This is outlined in many texts on qualitative data analysis, as "*coding the data*", which in the context of qualitative research is a system of shorthand symbols, letters or words (Bryman, 2008, p. 542; Creswell, 2009, p. 183; Denscombe, 2010, p. 285; Maykut & Morehouse, 1994, p. 133; Miles & Huberman, 1994, p. 56; Savin-Baden & Howell Major, 2013, p. 421). Codes are used to retrieve and organise the cut data for analysis (Miles & Huberman, 1994).

The next phase of qualitative data analysis is to group the codes into categories that relate to similar content such as topics, patters, phrases or concepts (Denscombe, 2010; Maykut & Morehouse, 1994; Savin-Baden & Howell Major, 2013). This process is defined by Robson (2011, p. 489) as "*initial coding*", while Bryman (2008, p. 542) describes a similar process which he defines as "*open coding*".

Maykut & Morehouse (1994) and Denscombe (2010) maintain that qualitative data analysis is predominantly carried out inductively, where detailed analysis of words, sentences and paragraphs (coding) give rise to the initial categories. Braun & Clarke (2006, p. 12) state that data analysis can also be carried out deductively or in a "*top down way*". Initial categories can be a product of the research question and be explicated to some extent prior to the start of analysis. Braun & Clarke (2006) note that there are no hard and fast rules and thus inductive and deductive analysis can be combined. Maykut & Morehouse (1994) state that due to the iterative nature of data analysis, even if the categories are predetermined others can emerge. For example, if a certain unit of meaning does not fit with a provisional category a new category could be formed.

Once codes and categories have been developed there is a movement from statement into analysis and interpretation (Savin-Baden & Howell Major, 2013). Robson (2011, p. 481), Maykut & Morehouse (1994, p. 139) and Braun & Clarke (2006, p. 5) outline a process of analysing the codes within the categories to develop common “*themes*” or “*proposition statements*”. According to Maykut & Morehouse (1994), a proposition statement is a statement that expresses a common link between the content of the categories or a rule for inclusion which governs them. Bryman (2008, p. 542) and Robson (2011, p. 490) describe this process as “*axial coding*”, while Miles & Huberman (1994, p. 69) outline a process of “*pattern coding*”. This is the essence of qualitative data analysis, as the themes and proposition statements should emerge out of a process of inductive reasoning to form the rough outcomes of your study (Maykut & Morehouse, 1994). Miles & Huberman (1994) state that this process is useful as it helps the researcher elaborate a cognitive map of links and patterns between the categories. They note that this can form the basis of displays.

Robson (2011) and Braun & Clarke (2006) agree that data analysis is an iterative on-going process where the researcher will continuously move back and forth between the data and the themes. The themes do not emerge in a linear process, the researcher is constantly dipping back into the data in a cyclical manner, generating new codes and themes, merging similar ones, discounting others and comparing and synthesising new data into the analysis. It is only when the researcher is satisfied that more analysis will not yield further themes that the process is complete (Maykut & Morehouse, 1994).

6.5.2 Formulated Methods

Creswell (2009) and Miles & Huberman (1994) agree that today many qualitative researchers go beyond the generic analysis outlined above to a more specific formulated processes aligned, in some instances, to one of the qualitative strategies of inquiry such as grounded theory or narrative analysis. These formulated approaches are evident in qualitative research publications such as Savin-Baden & Howell Major (2013), Robson (2011), Creswell (2009), Denscombe (2010) and Bryman (2008). Some researchers follow these approaches, while others pick aspects from a number of them. Robson (2011) emphasises that whatever approach is used the researcher has the responsibility to describe it in detail.

Robson (2011) outlines that the approaches differ depending on the depth of analysis. Facts can be extracted on a surface level based on what is said, or at a deeper level on what can be presumed or implied by reading through the lines. Savin-Baden & Howell Major (2013, p. 435) and Denscombe (2010, p. 280) outline a number of approaches such as “*keyword analysis*” and “*content analysis*”, which are processes of examining a text at its most functional level, i.e. what is said and the number of times it is said. Other more specialised data analysis approaches which tend to be carried out with their applicable theoretical research approaches are “*narrative analysis*”, “*ethnographic analysis*”, “*discourse analysis*”, “*phenomenological analysis*” and “*hermeneutical analysis*” (Braun & Clarke, 2006, p. 5; Denscombe, 2010, p. 288; Savin-Baden & Howell Major, 2013, pp. 441-445). Savin-Baden & Howell Major (2013) advise that these theoretical approaches tend to require a high level of skill on the part of the analyst along with extensive reading to acquire the knowledge to carry out the process. Denscombe (2010) maintains that these approaches tend to focus on implied meaning rather than explicit content, where analysts examine what message can be found through the body language of the participant, their tone, and possibly what they are not saying.

Two of the most frequently used and referenced methods of data analysis are “*thematic analysis*” and “*grounded theory*” (Bryman, 2008, p. 538; Robson, 2011, p. 474; Savin-Baden & Howell Major, 2013, p. 439). Thematic analysis involves grouping the codes that are about the same thing or exemplifies the same thing into themes (Braun & Clarke, 2006; Robson, 2011; Savin-Baden & Howell Major, 2013). Robson (2011) adds that the themes can emerge inductively as the analysis is carried out or can be predefined. Braun & Clarke (2006) describe thematic analysis as a method for identifying and reporting patterns (themes) within data, which they state can be done both at a surface level or at a latent interpretative level. Braun & Clarke (2006, p. 9) also describe thematic analysis as a “*flexible tool*” because it is not bound to a theoretical or epistemological position and thus can be applied within different epistemological approaches.

While thematic analysis is presented as an identifiable approach in publications such as Savin Baden & Howell Major (2013) and Robson (2011); Bryman (2008) argues that thematic analysis is not an identifiable approach. He believes that thematic analysis is rather an activity within a number of identifiable approaches, such as

grounded theory, discourse analysis, content analysis and narrative analysis. Braun & Clarke (2006) counteracts Bryman's position by claiming that thematic analysis is an identifiable approach, just poorly labelled and masquerading as other named approaches or embedded in other approaches. For example, in Braun & Clarke's (2006, p. 8) opinion, grounded theory has increasingly been used in a way they describe as "*grounded theory lite*", which is more akin to thematic analysis rather than the formulated grounded theory process outlined in Maykut & Morehouse (1994). Thus, Braun & Clarke stress that a lot of analysis is essentially 'thematic', just labelled as something else or generally labelled as 'data analysis'.

Maykut & Morehouse (1994, p. 126) and Savin-Baden & Howell Major (2013, p. 437) address another method of "*constant comparison*" developed by Glazer & Strauss (1967, cited in Maykut & Morehouse, 1994, p.127). This method is embedded in grounded theory but can also stand on its own. It is very similar to thematic analysis but accentuates the cyclical nature of data analysis by stressing that the researcher must go back and forth through the codes and categories, the categories and themes constantly comparing, constantly modifying and sharpening their emerging theory.

6.5.3 Approach to Data Analysis

The adopted approach to data analysis will follow the general principles of coding and inductive analysis outlined in Section 6.5.1, by breaking the data into coding and themes which recognise the details of the transcribed text or the interviewee's observations and notes. The analysis will include elements of what Savin-Baden & Howell Major (2013, p. 435) outline as "*keyword analysis*" and "*content analysis*", where the focus is on the surface level feedback from the participants of the study, i.e. as in what they actually think of leveraging 5D for LCC and the prevalence of this feedback across the data set.

The approach that has been pursued has similarities to constant comparison and the open and axial coding process in grounded theory, but because the focus is on themes the process is more aligned with the formulated process of 'thematic analysis' outlined by Braun & Clarke (2006). One ultimate central theme (grounded theory) is not what is required from the data, but a number of themes and categories which can offer feedback on the goals of the system and comments and attitudes in

engaging with the process. The goals of the system formed the pre-analysis categories prior to coding. However, this was just a starting point and categories materialised out of the inductive process of analysing the data. Thus, to some extent the research analysis was both ‘deductive’ (predefining the codes based on the research question and the goals of the system) and ‘inductive’ (giving rise to latent themes) which may identify underlying ideas, assumptions and conceptualisations of the participants, not just in using the software, but also when engaging in the 5D process to carry out LCC. Thematic analysis facilitated this process as it gave the opportunity to analyse data on these two levels; one which was researcher lead, based on the project’s focus of inquiry; and one which was participant lead, derived from the participant’s customs and language (Braun & Clarke, 2006).

The epistemological position as outlined in the research methodology is what Crewell (2009; 2007) outlines as advocacy/participatory and pragmatism. Thematic analysis does not align with a particular research tradition thus the researcher has the ability to apply it in the context of what works for the research, which is at the centre of a pragmatic worldview (Braun & Clarke, 2006). The flexibility of thematic analysis was also beneficial because a tool was needed which could take account of the researchers role as an active participant.

Being explicit about the process the researcher follows in relation to analysing their data is of utmost importance to ensure validity (Robson, 2011; Savin-Baden & Howell Major, 2013). Braun & Clarke (2006) outline six phases of analysis which they summarise in Table 6.2.

Phase	Description of the process
1. Familiarising yourself with your data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2. Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes:	Checking in the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5. Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells; generating clear definitions and names for each theme.
6. Producing the report:	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

Table 6.2: Braun & Clarke (2006, p.35)

The phases outlined in Table 6.2, follow a process of six phases of data analysis, from the initial process of 'Familiarising yourself with the data' to the final phase of 'Producing the Report'. As presented in Figure 6.1 there are two stages of evaluation and thus Braun & Clarke's framework was applied in this research to both stages. This process is articulated in more detail in Section 6.6 and presented in Table 6.3 applying phase 1-6 to data analysis Stage 1 and again in data analysis Stage 2.

6.5.4 Computer Assisted Qualitative Data Analysis (CAQDAS)

Several computer packages have been designed for qualitative data analysis (Bryman, 2008; Creswell, 2009; Robson, 2011; Savin-Baden & Howell Major, 2013). These packages offer advantages in the mechanics of processing large quantities of data. Denscombe (2010) advises the researcher should use one of the CAQDAS packages to take advantage of the software's ability to store, code and retrieve the data. Robson (2011) claims that NVivo software is the preferred option for many researchers in qualitative data analysis. Savin-Baden's & Howell Major's (2013) and Robson (2011) opine that the researcher should carefully consider

whether CAQDAS is appropriate for their particular study and to consider the time it takes to learn the application against the time saved by using it. It is their view that the researcher would be well served to do it the “*old fashioned by hand method*” initially to familiarise themselves with the data and weight up what approach to take. Denscombe (2010), Savin-Baden & Howell Major (2013) and Robson (2011) agree that CAQDAS packages do not replace the analytical functions of the researcher in developing the themes and making the connections between the themes.

Data analysis was initiated by transcribing the audio, printing out and reading the transcript from pilot Participant 1c. Text was highlighted and manually coded by making notes in the margin of the transcript and writing ideas on a separate piece of paper. During this process a decision was taken to adopt a computerised package as a sizeable amount of data had been generated, which was proving to be unwieldy and cumbersome in its management (Miles & Huberman, 1994; Robson, 2011).

NVivo CAQDAS was selected to aid in the task of analysing the data. NVivo was chosen for its suitability and availability through a licensing agreement with DIT. A full day training workshop was attended and a decision was made that the package was suitable for use in the data management of this research. The latest version of NVivo (NVivo 10) was down-loaded and the data, once collected and transcribed, was imported into NVivo. It must be stressed however that in using the software, the hermeneutic task of data analysis was not capitulated to the computer. The CAQDAS software was used as an aid for data analysis and not as a tool which in itself conducts analysis and draws conclusions. Importantly the software produced a database and audit trail of the process that was carried out leading to the project’s conclusions. The different stages of this process are described in detail in the next sections.

6.6 Data Analysis 1 for Fieldwork Stage 1

As demonstrated in Table 6.3, data analysis is divided into two stages, replicating the two stages of evaluation, which were outlined in Section 6.3 and presented in Figure 6.1. The 1st Stage as outlined previously is based on data generated from the evaluation of the model development from six participants based on the prototype discussed in the previous chapter. NVivo was utilised so that it accommodates the different stages of Braun & Clarke’s (2006) formulated process (Table 6.2) by

mapping the different phases of data analysis in NVivo to Braun & Clarke's taxonomy in two stages. Table 6.3 illustrates the practical application of Braun & Clarke's methodology within the software.

Analytical Process (Braun & Clarke, 2006)		Braun & Clarke Practical Application in Nvivo
Data Analysis Stage 1		
1. Familiarising yourself with the data		Transcribing data (if necessary), reading and re-reading, noting down initial ideas, Import data into Nvivo
2. Generating initial codes	Open coding	1st Phase. Deconstructing the field data into open codes (i.e. 55 nodes) using thematic analysis.
3. Searching for themes	Categorisation of codes	2nd Phase. Re-ordering the broad general codes into categories of themes
4. Reviewing themes	Coding on	3rd Phase. Breaking down the new re-ordered themes into sub-themes within their categories.
5. Defining and naming themes	Data Reduction	4th Phase. (4a&4b) Generating clear definitions & themes, consolidating codes, relabeling & merging codes
6. Producing the Report	Findings	5th Phase. Generating analytical memos & making changes to system per feedback from participants
Data Analysis Stage 2		
2. Generating initial codes - 2	Open Coding&Categorisation (2)	6th Phase. Deconstructing the field data into open codes (i.e. 127 nodes) using thematic analysis based on general themes outlined in 4th Phase of Stage 1.
3&4. Searching for themes & reviewing themes	Sub-Categorisation & Coding on (2)	7th Phase. Further analysis & Coding - Re-ordering initial codes into categories & into sub-themes within their categories.
5. Defining and naming themes	Data Reduction 2	8th Phase. Generating clear definitions & themes, consolidating codes, relabeling & merging codes
6. Producing the Report	Findings	9th Phase. Produce the report - generating memos, testing and validating

Table 6.3: Analytical Process in NVivo

As can be seen in Table 6.3 (per the right column) there are some minor changes to the structure of Braun & Clarke's methodology outlined previously in Table 6.2. This is to accommodate processes and procedures with using NVivo and the iterative development and collection process which requires two stages of analysis in this research. Table 6.3 proposes two stages of data analysis with nine phases; divided into five phases of analysis in the 1st Stage and a further four phases in the 2nd Stage. The process starts with 'generating the initial codes', because Phase 1 in Braun & Clarke's taxonomy, 'familiarising yourself with the data', was not carried out with the CAQDAS and thus was not presented here as a phase in the CAQDAS cycle. However, it is part of the analytical process and thus is addressed below. The phases are identical in both stages of data analysis albeit Phase 7 in the 2nd Stage

encompasses both ‘searching for themes’ and ‘reviewing themes’. The subsequent sections describe step by step, the analytical process outlined in Table 6.3.

6.6.1 Familiarise yourself with the data

Braun and Clarke’s (2006, p. 16) analytical process begins with “1. *Familiarising yourself with the data*”. Braun & Clarke (2006) state that it is important that the researcher immerses themselves in the data, repeatedly reading their data, searching for meaning and possible patterns. After a decision was made to use NVivo, data analysis began by printing out and reading most of the transcripts. Initial impressions were written down along with possible categories/themes which formed the basis of the coding structure for the open coding phase. These categories were based on the different elements of the evaluation which are outlined in Section 6.2 and 6.3. As can be seen in Table 6.4, these preliminary categories structured possible codes into five preliminary categories based on codes from the debriefing stage of the evaluation; the scenarios (whether participants completed scenarios and tasks successfully); the success of the evaluation itself (whether the evaluation was clear and administered to the satisfaction of the participant); a thinking aloud category which encompasses codes related to the usability of the system (easy to use, easy to learn, effectiveness, satisfaction, low error rate) and an emergent category for codes related to ideas and comments from the participants.

APPENDIX 2a: PHASE 1 - OPEN CODING				
Nr	Code	Name	Sources	Units of Meaning Coded
	1.0	Debriefing	12	85
	2.0	Emergent Codes	12	407
	3.0	Evaluation of Test	6	38
	4.0	Scenarios	12	117
	5.0	Thinking Aloud	12	148

Table 6.4: Open coding categories

6.6.2 1st Phase of Data Analysis

Phase 1 - Open-coding is the 1st Phase of Braun & Clarke’s (2006) data analysis process using the NVivo software. Open coding involved broad participant driven coding of the transcripts supported by descriptions of the codes, to deconstruct the data into general themes in the next phases. Table 6.5 outlines fifty eight open coding nodes, in five categories, complete with supporting descriptions. As

evidenced from this table, these codes have clear labels and definitions which serve as rules of inclusion for units of meaning (segments) from the coded transcripts (Maykut & Morehouse, 1994). For example, the code about whether the participants could ‘follow the tasks easily’ (Code Nr. 44, 3.4) includes thirteen segments from six sources.

APPENDIX 2a: PHASE 1 - OPEN CODING				
Nr	Code	Name	Sources	Units of Meaning Coded
	1.0	Debriefing	12	85
1	1.1	Carried out LCC calculations	6	6
2	1.2	What software did you use	6	13
3	1.3	Develop LCC template on your own	9	15
4	1.4	If you had would you use it in work	6	6
5	1.5	Built into QS software	6	9
6	1.6	Evident to do WLCC using template	9	10
7	1.7	Best thing about Prototype	6	6
8	1.8	Worst Thing about Prototype	8	13
9	1.9	Any recommendations	6	7
	2.0	Emergent Codes	12	407
10	2.1	Applications & uses of LCC template	8	22
11	2.2	Barriers to LCC	9	22
12	2.3	BIM	6	13
13	2.4	Cash Flows	9	24
14	2.5	Check Validity & Calculations	7	8
15	2.6	Client demand willing to pay	3	4
16	2.7	Collaboration between FM and QS to produce estimate	1	1
17	2.8	Confusion with Task	11	32
18	2.9	Educational Tool	11	43
19	2.10	Fluidity and Changeability	5	8
20	2.11	Graphical representation	4	5
21	2.12	Inaccuracies-deficiencies in template	12	51
22	2.13	Like a tool in itself	1	2
23	2.14	Marketing Tool	1	1
24	2.15	Notes or guidance for user	1	1
25	2.16	Prefers separate line items for maintenance costs	2	3
26	2.17	Professional Experience with LCC	7	11
27	2.18	Study Period	1	1
28	2.19	Summary Tab	11	19
	2.20	Understanding of LCC	12	123
29	2.20.1	Confusion of LCC terminology	9	19
30	2.20.2	Full replacement Sheet	5	5
31	2.20.3	Item Specific Escalation	12	21
32	2.20.4	Occurrences in annual Costs	9	11
33	2.20.5	Periodic Maintenance Replacement & Factor	11	27
34	2.20.6	Setting up similar Template	4	4
35	2.20.7	Taking information from cost plan	7	15
36	2.20.8	Uplift Factor	10	19
37	2.20.9	Where in supply Chain LCC is used	1	1
38	2.21	Use of Excel Experience	8	11
39	2.22	Value Added Service	1	1
40	2.23	Would this be already developed	1	1
	3.0	Evaluation of Test	6	38
41	3.1	Understanding of pretest instructions	6	6
42	3.2	Recording Equipment Intrusive	6	6
43	3.3	Easy to Talk Continuously	6	7
44	3.4	Follow Tasks Easily	6	13
45	3.5	Anything did not Like	5	6
	4.0	Scenarios	12	117
46	4.1	Task 1	12	15
47	4.2	Task 2	12	18
48	4.3	Task 3	12	12
49	4.4	Task 4	12	15
50	4.5	Task 5	12	13
51	4.6	Task 6	12	16
52	4.7	Task 7	12	13
53	4.8	Task 8	12	15
	5.0	Thinking Aloud	12	148
54	5.1	Ease of Use	12	48
55	5.2	Easy to Learn	7	11
56	5.3	Effectiveness	12	47
57	5.4	Low Error Rate	5	7
58	5.5	Satisfaction	8	35

Table 6.5: 1st Phase (Open Coding)

As evidenced in Table 6.5 both video and transcribed texts were initially used as sources for coding (i.e. some sources are doubled in Table 6.5). This led to a considerable amount of duplication in the analysis as both a video segment and a transcribed audio segment were coded into the same node in NVivo. This became very time consuming as the analysis continued. A decision was made to utilise the transcribed audio for analysis and only refer to the video, if needed, for clarification.

6.6.3 2nd Phase of Data Analysis

A 2nd Phase of data analysis was then conducted. This entailed re-ordering the broad codes identified in the 1st Phase into categories of codes, i.e. categorisation of codes by grouping related codes under categories and sub-categories that makes sense for further analysis. This phase also included distilling, re-labelling and merging categories to ensure that labels and rules for inclusion accurately reflected coded content. Braun & Clarke (2006, p. 20) name this phase the “*categorisation of codes*” which should lead to a proliferation of categories and codes. In this instance the data from the 1st Phase was further coded into five themes, 30 sub-themes and 143 codes. This represented a detailed examination and breakdown of the data. This process gave rise to an initial hierarchical thematic framework, as evidenced in the sample extract in Table 6.6. The complete set of categories and codes in this phase are included in Appendix 2b.

Appendix 2b: PHASE 2 - CATEGORISATION OF CODES				
Nr	Code	Name	Sources	Units of Meaning Coded
	1.0	Debriefing	12	78
1	1.1	Carried out LCC calculations	6	6
1	1.1.1	No have not carried them out	2	2
2	1.1.1.1	Only in College	3	3
3	1.1.2	Yes Professionally	1	1
4	1.1.2.1	Discussed them but no calculations	1	1
2	1.2	What software did you use	6	13
5	1.2.1	Custom	5	11
6	1.2.2	Excel	6	13
3	1.3	Develop LCC template on your own	9	15
7	1.3.1	No	7	7
8	1.3.2	Yes	5	8
4	1.4	If you had would you use it in work	6	6
9	1.4.1	Yes	4	4
10	1.4.1.1	Comparative Analysis	1	1
11	1.4.1.2	Depends on client demand	2	2
5	1.5	Built into QS software	6	9
12	1.5.1	Easier - More Likely to do LCC	5	6
13	1.5.2	QS don't do it because systems aren't there	2	2
14	1.5.3	Spreadsheet can be imported into other packages	3	4
15	1.5.4	Yes - Value added Service	1	1
6	1.6	Evident to do WLCC using template	9	10
13	1.6.1	Use Cost Plan & or Bill - Copy & Paste	9	10
7	1.7	Best thing about Prototype	6	6
14	1.7.1	Automation of Calculations	3	3
15	1.7.2	Getting user to think of life cycle	1	1
16	1.7.3	Leveraging the cost plan	1	1
17	1.7.4	Spreadsheet Form	2	2
8	1.8	Worst Thing about Prototype	8	13
15	1.8.1	Appearance - Layout could be enhanced	7	11
16	1.8.2	Hide information you don need	1	2
17	1.8.3	Lock down Cells	5	5
18	1.8.4	Separate tabs for cash flows	5	5
19	1.8.5	Some sort of prompt Guidance initially	5	6
20	1.8.6	Some Terminology needs to be explained	1	2
	2.0	Emergent Codes	11	689
9	2.1	Applications & uses of LCC template	11	57
21	2.1.1	Applicable to concept and detailed estimates	3	5
22	2.1.2	As a Contractors VE Tool	1	1
23	2.1.3	Holistic Client Service	2	2

Table 6.6: 2nd Phase- Sample (Categorisation of codes)

6.6.4 3rd Phase of Data Analysis

A 3rd Phase of data analysis was then conducted, i.e. “coding-on”, which consisted of continued distilling, re-labelling and merging of codes and categories (Braun & Clarke, 2006). In some instances the newly restructured sub-themes were further broken down to offer clearer insights into the meanings embedded therein. This process gave rise to a hierarchical structure which provided a framework for the highly qualitative aspects of the study, such as divergent views, negative cases, attitudes, beliefs and behaviours coded to the sub-categories. This phase of data analysis incorporated the initial 5 major themes, a consolidation into 24 sub-theme categories and a slight reduction in the number of codes from 143 to 136. Table 6.7 is an extract from this phase of evaluation. Refer to Appendices 2c for the complete set of codes.

Appendix 2c: PHASE 3 - CODING ON				
Nr	Code	Name	Sources	Units of Meaning Coded
	1.0	Debriefing	12	46
	2.0	Emergent Codes	22	492
	2.1	Applications & uses of LCC template	11	57
36	2.1.1	Applicable to concept and detailed estimates	3	5
37	2.1.2	As a Contractors VE Tool	1	1
38	2.1.3	Holistic Client Service	2	2
39	2.1.4	LCA	1	1
40	2.1.5	Like a tool in itself	2	3
41	2.1.6	Marketing Tool	1	2
42	2.1.7	Operations	1	1
43	2.1.8	PPP's	2	2
44	2.1.9	Sensitivity Analysis	3	3
45	2.1.10	To address to alternative items	7	15
13	2.2	Barriers to LCC	10	58
14	2.2.1	Calculations help do LCC & Save Time	7	15
46	2.2.1.1	Its Still Time Intensive	2	3
15	2.2.1	Client requirements	3	5
47	2.2.1.1	Can facilitate a more Holistic Client Service	0	0
48	2.2.1.2	Depends on Client Type (Short Term)	1	1
49	2.2.1.3	Easier to Sell Service to Client	0	0
50	2.2.1.4	Might not be requested & Not Paid	1	1
51	2.2.2	Get LCC info from Supplier	1	2
16	2.2.3	Lack of Understanding of LCC process and Terminology	1	1
52	2.2.3.1	Confusion of LCC terminology	9	19
53	2.2.3.2	Demonstrates understanding of Task 4 cyclical maintenance	1	1
54	2.2.3.3	Full replacement Sheet	5	6
55	2.2.3.4	Item Specific Escalation	12	21
56	2.2.3.5	Its More a Design Issue	1	1
57	2.2.3.6	Occurrences in annual Costs	9	11
58	2.2.3.7	Periodic Maintenance Replacement & Factor	11	27
59	2.2.3.8	Setting up similar Template	4	4
60	2.2.3.9	Taking information from cost plan	7	16
61	2.2.3.10	Uplift Factor	10	19
62	2.2.3.11	Where in supply Chain LCC is used	1	1
63	2.2.4	No applicable Technology so this helps	7	7
64	2.2.5	Overlapping of services - who specifies	1	1
65	2.2.6	Presentation of the LCC estimate	1	2
66	2.2.7	What life Spans to Use	2	3
17	2.3	BIM	6	22
67	2.3.1	Enhance Visual Presentation	2	3
68	2.3.2	Getting information from the object	2	4
69	2.3.3	Save time for other activities	1	1
70	2.3.4	Where spreadsheet can be linked to BIM	1	1
18	2.4	Confusion with Task	11	54
71	2.4.1	Task 1 - Project Details Label items	4	4
72	2.4.2	Task 3 - Separate Lines or in One Cell	2	2

Table 6.7: 3rd Phase - Sample (Coding On)

6.6.5 4th Phase of Data Analysis

After completion of the 3rd Phase, the emerging structure was too complex to provide meaning to any possible analytical memos or proposition statements. Thus, Phase 4 encompassed significant data reduction to create a final framework of themes for reporting purposes (Braun & Clarke, 2006). This took place in two phases (Phase 4 & 4a) where the coding structure in Phase 3 was re-labelled and re-orientated towards a more abstract, philosophical and literature-based coding configuration. This process entailed significant relabeling and merging of themes and consolidation of codes from all three cycles. Appendix 2d and Appendix 2e outline the thematic structure in Phase 4 and 4a, respectively. Phase 4 demonstrates data reduction into 5 themes, 36 sub-themes and 118 codes. Phase 4a displays further reduction into 5 themes, 38 sub-themes and 97 codes. The categories and subcategories now gave rise to a more relevant thematic framework in Phase 4a from which analytical memos could be written against thematic categories and subcategories. An example of the structure generated in Phase 4a is included in Table 6.8 below.

Appendix 2e: PHASE 4a & 5 - DATA REDUCTION 2					
Nr	Code	Codes	Sources	Units of Meaning Coded	Analytical Memos
	1.0	Addressing Barriers - Advantages of Template - EFFECTIVENESS	6	6	
1	1.1	Access to Information	2	5	X
2	1.1.1	Collaboration	2	2	
1	1.1.1.1	Collaboration between FM and QS to produce estimate	1	1	
2	1.1.1.2	Overlapping of services - who specifies	1	1	
3	1.1.2	Get LCC info from Supplier	2	3	
3	1.2	Client requirements	5	21	X
4	1.2.1	Depends on Client Type (Short Term)	2	3	
4	1.2.1.1	Might not be requested & Not Paid	1	1	
5	1.2.2	Easier for QS - More Likely to do LCC	5	7	
6	1.2.3	Easier to Sell Service to Client - Marketing	1	2	
5	1.2.4	Facilitate Holistic Service & Informed Decisions	2	4	
7	1.2.4.1	Applicable to concept and detailed estimates	3	5	
8	1.2.4.2	As a Contractors VE Tool	1	1	
9	1.2.4.3	Link to LCA	1	1	
10	1.2.4.4	PPP's	2	2	
11	1.2.4.5	Sensitivity Analysis	3	3	
12	1.2.4.6	To address to alternative items	7	15	
6	1.3	LCC Time & Calculations	12	106	X
7	1.3.1	Calculations	12	37	
8	1.3.1.1	Automation of Calculations	8	25	
13	1.3.1.1.1	Auto fills Cash Flows	8	13	
14	1.3.1.1.2	Calculates PV, Escalated Costs	9	13	
15	1.3.1.1.3	Saves user time	6	6	
16	1.3.1.2	Leveraging the cost plan to do WLCC	9	12	
9	1.3.2	Calculations help to do LCC & Save Time	11	21	
17	1.3.2.1	But Its Still Time Intensive	2	3	
18	1.3.3	Ease of input	11	24	
10	1.3.4	Easier - QS More Likely to do LCC	5	7	
19	1.3.4.1	Input Cells are highlighted	1	2	
20	1.3.5	Quick Learning Curve	8	13	

Table 6.8: 4th(a) Phase - Sample (Data Reduction 2)

As can be seen from Appendix 2e and the sample extract in Table 6.8 the old categories aligned to themes such as ‘debriefing’, ‘emergent codes’ and ‘scenarios complete’ (which are based on the format and structure of the evaluation) are replaced with themes such as ‘addressing barriers’, ‘experience with LCC’ and ‘suggestions and feedback’. These new hierarchical themes are applicable to the aim, objectives and literature of the research, making it easier to generate appropriate analytical memos.

6.6.6 5th Phase of Data Analysis

A number of analytical memos were written against the higher level themes of the coding structure in Phase 4a to summarise the content of each category of codes and propose empirical findings against such themes. Table 6.8 indicates the theme or sub-theme the analytical memos are written for with an ‘X’. In the sample in Table 6.8 three memos are written to summarise the content of each category and propose empirical findings that relate to the coded content within the theme. For example, the analytical memo written against ‘1.3 LCC Time and Calculations’ from Table 6.8 is outlined below:

This node contains contributions from participants whom mention the time it takes to carry out the process and the automation of the calculations which make it easier for QS's.

A number of participants mention that they are less likely to carry out LCC if it is not requested and not paid for by the client because of the time it takes to carry out the calculations. However, all six participants make reference to the automation of the calculations including the ease of inputting LCC information in the template which will save them time and make it more likely that they will carry out LCC calculations.

"Everything is done automatically. You are only typing in your quantities, rates, your escalation and discount rates and everything is calculated automatically. So it's useful in that way, that it's...it saves time".

All the participants made reference to the use of the Cost Plan in the production of the LCC estimate. Stating that it is useful that the cost plan/BOQ is the starting point for the LCC estimate whereby LCC data requirements can be added. 5 out of 6 participants also mention that due to their familiarity with spreadsheets and the cost planning process it accelerates the learning curve when using a template that leverages both.

The memos written as part of this stage of analysis form the basis of ‘*producing the report*’ in Braun & Clarke (2006), which is discussed in the next ‘Chapter 7 - Findings and Discussion’. These memos deal with the prototype evaluation and

address how the prototype LCC Excel calculation structure informed the more developed version of the system and how a process with these calculations embedded in it could address some of the barriers to the implementation of LCC. The next stage of data analysis deals with the more developed version (i.e. Stage 2 of the evaluation).

6.7 Data Analysis 2 for Fieldwork Stage 2

Figure 6.1 at the start of the chapter outlines the overall data analysis framework employed in this research. This was constructed to illustrate the two different stages of data collection and data analysis and the link between them. The process outlined in Fieldwork Stage 1 is represented in the first half of the table with Braun & Clarke's methodology illustrated through the centre column. The next stage is represented in the second half of Figure 6.1 illustrating a similar process through a 6th, 7th, 8th and 9th Phase.

Data analysis in the 2nd Stage is based on data generated from ten participants whom engaged in the developed process informed from the 1st Stage. As can be seen in Table 6.8, the coding structure in Phase 4a, (data reduction) informed the open coding structure in the 2nd Stage of the data analysis. The subsequent data analysis was applied in a manner similar to what was outlined above but with data generated from the developed 5D LCC solution and with 10 new participants.

6.7.1 6th Phase of Data Analysis

The 2nd Stage of data analysis began with open coding to the categorisation structure of Phase 4a. At the end of this process the initial categorisation structure from Phase 4a was expanded to 8 categories with a total of 127 codes. Table 6.9 outlines an extract from this phase and Appendix 2f represents the full table.

Appendix 2f: PHASE 6 - OPEN CODING				
Nr	Code	Name	Sources	Units of Meaning Coded
	1.0	Addressing Barriers	8	296
1	1.1	Access to Information	7	14
2	1.2	Client requirements	8	46
3	1.3	Lack of Knowledge	8	34
4	1.4	LCC Time & Calculations	8	51
5	1.5	Methodology - Understanding LCC process and Terminology	9	88
6	1.6	Resistance to Change	8	21
7	1.7	Technology - Leverages IT for LCC	6	42
	2.0	Benefits of LCC	8	246
8	2.1	Addressing Alternatives - optioneering	8	28
9	2.2	Another service for the QS	6	12
10	2.3	Assessing Maintenance Programmes	3	9
11	2.4	Banks and pension funds	1	1
12	2.5	Benefits to Property Managers	4	11
13	2.6	Better value for client - more holistic service	8	26
14	2.7	Contract evaluation-calculation	1	1
15	2.8	Contractors Value Engineering tool	4	7
16	2.9	Could use it for WLLC	4	5
17	2.10	Evaluation of LCC tenders - what your being offered esp Design & Build	5	7
18	2.11	Evaluation of sustainability measurers - measure os sustainability	4	10
19	2.12	Extra Fees	3	3
20	2.13	Graphical Representation	3	4
21	2.14	LCC durations might not be actually used	1	1
22	2.15	Marketing tool	3	6
23	2.16	More awareness now on LCC	4	9
24	2.17	More informed Design Decisions - effect on future expenditure	8	37
25	2.18	PPP	1	2
26	2.19	Tendering	1	2
27	2.20	To educate clients with hard data	5	14
28	2.21	Useful for Calculating Prelims	2	3

Table 6.9: 6th Phase - Sample (Open Coding)

6.7.2 7th Phase of Data Analysis

The 7th Phase of data analysis represents both the ‘*categorisation phase*’ and the ‘*coding on*’ phases. As evidenced in Table 6.10, the categorisation structure and associated codes are expanded into a number of sub-categories and additional themes, based on continued distilling, re-labelling and merging of codes & categories. At the end of this phase there were 8 categories, 37 sub-categories and 167 codes, which represents somewhat of a proliferation on the 6th Phase. These are outlined in Appendix 2g.

Appendix 2g: PHASE 7 - CATEGORISATION & CODING ON				
Nr	Code	Name	Sources	Units of Meaning Coded
	1.0	Addressing Barriers	8	264
	2.0	Benefits of LCC	6	49
	3.0	BIM	8	62
16	3.1	Barriers	8	45
17	3.1.1	Architects not using BIM	6	10
59	3.1.1.1	BIM not used as BIM but just for design	4	8
60	3.1.1.2	Not giving model	2	4
61	3.1.2	BIM in concept but then not used after	1	1
62	3.1.3	Clients not aware of BIM capabilities	3	3
63	3.1.4	Cost of using BIM	4	8
64	3.1.5	Extra charge - fees	2	2
65	3.1.6	Larger companies using BIM	3	3
18	3.2	Benefits	8	18
66	3.2.1	Benefits in Optioneering	2	2
67	3.2.2	Benefits of BIM Visualisation	4	11
68	3.2.3	Benefits of quantification	3	4
69	3.2.4	Benefits of Revisioning	5	9
70	3.2.5	Easier to do LCC	6	10
71	3.2.6	Get FM info off design team	1	2
72	3.2.7	Puts pressure on QS to offer more services	3	5
73	3.2.8	Saves QS time	3	12
19	3.3	Have you used BIM	8	14
20	3.3.1	No	4	7
74	3.3.1.1	But is in our plans	2	4
21	3.3.2	Yes	4	4
75	3.3.2.1	But not full measurement - partially used	1	1
76	3.3.2.2	But on a trial basis	2	3
77	3.3.2.3	Majority of work is BIM	1	1
22	3.4	Problems in 5D BIM	8	16
78	3.4.1	BIM not used as BIM - geometry & efficiency in design	4	8
79	3.4.2	Contractor not prepared to agree BIM Quantities	1	2
80	3.4.3	Cost of using BIM	4	9
81	3.4.4	I don't have the training or knowledge of 5D BIM	3	3
82	3.4.5	Incorrectly categorised	2	2
83	3.4.6	Not everything in the model - details, schedules	2	3
84	3.4.7	Not in the correct QS format - lot of interpretation	6	16
85	3.4.8	Software we use cant accommodate BIM	2	3
86	3.4.9	Validation of quantities- check with 2D	5	11
23	3.5	Promoting Use	4	5
87	3.5.1	Request for BIM driven by FM	4	5
24	3.6	Recommendations by QS	8	14
88	3.6.1	5D BIM needs to have spreadsheet function	1	2
89	3.6.2	Add parameters in Authoring application	4	7
90	3.6.3	Ask architect to set up model a certain way	4	7
91	3.6.4	Got to ask for the Model	4	6
92	3.6.5	Included in project brief	1	2
93	3.6.6	Needs to be collaborative	3	7
94	3.6.7	Pitch it to Client - demonstrate its use	4	6
95	3.6.8	Pushed with government work	2	8
96	3.6.9	Training	2	2
97	3.6.10	Used as a Trial - Own Initiative	5	9

Table 6.10: 7th Phase - Sample

6.7.3 8th Phase of Data Analysis

The 8th Phase of analysis follows the same process of data reduction that was applied in the 1st Stage per Phase 4 above. In this context, codes and categories generated in the last phase were reduced into a thematic framework of 7 themes, 42 sub-themes and 132 codes, which were used to generate memo statements. Table 6.11 provides a

sample of the framework at this phase and illustrates the memos that were written against the themes and sub-themes in the ‘Recommendations for Improvement and Feedback’ category. The full framework is evident in Appendix 2h.

Appendix 2h: PHASE 8 - DATA REDUCTION					
Nr	Code	Codes	Sources	Units of Meaning Coded	Analytic al Memos
	1.0	Barriers to LCC	10	248	X
	2.0	Benefits LCC	11	304	X
	3.0	BIM	10	266	X
	4.0	Evaluation of Test - everything ok	10	22	X
	5.0	Experience with LCC	10	57	X
	6.0	Recommendations for Improvement and Feedback	11	497	X
31	6.1	Feedback on template	10	300	X
32	6.1.1	Could you develop template	8	11	
83	6.1.1.1	No - not like that with automation	7	10	
84	6.1.1.2	Yes	3	3	
33	6.1.2	Different to other LCC systems	10	72	
85	6.1.2.1	An integrated Cost - LCC System w links between quantum & cost & LCC	10	48	
86	6.1.2.2	Likes the specific escalation rate	2	4	
87	6.1.2.3	Looks and feels like excel & other QS software - familiarity	8	20	
34	6.1.3	Presentation & Reporting	10	55	
88	6.1.3.1	Can follow this as a methodology to do LCC - standardised structure - leads to more	7	14	
89	6.1.3.2	Can show level of detail you want - generate your own reports	6	22	
92	6.1.3.5	It is evident you could use it to do WLLC - item by item in your estimate	10	13	
94	6.1.3.7	Real time Sensitivity Analysis on Inflation etc	4	6	
35	6.1.4	Quick Learning curve - user friendly	10	31	
95	6.1.4.1	Clear & easy inputting data	7	15	
96	6.1.4.2	Looks and feels like excel & other QS software	11	23	
36	6.1.5	Result of using	10	65	
97	6.1.5.1	If you had this would you use it in work	9	25	
102	6.1.5.6	More likely carry out LCC - easier to do LCC	10	25	
103	6.1.5.7	QS Getting more from your software - built on existing system	6	10	
104	6.1.5.8	Use it for building database	2	4	
105	6.1.5.9	Would save us outsourcing LCC work	1	1	
37	6.1.6	Speed Efficiency Automation	10	66	
106	6.1.6.1	Automation of the calculations & population of cash flows	10	50	
107	6.1.6.2	Can reuse it - forms template	5	5	
108	6.1.6.3	Leveraging Cost Plan - BOQ	5	8	
38	6.2	Scenarios	10	86	X
109	6.2.1	Task 1	10	12	
110	6.2.2	Task 2	10	10	
111	6.2.3	Task 3	10	12	
112	6.2.4	Task 4	10	13	
113	6.2.5	Task 5	9	9	
114	6.2.6	Task 6	8	10	
115	6.2.7	Task 7	10	11	
116	6.2.8	Task 8	8	8	
39	6.3	Recommendations for improvement	10	49	X
40	6.3.1	Appearance	6	10	
117	6.3.1.1	Graphical representation	1	1	
118	6.3.1.2	Prefers the proportional breakdown	1	2	
119	6.3.1.3	Prefers the detailed maintenance LCC calculations	5	5	
120	6.3.1.4	What if there was more than 4 maintenance actions	2	2	
41	6.3.2	Avoid making errors	6	11	
121	6.3.2.1	Double check calcs - sanity check	2	2	
122	6.3.2.2	Dropdown menu for data requirements	1	2	
123	6.3.2.3	Highlight in colour where you need to input	1	3	
124	6.3.2.4	More explicit on link between Maintenance Periods & Actions	2	3	
125	6.3.2.5	Protect non input cells	1	1	
42	6.3.3	Efficiency	7	28	
126	6.3.3.1	Access to LCC databases or LCC information - within system	6	9	
127	6.3.3.2	Get LCC info from the object properties - more automation in linking LCC to Object	5	11	
128	6.3.3.3	Link cells so you only have to drag qty once	2	2	
129	6.3.3.4	Not the same level of excel functionality	1	2	
130	6.3.3.5	Smoothing cash flows	1	2	
131	6.3.3.6	Standard uplift factor	1	1	
132	6.3.3.7	Still will be time intensive exercise even with this	1	1	

Table 6.11: 8th Phase - Sample (Data Reduction)

6.7.4 9th Phase - Produce the report

This 9th Phase follows the same process that is outlined in the 5th Phase of analysis above but for the more developed version (2nd Stage). The memo statements that were written against the thematic framework in Table 6.11 form the basis of findings outlined in the next chapter.

6.8 Summary

This chapter outlines the data collection procedures for the evaluation phase of the research methodology presented in Chapter 4. Evaluation occurs in two stages, the first collecting data based on the evaluation of the proposed prototype and the second stage collecting data based on the evaluation of the developed version and proposed 5D BIM/LCC work-flow. The data analysis techniques described in the latter half of the chapter, outline that data was collected based on Braun & Clarke's (2006) thematic analysis framework. Data analysis aligns with the two stages of data collection by analysing data in a phased process. Data analysis in both stages gives rise to a thematic structure which provides the material for memo statements. These memo statements inform the content of the findings presented in the next chapter.

7 Findings and Discussion

7.1 Introduction

In the previous chapter, two stages of evaluation and nine phases of data analysis were presented. The findings of the 1st Stage and 2nd Stage of evaluation are initially addressed in this chapter separately, to demonstrate the staged development process and the data that was used to inform the developed artifact. The findings are informed from the analytical memos that were written to encapsulate the categorical structure in the 5th Phase (for the 1st Stage) and the 8th Phase (for the 2nd Stage) of evaluation. As indicated in Figure 6.1, the 5th and 8th Phases of analysis represents the data from the evaluation of the prototype LCC calculation structure (5th Phase) and the developed 5D BIM LCC version (8th Phase). Later in the chapter, the data from these two stages of evaluation are cross referenced, and similarities and themes prevalent across all cases are highlighted and reviewed. The latter part of the chapter discusses the findings of the research in comparison to what is discussed in the review of literature and describes the relevance and originality of this research within the context of BIM and LCC.

7.2 Findings –Data Analysis Stage 1

This section encapsulates the findings of the 1st Stage of data analysis, which encompasses data generated from six participants using the model development (prototype) outlined in Chapter 5. The prototype entails a spreadsheet LCC calculation structure which was evaluated through the TA cooperative evaluation procedures outlined in the previous chapter. As presented in Table 7.1, a number of memo statements were written at the 5th Phase of data analysis to encapsulate the themes that emerged during data reduction at this stage. These themes related primarily to feedback from the participants, which were incorporated where possible into the more developed version for further analysis in the 2nd Stage of evaluation. The prototype's advantages in addressing the barriers to LCC are also analysed, to gauge its possible effectiveness as a tool for LCC and as a means for a more automated method of LCC analysis. The advantages of carrying out a staged fieldwork process, was that the participants whom took part in the prototype evaluation, provided a means to validate the proposed LCC calculations structure

prior to it being incorporated into the 5D BIM process. The data stands on its own as a result of participants engaging in automated LCC calculations, but the evaluation process was also a valuable vehicle to prompt informed discussions on whether a more efficient automated LCC process would be beneficial.

Appendix 2e: PHASE 4a & 5 - DATA REDUCTION 2					
Nr	Code	Codes	Sources	Units of Meaning Coded	Analytical Memos
	1.0	Addressing Barriers - Advantages of Template - EFFECTIVENESS	6	6	
1	1.1	Access to Information	2	5	X
3	1.2	Client requirements	5	21	X
6	1.3	LCC Time & Calculations	12	106	X
11	1.4	Methodology - Understanding LCC process and Terminology	13	207	X
16	1.5	Technology - Leverages IT for LCC	11	60	X
	2.0	Evaluation of Test	6	38	X
	3.0	Experience with LCC	9	66	X
	4.0	Recommendations for Improvement and Feedback	16	272	X
	5.0	Usability - Thinking Aloud	16	152	X

Table 7.1: Memo statements for 5th phase

7.2.1 Improvement and Feedback on Prototype

All three scenarios and all tasks within each of the scenarios were completed successfully and in many instances without any cooperation from the evaluator. On completing these tasks, the participants demonstrated possible areas that needed to be addressed and also explicated recommendations that may improve the process and make it more usable. As demonstrated in Table 7.3, the main themes in this category are based on the ‘Appearance’ of the interface and improvements that would help the user ‘Avoid making errors’. Table 7.2 is an MS Excel extract from NVivo demonstrating the colour coded structure which encompasses the memo statement written to encapsulate this category. This category also includes a theme that represents the completion of the tasks by the participants. These nodes contain evidence that the participants completed the evaluation tasks in a reasonable time and obtained the correct answer. In the case of all participants the correct answer was obtained within the allocated time frame.

	4.0	Recommendations for Improvement and Feedback	16	272	X
29	4.1	Appearance - Too much scrolling for cash flows - too much information	9	59	
30	4.1.1	Cash flows under each other - in the same frame	5	6	
61	4.1.1.1	Separate tabs for cash flows	5	5	
62	4.1.2	Drill down detail	7	10	
63	4.1.3	Hide information you don't need	8	17	
64	4.1.4	Overall summary	8	10	
31	4.2	Questions	3	8	
65	4.2.1	Explain Calculations Working on One Line	3	6	
66	4.2.2	What if Study Period is greater than 30	1	1	
67	4.2.3	What if there is more than four replacement items	1	1	
32	4.3	Tasks Complete	13	115	
68	4.3.1	Task 1	12	13	
69	4.3.2	Task 2	12	18	
70	4.3.3	Task 3	12	12	
71	4.3.4	Task 4	12	15	
72	4.3.5	Task 5	12	13	
73	4.3.6	Task 6	12	16	
74	4.3.7	Task 7	12	13	
75	4.3.8	Task 8	12	15	
33	4.4	To avoid Making Mistakes	9	39	
76	4.4.1	Input Prompts - Guidance	7	10	
77	4.4.2	Lock - hide content of cells so they cant be changed	5	11	
34	4.4.3	Project Specific Escalation	3	4	
78	4.4.3.1	Hide formulae in cell for escalation	3	4	
35	4.4.4	Some Terminology needs to be explained	3	4	
79	4.4.4.1	More Specific Column Titles	4	8	
36	4.4.5	Unit of Measure	6	10	
80	4.4.5.1	Percentages vs. Factors	3	4	

Table 7.2: Extract from 5th phase (a)

A. Appearance

All the participants commented on the amount of information on each sheet, referring mainly to the excessive amount of cash flow columns as the user scrolls across the spreadsheet. Participant 1v noted that clients are only really interested in what is presented to them and are unlikely to keep scrolling across pages and pages of data on a screen. The participants made a number of recommendations that may help address this issue.

1. Drill Down: Three participants recommended - if there could be a drill down function which would isolate the detail and complexity, but could also summarise it at a higher level. Participant 1c stated it would be advantageous “if it could be similar to Buildsoft Global Estimating (QS software) where I can isolate detail by double clicking into the level below and see all the information to make up that figure behind it”

2. Hide/Filter Information: Five participants mentioned that it would be valuable if there was a mechanism to hide or filter cash flow information that you did not want to display. In asked “*is there a way of selecting the cash flow information you want rather than see all the different types of cash flows*”
3. Overall Summary: Five participants commented that it would be beneficial if the structure had a summary page. This is similar to the suggestions for a ‘drill down’ function and for ‘hiding/filtering information’, where participant 1m suggested that it would be beneficial if a summary page could be developed that would pull-together the exercise that we are undertaking from the detail.
4. Cash Flow: Participant 1d and 1v advised that it would be beneficial if the different cash flows (Escalated, Real & PV) were under each other, rather than across the spreadsheet. 1v stated “*rather than scrolling across to get the cash flow detail, it would be beneficial if I could see them under each other – for ease of visualisation rather than printing out all that detail*”

B. To avoid making mistakes

There is considerable information generated from the tasks and explicit feedback from the participants regarding possible improvements which would help the user ‘avoid making errors’ and improve the overall usability of the calculation structure.

1. Input Prompts: Four participants recommended that there should be some way for guidance “*on a step by step basis*” (participant 1c) or “*prompts*” (participant 1d) to initially enhance learnability. 1c stated that “*when it comes out of prototype form, it should prompt on a line by line or step by step basis what you need to do*”.
2. Lock Cell Content: Two participants suggested hiding or locking the content of the cells that are not input cells. This would prevent the user inadvertently changing the automatic calculations and formula in these cells and thus stop them “*messing up the calculations*” (Participant 1v & 1d).
3. Terminology: Three participants noted that some terminology would need to be explained to facilitate an understanding of the LCC process. Notably all the participants required an explanation of the ‘uplift factor’. Four participants suggested more specific or explanatory column titles.

4. Unit of Measure: All the participants mentioned that the data in the project details sheet should be labelled so that the user knows the unit of measurement of what they are entering (i.e. factor, weeks, percentage, etc.). Three participants noted that they would prefer to see factors (expressed in decimal places) in a percentage format.
5. Project Specific Escalation: Three participants went to the wrong sheet to change the item specific escalation rate and override the general rate. They suggested a way to avoid making this error was to hide the formula in the cell so that they do not feel, via the formulae, that they are being directed to another sheet.

Recommendations	Incorporated
A. Appearance	
1 Drill Down A drill down function which would isolate the detail and complexity, but could also summarise it at a higher level	Yes
2 Hide/Filter Information A mechanism to hide or filter cash flow information that you did not want to display.	Yes
3 Summary Page If the structure had a summary page	Yes
4 Cash Flow The different cash flows (Escalated, Real & PV) were under each other, rather than across the spreadsheet.	No - this suggestion lacked general consensus; it was agreed that it would be left up to the user to customise
B. To Avoid Making Errors	
1 Input Prompts A way for guidance or prompts to initially enhance learnability.	No. There is no facility for this in the software but it is envisaged a user manual would be produced
2 Lock Cell Content Hiding or locking the content of the cells that are not input cells.	Yes
3 Terminology Some terminology would need to be explained to facilitate an understanding of the LCC process	No. There is no facility for this in the software but it is envisaged a user manual would be produced
4 Unit of Measure The data in the project details sheet should be labelled so that the user knows the unit of measurement of what they are entering	Yes
5 Project Specific Escalation Hide the formulae in the Project Specific Escalation cell	Yes

Table 7.3: Recommendations/Incorporated

7.2.2 Recommendations Incorporated into Developed Version

The recommendations for improvement and feedback outlined above were considered and incorporated, where possible, into the developed version evaluated in Stage 2. These are summarised in Table 7.3, outlining which recommendations were incorporated in the developed version. Not all recommendations from every participant could be considered for implementation. Some were not possible (restrictions with the software), some were not relevant and a number had already

been incorporated, but were not evident because the MS Excel prototype represented a lower fidelity concept to that that would eventually be represented in CostX.

This is the case for two recommendations made on the ‘Appearance’ [A] theme, where an ‘Overall Summary’ [3] was constructed early in the development cycle and the CostX software already has the ability to ‘Drill-Down’ [1] into further sub-sheets, to isolate detail. The overall summary was not included in the prototype evaluation but in hindsight would have clarified issues addressed by some participants and also would have presented the calculations within a standard methodology. The ‘Drill Down’ suggestion was not possible in MS Excel due to the software not having this capability, but was evident in the CostX version in Stage 2. In response to item ‘2.’ of the ‘Appearance’ [A] theme, a code was written in the developed version so that users can ‘Hide/Filter Information’ [2] based on the type of LCC cash flow they want to demonstrate (Real, Escalated or PV). The separate tabs for different ‘Cash Flows’ [4] is possible but this suggestion lacked general consensus (two participants); it was agreed that it would be left up to the user to customise the workbook in this regard.

Recommendations from ‘To Avoid Making Errors’ [B] themes are possible. There is no mechanism in CostX to make notes/comments to ‘Prompt’ [1] users or explain the ‘Terminology’ [3] but it is envisaged there will be a ‘user manual’ or ‘help’ function to guide participants through the initial learning curve. Suggestion ‘2.’ and ‘5.’ in this theme were incorporated into the developed version, where non-input cells were ‘Locked’ [2] and the formulae in the ‘Project Specific Escalation’ [5] rate was hidden. The ‘Unit of Measure’ [4] in the project details was also addressed in the developed version by adding a column to label the information requested in the input cells.

7.2.3 Advantages of Calculation Structure – Addressing Barriers to LCC

A number of themes emerged during the 1st Stage of data analysis that related to some of the barriers to LCC, which are addressed through the effectiveness of the tool. Although these themes are not directly applicable to the usability of the interface, they are relevant in this research due to the interfaces ability to address the barriers that prevent its widespread application. This is ultimately the barometer of the tools effectiveness and one of the goals of usability. As presented in Table 7.4,

categories emerged based on themes that related to client demand for LCC; the time intensive and complex nature of the calculations; interacting with technology when carrying out LCC and the users understanding of the LCC process and terminology.

Appendix 2e: PHASE 4a & 5 - DATA REDUCTION 2					
Nr	Code	Codes	Sources	Units of Meaning Coded	Analytical Memos
	1.0	Addressing Barriers - Advantages of Template - EFFECTIVENESS	6	6	
1	1.1	Access to Information	2	5	X
2	1.1.1	Collaboration	2	2	
1	1.1.1.1	Collaboration between FM and QS to produce estimate	1	1	
2	1.1.1.2	Overlapping of services - who specifies	1	1	
3	1.1.2	Get LCC info from Supplier	2	3	
3	1.2	Client requirements	5	21	X
4	1.2.1	Depends on Client Type (Short Term)	2	3	
4	1.2.1.1	Might not be requested & Not Paid	1	1	
5	1.2.2	Easier for QS - More Likely to do LCC	5	7	
6	1.2.3	Easier to Sell Service to Client - Marketing	1	2	
5	1.2.4	Facilitate Holistic Service & Informed Decisions	2	4	
7	1.2.4.1	Applicable to concept and detailed estimates	3	5	
8	1.2.4.2	As a Contractors VE Tool	1	1	
9	1.2.4.3	Link to LCA	1	1	
10	1.2.4.4	PPP's	2	2	
11	1.2.4.5	Sensitivity Analysis	3	3	
12	1.2.4.6	To address to alternative items	7	15	
6	1.3	LCC Time & Calculations	12	106	X
7	1.3.1	Calculations	12	37	
8	1.3.1.1	Automation of Calculations	8	25	
13	1.3.1.1.1	Auto fills Cash Flows	8	13	
14	1.3.1.1.2	Calculates PV, Escalated Costs	9	13	
15	1.3.1.1.3	Saves user time	6	6	
16	1.3.1.2	Leveraging the cost plan to do WLCC	9	12	
9	1.3.2	Calculations help to do LCC & Save Time	11	21	
17	1.3.2.1	But Its Still Time Intensive	2	3	
18	1.3.3	Ease of input	11	24	
10	1.3.4	Easier - QS More Likely to do LCC	5	7	
19	1.3.4.1	Input Cells are highlighted	1	2	
20	1.3.5	Quick Learning Curve	8	13	
11	1.4	Methodology - Understanding LCC process and Terminology	13	207	X
12	1.4.1	Educational Tool - Addresses Confusion	11	99	
21	1.4.1.1	Demonstrates how you can leverage Cost Plans	5	12	
22	1.4.1.2	Gets Qs thinking of LCC	3	4	
23	1.4.1.3	How cyclical LCC affects future cash flows	4	11	
24	1.4.1.4	How escalation & discount are used in LCC to show Real Nominal & P	4	9	
25	1.4.1.5	Uses to explain terminology	6	19	
13	1.4.2	Indicates Confusion - Questions on LCC terminology & Process	9	19	
26	1.4.2.1	Its More a Design Issue	1	1	
27	1.4.2.2	Occurrences in annual Costs	5	5	
28	1.4.2.3	Uplift Factor	10	19	
29	1.4.2.4	What is PPM	2	3	
30	1.4.2.5	Where in supply Chain LCC is used	1	1	
14	1.4.3	Presentation of the LCC estimate is important	4	7	
31	1.4.3.1	Applicable to concept and detailed estimates	3	5	
15	1.4.4	User Demonstrates Understanding of LCC Terminology & Processes	13	81	
32	1.4.4.1	How to Calculate cyclical LCC Maintenance Costs	11	27	
33	1.4.4.2	How you calculate full replacement	5	6	
34	1.4.4.3	How you can leverage cost plan	7	16	
35	1.4.4.4	Item Specific Escalation	12	21	
36	1.4.4.5	Occurrences in annual Costs	9	11	
16	1.5	Technology - Leverages IT for LCC	11	60	X
17	1.5.1	Advantage of it in Spreadsheet	8	11	
18	1.5.1.1	QS already familiar with Excel - increases learnability	8	10	
37	1.5.1.1.1	Demonstrate Graphs	2	2	
38	1.5.1.1.2	Fluidity and Changeability - can manipulate	6	9	
39	1.5.1.1.3	Like a tool in itself	3	4	
40	1.5.1.1.4	Quick Learning Curve	8	13	
41	1.5.1.1.5	Similar to a Cost Plan - so easily understood	3	3	
42	1.5.1.1.6	Universal Medium for QS so Validates calculations - transparent and	7	12	
19	1.5.1.2	Spreadsheet can be imported into other packages	3	4	
43	1.5.1.2.1	So potential Link to BIM	2	3	
20	1.5.2	Could you Develop LCC template on your own	9	15	
44	1.5.2.1	No	7	7	
45	1.5.2.2	Yes	5	8	
21	1.5.3	Link to BIM could be used to	6	20	
22	1.5.3.1	Enhance Visual Presentation	2	3	
46	1.5.3.1.1	Visual link to options	1	2	
47	1.5.3.2	Getting information from the object	2	4	
48	1.5.4	No applicable Technology so this helps	7	7	

Table 7.4: Extract from 5th phase (b)

Client Demand

A number of participants noted that providing LCC services are dependent on the client's objectives. 1m stated that a developer with short term financial objectives "who is going to sell on an apartment in six months may not want to spend an

additional €20 per door to realise savings they won't benefit from". Both 1d & 1m noted that it is time intensive enough for Qs providing normal cost services without doing an "add-on" that will take time and that you might not get paid for. 1c proposed that this LCC calculation structure could be used to give his company a market advantage, whereby it makes "it easier to sell services to a client and provide more intelligent building on that basis". All six participants stated that making LCC simpler and less time consuming makes it more likely that the QS will provide the service. Participants agreed this leads to a more holistic service for a potential client, with more informed decision making, based not only on CAPex, but also on OPex.

Time intensive & complex calculations

A number of participants mentioned that they are less likely to carry out LCC if it is not requested and not paid for by the client because of the time it takes to carry out the calculations. However, all six participants made reference to the automation of the calculations in this structure, including the ease of inputting LCC information – *"where at least it takes the number crunching out" (1n)*. The participants maintained that it will save them time and make it more likely that they would carry out LCC calculations. 1d commented that *"everything is done automatically, you are only typing in your quantities, rates and everything is calculated – it is useful in that way, that it saves time"*.

All the participants reported that it is useful that the cost plan/BOQ is the starting point for the LCC estimate, whereby LCC data requirements can be added to the CAPex information in the same system. Five participants mentioned that due to their familiarity with spreadsheets and the cost planning process, it accelerates the learning curve when using a template that leverages both.

Standards & Methodology

A number of issues emerged during the TA cooperation evaluation pertaining to the participant's knowledge of carrying out LCC. The participants asked a number of questions relating to LCC terminology and asked for clarification of acronyms associated with the terminology in a number of instances. The evaluator was able to use the LCC calculation structure to address any confusion and questions relating to LCC and explain the terminology - essentially using it as an educational tool and standard structure. One issue that needed explanation in all cases was an explanation of the 'uplift factor' and how it applied in LCC. Participant 1m outlined that there

should be some clarification/description of what this factor is in the interface and 1n noted that it might be easier to understand if it was a percentage rather than a factor.

Technology

The participants were asked in the debriefing session "*could you develop this calculation structure on your own*". Two of the more experienced Qs (+10 years' experience) outlined that they could put together something similar if they had the time. The other four participants (two of which had +10 years' experience) stated that they would not be able to develop this template or a similar version to carry out LCC calculations. Responses were "*it's too complex*", "*it's too time consuming*", "*I lack understanding of LCC*", "*I wouldn't have the patience*" and "*I wouldn't be proficient enough with Excel*".

The most referenced advantage was that the calculation structure is already familiar because it is in spreadsheet form. Participants claimed its familiarity increases learnability, leading to a process that has a quick learning curve, but is also easily understood. Participant 1v stated spreadsheets are the universal medium for the QS and thus the calculation structure provides transparency, as it can be checked and validated. The fact that the calculation structure can be manipulated and changed was cited as an advantage by 1n, which she stated "*is unlike other LCC tools which you can't change!*" Two participants mentioned that the calculation structure in its current MS Excel prototype form would be useful, in itself, as an LCC calculation tool. A number of participants mentioned that because it is a spreadsheet, visual data representation can be achieved through generating graphs and information can be imported into other packages.

Participant 1c noted that the advantage of a process based on MS Excel is that the calculations could be imported into other IT packages. Participant 1m expanded on this by stating that a BIM parametric object could be used to provide information for the LCC calculations, if it contained LCC data within the object. He added that the onus could be put on the supplier of the product to provide LCC information in a digital object, such as warranty information and life expectancies, which could be used in the LCC calculations. 1m mentioned that this would facilitate the LCC process and also enhance the visual representation of the LCC report, where the object could be illustrated in the cost plan. Participant 1n claimed that Qs would

use a system like this because there is nothing available at the moment that can carry out automated calculations in the structure required.

7.2.4 Summary - Data Analysis Stage 1

The findings presented in the previous section are based on the memo statements which were written against the categorical structure of the 1st Stage of data analysis. The findings outlined the themes that emerged when the participants engaged with the calculation structure proposed in the LCC prototype. The findings (as a result of the evaluation) provided a means to validate the LCC calculation structure before it was finally engrained in the developed 5D BIM process. The participants made a number of suggestions and recommendations, which they felt would improve the calculation structure proposed. Thus, incorporating these recommendations would provide a more efficient LCC model to be embedded in 5D BIM. The participants through engaging in this process made comments and observations which provided evidence of how a process, with this structure embedded in it, could have an effect on the barriers that prevent LCC being widely practiced.

7.3 Findings – Data Analysis Stage 2

As discussed in Section 7.2.2, a number of recommendations from participants in the 1st Stage of data analysis were incorporated into a developed version. This represented a more evolved development in BIM/LCC integration, rooted in practitioner validation from the 1st Stage. The developed version used by ten participants in the 2nd Stage of data analysis represented the 5D LCC technological solution outlined in Chapter 5 along with the changes to the calculation structure based on recommendations from 1st Stage participants. At this stage the solution was presented in the CostX system providing an LCC add-on to its existing 5D BIM functionality. This embodied a 5D-LCC work-flow which was facilitated by the LCC calculation structure validated and improved on by Stage 1 participants. Using this design sciences artifact (the developed technological solution), the participants in the 2nd Stage of evaluation were guided through the 5D-LCC work-flow presented in Chapter 5 by carrying out a number of scenarios and tasks which were described in the previous chapter.

Figure 7.1 represents a screen capture from the developed version which was evaluated in the 2nd Stage of data collection, including an example of Task 3 that users followed in the evaluation.

Extract & Link

Description	Quantity	Unit	Rate	Sub-Total	Factor	Total
Internal Wall Completions				363.00		363.00

Cost Plan Descriptions	Qty	Unit	Rate	Cost	Period	Annual Costs	Replacement Period	Uplift Factor	Real Cost	Escalated Cost	Present Value
910 x 2110 internal door, flush, veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery	9	nr	1,100.00	9,900.00	30.00000	363.00	20	1.10	10,890	17,845	5,670

Task 3 – Approx Time (4min)

Click back to the 'Cost' sheet and double click on the 'Subtotal' column for '2.1 Major Maintenance and Replacement'; '(32) Internal Wall Completions'.

Drag and drop the dimension group 'IntSgl (1) 910 x 2110mm' into the quantity cell for the internal door description in the LCC workbook and select 'update'.

- Enter a Rate of 1100.
- Enter a Replacement period of 20 years and a Uplift Factor of 1.10 in the relevant cells.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
10.890	17.845	5.670

Return to the summary page by clicking by return arrow in left corner.

Complete -- Yes/No

Figure 7.1: Example - Developed System

As illustrated in Figure 7.1, there was a link between the quantities extracted from the model and the LCC workbook by a code that was created automatically when the quantity was 'dragged & dropped' from dimension groups into the workbook (Lovegrove, 2014). The BIM element of the application was at centre stage in the developed 5D-LCC process and was embodied in all the tasks of the 2nd Stage evaluation. Thus, the first tasks of the evaluation dealt with extracting BIM quantities from the model, followed by a number of tasks that required the user to utilise those quantities in the LCC calculation structure.

The aim of the study is to address if leveraging BIM to carryout LCC can have an effect on the reported barriers to implementing LCC for QSs. The solution proposed

firstly demonstrated how 5D BIM could be leveraged for LCC. Then, by providing a means (through the TA cooperative evaluation) to demonstrate the proposed artifact to a number of potential users, the data generated in the evaluation can answer the research question of whether it is proffers an effective solution.

The research investigated themes based on the participant's experiences and views on engaging with the 5D BIM/LCC process developed in Chapter 5. These findings (outlined below) initially attended issues on LCC and BIM, which provided a means to compare primary data to what was outlined in the review of literature. These findings are presented to provide the backdrop to how this process could potentially address those issues. Subsequently, findings based on participants engaging in the integrated 5D-LCC process are discussed. The findings for this stage of analysis are predominately extracted from the memo statements written against the coded structure at the 8th Phase of analysis illustrated in Table 7.5.

The overall themed categorical structure from the 1st Stage of data analysis was used as the initial coding structure in the developed version; forming a number of predefined themes for analysis in the 2nd Stage. These change significantly throughout the later stages of analysis but provide an initial analytic lens which was informed from the 1st Stage. The resultant categories from the 2nd Stage of evaluation are evident in the 8th Phase of analysis presented in Table 7.5. Each category in Table 7.5 is discussed per a section heading in the following sub-sections. Item '4.0 Evaluation of the Test' and 5.0 'Experience with LCC' do not have their own headings, but are included in Section 7.3.2 and Section 7.3.1 respectively. Item 6.0 is divided into two sub-sections (items 6.1 & 6.2) - Section 7.3.4 outlining themes on 'Feedback' on the 5D-LCC solution and Section 7.3.5 outlining themes for 'Recommendations for Improvement'.

Appendix 2h: PHASE 8 - DATA REDUCTION					
Nr	Code	Codes	Sources	Units of Meaning Coded	Analytic al Memos
	1.0	Barriers to LCC	10	248	X
	2.0	Benefits LCC	11	304	X
	3.0	BIM	10	266	X
	4.0	Evaluation of Test - everything ok	10	22	X
	5.0	Experience with LCC	10	57	X
	6.0	Recomendations for Improvement and Feedback	11	497	X
	7.0	Usability - Thinking Aloud	10	117	X

Table 7.5: Categories Phase 8

7.3.1 Barriers to LCC (Item 1.0)

Table 7.6 represents an extract from the coded categorical structure from Phase 8, which emerged based on comments and observations from participants pertaining to barriers to implementing LCC. As indicated in this figure, the following findings represent the memo statement which was written in relation to this category and are presented hereafter per the node headings from the NVivo extract. These node headings are; the client is not requesting LCC; the calculations are complex and time consuming; there is a lack of access to relevant LCC data; there is a lack of knowledge and know-how on LCC; and there is a lack of applicable technology to help carry out LCC.

	1.0	Barriers to LCC	10	248	X
1	1.1	Client requirements - Client not requested it	10	59	
1	1.1.2	Client not aware of how useful it is - lack of awareness - wouldn't know how to read it	4	6	
2	1.1.3	Some clients not concerned - budgets not integrated	4	8	
2	1.2	Complex & Time Intensive LCC Calculations & Formulae	9	23	
3	1.2.1	Burns companies fee- don't get paid for it	2	2	
4	1.3	Lack of Access & Knowledge on LCC information	9	16	
4	1.3.1	Especially M&E costs are difficult to get access too - cost advice on energy savings	3	4	
5	1.3.2	Using information when you get it - Experience	1	1	
5	1.4	Lack of Knowledge - know how	7	28	
6	1.4.1	Separate department specialising	2	2	
7	1.4.2	We had to outsource to get capabilities	3	3	
6	1.5	Methodology - Understanding LCC process and Terminology	8	83	
7	1.5.1	Demonstrates a lack of understanding during exercises	8	20	
8	1.5.1.1	Asked for the difference between percentage calc and detailed calc	1	1	
9	1.5.1.2	Doesn't understand cost plan percentages	6	7	
10	1.5.1.3	Nr of occurrences	3	3	
11	1.5.1.4	What is ISO	1	1	
12	1.5.1.5	What's minor replacement repair	1	1	
13	1.5.1.6	What's uplift factor	6	6	
14	1.5.1.7	Why higher rate of escalation	1	1	
8	1.5.2	Demonstrates understanding of process & terminology	9	38	
15	1.5.2.1	Is uplift factor taken into account in percentage calculation	2	2	
16	1.5.2.2	Understands cost plan percentages	4	5	
17	1.5.2.3	Understands cyclical maintenance	6	7	
18	1.5.2.4	Understands theory of NPV & LCC calculations	1	5	
19	1.5.2.5	No standardisation-everyone does a different spreadsheet	2	2	
9	1.6	Technology	7	53	
20	1.6.2	Cost & Training to leverage latest technology	4	10	
21	1.6.3	Separate applications for LCC & Capital Cost	3	8	
22	1.6.4	Trusting the technology - checking LCC calcs	2	2	

Table 7.6: Barriers to LCC - coded category

Client Requirements

All ten participants stated that the 'client is not generally requesting LCC', other than for PFIs and design build maintain projects. Five participants noted the reason for this, is that there is a lack of knowledge and awareness to the benefits of LCC. 2dr believed "the key barrier is that clients do not know how useful LCC is....you (the

QS) are trying to get something across to them but they don't have the background to comprehend it.... they just want to know what the (capital) cost is". 2p noted "that government sanctioning authorities in Ireland do not request LCC....and wouldn't have the expertise to interpret it even if you gave them LCC information".

Four participants agreed that some 'clients are not concerned with LCC' as their budgets are not connected and thus their success criteria are not amalgamated. 2m elaborated on this, stating sometimes in large multinational organisations different departments control the costs of CAPex and OPex. Thus, he contended that there is no impetus for the CAPex department to be concerned with future OPex. 2dv and 2m also maintained that clients are still very focused on CAPex and unless they are owner-occupiers they are not concerned with future expenditure, because they are not responsible for it. 2dv also noted that even when you are working for an owner-occupier that is conscious of OPex; if the project is over budget they will forsake OPex to reduce their CAPex.

Complex and Time Intensive Calculations

Nine participants mentioned 'complex and time intensive calculations' as a barrier to LCC. 2dm said for this reason "*many QSs shy away from carrying out LCC*". A number of participants, with experience carrying out LCC, quoted that LCC calculations "*take a very long time*" (2c), are "*long winded*" (2k) "*labour intensive*" (2dm), "*time consuming*" (2dr) and "*impossible to do it for every item in the BOQ*" (2r). 2c clarified "*that setting up a bespoke LCC spreadsheet with the calculations is a probative thing because it just takes too long to set up and test (validate) the calculations*". 2dv also stressed that in his experience, carrying out LCC on M&E items is very labour intensive because there are multiple LCC considerations and associated calculations in any one item or piece of equipment. 2dm & 2k agreed when doing LCC calculations companies could burn their fee quickly. 2k also maintained he "*could not see companies overspending with LCC on their procurement costs in the current very competitive fee environment*".

Lack of Knowledge / Know How

Along with the calculations being time intensive, nine participants mentioned that there is also a 'lack of knowledge and know-how' to carrying out LCCs and presenting them to the client. 2k believed the "*reason that surveyors have not used LCC to date is probably through lack of knowledge of what it can actually do*".

2dr stated that the company he works for is a small company and they do not have the resources or knowledge to carry out LCC. 2dc also reported that unless the organisation carrying out LCC services is a large company they may not have the capabilities in-house to provide LCC. Four participants agreed that QSs tend to out-source this function. 2p stated that companies providing cost consultancy services for his city council are entitled to acquire the expertise externally “*and of course in doing so they should get up to speed with it themselves and learn from it*”, so they can do it themselves the next time.

During the course of the evaluation participants demonstrated an understanding of the process and terminology; however, there were a number of instances where they demonstrated that they did not understand some fundamentals of LCC. Common problems and questions related to how and why an uplift factor is applied to a cost plan item and how LCC can be carried out by applying percentages to cost plan items for cyclical maintenance.

Access to LCC Information

‘Access to LCC information’ (cost data and replacement years) was mentioned as a barrier by nine participants. 2t noted that “*QSs do not have LCC information to hand like they have capital construction costs*”. He proposed that “*it is really important that QSs get access to a pool of LCC information*” such as “*when items will be replaced and maintained*” so that they can carry out the LCC calculations. For example, 2m maintained that “*QSs would not have databases that would tell them when hinges of a door need to be replaced, when the door needs to be painted and when it needs to be cleaned*”. 2m, 2k & 2dv agreed that M&E LCC data, such as maintenance activities and replacement values, are not in the domain of the QS because traditionally they would tend to focus on architectural and structural costs and get input from the building services engineer for M&E costs. 2dv highlighted that it is the M&E surveyor working for the services contractor that would have this information and it is not something the professional QS would have access to. 2dc advised that QSs must realise that suppliers or manufacturers are a good source of LCC data because in their data specifications they should describe the maintenance actions and replacement profiles of their components.

Technology

In terms of the cost of training staff to carry out LCC, leveraging the latest technologies is discussed by four participants as a barrier. 2k stated that “*the way things have gone in the industry over the last couple of years such as the economic downturn, that upskilling staff in areas like LCC has fallen to one side*”.

Three participants noted that it is not ideal that QSs generally have to carry out LCC in a separate application to the software they use for CAPex estimating. Two participants stated that they do not fully trust the LCC calculations in existing LCC applications and would carry out a sanitary check to make sure they are correct.

7.3.2 Benefits of LCC (Item 2.0)

Benefits of LCC, particularly to clients, were coded as a prevalent category in the 2nd Stage of analysis. Table 7.7 is an MS Excel export from NVivo and represents the coded categorical structure (8th Phase) for the memo statement which informs the findings outlined hereafter.

	2.0	Benefits LCC	11	304	X
10	2.1	Changing attitudes to LCC	7	32	↑ ↓
11	2.1.1	Government requirement - will be and already is	4	6	
23	2.1.1.1	But unclear exactly what they want	1	1	
24	2.1.1.2	Will be more specific in the future	1	1	
12	2.1.2	Growing awareness-recognition of LCC	5	11	
25	2.1.2.1	BIM will push clients into LCC space	3	5	
26	2.1.2.2	Indirectly looking for it through sustainability & energy efficiency	1	1	
27	2.1.2.3	Will be driven by more FM related decisions & involvement	4	7	
28	2.1.3	QS needs to educate client on LCC	5	15	
13	2.2	To Clients	11	170	
29	2.2.1	Addressing Alternatives (optioneering) Demonstrate with hard data	11	48	
30	2.2.2	Benefits to Property Managers & FM - future expenditure	8	29	
31	2.2.3	Better value for Client - more collab. holistic service	11	58	
32	2.2.4	Evaluation of sustainability measurers - measure of sustainability	6	14	
33	2.2.5	To calculate and evaluate tenders with FM element	7	21	
14	2.3	To Contractors	5	19	
34	2.3.1	Contractors Value Engineering tool	4	7	
35	2.3.2	To calculate and evaluate tenders with FM element	5	9	
36	2.3.3	Useful for Calculating Prelims	2	3	
15	2.4	To Quantity Surveyors	10	35	
16	2.4.1	Another service for the QS	10	19	
37	2.4.1.1	Extra Fees	3	3	
38	2.4.1.2	Would give me the ability possibly to offer as normal service	3	3	
39	2.4.2	Marketing tool-get work	6	11	
40	2.4.3	Qs's need to change attitude - Diversify to survive	4	5	

Table 7.7: Benefits of LCC - coded category

Benefits to Clients

The most prevalent theme in this category is how LCC can provide better value to clients by providing them with a ‘more holistic cost management service’. All ten participants commented how a whole life focus brings the operational phase into design decisions. 2t added that Qs are “*providing a partial service if they only focus on capital cost*”.

All ten participants noted how ‘LCC can be used to evaluate alternative design options’ based on their impact on future expenditure. A number of participants maintained that the advantage of this is where Qs are educating their clients so that they can make their design decisions based on economic evidence. Six participants agreed that this is particularly useful in the evaluation of sustainable options and energy efficiency.

A tangible benefit of life cycle informed design decisions is that it will also ‘benefit the facilities manager during the operational phase’. 2p emphasised that this is particularly important as he works for a city council that manages a large building stock, “*where most of our maintenance is done on an emergency basis*”. He noted that his council are becoming more aware of the effects of design on future expenditure and will be requiring their construction supply chain to provide buildings which are efficient to run.

A theme which was coded in this category related to ‘how LCC can be used as a basis to calculate and evaluate tenders with an FM element’. 2dm ascertained that LCC should be applied to all procurement types. He provided an example of LCC being used as a mechanism to evaluate design build contracts, “*where you (QS) should interrogate through LCC what the design build contractor is offering you*”. 2dc and 2dv both reported that they have recently completed a large PFI tender, where design decisions with consideration to their impact on future expenditure were carefully considered. 2dv emphasised on his project, “*we (tenderer) sat down together as a consortium and went through in detail all CAPex components, especially Mechanical and Electrical (M&E) and how our design affected the LCC of our OPex*”. Both 2dc and 2dv described that these considerations were laid out in their tender for the client. In this instance 2dm is giving the professional QS perspective acting on the clients behalf, where he outlined that LCC offers a mechanism to evaluate a contractor’s tender for OPex. On the other hand, 2dc and

2dv, whom are contractors QSs noted that LCC aids them communicating transparency on the OPex element of their tender. Both sides of the supply chain are providing value to the client.

Benefit to Quantity Surveyors

A number of themes were coded in this category that relate to the direct benefits of LCC to QSs. All ten participants maintained that ‘LCC provides QSs with an additional service’ to offer their clients. 2c remarked that LCC could provide QSs with additional fees, whereas participant 2dm and 2m stated that an automated calculation process could help QSs carry out LCC within existing fee structures.

Six participants referenced ‘LCC as a marketing tool’. 2k stated that his company “*could sell themselves better by providing an LCC service*”, possibly giving them “*the market edge*” on their competitors. 2c ascertained that because there is no real push yet from the client side, professionals should offer LCC as a best practice and demonstrate their capabilities in this field. 2m noted that LCC gives the QS the economic detail to communicate with their clients and offer figures that can supplement the decision making process on future expenditure. 2c stressed that clients “*should be looking for those answers*” with respect to future costs and “*QSs should able to provide them*”.

Four participants mentioned that ‘LCC can be used as a value engineering tool for contractors’. 2k emphasised from a main contractor’s perspective, LCC is a real opportunity to demonstrate their professional capabilities and suggest value engineering proposals that could save their client money. 2k clarified that a contractor could propose to “*break a compliant bid*” by demonstrating that “*an alternative product provides better value*”. 2k and 2r also stated that LCC could be used to evaluate contractor’s preliminaries, where a large job may run over a number of years and LCC could be used as a tool to “*factor an allowance within your bid to actually cover your general overheads*”.

Changing attitudes to LCC

The general consensus amongst the participants was that there is growing awareness and recognition of the benefits of LCC among construction clients. 2t stated that there is a growing awareness in government agencies that “*operational cost is key*”. However, 2m and 2p outlined that it is unclear in Irish government proposals the

extent of the LCC service they are looking for. 2p expects this will be more explicit in the future, as he has been told by the Office of Public Procurement in Ireland that there are proposals for *“looking at a 30 year or 40 year lifecycle for some developments”*.

Participants mentioned a number of potential drivers that are increasing the use and awareness of LCC. Five participants mentioned that some clients have become more FM orientated. 2dc and 2dv gave an example where they have recently completed a large PFI tender for the Irish State, in which LCC was a necessity to evaluate and present the FM component of the bid. 2dv stated that they had to input all the information in the PFI tender in terms of *“frequency of maintenance actions and frequency of replacements and the costs associated with them”*. 2dc noted that *“from a financial modelling point of view LCC was critical in terms of creating our bid.....we had to carefully consider every item because we were obliged to hand the building back to the state after 25 years with every item having residual value of at least 10 years”*. 2p outlined that in the city council he is working for, there is an understanding that more of a focus on *“LCC and planned preventative maintenance”* at tender stage could have an impact on reducing emergency maintenance during the occupancy stage.

2m mentioned that by *“looking for more sustainable buildings, they (clients) are indirectly looking for a way to evaluate them”*. 2t said that a reason *“why LCC has come to the fore now, is that BIM allows designers to run through multiple options for a building quickly and often, and they need an associated metrics to evaluate between different designs”*.

Five participants agreed that ‘it is the responsibility of the QS to educate clients to the benefits of LCC’. 2m gives an example whereby they *“implemented LCC on a project to promote the service to their client”*. However, he stressed if this is to be successful it requires more *“joined up thinking”* from the whole design team. Four participants feel it is inevitable that LCC will be a common requirement on construction projects and QSs must diversify into this field if they are going to survive.

7.3.3 BIM (Item 3.0)

Table 7.8 represents the three main nodes that are coded in the BIM category. These are; the benefits that BIM can offer QSs; the problems and barriers encountered by the QS when utilising BIM and recommendations by participants when using 5D BIM to increase its effectiveness. The following headings encapsulate the memo statement which was written for this category.

	3.0	BIM	10	266	X
17	3.1	Benefits to QS - in efficiency - can offer more services	9	52	↑
41	3.1.1	Benefits in Optioneering	2	2	
42	3.1.2	Benefits of BIM Visualisation	6	17	
43	3.1.3	Benefits of Quantification & saves QS time	4	13	
44	3.1.4	Benefits of Revisioning	7	12	
45	3.1.5	Fabrication	1	3	
18	3.2	Have you used BIM	8	14	
19	3.2.1	No	5	8	
46	3.2.1.1	But is in our plans	4	6	
20	3.2.2	Yes	6	11	
47	3.2.2.1	But not full measurement - partially used	1	1	
48	3.2.2.2	But on a trial basis	2	3	
49	3.2.2.3	Just for qty's - export them out	1	5	
50	3.2.2.4	Majority of work is BIM	3	5	
51	3.2.2.5	We see ourselves as leaders	1	1	
21	3.3	Problems & Barriers in 5D BIM	10	93	
22	3.3.1	Hardware & Software	8	18	
52	3.3.1.1	Cost of using BIM - Training, Software, Hardware	6	11	
53	3.3.1.2	I don't have the training or knowledge of 5D BIM	3	3	
54	3.3.1.3	Software we use cant accommodate BIM	2	3	
23	3.3.2	Problems with the model	9	61	
55	3.3.2.1	Architects not using BIM & not giving it	6	12	
56	3.3.2.2	BIM not used as BIM - used for geometry & efficiency in design	5	9	
57	3.3.2.3	Contractor not prepared to agree BIM Quantities	3	4	
58	3.3.2.4	Not everything in the model - details, schedules	4	6	
59	3.3.2.5	Not in the correct QS format - lot of interpretation & validation	7	30	
24	3.3.3	Process	6	14	
60	3.3.3.1	Clients not aware of BIM capabilities	3	3	
61	3.3.3.2	Extra charge - fees	3	3	
62	3.3.3.3	Larger companies using BIM - im too small	3	4	
63	3.3.3.4	Wont give you Bim when pricing	1	3	
25	3.4	Recommendations by QS	9	59	
26	3.4.1	The Client	5	29	
64	3.4.1.1.	Include in project brief	1	2	
65	3.4.1.1.	Needs to be collaborative	3	8	
66	3.4.1.1.	Pitch it to Client - demonstrate its use	4	6	
67	3.4.1.1.	Pushed with government work	2	8	
68	3.4.1.1.	Request for BIM driven by FM	4	5	
27	3.4.2	The Model	6	18	
69	3.4.2.1	Add QS related parameters in authoring application	6	11	
70	3.4.2.2	Ask for the Model	5	7	
28	3.4.3	Use it	6	12	
71	3.4.3.1.	Training	2	2	
72	3.4.3.1.	Used as a Trial - Own Initiative	5	10	

Table 7.8: BIM: coded category

Benefits of BIM for QSs

The main benefit of BIM and in particular 5D BIM is the efficiencies it can offer users. Six participants said that they used BIM in their work practices and four

participants said they have not used it. All six participants that have used BIM for QS practices agreed that the major benefit is in the automation of taking off quantities. 2m stated that their company *"has seen the benefits on one of their jobs"*, in terms of time saved compared to the manual process. 2t maintained that the BIM quantification process saves the QS time and thus gives them the opportunity to offer more services. The other four participants also commented, when using 5D BIM in the evaluation, they were able to extract the quantities from the model quickly, which they stated would be beneficial to them.

Five participants made positive comments relating to the automated link between the quantities extracted from the model and the CostX workbook. They agreed that this is advantageous when there is revisions to the drawing, because when the quantity changes, it will update the workbook everywhere there is a link to that quantity.

Six participants outlined that 3D visualisation is a benefit to measurement. Participant 2dm emphasised that this is particularly beneficial to less experienced QSs as *"they can make the connection visually to what they are measuring"*. Visualisation also facilitates *"clash detection"* (2dv) which 2dv maintained is particularly useful in the operational phase, because it makes it easier for additional works to be tied into the existing systems seamlessly. Another benefit mentioned by two participants, is the advantage in what participant 2t called *"optioneering"*. He stressed that BIM *"allows designers 'optioneer' to run through multiple design options for a building...and 5D BIM gives QS the metrics to evaluate between different designs"*.

Problems and Barriers

5D BIM is not without its problems. The main issue seems to be the model that the QS receive from the designer. Six participants agreed that the majority of Architects are not using BIM and thus there is no BIM availability. 2p outlined that *"there is no point on us going on a solo run without them"* (Architects). 2dv added that many designers have a model but they *"do not want to send the model out because there may be some confidentiality issues - where they are worried if it got into the wrong hands it could be replicated"*. 2dv said that on a large project he worked on, the Architects told them that they had a BIM, but it was not available for them at tender stage. He clarified *"they did not want their design in the hands of all six tenders"*. He said that even when they won the job, the BIM information he received was a

mixture of 3D models and 2D sheets, in which the information was not always consistent.

All six participants that have used BIM stated that even when they receive a model from the designer it is not always workable, because designers are using the authoring tool as a design tool rather than a BIM (information) tool. 2c gave an example, where objects can be used incorrectly in the model because they look good on a drawing (*"i.e. floor and foundations objects are categorised as roofs"*). She stated that because of this, it can take longer to validate the model than it would to measure it traditionally.

Four participants also outlined that not everything is in the model. 2m determined that items such as finishes and temporary works can be omitted from the model. 2m provided an example, that in a BIM project he had worked on, *"skirting was included in a finishes schedule but not available in the model for automated take off"*.

A prevalent issue commented on by six participants is that when the quantities are extracted from the model they are not in the correct QS WBS. They contend that there is a significant amount of work to convert quantities into a format they can use in their estimates – adding time for checking, validating and manipulation before information can be used. 2c stated that this can be *"more work"* than the traditional process. 2t highlighted that *"models are not constructed for quantity take-off"*, describing measurement as an *"afterthought to spatial coordination and clash detection"*. However, 2t, 2m and 2dc agreed that Qs have the ability to come up with work-flows to extract quantities in a way that is usable for cost reports.

Another issue commented on by three participants is that there is distrust amongst some Qs of the quantities extracted from a model. Two participants said that they would carry out spot checks on the quantities that are available from the model before deciding on using them. 2m stated that this could be problematic when agreeing quantities with contractors that are not comfortable with the BIM output. He did temper this statement by adding that this is *"similar to seven or eight years ago, where we were using onscreen take-off to do QTO and contractors couldn't get their head around the quantities and now they do"*.

The cost of implementing BIM was determined as an impediment for utilisation in QS practice by six participants. Three participants mentioned that there is significant expense in updating software. 2m also stated that hardware may have to be upgraded to accommodate BIM software. 2p and 2k also mentioned that there are significant costs in up-skilling and training staff in 5D BIM programmes. Two participants outlined that the software they currently use cannot effectively accommodate BIM because "*it only works with 2D*". Participant 2r and 2dr stated that considering these issues, their company is too small to make an investment in BIM.

Similar to LCC, a barrier to using BIM on construction projects that was commented on by three participants is that clients are not requesting it or including it in their project briefs. 2c and 2m reported that some engineers are using it because there is direct benefit for them in terms of efficiency in design, but this does not necessarily translate to a model which can be utilised by the design and construction team.

Recommendations

Participants had a number of suggestions and recommendations for QSs working in a 5D BIM environment. These recommendations are reflected in the issues and problems outlined above. Four participants mentioned that BIM needs to be collaborative, where models are created with other consultants in mind. For this to be implemented successfully, 2m stated that "*BIM needs to be included in the project brief from the outset*". Four participants agreed that QSs could promote a BIM approach by pitching its capabilities to their clients. Six participants noted that this process could be a trail project which could be demonstrated to potential clients.

Four participants recommended that training is important for QSs to utilise the full benefits of 5D BIM. 2p who works for a local Dublin city council, said that all his QS staff are currently getting formally trained in 5D BIM technology. He sees it "*as my remit to make sure BIM is up and running and functioning over the next couple of years....and we have already included it in one of our recent briefs*". 2m said that he is seeing BIM already starting to show up on government project briefs where "*it was included in the description of services*" sought by the client.

Five participants agreed that the first step for the QS is to ask the Architect for a BIM. 2dm noted that they have started to ask design consultants for drawing files in different file formats. He acknowledged that some Architects have 3D models and

others do not, but at the very least if one is available, “*you can import it into your estimating software and have a look in the 3D view*”. 2m noted that in addition to the 2D traditional file formats, his company always ask now, “*is a BIM available*”? 2r maintained that all he gets is PDF 2D drawings and even if the Architects have designed it in Revit, then all that is sent is the PDF exports.

When a model is available, six participants indicated that the QS should communicate to the Architect how they want the model set up from a cost perspective. 2c stated that it would be “*fantastic if the people constructing the models do it in a complete way*”. 2m recommended an initial “*session*” with the Architect “*to say look! this is what we are trying to get out of the model*”. 2dc explained that he had recently worked on two similar BIM projects, in the first one, his employees from the outset “*went to the BIM Architect and sat down with them to enter the relevant QS coding (WBS) in the design.....and in doing so saved 50-60% of time versus my other surveyor that tried to code the QS data himself subsequent to receiving the model*”. 2dc recommended that QSS should visit the Architect “*on day one and explain to them - that your speak and our speak are totally different, so when you call this item ‘X’ I need to call it ‘Y’ to utilise it in my format. He added - “an Architect will not know what an elemental breakdown is unless you tell them to code it into the original model”*”.

7.3.4 Feedback on 5D BIM LCC process (Item 6.1)

The following findings, illustrated in Table 7.9, are summarised from the memo statement developed from coding and analysis pertaining to how the 5D BIM/LCC integrated process could address the barriers to LCC through effective utilisation of 5D BIM technologies. These findings are presented in a structure that responds to the issues in BIM and LCC outlined above.

	6.0	Recommendations for Improvement and Feedback	11	497	
31	6.1	Feedback on template	10	300	X
32	6.1.1	Could you develop template	8	11	
83	6.1.1.1	No - not like that with automation	7	10	
84	6.1.1.2	Yes	3	3	
33	6.1.2	Different to other LCC systems	10	72	
85	6.1.2.1	An integrated Cost - LCC System w links between quantum & cost & LCC	10	48	
86	6.1.2.2	Likes the specific escalation rate	2	4	
87	6.1.2.3	Looks and feels like excel & other QS software - familiarity	8	20	
34	6.1.3	Presentation & Reporting	10	55	
88	6.1.3.1	Can follow this as a methodology to do LCC - standardised structure - leads to more	7	14	
89	6.1.3.2	Can show level of detail you want - generate your own reports	6	22	
90	6.1.3.3	Export to excel	6	12	
91	6.1.3.4	Graphical Representation	3	4	
92	6.1.3.5	It is evident you could use it to do WLLC - item by item in your estimate	10	13	
93	6.1.3.6	But access to information	3	3	
94	6.1.3.7	Real time Sensitivity Analysis on Inflation etc	4	6	
35	6.1.4	Quick Learning curve - user friendly	10	31	
95	6.1.4.1	Clear & easy inputting data	7	15	
96	6.1.4.2	Looks and feels like excel & other QS software	11	23	
36	6.1.5	Result of using	10	65	
97	6.1.5.1	If you had this would you use it in work	9	25	
98	6.1.5.2	But not Daily	1	1	
99	6.1.5.3	If its a standard template like this	1	1	
100	6.1.5.4	No - I wouldn't need it	1	1	
101	6.1.5.5	Yes great for PPP	2	3	
102	6.1.5.6	More likely carry out LCC - easier to do LCC	10	25	
103	6.1.5.7	QS Getting more from your software - built on existing system	6	10	
104	6.1.5.8	Use it for building database	2	4	
105	6.1.5.9	Would save us outsourcing LCC work	1	1	
37	6.1.6	Speed Efficiency Automation	10	66	
106	6.1.6.1	Automation of the calculations & population of cash flows	10	50	
107	6.1.6.2	Can reuse it - forms template	5	5	
108	6.1.6.3	Leveraging Cost Plan - BOQ	5	8	

Table 7.9: Coding - Feedback

Could the QS develop the template?

A question was asked in the debriefing process whether the participants could carry out the calculations necessary for LCC and whether they could generate a similar calculation structure to the proposed template. The rationale to this question is that the review of literature indicated that QSs find the calculations ‘complex and time consuming’ and ‘they do not have the know-how to carry them out’ and thus may find value in the automated process presented in the research.

2t believed that he could generate a similar calculation structure in MS Excel. The nine other participants outlined that they could attempt to put something together but not with the automation demonstrated in this process. 2dv clarified that he could construct the calculations “*if he had a bit of grooming and assistance from an LCC point of view*”. Most participants said they could probably attempt a more “*dumbed down version*” (2c), but it would take them some time.

Different to other systems and processes

A number of themes emerged that indicated that the participants felt this process was somewhat unique. All ten participants commented that they saw the value of the

system being integrated with a traditional estimating software package, which represents a link between 5D-LCC work-flows. The primary advantage noted (highlighted in Figure 7.2) was that there is a link between the quantum from the model and the LCC calculations in the workbook, within the same interface.

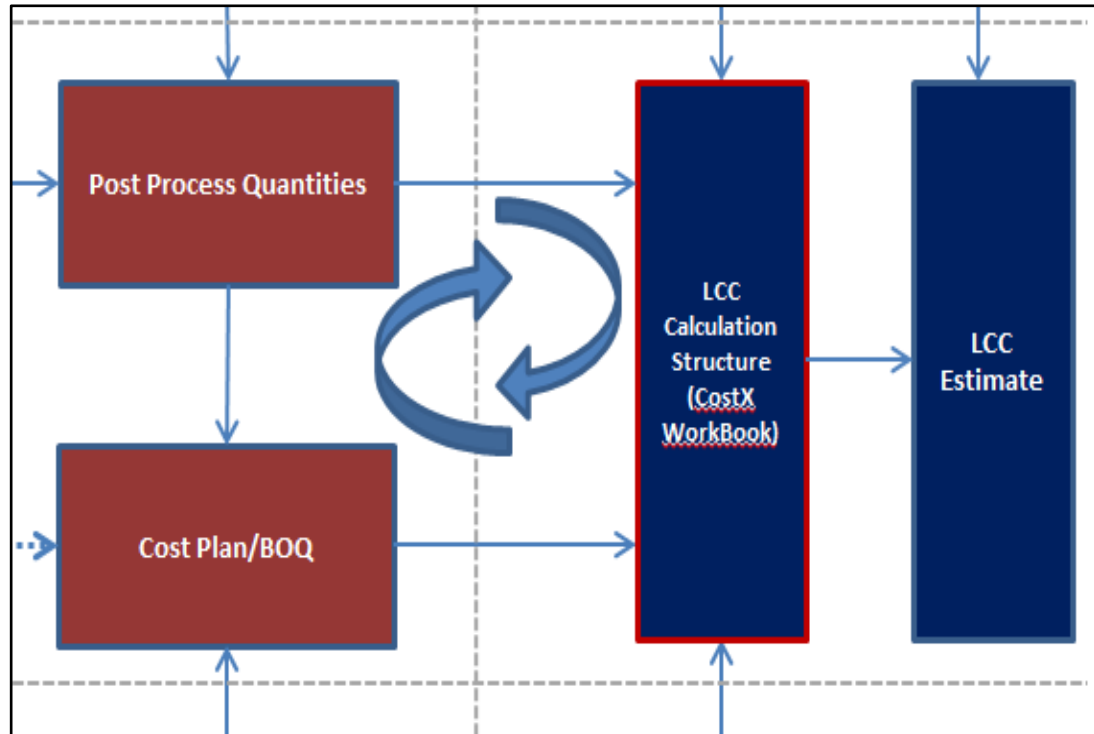


Figure 7.2: Extract from 5D-LCC BIM work-flow

2c said that *"it demonstrates a further capability of 5D BIM....tagging on LCC...where it is not in a separate application"*. 2dv stated that the process is *"encapsulating all you need as a QS, all in one go and it enables real-time analysis of LCC"*. 2dc determined from the QS point of view, it *"could tie us closer to our FM guys, if we can all tie into the same process"*. He noted that it makes the decision process more transparent right across the life cycle and *"from a company point of view that's very good"*.

An advantage of the link between the quantum and the LCC calculations was described by 2p and 2dr, where if you change a quantity *"it will automatically update in the LCC estimate"*. 2dc gave an example of this on a recent PFI where *"design changes were constantly being made right up to the final submission and these changes had an effect on the FM side. It would have been very beneficial if I had something like this where I could quickly see how any change in the variables affected the entire tender, rather than have to change items in a number of estimates"*

and formats. 2dr stated that at the moment his company uses two separate programmes, one for CAPex estimating and one for LCC. In the LCC system they have difficulty understanding the output because “*we cannot see the inner workings (calculations/formulae) of the software and thus we cannot see the link between the variables....but if we had this, we could do both in the same system and having done the work anyway (on the Capex) we could use this to add on LCC, which would be very beneficial*”. 2p outlined what makes this process particularly useful is that “*you can apply different levels of escalation on different items*” rather than an overall inflation rate to the entire estimate that may not be applicable in every instance.

Familiarity & Learning Curve

Another advantage reported by all ten participants, was that the LCC calculation structure has similarity with MS Excel and other QS software. 2dm, 2r and 2m agreed that the LCC calculation structure is built on an existing estimating system that Qs are familiar with. They noted that it would make it more likely if LCC was available in an integrated system like this that they would carry it out. 2m made the point that “*it is in a working and operating system that people use every day....it’s only a slight extension (for LCC)*”.

All participants agreed that the process has a quick learning curve and is user friendly. 2dr ascertained that most Qs are familiar with MS Excel and because the LCC calculations are in spreadsheet form, it makes it easier to understand the process. 2k added “*you could get somebody not involved with construction and if you gave them some of the key information.....they could probably even do one of these [tasks of the evaluation]*”. Seven participants highlighted that it is easy to input the data in the interface using terms such as “*logical*”, “*straightforward*”, “*clear*” and “*easy*”. 2dc said “*once you get it....you will start flying through it*”. 2dr established “*that there was nothing that was taxing in any way...it was something that I found myself picking up quite quickly*”.

Presentation and Reporting

Advantages of using this process for LCC presentation and reporting emerged as a category during data analysis. All ten participants referenced its applicability in generating LCC reports.

All participants agreed that it is evident that the integrated process could be used to carry out a WLCC estimate. Five participants noted that it is beneficial that you can manipulate the calculation structure depending on the level of detail you want to show in the estimate report. 2dm added that you could filter the detailed data and set your estimate up in a way that would be applicable to your client, i.e. *“that you would be just pulling out the relevant data...and if you were asked for the detail you have it as a backup”*. 2m noted that having the detail at hand on LCC is advantageous because you can demonstrate to the client in a design team meeting the effect of changing certain variables on future expenditure, in real-time. 2dr contended that the current MS Excel based programme that *“they use, is very rigid,....the format it is presented in, is locked”* and thus, we have no ability to tailor it to our needs. The ability to export to MS Excel was seen as advantageous by six participants. Three participants agreed that this is particularly beneficial as you can create graphs and customise your presentation. 2k outlined that this is beneficial when *“generating an ‘S curve’ for his client on the future expenditure cash flows”*.

Six participants made reference that this process provides a standardised work-flow to carrying out LCC. 2m revealed having a standardised process like this helped him *“understand the working of LCC”*. 2c stated that *“everyone does a different spreadsheet.....and even the way they present it can be different”*, so she believed that this can help standardise the process. Three participants agreed that they could use the system to carry out sensitivity analysis with 2r noting that you could *“test how inflation might affect energy costs and you could compare two or three options on one page”*. Four participants commented on the system’s applicability during the operational phase to store LCC information - to start generating a database of LCC.

Speed, efficiency and automation

One of the most coded themes was that the process automates LCC calculations. All ten participants mentioned the automation of the process as being an advantage. 2c and 2r stated that they can see that *“a lot of work”* has gone into automating this process (referring to the formulae/codes). 2k accentuated that these calculations *“can be painstaking.....it means that something that could take you a week or so to do, can actually be done quite quickly”*. 2c, 2k & 2p found it beneficial that the cash flows are automatically populated from the replacement periods. 2t stated that if *“you*

are using Revit templates; an awful lot of the input you are doing can be automated" – (referring to using information from the object properties in CostX).

Five participants acknowledged the link and integration between the cost plan/BOQ and the LCC calculation structure. 2c said *"that whatever you have in your costing schedule, you can perform a LCC calculation on"*. 2dm liked that the process is transparent because there is a direct link between the drawings, the QTO and the LCC calculations. 2k noted that you *"can pull the relevant information (from the cost plan & BOQ) quite quickly"* because it is available in the same system. 2dr also stated that the LCC calculations are performed *"quickly"* in this system.

Result of using the system

The acid test of the interface and proposed 5D-LCC process is whether QSs would use it. All ten participants maintained that they would use the system and proposed work-flow if it was available to them. 2k added that *"I would use it to demonstrate to the client our capabilities as a main contractor"*. 2dm commented that there *"would be a learning curve, but once you are comfortable with it....I would definitely use it"*. 2m stated that he would use it so long as it *"could be carried on to other projects and not have to be repeated all the time"*. 2c stressed that she would *"probably not use it daily - but it would be what I would turn to if I had to"*.

All ten participants agreed that using a process like this would make it more likely that they would provide LCC as a service. 2c admitted that *"it makes me feel terrible I haven't been doing it....I can see now how I would actually be able to do it and it has made me think about LCC again"*. 2dm said that once you set up LCC, you can just add it onto your existing service, *"where before you would shy away from it"*. 2dr determined that we would definitely use it, because we have the *"knowledge available but not the programmes to carry it out effectively"*. 2k stated that *"I would certainly like to become more familiar with this tool so I could use it for speed and efficiency with the LCC calculations and also link it in to the BIM"*. 2t believed that this system would *"open QSs eyes (to LCC),...they would see this is something I could do quite easily and it is a service that forward thinking QSs should be offering"*. 2dc mentioned that *"if this was available for us six months ago when we were preparing a very large PFI, we would have used it. It would have speeded things up for us and because we were already using 5D BIM, it would have enabled*

us to locate our FM LCC calculations within the same system as our capital costs". 2dc noted that his CAPex estimate was four hundred pages long and all the items in his estimate had to be manually transferred into an LCC estimate with many more variables. He stressed that the process proposed in this research would greatly facilitate efficiency and integration between their CAPex and OPex estimates.

Six participants indicated that the process demonstrates how Qs can get more from their existing software. 2r stated that the *"best thing about this process is that you are killing two birds with one stone (CAPex & OPex), you are using the inputs from the cost plan to help do your LCC "*. 2t noted that *"it's not difficult! - once you understand where the quantities are coming from in the model and the LCC formulas are set up.... you are essentially demonstrating how Qs can get more of a return from their investment in the software"*. 2r mentioned, *"once he gets up-to speed with this"*, it may save him outsourcing LCC work. He added that what he is looking for *"is a way that I can improve and better my service by being more efficient with my measurement and estimating. This shows me I can provide LCC quiet easily because it is already incorporated into the same process"*.

2p outlined that the information generated by the QS when carrying out LCC calculations through this process and the assumptions they make in terms of *"planned and periodic maintenance and time scales"*, would be very beneficial information to FM personnel in the city council he is working for. He stressed that this process would give the FMs the opportunity to be involved in the design, enabling more *"informed maintenance decisions"*. 2p envisaged that *"the QS could sit down with the FM and say, now look, this is what you are doing every five years, this is what you are doing every ten years....and he might decide to change it....but at least the information is there"*.

7.3.5 Recommendations for Improvement (Item 6.3)

The findings outlined in this section, illustrated in Table 7.10, relate to feedback from the participants, where they made recommendations on improving the system and process. Some of these are similar to the recommendations made on the prototype, where we were not able to accommodate them in the developed system.


	6.0	Recommendations for Improvement and Feedback	11	497	
39	6.3	Recommendations for improvement	10	49	X
40	6.3.1	Appearance	6	10	
117	6.3.1.1	Graphical representation	1	1	
118	6.3.1.2	Prefers the proportional breakdown	1	2	
119	6.3.1.3	Prefers the detailed maintenance LCC calculations	5	5	
120	6.3.1.4	What if there was more than 4 maintenance actions	2	2	
41	6.3.2	Avoid making errors	6	11	
121	6.3.2.1	Double check calcs - sanity check	2	2	
122	6.3.2.2	Dropdown menu for data requirements	1	2	
123	6.3.2.3	Highlight in colour where you need to input	1	3	
124	6.3.2.4	More explicit on link between Maintenance Periods & Actions	2	3	
125	6.3.2.5	Protect non input cells	1	1	
42	6.3.3	Efficiency	7	28	
126	6.3.3.1	Access to LCC databases or LCC information - within system	6	9	
127	6.3.3.2	Get LCC info from the object properties - more automation in linking LCC to Object p	5	11	
128	6.3.3.3	Link cells so you only have to drag qty once	2	2	
129	6.3.3.4	Not the same level of excel functionality	1	2	
130	6.3.3.5	Smoothing cash flows	1	2	
131	6.3.3.6	Standard uplift factor	1	1	
132	6.3.3.7	Still will be time intensive exercise even with this	1	1	

Table 7.10: Suggestion for Improvement

Appearance

Similar to the prototype evaluation, four participants indicated that they preferred the detailed calculation (line items) rather than the percentage calculation of minor maintenance and repair work. 2dc stated that personally he likes to split the LCC calculations into detailed items but he noted that it depends on the level of detail on the drawings and in the cost plan – “*if you are looking at higher level estimates the percentage calculations are more applicable, whereas with more detailed estimates you might want to split it out*”. Three participants agreed that it would be beneficial if there was a way of visually representing the cash flows in charts/graphs in the system. 2dr stated that “*one thing that might be beneficial for the client is that the system could graph the results.....where the client could visually see what’s in the figures*”.

A further two participants asked whether the system could accommodate calculations where there are more than four maintenance actions within the one line calculation, for minor maintenance and repair.

To avoid making errors

Participants had a number of recommendations that could help the user to ‘avoid making mistakes’. Unlike feedback on the prototype, there was no real consensus here. One participant stated that non-input cells should be protected. Another participant felt it would be beneficial if there was a different colour to the input cells. 2k recommended that for the data requirements – *“it would be beneficial if the input information here is a dropdown menu, because you could make a mistake spelling it wrong”*. 2t and 2dv noted that there should be a more definitive link between the maintenance actions and the subsequent input columns, so that the user knows *“which action relates to which input (2dv)”*. Two participants mentioned that they would recommend a potential user to perform a *“sanity check”* on the calculations to make sure they are accurate and working effectively.

Improving efficiency

Participants made a number of comments throughout the evaluation and in the debriefing session that could improve the efficiency of the process and areas where they would like to see it developed further. One of the most prevalent themes in this category was that five participants noted that there could be more automation between the LCC workbook and the object properties of the BIM. 2t clarified that with *“IFC4 a lot of manufactures will start producing and putting in (to the object properties) maintenance periods which could be automated”* by linking it to the LCC workbook. 2c gave an example; *“if you had a water pump and the object properties tells you that it needs to be replaced in ten years....you could link that (10 years) to your LCC estimate....it would be a further thing to add”*. 2c stated LCC information contained in the objects of the model *“would be fantastic but its having people designing to actually input that information in a complete way.....there would be no point half the components of a BIM having LCC information and the rest just not”*. 2dc noted that many suppliers have LCC information on their respective products such as replacement and maintenance information which come in the form of data sheets. He stressed that if this information is in the model it would be very valuable because you could extract it for LCC and in a system like this, link it to your LCC estimate in the same process.

The other prevalent theme within this category is that six participants would like to see access to LCC databases or LCC information within the system. 2t maintained

that “*one of the reasons QSs haven’t been offering LCC information is that they don’t have the data on replacement costs and maintenance periods.....they feel that they don’t have the relevant information*”. 2c recommended that it would be beneficial if the user could access a database within the system “*in the same way the Building Energy Rating software works*”. 2t said “*where I would like to see it going is...if you have a LCC rate library...so that you can link a particular description to an entry in the library, that you can automate it so that when you import your dimensions it finds that group and it automatically knows what the replacement period should be for that item*”.

Commenting on the level of functionality in the CostX workbook, one participant commented that it does not have the same capabilities as MS Excel and thus might not give you the same manipulability in terms of generating a bespoke LCC estimate. Another participant argued that although it automates the process it is still time intensive and “*when you start adding in M&E activities it still might be quiet tricky*”. 2dv confirmed this by explaining that there are many more variables in calculating LCC for M&E over that of architectural components; however, he noted that they could be accommodated in this process. 2m stated that “*rather than inputting the uplift factor on every line*”, insert a standard uplift factor in the data requirements and build in the facility to change it similar to overriding the escalation.

7.3.6 Usability (Item 7.0)

Extracts were coded based on the five main criteria of usability. Overall the users demonstrated ‘satisfaction’ in using the system using words such as “*beneficial*”, “*interesting*”, “*very good*”, “*excellent*” and “*I like the way*”. The participants also addressed ‘ease of use’ by describing the system as “*handy*”, “*intuitive*”, “*straightforward*”, “*useful*” and “*user friendly*”. ‘Effectiveness’ is based on the advantages of the process which are outlined in the previous section. ‘Easy to learn’ responses were indicated by references to a quick learning curve and the successful completion of the scenarios and tasks. All the participants completed the tasks without any ‘errors’, however this was somewhat influenced by the evaluator’s coaching when using the system.

Figure 7.3 is a word cloud automatically generated with NVivo, presenting the most used words from the ‘Feedback’ category. It must be recognised that the context of

data that was generated when ten participants engaged with the more developed 5D-LCC process.

The next section addresses findings that were common across both stages of evaluation, followed by a discussion on how these findings compare to content in the review of literature.

7.4 Cross Stage Analysis

There are themes that are evident across cases from both Stage 1 and Stage 2 of data analysis. Although the barriers to LCC were not explicitly explored in the 1st Stage, they are evident in how the participants responded to using the MS Excel prototype. Participants in Stage 1 noted that the LCC prototype could have an effect on some of these barriers, notably in addressing clients requirements for LCC; to increase the speed and efficiency doing the calculations; presenting a standard structure for LCC and the effect utilising technology has on LCC. Similar themes emerge in the 2nd Stage of analysis, where barriers such as a lack of knowledge of LCC; time consuming calculations; access to LCC information; client not requesting LCC and issues using technology were addressed by participants.

Even though Stage 1 analysis was based on the prototype, there were significant similarities to the products of the 2nd Stage of analysis on the developed system. Common themes considering the benefits included; the process makes it easier and more likely that Qs would provide the service; there is a quick learning curve; calculations are automated; it helps present LCC in a standard structure; it facilitates a more holistic service for clients and it helps market QS services to potential clients.

Comments and recommendations for improvement on the prototype were incorporated into the more developed version. These recommendations and subsequent changes to the developed system encompassed the ‘appearance’ of the interface and improvements that would help the user ‘avoid making errors’. When evaluating the more developed version the prevalence of the issues outlined when evaluating the prototype was not as evident. Some of the same issues came up again but unlike the prototype version there was no real consensus regards improvements on the developed version (primarily 1 participant per suggestion). 2r did mention ‘*protecting/locking cells*’, (which was addressed by five participants at the prototype

stage) but this was already accommodated in the developed system, he just failed to notice it. 2r & 2t mentioned again that some of the terminology needs to be explained such as ‘maintenance factor’ and ‘replacement period’. 2r proposed that input cells be colour coded, which is in line with the ‘input prompts’ suggestion on the prototype. It is not possible to accommodate the latter two suggestions based on restrictions with the CostX workbook but as stated in Section 7.2.1 a user manual or help function could be included to address issues regarding entering formation.

A common theme that emerged from both stages of data analysis is that there could be more of an automated link between the objects of the model and the LCC workbook. A number of participants across both stages suggested that this is where there is scope to improve the process; by utilising LCC properties from the BIM to populate information in the LCC workbook such as maintenance and replacement information.

7.5 Discussion

In this section, the findings and review of literature are discussed, through which similarities, differences and topical issues are addressed. The subsequent sections are presented per the main themes that emerged from data analysis, outlining issues in LCC, BIM and the integration of both LCC and BIM under the process proposed in this research. This section firstly addresses LCC and BIM separately, discussing the content from the findings and comparing it to what was discussed in the review of literature. Discourse in LCC and BIM attend to the first number of research objectives and provide the context to the integrated 5D-LCC process, which is discussed later in the chapter.

7.5.1 LCC

In the review of literature it was established that LCC has the potential to assess value for money for construction clients (Clift & Bourke, 1999; Schaudé, 2011). The central advantage described in the review of literature is that LCC enables a whole cost approach to the acquisition of a capital asset, providing the client with a total-cost view of the project, rather than just the initial CAPex (Clift, 2003; Cole & Sterner, 2000; Kelly & Hunter, 2009). The review of literature determined that providing value to the construction client is enabled through a number of benefits of

LCC. These are that; LCC is an effective monetary mechanism for evaluating the effects of potential design decisions on future expenditure; LCC can evaluate sustainable construction and energy efficiency; LCC can be used in effective FM and that LCC can be utilised in the production and evaluation of tenders, which is specifically applicable in PFI projects (Ashworth, 1996; Churcher, 2008; Kirkham, 2012).

The findings of this study promoted the central advantage of LCC, indicating that utilising LCC can provide added value to construction clients by providing them with a more holistic cost management service. Participants commented on how a whole life focus brings the operational phase into design decisions, enabling more informed decisions based on future expenditure. Other reported benefits of LCC were confirmed in the findings, where participants noted advantages in the evaluation of sustainable construction and how LCC can be used as a basis to calculate and evaluate tenders with an FM element, especially with PFI.

In addition to these benefits, the research established a number of QS specific advantages that were not evident in the existing literature. The prominent benefit to Qs is that it provides an additional service to offer their client(s), potentially widening their revenue potential and giving them a market advantage on those competitors not offering the service. Participants also commented that LCC can provide them with the means to economically evaluate the future impact of making decisions during the design period and the fiscal merits of selecting one construction material or component over another, which was traditionally evaluated subjectively. LCC also proffers an opportunity to Qs working for contractors, to provide value engineering suggestions that will save their clients throughout the life cycle of the building and promote them as a best practice contractor adding value to their services.

As outlined by a number of surveys which are addressed in the review of literature, there is a lack of application of LCC in UK and Ireland (Chiurugwi et al., 2010; Hourigan, 2012; Oduyemi et al., 2014). This research indicates a similar issue, where the majority of participants had carried out LCC to some extent, but it was carried out infrequently and in most cases as a once off service for clients who specifically required it.

In all cases, participants noted that MS Excel was the programme they use to carry out LCC calculations. This approach is endorsed in documents such as NRM 3 (RICS, 2014), BSI/BCIS (2008) and the SCSi (Kehily, 2011) methodologies. These standards promote the use of spreadsheets through guidance notes and associated templates that are built in MS Excel.

The review of literature established that although the benefits of LCC have been touted by a number of eminent authors in the field, the application of LCC has not been implemented into standard practice (Chiurugwi et al., 2010; Clift & Bourke, 1999; Cole & Sterner, 2000; Kelly & Hunter, 2009). The review of literature discussed these issues in detail and determined that the reason LCC continues to find limited adoption is predominantly due to; a lack of understanding on behalf of construction clients and professionals; the lack and validity of historical data on operation and maintenance costs; the perceived complexity of the LCC process and calculations; and the absence of LCC standardisation (methodology) across the construction industry (Chiurugwi et al., 2010; Oduyemi et al., 2014; Opoku, 2013; Schaudé, 2011).

It is evident from the findings in this research that barriers to implementing LCC still exist. The participants' experience and comments are concurrent with the barriers noted in publications such as Opoku (2013), Oduyemi et al. (2014), Schaudé (2011) and Hourigan (2012). However, the majority of the barriers addressed in the review of literature are results from quantitative research and do not give any insight into their participants' experiences. Considering the efforts in recent years to promote LCC and provide guidance to Qs in providing this service, this study offers an insight into the reasons why these barriers still exist.

'Clients not requesting LCC' emerged as a prominent barrier in this research. Moreover, the findings elaborated on the existing literature by indicating that this issue is a product of the prevailing focus on CAPex and the lack of understanding of LCC from the client. Some participants ascertained that clients are not concerned with LCC because they are not responsible for the assets future OPex and thus are not likely to request a service that that does not add value to them specifically.

Another fundamental issue with LCC outlined in the review of literature is that Qs do not have the expertise to carry out the calculations (Chiurugwi et al., 2010; Fu et

al., 2007; Pelzeter, 2007). This is compounded by the calculations being ‘complex and time intensive’ (Kelly & Hunter, 2009; Opoku, 2013). This study concurs by indicating that LCC calculations take a long time to carry out and thus Qs tend to avoid offering their clients this service. The research suggests that Qs do not have the capabilities or know-how to provide an adequate LCC service to their clients. Many firms either avoid providing this service or hire in LCC expertise from other consultants.

A barrier which is evident in both the findings and review of literature is that there is difficulty obtaining relevant data to be utilised in LCC calculations. This study elaborates on this issue, indicating that LCC is not a traditional QS discipline, thus, Qs will not have a database of OPex information in the same way they have information on CApex. Based on the findings in this research, this is particularly applicable to M&E cost data, which from a life cycle perspective has multiple maintenance and replacement occurrences and thus requires numerous LCC calculations.

A prevalent barrier established in the review of literature was that there is a lack of standardisation and methodology across the construction industry. This issue did not emerge in the findings of this study. There has been significant efforts to improve this barrier over the last ten years, evidenced in the publications of LCC methodologies such as ISO 15686-5 (BS-ISO, 2008), BSI/BCIS 15686-5 (2008) and NRM 3 (RICS, 2014). This was the only barrier outlined in the literature review that was not replicated in the findings of this research. This could indicate that that this issue has been addressed by these publications and that it may no longer be a significant barrier. Although it may also be a product of the fact that most of the participants did not regularly carry out LCC and thus are not aware of the relevant standards and methodologies.

7.5.2 BIM and the QS

This section deals with BIM, notably its applicability and use in the QS profession. The wider implications of BIM in QS practice are discussed prior to addressing the aim of the research, which pertains to the utilisation of BIM for LCC. This is carried out (similar to discussions on LCC above), to provide context to any findings on the more specialised application of BIM for LCC.

BIM has the potential to automate the QTO process leading to more accurate take off and quicker measurement of quantities (Eastman et al., 2011; Goucher & Thurairajah, 2012; Monteiro & Martins, 2013). Participants in this research, that have been involved in BIM projects and utilised 5D BIM software, also appreciated the benefits BIM can bring to efficiencies in QTO.

One of the advantages of the 5D process, outlined in the findings and which also aligns with the review of literature, is that the automation of quantities and their link to the cost estimate can provide a more effective means of revising the cost report (Fung et al., 2014; Lovegrove, 2014; Wong et al., 2014). If a change is made to the BIM, the cost report can be easily revised and the costs updated to reflect this revision. This also provides Qs with the capabilities to expand the scope of their services, by saving them time in the traditional quantification and costing process.

Another benefit which was addressed in both the review of literature (Shen & Issa, 2010; Sylvester & Dietrich, 2010; Wong et al., 2014) and the findings of this study is that BIM can help Qs visualise real world construction conditions through a three-dimensional representation. As evidenced in this research, this is particularly helpful to less experienced Qs whom can make an easier connection between the construction elements in the design and what they are measuring for their estimate. The visualisation capabilities of BIM software are also helpful to identify clashes and analyse interference amongst different design disciplines (Fung et al., 2014; Wong et al., 2014). While this capability is echoed in the findings, it was also accentuated that when the BIM is handed over to the client, it will make it easier for potential additional works to be tied into the existing conditions. This is because the visual capabilities of the model can easily illustrate the as-built conditions of the project.

A benefit that was identified in the review of literature, is that 5D BIM enables Qs to investigate the cost impact of various design alternatives (Crowley, 2013; Mitchell, 2012). This is facilitated through the automation in the 5D BIM process and the links instigated by the QS between the model quantities and their estimate (Cheung et al., 2012; Mitchell, 2012). This research proposes that this type of 'optioneering' on design alternatives provides a more cost informed decision making process, especially early in the design process.

Crowley (2013) and Fung et al. (2014) contend that Qs are slow to adopt BIM due to a lack of understanding of its capabilities and that there are some significant obstacles yet to be fully addressed. These are evident through a number of consistently reported barriers which are outlined in the review of literature and also evident in the findings. The findings indicated that one of the main reasons for Qs not engaging with 5D BIM, is because of the expense involved in changing their work practices. This is both due to the necessity of upgrading their equipment but also in terms of training their staff.

The 5D work-flow (illustrated in Figure 3.7 in Chapter 3) requires the 5D QS to post-process quantities extracted from the model into a WBS that can be utilised in their cost plans/BOQs (Drogemuller & Tucker, 2003; Monteiro & Martins, 2013). Crowley (2013), Matipa et al. (2010) and Drogemuller & Tucker (2003) explain, that although utilising 5D BIM can automate QTO, post-processing the quantities can be a time consuming activity. This research indicates that this process is also problematic because there is significant work in converting raw quantities from the model into a format Qs can use in their estimates. Despite these difficulties a number of participants contend that 5D BIM technologies give Qs the ability to extract quantities in a way that is usable, and that it is up to Qs to develop the skills necessary to utilise 5D BIM in a way that would work for them.

Another significant problem discussed in the review of literature, is that there are issues with the model when utilising it for cost control (Ajibade & Venkatesh, 2012). These include that; the model has incomplete and/or inaccurate information; the file format cannot be utilised in the QS's software; and fundamentally that there is no model available for the QS (Crowley, 2013; Matipa et al., 2008; Smith, 2014). A theme that emerged in this research noted that the majority of Architects in Ireland are still not using BIM and thus there is usually no model available for the QS. Even when an Architect has designed the project with BIM software, there is a reluctance to make the model available to other consultants because of confidentiality issues and concerns/risks with other stakeholders using their data. When the model is available the findings and the literature convey that not everything is in the model and that objects can be incorrectly categorised making it difficult for Qs to interpret the design and generate applicable quantities (Crowley, 2013; Forgues et al., 2012; Matipa et al., 2008; Smith, 2014).

These issues have led to an element of distrust amongst some Qs of the quantities extracted from the model (Goucher & Thurairajah, 2012). Participants in this research maintained, that currently, they spend a lengthy amount of time validating the quantities that are coming from the BIM and putting them in a format that is useful. A number of participants reported that the industry has not fully accepted BIM and the supply chain is not completely utilising it. Thus, they stated it could be problematic agreeing QTO with other consultants and contractors whom are not yet comfortable with the automation in BIM quantity outputs.

Considering these challenges, both the review of literature and the findings indicated that a BIM approach is still beneficial. The findings provided evidence of a number of suggestions and recommendations for Qs working in a 5D environment to increase efficiency in the 5D BIM process. The first recommendation was that BIM needs to be collaborative, where models are created by designers that can be utilised by other consultants. Making the model available to the QS is fundamental to a joined up process, but the QS must ask for the model in a format that they can utilise. This may require the QS to upgrade their software and hardware and provide training for their staff in utilising BIM. However, the review of literature indicated that many existing estimating applications have updated their system to include BIM visualisation and automatic QTO, thus, a significant upgrade to a different system may not be required.

From the QS perspective the findings elaborated that it would make it easier in post-processing the quantities if the WBS was included in the object properties of the BIM. A number of participants indicated that this may require the QS to communicate this structure to the Architect at the design stage, so that the relevant QS classification can be incorporated into the design. A number of participants mentioned that Qs should promote a BIM approach by pitching its capabilities to their clients.

7.5.3 5d BIM LCC Integrated Process.

This section discusses the two topics outlined above (LCC and BIM) based on the potential benefits and issues with facilitating LCC in the BIM work-flow, through extending the 5D BIM process to accommodate LCC. As discussed in the review of literature, BIM makes it possible for consultants to expand the scope of their services

by freeing up time in the laborious QTO process (Sabol, 2008; Wu et al., 2014). It was established through the review of literature and validated in the findings of this research, that despite the benefits of LCC, it is a service that is not widely practiced by QSs. This is due to a number of barriers that impede its implementation (Chiurugwi et al., 2010; Hourigan, 2012; Oduyemi et al., 2014).

Goucher & Thurairajah (2012) determine that while consultants are developing capabilities in BIM for QTO and CAPex estimating, there is an overall lack of enthusiasm utilising BIM for LCC. Boon (2009) notes that this is not a product of QS's lack of experience with BIM but rather their lack of knowledge of LCC and how BIM could be utilised to increase efficiency in providing this service. This was also evident in the findings, where the majority of participants had utilised BIM for CAPex but none had utilised it for LCC and most were not aware that BIM could be harnessed in this regard.

Whyte & Scott (2010) ascertain that construction clients will increasingly demand buildings with low operating costs, driving demand for ICT that can quickly account for operational performance. The review of literature discussed the legislative requirements that will drive this demand, where LCC will be required by new EU directives in procurement of MEAT tenders and the evaluation of the performance of energy efficient solutions. Thus, the status quo where LCC is not widely carried out by QSs cannot prevail and enabling QSs to carry out this service is needed through the most effective means.

The issue with BIM is that it has good scheduling (4D) and pricing (5D) capabilities, but does not have a good LCC function/perspective (Whyte & Scott, 2010). Sylvester & Dietrich (2010) note that there are restrictions in the current BIM process when carrying out LCC, because BIM authoring software does not have the computation capabilities to accommodate the variables of LCC. Whyte & Scott (2010) and Kirkham et al. (2004) call for further work to be carried out in the area of 5D BIM and LCC.

The review of literature established that spreadsheet capabilities are particularly advantageous in the production of LCC estimates, due to their ability to accommodate multiple job conditions that enable probabilistic calculations (BSI/BCIS, 2008; Kehily, 2011; OGC, 2007). Eastman et al. (2011) maintain that no

BIM tool provides the full capabilities of spreadsheet software and thus not having these capabilities is an impediment to carrying out LCC in BIM. If the stochastic LCC calculations from a spreadsheet could be incorporated into a 5D BIM technology then it could integrate LCC into the BIM work-flow and extend the 5D BIM process for LCC. This would address Eastman et al's. (2011) assertion that no BIM tool provides the capabilities of a spreadsheet and it would also provide an interface where recommendations from methodologies such as the BSI/BCIS (2008) and NRM 3 (RICS, 2014) (which propose a spreadsheet LCC structure) can be facilitated in the BIM work-flow.

Chapter 5 described the process of incorporating a spreadsheet calculation structure in the 5D BIM process by integrating LCC calculations into the spreadsheet workbook of CostX's 5D estimating software. This was validated through a collaborative project with Exactal technologies where LCC was incorporated into CostX estimating software. This integrates LCC functionality within the 5D BIM work-flow and enables the computation capabilities of spreadsheet software to be utilised in the production of LCC in BIM. This process was the work-flow that participants engaged in when completing the scenarios and tasks of the evaluation. Data gathered from the evaluation is discussed in the next section, in the context of how it could address issues in LCC.

7.5.4 Extending the Existing 5D Process

Chapter 5 presented a design science artifact that was developed over a number of iterations that incorporated a LCC calculation structure within an existing 5D BIM platform. As outlined in Chapter 5 and illustrated again in Figure 7.4 this outlines a process that extends the 5D BIM work-flow to encompass LCC, within the same system.

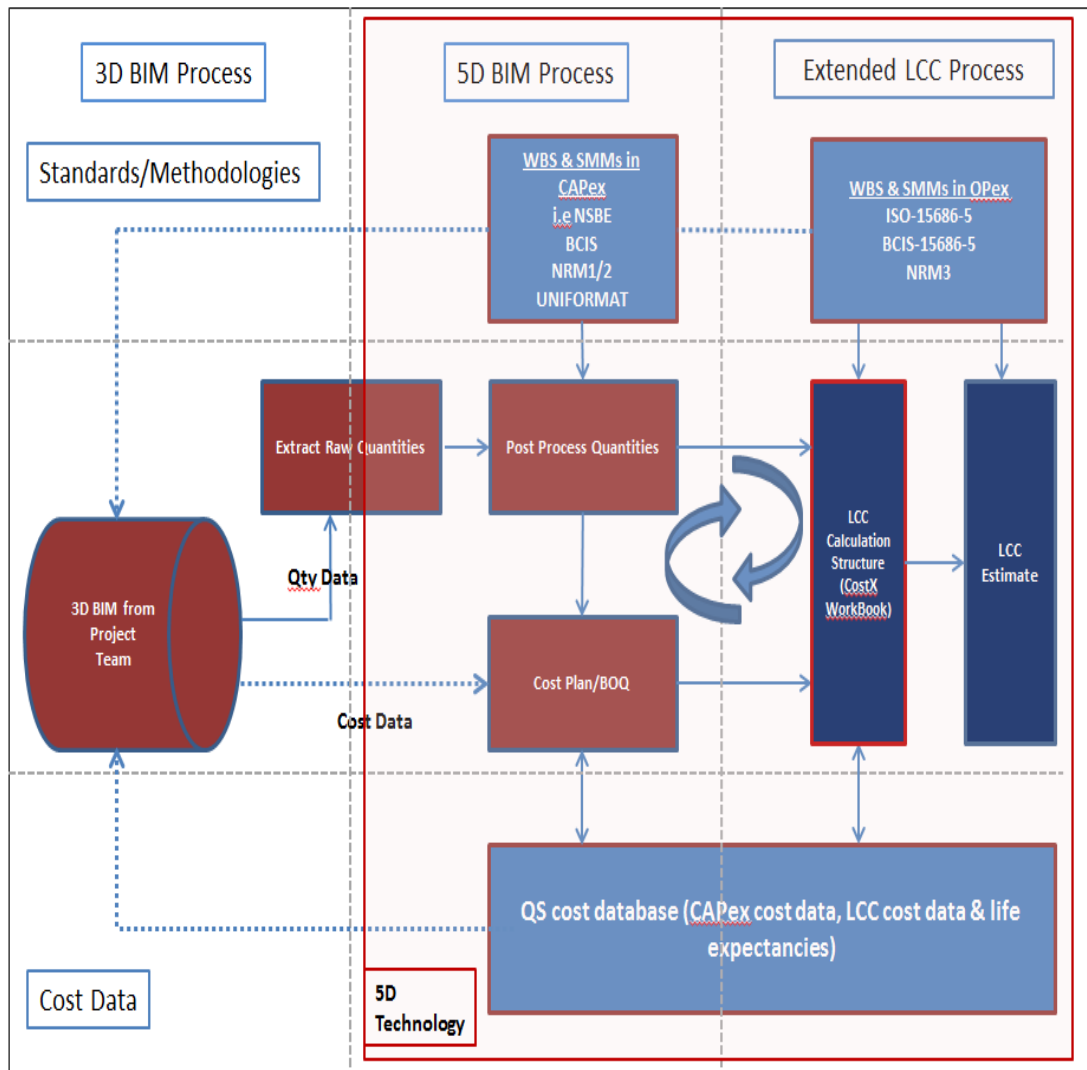


Figure 7.4: 5D LCC extension

Working through the scenarios and tasks outlined in Chapter 6, six participants initially utilised the prototype developed in MS Excel. Feedback and recommendations for improvement, (where applicable), were incorporated into a more developed version to improve the calculation structure within the process. A 2nd Stage of data collection entailed ten participants working through similar scenarios and tasks, based on the more developed version, which guided them through the BIM work-flow shown in Figure 7.4.

Feedback from the participants indicated that leveraging 5D BIM and incorporating a LCC calculation structure automates LCC, thereby making it easier and significantly quicker to carry it out. Participants indicated satisfaction on how the LCC calculations were automatically generated based on formulae embedded in the LCC workbook. Participants noted that these calculations populate cash flows and cumulative LCC totals within a standard structure.

Rooting the LCC calculations in a spreadsheet format was expressed as a benefit, because it is the medium in which QSs are most familiar with and thus, expedites their learning curve. The findings indicate that grounding the structure and calculations in something that is familiar to QSs enables a transparency which brings an element of trust to the process.

The most prevalent theme that emerged from feedback from the participants is that this is a unique process enabled by an innovative integrated 5D/LCC BIM technology. Theoretically this extends the existing 5D BIM process to accommodate LCC. This is outlined by Smith. (2014), Barnes & Davies (2014) and Sawhney (2014) in the realm as 5D & 6D BIM modelling. Participants noted that this process is different from their current work practice because it enables an integrated workflow through the 5D LCC process, which is facilitated by an integrated technology (design science - artifact) that was developed in this research. Ultimately CAPex and OPex reports can be generated from the same integrated system. The benefits of an integrated process give users the tools to interrogate the effect of different variables in both their CAPex and their OPex LCC estimates. This advantage maintains transparency and links the work-flows across the 5D-LCC process, providing efficiencies in quicker calculations and presentation.

The findings indicated that this process would make it easier and more likely that QSs would provide LCC services for their clients. All participants noted that they would use this system, if it was available to them. The review of literature outlined that LCC will become more prevalent within the construction industry and within QS practices due to a number of drivers. These are that; EU Directive 2014/24/EU (EU, 2014) will require that LCC be adopted for tenders on publicly procured projects; LCC be utilised to appraise energy efficient and sustainable design solutions (SEAI, 2015); an increasing focus on OPex requires a matrix to measure future expenditure (Kirkham, 2005) and that BIM will bring capabilities in design 'optioneering' which will need to be evaluated (Crowley, 2013). This view is endorsed by a number of participants whom agree that this integrated process would aid them in meeting this need. This study indicated that the direct benefits to the QS are: it can aid them in the calculation of tenders with an FM element such as PFIs; it can save outsourcing LCC to external consultants; CAPex and OPex can be

incorporated in the same process; and QSs can get more from their existing software without the expense of buying additional BIM LCC software.

There were a number of recommendations for improvement articulated by the participants in the system and process proposed in this research. These improvements are outlined in the findings above and represent proposals that would improve the LCC calculation structure within the 5D process. The LCC calculation structure incorporated into CostX 5D BIM software was not envisaged to be inflexible. The structure and even the inherent calculations can be manipulated to adjust to the user's needs. Thus, the recommendations that are expressed by participants can either be accommodated in a future iteration or left up to the user to change. This is the essence of a 'technological solution' in design science, where the output of the research is not a fully operational piece of software but a process that proposes a new 'rule' (practice) for practitioners or researchers to follow and apply in other similar circumstances and to other applicable software (Hevner et al., 2004; van Aken, 2005).

It was not the completeness of the interface that was evaluated but that the proposed technological solution can successfully provide a 'means to an end' as a design sciences artifact. In terms of this research, the 'means to an end' was based and evaluated on whether the process has an effect on the barriers that prevent its widespread use.

The findings indicated that utilising this process has an effect on a number of the barriers to carrying out LCC. The findings outlined that this process provides a system which automates the LCC calculations and offers a structure which standardises the format and presentation of the OPex report. It does not give users access to a database of LCC, but the CostX database tool could be used as a repository to build LCC data, much like construction costs. Whether a client requests LCC cannot be directly addressed by utilising a process or technology. However, participants noted that demonstrating the value of LCC to clients, by utilising a process like this, may encourage clients to request it on future projects.

A number of participants commented on improving the integration between the BIM output and the LCC calculation structure. These recommendations propose that LCC data could be contained in the object properties of the authored model, which could

then be utilised in the LCC calculations. This would essentially entail extracting LCC information from the model and linking it directly to the calculations in the LCC workbook. Existing practice highlighted in Figure 7.5 is that this information comes from the QS's database, but if, as a number of participants recommended, this information was included in the object properties of the design model, it would make it easier for QSs to access this information and provide further integration and automation in the BIM 5D-LCC work-flow. This could particularly have an effect on the access to LCC information barrier and speed up the production of LCC estimates by linking to data in the authored model.

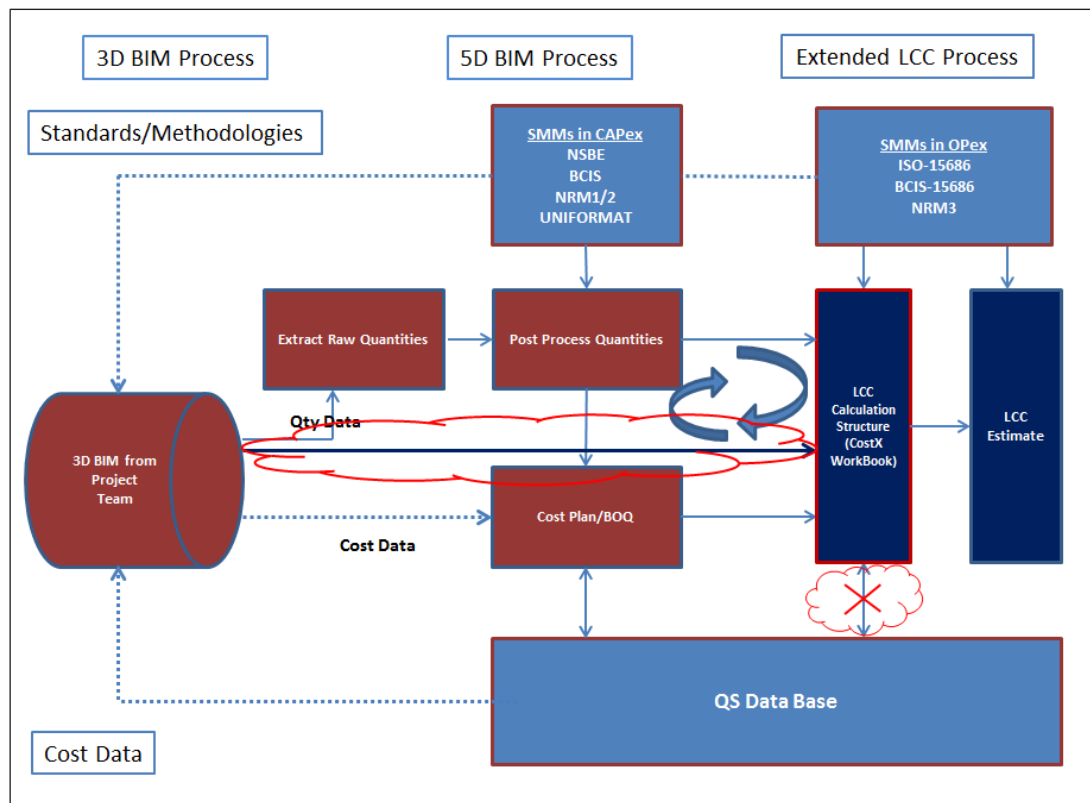


Figure 7.5: LCC Data from BIM

An issue that emerged in this research, which is not addressed in the review of literature, is that engaging with technology can be a barrier to implementing LCC. The benefits of 5D BIM are well documented but participants mentioned a number of issues when utilising BIM for QS practice. Some estimating software does not have the capabilities to utilise BIM and thus there can be significant cost in upgrading hardware and software. There is also the additional expense of training staff and changing work processes to cope with new technology. However, most participants mentioned that because this system is based on a spreadsheet, it helps the user gain proficiency quicker than a bespoke system. Another notable benefit is

that users can use their existing QS programmes, which directly links their CAPex cost plan or BOQ to their LCC in the same system, thus getting more from their existing investment.

7.6 Summary

This chapter outlines the findings from two stages of data analysis. The 1st Stage presents the findings from the evaluation of the prototype and the feedback from participants on the proposed LCC calculations structure. This revised calculation structure was subsequently developed in the 5D BIM software CostX and then evaluated in a 2nd Stage of analysis. The findings present data, firstly based on the subject matter of LCC and BIM (discussed in the review of literature) and subsequently whether the proposed process can address issues in LCC and BIM. The latter part of the chapter discusses data across both stages of analysis and discusses the relevance and originality of this research within the context of BIM and LCC. In the next chapter the findings and discussion are presented in the context of the aim and objectives of the research.

8 Conclusions

8.1 Introduction

Chapter 7 introduced discussions based on the evaluation findings. This chapter aims at concluding this study by discussing the research outcomes in relation to the aim and objectives of the study. This is presented as a discussion and commentary on each objective and whether the objectives have been achieved. The overall findings are subsequently collated and summarised to express the key outcomes of the research and how they address the overarching research aim. This chapter also provides a number of recommendations and discusses contributions to knowledge from an academic and practical perspective. Research limitations, as well as future research directions are also outlined in the latter sections of this chapter.

8.2 Reflection on Research Aim and Objectives

At the outset of the research, five overarching objectives to the research were set out. The following sub-sections present the research conclusions per each objective, highlighting the key findings:

8.2.1 Objective 1

“Determine the concept of LCC, outlining the background to the research area and its context in the QS profession”.

The review of literature discussed the background to the research area and outlined the difference between LCC and WLCC. The review of literature explained that LCC is an economic evaluation of CAPex and OPex over an evaluation period, while WLCC takes account of a broader economic evaluation, which includes income, externalities and non-construction development costs. Carrying out LCC predominantly enables the QS to investigate the building’s cost in use and the implications of different design options on future expenditure.

In addition, the review of literature provided an overview of QS practice and outlined its traditional focus on CAPex cost management. Developments in LCC over the last thirty years were discussed; outlining a peripheral awareness in the 1960s and 1970s through research and publications defining LCC in the 1980s and

1990s and subsequently the publication over the last ten to fifteen years of a raft of standards and guidance notes.

The Capital Works Management Framework (CWMF) (Dept. of Finance, 2009) and the OGC (2007) provide guidance notes for the management and control of costs on publically procured projects in Ireland and UK respectively. The OGC and CWMF, which are government publications, do not legislate for LCC in the procurement process, but rather recommend that LCC should be carried out on public works. This recommendation seems to be largely ignored, evidenced in the low application of the service in both UK and Ireland due to the barriers outlined previously.

The EU has also enacted a number of directives recently on LCC. When these directives are transposed into legislation, LCC will be further engrained in public procurement, thus necessitating providers of cost management services to overcome their issues in providing this service. Other drivers increasing the use of LCC is that it is used as an effective method of analysing long term operating costs on PFI projects; that it provides an economic metric for evaluating sustainability and energy efficiency and that it can be utilised to inform design decisions that could potentially have an effect on maintaining and managing the asset during its operation.

8.2.2 Objective 2

“Investigate the existence of benefits and barriers to LCC in order to identify what actions can be taken to increase usage levels”.

The review of literature investigated the use and benefits of LCC, both from an industry wide perspective and from the QSs standpoint. The main benefit of LCC is that it ensures design decisions take into account the overall performance of the building in use, which can significantly outweigh its initial CAPex. In this context it can be of particular value when assessing the sustainability of a building or the implementation of energy efficient proposals. Other benefits are that LCC can be utilised for the evaluation of tenders that incorporate OPex (Design Build Maintain and PFIs) and that it can be used to control operational costs during the FM stage.

This research supplements existing literature by indicating that LCC’s value resides in its focus on future expenditure, where it provides a mechanism for a more holistic cost management service. An emphasis on LCC’s benefit to the QS has emerged in this research, focusing on the specific advantages to QSs carrying out LCC services.

Participants propose that LCC is an opportunity for QSs to provide an enhanced service; set themselves apart from other practitioners; grow their fee base and increase efficiency in their work practices. A number of participants practicing as contractor's QSs note that it provides them with a mechanism to propose value engineering options for their clients.

Both the review of literature and this research find that although there are significant benefits to carrying out LCC, it is currently not widely practiced by QSs providing cost management services to construction clients. A number of well documented barriers still exist. An effort has been made in the recent past to address some of these barriers such as 'a lack of standard methodology, 'lack of knowledge and know-how' through a number of international and jurisdictional methodologies, but 'a lack of awareness' still prevails.

This study found that 'clients do not request LCC' as a service and thus there seems to be little motivation for QSs to provide it, specifically if they are not getting an additional fee. Given that the majority of participants could not carry out the calculations necessary for LCC, the status quo seems to be convenient. However, a number of participants did explain that there are signs that this is changing. They reported that some of their clients have recently requested LCC, notably on government procurement briefs. They ascertained that the motivation for this change stems from a shift from 'cost' to 'value' in the industry. A number of participants also claimed an emphasis on future expenditure is being brought about by changing work practices, such as BIM and a whole life focus for FM. To take advantage of changing work practices and alternative procurement, QSs need to be able to provide LCC without it being excessively time consuming or difficult.

The review of literature outlined the formulae used in LCC calculations and noted that spreadsheet based software is predominantly used in the calculation of LCC, because it enables sensitivity analysis of the different variables in LCC. This is echoed in the primary research as participants that carried out LCC, in every case, utilised MS Excel. It is evident, that although a very effective tool for LCC analysis, utilising an external spreadsheet programme for LCC disconnects the QSs measurement and pricing (which is predominantly carried out with their estimating software that focus on CAPex) from their LCC analysis. Therefore, if spreadsheet functionality for LCC could be utilised in QSs existing estimating programmes it

may address the limitations in providing this service and support a more integrated process.

8.2.3 Objective 3

“Determine the benefits and barriers of utilising BIM for cost management and address its opportunities for effective LCC”.

The review of literature described the development of CAD, discussed recent developments in construction informatics and presented the emergence of BIM. The general benefits, barriers and levels of adoption in BIM were explored through relevant literature, narrowing the focus to 5D BIM. 5D BIM recognises materials used within the model and, where available, assigns the associated cost to these components. The review of literature described how utilising 5D BIM for cost management provides the QS with efficiencies in measurement and QTO. This automates many of the time consuming and costly procedures which are traditionally prone to human error. However, one of the major issues with 5D BIM is that the model structure (categories and families) do not align with measurement classification structures (rules of measurement and elemental structures). For this reason, currently QSs post-process BIM data to align BIM schema to QS objectives. There are a number of other barriers presented in the review of literature, including; that the model can have incomplete and/or inaccurate information; the file format cannot always be utilised in QS's software and fundamentally that, in many instances, there is no model available for the QS. This research also explored these issues as participants engaged in 5D BIM as well as leveraging 5D BIM for LCC. The findings present similar issues amongst the sample of practitioners of this research, where the BIM may not provide the QS with the benefits outlined in the literature because it is missing information and is not built in a way that QSs can use effectively.

There are at present many QS estimating applications that provide the user with the ability to generate QTO from BIM and cost those quantities through a database tool within the application – essentially providing the 5D BIM practitioner with a medium to extract the BIM quantum in a format which aligns to the standard method of measurement. A number of participants suggest that it is up to the 5D QS to become familiar with this medium in an effort to devise their own means of extracting QTO from the BIM in a way they can use.

In recent years 6D, 7D and nD has become a term in BIM to describe the expanding application to include the broader aspects of the built environment, including analysis of operational expenditure (6D) and sustainability (7D). LCC spans both 5D BIM for CAPEX and 6D for OPEX. It was reported in the review of literature that BIM authoring tools are restricted in carrying out LCC because they do not have the facility to carry out the probabilistic calculations required. It was discussed that without incorporating LCC functionality within BIM a complete picture of the WLCC cannot be generated from the outputs of the model.

Construction clients will increasingly demand buildings with low operating costs driving demand for ICT that can quickly account for operational performance. The review of literature outlined that there was an opportunity to leverage the capabilities of 5D BIM so that there is a direct link between the quantum; the cost plan/BOQ and the LCC calculations in the same process. In this research, 5D BIM was proposed as an environment where the outputs of the model can be mapped to the LCC schema, adding on a facility for LCC. This is essentially post-processing BIM data for effective LCC, by adding LCC functionality into the 5D process. This can potentially provide the QS with the financial tools required to select the most economical advantageous solution and provide an effective way to address the barriers that prevent its widespread adoption.

8.2.4 Objective 4

“Develop a methodology to add LCC dimension to the BIM process by extending current 5D BIM capabilities”.

The methodology for extending the LCC process by utilising 5D BIM is discussed in Chapter 5. The basis of following a post-processing methodology for integrating LCC, rather than creating LCC definitions in the authored model, is outlined in Chapter 3. This is based on the premise that 5D BIM offers a better environment for LCC because it currently has greater computation capabilities over 3D modelling software and thus can accommodate the variable conditions necessary in stochastic LCC analysis.

The methodology outlined in Chapter 5 proposes an original process where LCC is appended within a 5D BIM environment. This essentially adds an LCC calculation

structure (developed through a number of iterations over five years) into an existing 5D BIM technology.

The review of literature established that spreadsheet capabilities are particularly advantageous for the probabilistic calculations in LCC. This is evident in LCC standards and guidance documentation which suggest that spreadsheets should be used to carry out the calculations. Thus, this research proposed incorporating this facility in the BIM process to provide a CAPex/LCC integrated environment.

It was demonstrated in Chapter 5 that an LCC calculation structure, in spreadsheet form, could be incorporated within the 5D BIM process to potentially address some of the documented barriers to successful implementation of LCC in practice. Chapter 5 outlined the development process to the construction of this LCC calculation structure and articulated the reflective process through the documentation of decisions that ultimately lead the proposal of this artifact. The LCC calculation structure included the relevant factors and formulae required to carry out LCC calculations automatically within a format that could respond to international and jurisdictional methodologies and guidance notes.

Building on this concept, Chapter 5 subsequently demonstrated through a collaborative project with Exactal (CostX), how an LCC spreadsheet calculation structure produced in recognition of the relevant LCC standards can be accommodated in 5D BIM software. This was achieved through the customisation of the CostX workbook, by adding in user defined columns, replicating the calculations from the LCC calculation structure spreadsheet. Collaborating with Exactal and incorporating the LCC calculation structure in the CostX 5D BIM platform, it was validated that the original technological solution (calculation structure) devised in the development process could in fact be accommodated in 5D BIM software. This essentially proposed an extension to the 5D BIM work-flow that facilitates ‘what if’ analysis for LCC. Chapter 5 demonstrated this extended 5D-LCC BIM work-flow in an integrated environment where CAPex estimating and LCC can be carried out together. In order to determine whether this process can have an effect on the barriers to LCC, it was necessary to evaluate this work-flow in use, and by participants whom would potentially use it.

8.2.5 Objective 5

“Evaluate this process to determine if the barriers preventing widespread application of LCC can be addressed”.

This research demonstrated a process which made use of an existing 5D BIM tool (not originally designed for LCC). This is applicable to one of the contributions of a design sciences artifact, where the artifact proposed (5D-LCC process) is utilised in a context (LCC) that it was not originally designed for. This integrated 5D-LCC BIM methodology was demonstrated to participants in a two staged process, which essentially evaluated its utility for effective LCC. Stage 1 encompassed the evaluation of the proposed methodology by six participants. Feedback from these participants was incorporated into a more developed version which was presented in Stage 2 to ten participants. The processes effectiveness is evident in the findings, firstly based on its advantages but also benchmarked against how it addresses the barriers that prevent LCC being widely practiced.

Participants noted that one of the primary benefits of the proposed process is that it allows for a link between their cost plans/BOQ's and their LCC calculations in an integrated environment. Participants maintained that this is a unique approach which is different than their current work practices because it enables an integrated workflow through the 5D-LCC process. This underscores the dynamic BIM process, where parametric adjustment attributes change throughout the outputs of the model simultaneously.

Incorporating LCC calculations in a spreadsheet format in 5D BIM was seen as a benefit because it is the medium that QS are most familiar with and thus expedites their learning curve. Grounding the structure and calculations in something that is familiar to QSs enables a transparency which brings an element of trust to the process. The findings outline that this process would aid QSs meeting requirements for LCC, which will be heightened by EU directives that will mandate the use of LCC in tender preparation and evaluation in public procurement.

The process that the participants engaged in, demonstrated that it has an effect on the automation and efficiency in carrying out LCC, which addresses barriers such as LCC being a 'time intensive process' with QSs lacking 'the know-how' in carrying out calculations. Participants also commented that the proposed LCC calculation

structure provides a format to present LCC estimates, thus addressing a 'lack of standardisation'. It also proposes that QSs can make use of their existing software without the expense of costly upgrading.

The research still finds that clients are not asking for LCC and thus the benefit of the service cannot be realised. Utilising this process will not have a direct effect on whether clients incorporate LCC into their project briefs, but it may provide the impetus to QSs to provide the service anyway. This could demonstrate to clients its capabilities, which may eventually, in turn, instigate its inclusion in the project brief by informing clients. CostX does not come preloaded with LCC data, thus its utilisation cannot have an effect on 'lack of access to LCC data'. Access to LCC data is a significant barrier for QSs, as no matter how proficient QSs become with the calculations, if they cannot use relevant information then the LCC will not have any level of accuracy. The validity of historical LCC information is argued where a number of eminent authors suggest estimating LCC from current costs. However, the system has the capability to store LCC information providing the QS with a database facility that can be used in conjunction with third party data or a means to build their own data.

8.2.6 Summary of key Findings

Based on the findings and discussions outlined in Chapter 7, the set of key findings are summarised hereafter:

Life Cycle Costing

- LCC is an economic evaluation in which all costs arising from owning operating and maintaining a building over an extended period are considered. WLCC includes a broader economic matrix encompassing non-construction costs such as site purchase, letting or selling agent fees, procurement costs and the cost of finance.
- The QS profession provides a cost management service for the construction client but has traditionally focused on CAPex. In the recent past there has been a lot of research carried out in LCC with the publication of a plethora of methodologies and guidance notes providing information to practitioners.
- Benefits of LCC are that it ensures design decisions take into account the performance of the building or a building component in use. This can be of

particular value when assessing the sustainability of a building or the implementation of energy efficient proposals. Other benefits are that LCC can be used for the evaluation of tenders with OPex and that it can be used to control operational costs during the FM stage.

- There is a growing awareness of LCC in the industry, but it is not widely practiced by QSs offering cost services due to a number of consistently documented barriers. These barriers are that; the calculations are perceived as time consuming and difficult; QSs lack the skills and knowledge to carry them out; there is a lack of accurate and valid LCC data; there is no standard methodology and that fundamentally it is not requested by the client. However, an increasing awareness on the importance of sustainability, energy efficiency and maintenance; including the emergence of procurement and tendering that incorporate the occupancy stage of the project, will necessitate a means to evaluate OPex. There are also a number of EU directives when enacted in national legislation will require LCC to be carried out in public procurement thus requiring QSs to overcome these barriers.
- There are a number of formulae and factors used in LCC which can be accommodated in spreadsheet software to provide the means to test variables in LCC.

Building Information Modelling

- BIM has the potential to revolutionise the construction industry by changing traditional 2D information exchange to a method of delivery that promotes collaboration and integration across the construction supply chain. BIM has a number of benefits including; better information exchange between stakeholders; more accurate visualisation; parametric modelling; clash detection; what if analysis and efficiencies in construction and fabrication. BIM adoption and uptake within the construction industry is increasing evidenced in a number of surveys outlined in the review of literature. This is being driven by a growing awareness that BIM can offer construction stakeholders value, but also that many countries are implementing protocols and procedures on publically procured projects.
- BIM use can provide a number of benefits for QSs in providing cost services. Particularly it's potential to automate the QTO process, leading to more accurate QTO and quicker measurement. This gives the QS the opportunity

to investigate the cost impact of various design alternatives quickly and provides them with more time to concentrate on value enhancing activities for their clients, such as LCC. BIM's 3D visualisation capabilities are also advantageous to QSs as it can help them visualise real world construction conditions and identify any potential clashes amongst design disciplines.

- In comparison with other disciplines, QSs are slow to adopt BIM due to a lack of understanding of its capabilities and there are still some significant obstacles yet to be fully addressed. These issues are that; changing to BIM practices could require significant expense in upgrading software, hardware and training staff for a new technology and new way of working; that the models may not have the required information for the QS to carry out QTO; that BIM files may not be operable in QSs software and that in many instances there is no model available to QSs.
- Due to these issues the time saved through BIM QTO automation may not be realised, because the QS can spend more time checking the correctness and accuracy of the model. However, 5D BIM provides the QS with a platform to extract quantities and link them to their cost reports in way that works for them. Becoming more proficient in this area may help QSs alleviate some of the issues presented.

BIM and LCC

- BIM makes it possible for QSs to provide alternative professional services by leveraging BIM technology and freeing up time in QTO. This enables QSs to carry out value enhancing services such as LCC. However, there has been limited development and research in the area of BIM and LCC.
- An LCC calculation structure, created in this research, was incorporated within the 5D BIM process. This demonstrated a technological rule, which presents the process to develop an integrated CAPex/LCC BIM artifact. Incorporating the LCC spreadsheet calculation structure in the 5D BIM workflow provides an agent in BIM that QSs are familiar with – increasing their learning curve and providing transparency.
- An output of the research is that this is a unique process that offers a change to the current BIM work-flow, through post-processing BIM data in the 5D environment. Its novelty is based on an integrated CAPex-LCC process that

facilitates an extension of 5D BIM for LCC, but when used in the operational phase it can be utilised for 6D.

- The primary benefit of the proposed process is that it allows for a link between the CAPex cost plans/BOQ's and LCC calculations in an integrated environment. This addresses some of the barriers to LCC, particularly that it can speed up LCC calculations, provide QS with the 'know how' to carry out LCC and provide a means to provide LCC in a standard format.

8.3 Recommendations

Qs must become more proficient in carrying out LCC calculations and presenting LCC estimates to their clients. They will no longer be able to avoid offering this service and must overcome the barriers which prevent its widespread practice. The first recommendation in this regard is to read and become familiar with the relevant LCC standards and methodologies. To gain further proficiency, Qs could implement a trial LCC on one of their projects, utilising spreadsheet software to carry out the calculations. Once they have increased their expertise in this area and possibly carried out a number of LCC estimates, they could follow the technological rule presented in this research and add their LCC calculations to their existing BIM software.

This would only be possible if Qs are utilising BIM software, but there is ample evidence to suggest that BIM use in the QS profession is increasing and in the future it is expected to be prevalent for QTO and cost estimating. This study outlines how 5D BIM can be leveraged to carry out LCC by post-processing BIM data. As Qs become more proficient in the 5D BIM process and develop capabilities mapping BIM quantum to QS classification structures, the next step is to link the BIM quantum and construction cost estimate to an LCC estimate. This study proposes a course of action that can aid them carrying out this process. The object properties of the model contain relevant information that can be used both in construction cost estimating and LCC. By following the information flow outlined in Figure 7.4 these attributes could be extracted and utilised in the LCC estimate. Maintaining links between CAPex and OPex in an integrated environment allows for easy revisioning and real-time estimating.

8.4 Contribution to knowledge

Contribution to knowledge in action orientated research has a dual goal of contributing to both practice and research at the same time (Iivari & Venable, 2009). From an academic point of view, the product of design science and action research is the explicit articulation of a practice, product, system or technique and the evaluation of its intervention in practice (Hevner et al., 2004; Iivari & Venable, 2009). Learning is specified through the explicit and systematic documentation of the reflective practice in the development of the solution and the outcomes of this solution in action, i.e. the findings of the evaluation.

Contribution to practice is that the practice, product, system or technique is effective in a practical context and offers a successful change in current work practice. A practical research contribution is more focused on the end product and its demonstrated effectiveness in a work setting, whereas academic research focusses on the process to come up with the product and the learning achieved through utilisation in a work setting. The following sections address both research and practice separately.

8.4.1 Contribution - Research

The review of literature outlined the barriers to adoption for LCC and the considerations Qs must take into account when carrying out LCC. These issues have been well documented and there is ample evidence that LCC's current application within the industry is still low, which is supported by findings in this research. This research investigated how BIM can be leveraged to carry out LCC and whether utilising 5D BIM could have a result on the reported barriers preventing LCC's widespread adoption. An automated LCC calculation structure was developed and was subsequently embedded in 5D BIM. This constitutes a development in 5D BIM estimating software, which extends the technology for LCC. The manipulation of an existing 5D BIM technology to carry out LCC represents a design sciences research output where an existing technology is used to solve a practical problem in a different context to which it was designed (Hevner et al., 2004). From a BIM practice perspective, this facilitates an integrated 5D BIM-LCC process, leveraged by the technology which constitutes both a 'technological rule' in design science and a new BIM 'practice' in action research (Azhar et al., 2010; Iivari & Venable, 2009;

van Aken, 2005). Both research outputs articulate an innovate process which could be applied to a different problem and another situation, i.e. it could be followed for another technology.

The development process articulated in Chapter 5 and illustrated in Figure 7.4 extends the 5D BIM process for LCC. This is based on the premise (discussed in the review of literature) that 5D BIM is the ideal environment to house the complexities of LCC calculations. It was outlined in Chapter 3 that creating the facility for LCC in the design model by extending BIM object definitions would not be successful, because BIM authoring software does not currently have the capabilities to test the variable conditions in LCC. This led to the articulation and proposal of a methodology of post-processing BIM data and linking that data to an LCC structure housed in 5D BIM. The contribution to knowledge is the process of extending 5D BIM for LCC by leveraging an existing 5D technology.

However, the primary focus of design science and action research is that the solution intervention can have an effect on the environment to which it has been introduced (Azhar et al., 2010; Hevner et al., 2004; Iivari & Venable, 2009). In this case this environment is QS practice and is benchmarked against its effectiveness in addressing the barriers to LCC. This research provided evidence that extending 5D BIM for LCC can have an effect on the barriers to LCC, mainly the complexity and time consuming nature of the process and standardisation of the process.

8.4.2 Contribution - Practice

The final artefact, i.e. the 5D BIM/LCC technology which accommodates the process described above, is a subsidiary contribution to this study. As noted previously the primary contribution to knowledge in design science is not the technology or finished piece of software but rather the methodology that underpins its development. However in terms of a practical contribution to knowledge, this research has also provided (and outlined) a validated and user informed technological aid for Quantity Surveyors carrying out LCC within a 5D BIM environment. An original aspect to this is the manipulation of existing BIM software so that the LCC estimate can be housed within the software, rather than have to be exported to another application for further analysis. The process links the QSs measurement to the LCC estimate within the same system and presents a process

where 5D BIM applications can be leveraged for LCC. The research outlines a BIM process or ‘technological rule’ which could be followed by practitioners in the context of any 5D BIM software with user customisation capabilities.

8.5 Limitations

There were limitations involved in this research, although every attempt was made to be aware of those limitations in an effort to minimise any negative effect on the research outcomes.

In this study there was considerable effort and time dedicated to the development of the design science artefact, i.e the 5D-LCC technological solution. Substantial resources were expended to develop a fully working technology and at times this deviated from the focus of the research, which was on the process it facilitated (extending 5D BIM for LCC). In the context of the research aim, this may not have been required; all that may have been needed is an operational form that could demonstrate the capabilities of the ‘idea’ or ‘practice’. However, because the artifact represented a fully functional development it was used effectively to demonstrate how 5D could be leveraged for LCC and provide an effective medium to generate discussion on the process.

A limitation which may have had a bearing on the study is that if the research had been designed differently, it may have had a different outcome. For example, if a different type of usability evaluation was selected the type of data that would have been generated may have been very different. Most usability evaluations entail an empirical test of the proposed application, logging the user’s inputs over a specified period of time with no cooperation from the evaluator. However, this did not fit when the aim of the research because it was necessary to avail of a method which gauged the participants subjective attitudes on both the proposed technology, but also on the process they were engaged in thus focusing on the methodology. If the focus was purely on the software and on its functionality, an empirical usability test would have been the course of action to follow.

The locations of the sample of participants in this study were all from Ireland. This may have had a bearing on the findings, as the cohort have experiences based on working in the Irish construction industry and are not necessarily representative of

the international QS community. This study is representative of a qualitative approach which is bound by the cases or people whom participate in the study. For this reason, another group of participants or participants selected across a number of countries/jurisdictions may have had an impact on the findings. However, every effort was made (evidenced in the user profile) to select participants that are representative of potential users of the proposed solution and obtaining participants from other jurisdictions was not possible due to limited resources. Selecting users in UK and beyond may not constitute any substantial change to the findings.

8.6 Future Research

The technology aspect of the research is not presented as a finished article; it is not intended as LCC software (in its current form). It does however demonstrate that LCC can be incorporated into existing 5D BIM software, but there could be further developments in CostX or other 5D BIM software with similar capabilities to expand its functionality. Following the design sciences ‘technological rule’ presented in this research, a future project could entail building a fully developed programme add-on or additional tab in CostX software which would provide a better structure than the existing CostX workbook - which was originally designed for CAPex calculation. This could entail a larger collaboration project with CostX, by possibly re-programming the system. This may in the future be developed as the ground work and road map for its construction are already proposed. However, for the purpose of this study the technological rule/process articulated here could be followed by other QSs to add-on LCC functionality to their existing work practices, without having to engage with the software vendor and to do it in a manner that works for them.

Access to relevant LCC information is an issue which could be pursued through collating LCC information and building a relevant (Irish) database which could be used with the process proposed here. There is a parameter in IFC4 which provides for ‘service life duration’. If this information is populated by the Architect in the authoring application and made available to the QS, it could add to the efficiency of the process and also provide access to data. Development of the IFC schema to incorporate other LCC data requirements would be of benefit to QSs performing LCC analysis. Information from COBie parameters would be particularly helpful in this regard and a related research project investigating how the process outlined in

this study could be integrated or utilised with COBie would be a worthwhile investigation.

This research focused on post-processing BIM data from the authored model for LCC integration rather than creating LCC object definitions for the authored model. This was based on the premise that the 5D BIM environment can currently better facilitate probabilistic LCC calculations. However, as BIM evolves and further integration is engrained in BIM (such as developing the LCC schema in the object definitions of the model, i.e. further developing the IFC and COBie), a means to effectively calculate LCC could be developed within the authored BIM. This would entail variable LCC analysis with an integrated model rather than exporting it to 5D QS specialist software for post-processing.

9 References

- Abbasnejad, B., Moud, H.I., (2013). BIM and Basic Challenges Associated with its Definitions, Interpretations and Expectations. *International Journal of Engineering Research and Applications*, 3(2), 287-294 .
- AIA (2012). *BIM Outreach - BIM in Practice*. Australia: Australian Institute of Architects & Consult Australia.
- Ajibade, A. A., & Venkatesh, S. (2012, June 26-29th). *The Rocky Road to BIM adoption: quantity surveyors perspectives*. Paper presented at the Joint CIB W055, W065, W089, W118, TG76, TG76, TG78, TG81 & TG84 International Conference on Management of Construction: Research to Practice, Montreal, Canada.
- Amaratunga, D., Baldry, D., Sarshar, M., & Newton, R. (2002). Quantitive and Qualitative Reserach in the Built Environmnet: Application of "Mixed" Method Research Approach. *Work Study*, 51(1), 17-31.
- Aouad, G., Amaratunga, D., Bakis, N., Sun, M., Kishk, M., Al-Hajj, A., & Pollock, R. (2002). *An Integrated Life Cycle Costing Database: System Proposal and Methodology*. Paper presented at the CIB Working Commission W70 - The 2002 Global Symposium, Glasgow.
- Aouad, G., Bakis, N., Amaratunga, D., Osbaldiston, S., Sun, M., Kishk, M., . . . Pollock, R. (2001). *An Integrated Life Cycle Costing Database: A Conceptual Framework*. Paper presented at the 17th Annual ARCOM Conference, University of Salford.
- Aouad, G., Lee, A., & Wu, S. (2005). nD Modelling for Collaborative Working in Construction. *Architectural Engineering and Design Management*, 1, 33-44.
- Aram, J. D., & Salipante Jr., P. F. (2003). Bridging Scholarship in Management Epistemological Reflections. *British Journal of Management*, 14, 189-205.
- Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., & O'Reilly, K. (2011). BIM adoption and implementation for architectural practices. *Structural Survey*, 29(1), 7-25.
- Arensman, D. B., & Ozbek, M. E. (2012). Building Information Modeling and Potential Legal Issues. *International Journal of Construction Education and Research*, 8(2), 146-156. doi:10.1080/15578771.2011.617808
- Ashworth, A. (1996). Estimating the Life Expectancy of Building Components in Life-Cycle Costing Calculations. *Structural Survey*, 14(2), 4-8.
- Ashworth, A., Hogg, K., & Higgs, C. (2013). *Willis's Practice and Procedure of the Quantity Surveyor* (13th ed.). West Sussex, United Kingdom: John Wiley & Sons.
- Autodesk. (n.d). Autodesk - Clash detection. Retrieved from <http://www.autodesk.com/products/navisworks/features/all/gallery-view>
- Aye, L., Bamford, N., Charters, B., & Robinson, J. (2000). Environmentally Sustainable Development; a Life Cycle Costing Approach For a Commercial Office Building in Melbourne, Australia. *Construction Management and Economics*, 18(8), 927-934.

- Azhar, S., Ahmad, I., & Sein, M. K. (2010). Action Research as a Proactive Research Method for Construction Engineering and Management. *Journal of Construction Engineering and Management*, 136(Special Issue), 87-98.
- Azhar, S., Hein, M., & Sketo, B. (2008). *Building Information Modeling (BIM): Benefits, Risks and Challenges*. Paper presented at the 44th ASC Annual International Conference, Auburn University, Auburn, Alabama.
<http://ascpro.ascweb.org/chair/paper/CPGT182002008.pdf>
- Bakis, N., Kagioglou, M., Aouad, G., Amaratunga, D., Kishk, M., & Al-Hajj, A. (2003). *An Integrated Environment for Life Cycle Costing in Construction*. Paper presented at the 20th CIB W78 Conference: IT in Construction, New Zealand.
- Barker, D. (2011). BIM - measurement and costing. Retrieved from
<http://www.thenbs.com/topics/bim/articles/bimMeasurementAndCosting.asp>
- Barnes, P., & Davies, N. (2014). *BIM in Principle and Practice*. London: ICE Publishing.
- Barrett, P., & Barrett, L. (2003). Research as a kaleidoscope on practice. *Construction Management and Economics*, 21(7), 755-766.
- BCIS. (2011). *RICS 2011 Building Information Modelling Survey Report*. London: BCIS.
- BCIS. (2013). *RICS 2013 Building Information Modelling Survey Report*. London: BCIS.
- Bell, J. (1993). *Doing Your Research Project: A Guide for First Time Researchers in Education and Social Science* (2nd ed.). Buckingham: Open University Press.
- Bevan, N., & Macleod, M. (1994). Usability Measurement in Context. *Behaviour and Information Technology*, 13, 132-145.
- Biggs, J. (1999). *Teaching for Quality Learning at University*. Buckingham: Open University Press.
- Boon, J. (2009, 17-18 August). *Preparing for the BIM Revolution*. Paper presented at the 13th Pacific Association of Quantity Surveyors Congress: World Summit for Quantity Surveyors and Cost Engineers. Building the Future Together, Malaysia, Kuala Lumpur.
- Boren, T. M., & Ramey, J. (2000). Thinking Aloud: Reconciling Theory and Practice. *IEEE Transactions on Professional Communications*, 43(3), 261-278.
- Botham, D., & Vick, D. (1998). Action Learning and the Program at the Revans Centre. *Performance Improvement Quarterly*, 11(2), 5-16.
- Bouachera, T., Kishk, M., & Power, L. (2007). *Towards a Generic Framework for Whole Life Costing in the Oil Industry*. Paper presented at the 23rd Annual ARCOM Conference, Belfast, UK.
- Boussabaine, H. A. (2007). *Cost Planning of PFI and PPP Building Projects*. New York: Taylor Francis.
- Braun, V., & Clarke, V. (2006). Using Thematic Analysis in Psychology. *Qualitative Research in Psychology*, 3(2), 77-101.
- Bryde, D., Broquetas, M., Volm, J.M. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, 31, 971-980

- Bryman, A. (2008). *Social Research Methods* (3 ed.). New York: Oxford University Press.
- BS-ISO. (2008). *BS EN 15868-5:2008 Building and constructed asset – Service life planning; Part 5 – Life cycle costing*. London; United Kingdom: BSI.
- BSI. (1974). *BS3811: British Standard Glossary of Maintenance of Physical Resources: Department of Industry*. London; United Kingdom: BSI.
- BSI. (2013a). *BS 8544:2013 Guide for life cycle costing of maintenance during the in use phases of buildings*. London; United Kingdom: BSI.
- BSI. (2013b). *PAS 1192-2: 2013 Specification for information management for the capital/delivery phase of construction projects using building information modelling*. London; United Kingdom: BSI.
- BSI. (2014). *BS 1192-4: 2014 Collaborative production of information Part 4: Fulfilling employer's information exchange requirements using COBie – Code of practice*. London; United Kingdom: BSI.
- BSI/BCIS. (2008). *Standardized method of life cycle costing for construction procurement, A supplement to BS EN ISO 15686-5 Building and constructed asset – Service life planning; Part 5 – Life Cycle Costing*. London; United Kingdom: BSI.
- BuildingSmart. Building Smart - International Home of Open BIM. Retrieved from <http://www.buildingsmart.org/>
- Burrows, P. (2015). The Digital BIM toolkit - Presentation at the RICS BIM Conference 2015. London: RICS.
- Bylund, C., & Magnusson, A. (2011). *Model Based Cost Estimations*. (Masters), Lund University, Sweden.
- Cabinet Office. (2011). *The Construction Strategy*. London; United Kingdom: Cabinet Office.
- Cartlidge, D. (2011). *New Aspects of Quantity Surveying Practice* (3rd ed.). London: Spon.
- Charette, R. (2005). *Life Cycle Cost Analysis Financial Tables*. Presented at LCC workshop, November 2010, DIT, Dublin.
- Charette, R. (2010). Life Cycle Costing Seminar/Workshop for Green Buildings. Dublin: Dublin Institute of Technology/Society of Chartered Surveyors Ireland.
- Cheung, F. K. T., Rihan, J., Tah, J., Duce, D., & Kurul, E. (2012). Early Stage Multi-Level Cost Estimation for Schematic BIM Models. *Automation In Construction*, 27, 67-77.
- Chiurugwi, T., Udeaja, C., & Hogg, K. (2010). *Exploration of Drivers and Barriers to Life Cycle Costing (LCC) in Construction Projects: Professional Quantity Surveying Assessment*. Paper presented at the International Conference on Computing in Civil and Building Engineering, University of Nottingham, UK.
- Churcher, D. (2008). *A BSRIA Guide: Whole-Life Cycle Costing Analysis* (BSRIA B6 5/2008). Berkshire; United Kingdom: BSRIA.
- Chynoweth, P. (2009). The Built Environment Interdiscipline. *Structural Survey*, Volume 27(4), 10.

- CILECCTA. (2013). Sustainability within the Construction Sector CILECCTA – Life Cycle Costing and Assessment (pp. 1-77). Oslo, Norway: SINTEF Academic Press.
- Clift, M. (2003). Life Cycle Costing in the Construction Sector. *UNEP Industry and Environment*, April-September, 37-41.
- Clift, M., & Bourke, K. (1999). *Study on whole life costing*. London; United Kingdom: BRE Press.
- Clough, P., & Nutbrown, C. (2002). *A Students Guide to Methodology - Justifying Enquiry*. London: Sage Publication.
- CBPP (1998b) Business benefits for whole life costing. Retrieved from [www.cbpp.org.uk/cbpp/word docs/Whole Life Costing Business Benefits.doc](http://www.cbpp.org.uk/cbpp/word_docs/Whole_Life_Costing_Business_Benefits.doc)
- Cohen, L., Manion, L., & Morrison, K. R. B. (2011). *Research Methods in Education* (7th ed.). Abingdon, Oxon. ; New York: Routledge.
- Cole, R. J., & Sterner, E. (2000). Reconciling Theory and Practice of Life-Cycle Costing. *Building Research and Information*, 28(5/6), 358-375.
- CostX. (2014a). *Advanced Training Exercise BIM and 3D Measurement*. Brisbane; Australia: Exactal.
- CostX. (2014b). *CostX 4.1: Advanced Manual*. Brisbane; Australia: Exactal.
- Creswell, J. W. (2007). *Qualitative Inquiry and Research Design: Choosing Among Five Approaches* (2nd ed.). London: Sage.
- Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (2nd ed.). London: Sage.
- Crotty, R. (2012). *The Impact of Building Information Modelling: Transforming Construction*. New York, New York: Spons Press.
- Crowley, C. (2013). *Identifying Opportunities for Quantity Surveyors to Enhance and Expand the Traditional Quantity Surveying Role by Adopting Building Information Modelling*. Paper presented at the CITA BIM Gathering, Dublin, Ireland.
- Davis, F., D. (1993). User Acceptance of Information Technology: System Characteristics, User Perceptions and Behavioral Impacts. *International Journal Man-Machine Studies*, 38, 475-487.
- Davis Langdon. (2007). *Life Cycle Costing as a contribution to sustainable design: a common methodology – Final report*. Europe: Davis Langdon.
- Dawood, I., & Underwood, J. (2010). *Research Methodology Explained*. Paper presented at the PM-05 - Advancing Project Management for the 21st Century, Concepts Tools & Techniques for Managing Successful Projects, Crete, Greece.
- Denscombe, M. (2010). *The Good Research Guide: For Small Scale Social Reserach Projects*. Berkshire, England: McGraw Hill.
- Department of Finance. (2009). *Capital Works Management Framework: Planning and Control of Capital Costs* (GN2.2). Dublin: Department of Finance.
- Dewey, J. (1933). *How we think*. New York: D.C Heath.

- Dhillon, R. K., Jethwa, M., & Rai, H. S. (2014). Extracting Building Data From BIM with IFC. *International Journal on Recent Trends in Engineering and Technology*, 11(1).
- Dispenza, J. (2007). *Evolve Your Brain - The Science of Changing Your Mind*. United States: Health Communications.
- Dragos, D., & Neamtu, B. (2013). Sustainable Public Procurement: LCC in the New EU Directive Proposal. *European Procurement & Public Private Partnership*, 8(1), 19-30.
- Drogemuller, R., & Tucker, S. (2003). *Automating the Extraction of Quantities*. Paper presented at the CRC for Construction Innovation, Program C : Delivery Management of Built Assets, Project 2003-037-C : Managing Information Flows with Models and Virtual Environments Brisbane, Australia.
- Dumas, J., S., & Redish, J., C. (1999). *A Practical Guide to Usability Testing* (3rd ed.). Oregon, United States: IntellectBooks.
- Dzambazova, T., Krygiel, E., & Demchak, G. (2009). *Introducing Revit Architecture 2010, BIM for Beginners*. Indianapolis: Wiley Publishing.
- Eastman, C., Teicholz, P., Sachs, R., & Liston, K. (2011). *BIM handbook : A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors* (2nd ed.). Hoboken, NJ: Wiley.
- Egan, J. (1998). *Rethinking Construction - Report of the Construction Taskforce*. London; United Kingdom: HMSO.
- El-Haram, M. A., Marenjak, S., & Horner, M. W. (2002). Development of a Generic Framework for Collecting Whole Life Cost Data for the Building Industry. *Journal of Quality in Maintenance Engineering*, 8(2), 144-151.
- EPA. (2014). *Green Procurement - Guidance for the Public Sector*. Dublin; Ireland: EPA.
- Eraut, M. (1985). Knowledge Creation and Knowledge Use in Professional Contexts. *Studies in Higher Education*, 10(2), 117-133.
- European Commission. (2004). *Directive 2004/18/EC on public procurement*. Retrieved from <http://eur-lex.europa.eu/>.
- European Union. (2010). *Directive 2010/31/EU on the energy performance of buildings*. Retrieved from <http://eur-lex.europa.eu/>
- European Union. (2014). *Directive 2014/24/EU on public procurement and repealing Directive 2004/18/EC*. Retrieved from <http://eur-lex.europa.eu/>
- Eurovent. (2005). Recommendation concerning calculating of life cycle costs for air filters. Retrieved from <http://212.123.1.105/web/eurovent/web/Recommendations/REC10.pdf>
- Faulkner, X. (2000). *Usability Engineering*. Hampshire, United Kingdom: Palgrave.
- Fellows, R. F., & Liu, A. (2008). *Research methods for construction* (3rd ed.). Oxford: Blackwell.

- Ferry, D. J. O., & Flanagan, R. (1991). *Life Cycle Costing – A Radical Approach*. CIRIA Report 122: London.
- Flanagan, R., & Jewel, C. (2005). *Whole Life Appraisal for Construction*. Oxford: Blackwell.
- Forfas. (2013). *Forfas Report: Ireland's Construction Sector: Outlook and Strategic Plan to 2015*. Retrieved from http://edepositireland.ie/bitstream/handle/2262/70205/19072013-Irelands_Construction_Sector-Publication.pdf?sequence=2&isAllowed=y
- Forgues, D., Iordanova, I., Valdivesio, F., & Staub-French, S. (2012). *Rethinking the Cost Estimating Process through 5D BIM: A Case Study*. Paper presented at the Construction Research Congress 2012, West Lafayette, Indiana, United States.
- Fu, C., Aouad, G., Lee, A., Mashall-Pointing, A., & Wu, S. (2006). IFC model viewer to support nD model application. *Automation in Construction*, 15(2), 178 - 185.
- Fu, C., Kaya, S., Kagioglou, M., & Aouad, G. (2007). The development of an IFC-based lifecycle costing prototype tool for building construction maintenance. *Construction Innovation*, 7(1), 85-99.
- Fuller, S. K., & Peterson, S. R. (1996). *Life Cycle Costing Manual for the Federal Energy Management Program*. Washington, United States: US Government Printing Office.
- Fung, W. P., Salleh, H., & Rahim, F. A. M. (2014). Capability of Building Information Modeling Application in Quantity Surveying Practice. *Journal of Surveying, Construction and Property*, 5(1), 1-13.
- GCCG. (2011). *A Report for the Government Construction Client Group - Building Information Modelling (BIM) Working Party Strategy Paper March 2011*. London; United Kingdom: GCCG.
- Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge : the dynamics of science and research in contemporary societies*. London: SAGE Publications.
- Gluch, P., & Baumann, H. (2004). The Life Cycle Costing (LCC) Approach: A Conceptual Discussion of its Usefulness for Environmental Decision Making. *Building and Environment*, 39, 571-580.
- Godager, B. (2011). *Analysis of the Information Needs for Existing Buildings for Integration in Modern BIM-Based Building Information Management*. Paper presented at the 8th International Conference, May 19-20, Vilnius, Lithuania.
- Goucher, D., & Thurairajah, N. (2012). *Advantages and Challenges of Using BIM: a Cost Consultant's Perspective*. Paper presented at the 49th ASC Annual International Conference, California Polytechnic State University (Cal Poly), San Luis Obispo, California. <http://ascpro.ascweb.org/chair/welcome.php>
- Stationery Office. (2012). *EU Energy Performance of Building Regulations 2012* (S.I. No. 243 of 2012). Retrieved from http://www.seai.ie/Your_Building/BER/EPBD/SI_243_of_2012_EPBD.pdf
- Grix, J. (2010). *The Foundations of Research* (2nd ed.). Basingstoke: Palgrave Macmillan.

- Gundersen, N. A. (1998). *Annual Cost Analysis: Description and users guide to the costing model*. Oslo: Statsbygg: Building Finance Section.
- Hall, R. (2001). Prototyping for Usability of New Technology. *International Journal of Human-Computer Studies*, 55, 485-501.
- Hallberg, B., & Tarandi, V. (2011). On the use of open BIM and 4d visualisation in a predictive life cycle management system for construction works. *ITcon*, 16, 445.
- Hannele, K., Reijo, M., Tarja, M., Sami, P., Korpela, J., & Teija, R. (2012). Expanding uses of building information modelling in life-cycle construction projects. *Work: A Journal of Prevention, Assessment and Rehabilitation*, 41, 114-119.
- Hardin, B. (2009). *BIM and the Construction Management: Proven Tools Methods and Work-flows*. Indianapolis, United States: Wiley.
- Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly*, 28(1), 75-105.
- Hinett, K. (2002). Improving Learning Through Reflection - Part One. Retrieved from www.new1heacademy.ac.uk/assets/documents
- HM-Government. (2015). Digital Built Britain: Level 3 Building Information Modelling - Strategic Plan. United Kingdom: HM Government.
- Holmstrom, J., Ketokivi, M., & Hameri, A. P. (2009). Bridging Practice and Theory: A Design Science Approach. *Design Sciences*, 40(1), 65-87.
- Holzinger, A. (2005). Usability Engineering Methods for Software Developers. *Communications of the ACM*, 48, 71-74.
- Hourigan, N. (2012). *Improving the service provision of life cycle costing in Ireland's PQS offices*. (MSc. Advanced Construction Cost Mangement), DIT, Dublin.
- Howell, I., & Batcheler, B. (2005). Building Information Modelling Two Years Later - Huge Potential, Some Success and Several Limitations. Retrieved from http://www.laiserin.com/features/bim/newforma_bim.pdf
- Hunter, K., Hari, S., & Kelly, J. (2005). A whole life cycle costing input tool for surveyors in UK local government. *Structural Survey*, 23(5), 346-358.
- IES. Impact. Retrieved from <http://www.iesve.com/research/current-projects/impact>
- Iivari, J., & Venable, J. (2009). *Action Reserach and Design Science Reserach - Seemingly Similar but Decisively Dissimilar*. Paper presented at the 17th European Conference on Information Systems, Verona, Italy.
- J, H., Ketokivi, M., & Hameri, A. P. (2009). Bridging Practice and Theory: A Design Science Approach. *Design Sciences*, 40(1), 65-87.
- Jain, P., Dubey, S. K., & Rana, A. (2012). Software Usability Evaluation Method. *International Journal of Advanced Research in Computer Engineering & Technology*, 1(2), 28-33.
- Jarvinen, P. (2007). Action Research is Similar to Design Science. *Quality and Quantity*, 41, 37-54.

- Johannesson, P., & Perjons, E. (2012). *A Design Science Primer*: CreateSpace.
- Kehily, D. (2011). *Guide to Life Cycle Costing*. Dublin; Ireland: SCSI.
- Kehily, D., & Hore, A. (2012). *Life Cycle Cost Analysis Under Ireland's Capital Works Management Framework*. Paper presented at the Joint CIB W070, W092 & TG72 International Conference on Facilities Management, Procurement Systems And Public Private Partnership, Capetown, South Africa.
- Kehily, D., B., & Hore, A. (2012). Leveraging Whole Life Cycle Costs When Utilising Building Information Modelling Technologies. *International Journal of 3-D Information Modeling*, 1(4), 40-49.
- Kelemen, M. L., & Bansal, P. (2002). The Conventions of Management Research and their Relevance to Management Practice. *British Journal of Management*, 13(1), 97-108.
- Kelly, J., & Hunter, K. (2009). *Life cycle costing sustainable design*. Coventry; United Kingdom: RICS.
- Kirk, S. J., & Dell'Isola, A. J. (1995). *Life Cycle Costing for Design Professionals*. New York: McGraw-Hill.
- Kirkham, R., Alisa, M., Pimenta de Silva, A., Grindley, T., & Brondsted, J. (2004). *EUROLIFEFORM: An Integrated Probabilistic Whole Life Cycle Cost and Performance Model for Building and Civil Infrastructure*. Paper presented at the The construction and building research conference of the Royal Institution of Chartered Surveyors, London, UK.
- Kirkham, R. J. (2005). Re-engineering the Whole Life Cycle Costing Process. *Construction Management and Economics*, 23(1), 9-14.
- Kirkham, R. J. (2012). *Ferry and Brandon's Cost Planning of Buildings* (8th ed.). Oxford: United Kingdom: Blackwell Publishing.
- Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N., & Sun, M. (2003). *Whole Life Costing in Construction: A state of the art review*. Coventry; London: RICS.
- Knight, A., & Ruddock, L. (2008). *Advanced research methods in the built environment*. Chichester, West Sussex, United Kingdom ; Ames, Iowa: Wiley.
- Kuechler, W., & Vaishnavi, V. (2008). The emergence of design research in information systems in North America. *Journal of Design Research*, 7(1), 1-16.
- Latham, M. (1994). *Constructing the Team, Final Report of the Government / Industry Review of Procurement and Construction Arrangements in the UK Construction Industry*. London; United Kingdom: HMSO.
- LCI. (2013). *Integrated Project Delivery*. Retrieved from <http://www.leanconstruction.org/>
- Liu, H., Fei-Ching, & Chen, T. Y. (2010). *Teaching an End User Testing Methodology*. Paper presented at the 23rd IEEE Conference on Software Engineering Education and Training. Retrieved from [file:///C:/Users/dermot.kehily/Desktop/PDF%20\(Published%20version\).pdf](file:///C:/Users/dermot.kehily/Desktop/PDF%20(Published%20version).pdf)
- Lovegrove, S. (2014). *BIM and Cost Estimating*. Retrieved from www.exactal.com

- Maguire, D. (2015). Building Information Modelling - Boom, Bang, BIM. *Irish Building Magazine*, 1-84.
- Mann, P. (1998). Trust Your Tacit Knowledge. *Times Higher Education Supplement*.
- March, S. T., & Smith, G. F. (1995). Design and Natural Science Research on Information Technology. *Decision Support Systems*, 15, 251-266.
- Mathews, O., & Howell, G. (2005). Innovative Contractual Structure. *Lean Construction Journal*, 2(1), 46-61.
- Matipa, W. M., Cunningham, P., & Naik, B. (2010). *Assessing the Impact of New Rules of Cost Planning on Building Information Modelling (BIM) Schema Pertinent to Quantity Surveying Practice*. Paper presented at the 26th Annual ARCOM Conference, Leeds, UK.
- Matipa, W. M., Kelliher, D., & Keane, M. (2008). How a Quantity Surveyor can ease cost management at the design stage using a building product model. *Construction Innovation*, 8(3), 164-181.
- Maykut, P., & Morehouse, R. (1994). *Beginning Qualitative Research : : A Philosophic and Practical Guide*. London: Falmer Press.
- McAuley, B., Hore, A., West, R., & Rowland, D. (2013). Enhancing the Facilities Management Process Through the Application of Building Information Modelling as a Tool for Managing the Irish Public Sector Estates. *International Journal of 3-D International Modelling*, 2(4), 38-51.
- McAuley, B., Hore, A. V., & West, R. (2012a). *Implementing of Building Information Modelling in Public Works Projects*. Paper presented at the 9th European Conference on Product and Process Modelling, Reykjavik, July 25-27th.
- McAuley, B., Hore, A. V., & West, R. (2012b). *Use of BIM in Responding to Low Carbon Construction Innovations: An Irish Perspective*. Paper presented at the Joint CIB International Conference on Management of Construction: Research and Practice, Montreal, June 26th.
- McGill, I. (1995). *A Guide for Professional Management and Educational Development*. London: Kogan Page.
- McGraw-Hill. (2014). *The Business Value for BIM for Construction in Major Global Markets*. Retrieved from Massachusetts, United States:
- McLeamy, P. (n.d). Future of the Building Industry. Retrieved from <http://www.hok.com/thought-leadership/patrick-macleamy-on-the-future-of-the-building-industry/>
- McNell, D., Allison, H., Black, W., Cukrow, M., Harrison, K., Hutchins, T., . . . Wilts, D. (2011). *Building Information Modelling*. Retrieved from http://www.infocomm.org/cps/rde/xbcr/infocomm/Brochure_BIM.pdf
- Meng, X., & Harshaw, F. (2013, 2-4 September). *The Application of Whole Life Costing in PFI/PPP Projects*. Paper presented at the 29th Annual ARCOM Conference, Reading, UK.
- Miles, M. B., & Huberman, M. A. (1994). *Quantitative Data Analysis: An Expanded Sourcebook* (pp. 338). London: Sage Publications.

- Mitchell, D. (2012). *THE 5D QS: Today's Methodology in Cost Certainty*. Paper presented at the RICS COBRA, Las Vegas, Nevada.
- Monk, A., Wright, P., Harber, J., & Davenport, L. (1993). *Improving Your Human-Computer Interface: A Practical Technique*. United Kingdom: Prentice Hall International.
- Monteiro, A., & Martins, J. P. (2013). A Survey on Modeling Guidelines for Quantity Takeoff-Oriented BIM-Based Design. *Automation in Construction*, 35, 238-253.
- Moon, J. A. (1999). *Reflection in learning and professional development: theory and practice*. London: RoutledgeFalmer.
- Moore, R. (2015). *PAS-1192-2 As a BIM Collaboration Standard for the Irish AEC Industry*. (MSc. In Construction Informatics), Dublin Institute of Technology, Dublin, Ireland.
- Nagalingam, G., Jayasena, H. S., & Ranadewa, K. A. T. O. (2013). *Building Information Modelling and Future Quantity Surveyor's Practice in Sri Lankan Construction Industry*. Paper presented at the The Second World Construction Symposium 2013: Socio-Economic Sustainability in Construction, Colombo, Sri Lanka.
- Naoum, S. G. (2013). *Dissertation Research and Writing for Construction Students* (3rd ed.). New York: Routledge.
- NBS. (2014). *NBS National BIM Report 2014*. Retrieved from <http://www.thenbs.com/topics/bim/articles/nbs-national-bim-report-2015.asp>
- NIBS BuildingSMART alliance. (2012). *National BIM Standard - United States, Version 2*. Retrieved from <http://www.bim.org.tw/.%5CThesisFile%5C20120629001%5CNational%20BIM%20Standard-United%20States%20Version%202.pdf>
- Nielsen, J. (1992). Usability Engineering Life Cycle. *Computer*, 25(3), 12-22.
- Nielsen, J. (1993). *Usability Engineering*. San Diego: Academic Press.
- Nielsen, J. (1995). Applying Discount Usability Engineering. *Software, IEEE*, 12(1), 98-100.
- Nisbet, N. (2012). *UK-COBie 2.4 Requirements*. Retrieved from AEC3: <http://www.bimtaskgroup.org/cobie-uk-2012/>
- NIST. (2004). *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry* (Vol. NIST GCR 04-867, pp. 1-210). Gaithersburg, MD, United States: National Institute of Standards and Technology.
- NSW-Treasury. (2004). *Life Cycle Costing Guideline*. Retrieved from http://www.treasury.nsw.gov.au/_data/assets/pdf_file/0005/5099/life_cycle_costing.pdf
- Oduyemi, O., Okoroh, M., & Dean, A. (2014). *Barriers to Life Cycle Costing Usage*. Paper presented at the 30th Annual ARCOM Conference, Portsmouth, UK.
- OGC. (2007). *Whole-life costing and cost management - Achieving Excellence in Construction Procurement Guide*. London; United Kingdom: OGC.

- O'Keeffe, S. (2012). *Developing 6D BIM Energy Informatics for GDL LEED IFC Model Elements*. Proceedings of the 2012 International Conference on Industrial Engineering and Operations Management, Istanbul, Turkey, July 3 – 6.
- Olatunji, O. A., Sher, W., & Gu, N. (2010). Building Information Modelling and Quantity Surveying Practice. *Emirates Journal for Engineering Research*, 15(1), 67-70.
- Olmsted-Hawala, E. L., Murphy, E. D., Hawala, S., & Ashenfelter, K. T. (2010). *Think-aloud Protocols: Analyzing Three Different Think Aloud Protocols with Counts of Verbalised Frustrations in a Usability Study of an Information-rich Web Site*. Paper presented at the Professional Communications Conference, Enschede.
- Olubodun, F., Kandwa, J., Oladapo, A., & Thompson, J. (2010). An Appraisal of the Level of Application of Life Cycle Costing within the Construction Industry in the UK. *Structural Survey*, 28(4), 254-265.
- Opoku, A. (2013). The Application of Whole Life Costing in the UK Construction Industry: Benefits and Barriers. *International Journal of Architecture, Engineering and Construction*, 2(1), 35-42.
- Pelzeter, A. (2007). Building Optimisation with Life Cycle Costing - The Influence of Calculation Methods. *Journal of Facilities Management*, 5(2), 115-128.
- Redmond, A., Hore, A., West, R., Underwood, J., & Alshawi, M. (2011). *Developing a Cloud Integrated Life Cycle Costing Analysis Model Through BIM*. Paper presented at the CIB W78-W102: International Conference, Sophia Antipolis, France.
- RIAI. (2011). 2011 BIM Survey. Dublin: Ireland: Royal Institute of Architects Ireland.
- RIB. (2015). 3, 4 & 5D. Retrieved from <http://www.rib-software.com/en>
- RICS. (1986). *A Guide to Life Cycle Costing*. London; United Kingdom: RICS.
- RICS. (1987). *Life Cycle Costing: A Worked Example*. London; United Kingdom: RICS.
- RICS. (1999). Part Two: Construction Design and Economics, Section 2 Life Cycle Costing *The Surveyors' Construction Handbook*. Coventry; United Kingdom: RICS.
- RICS. (2012a). *New Rules of Measurement 1 - Order of Cost Estimating and Cost Planning for Capital Building Works (2nd ed.)*. Coventry; United Kingdom: RICS.
- RICS. (2012b). *New Rules of Measurement 2 - Bill of Quantities for Works Procurement*. Coventry; United Kingdom: RICS.
- RICS. (2014). *New Rules of Measurement 3 - Order of Cost Estimating and Cost Planning for Maintenance Works*. Coventry; United Kingdom: RICS.
- RICS. (2015). LCC: RICS Guidance Note (Draft ed.). Coventry; United Kingdom: RICS.
- Riddell, C. (2009). Building Information Modelling, Who is Liable? Retrieved from <http://christopherriddell.com/Building%20Information%20Modeling.pdf>
- Robson, C. (2011). *Real World Research: A Resource for Users of Social Research Methods in Applied Settings (3rd ed.)*. West Sussex: Blackwell.

- Sabol, L. (2008). *Challenges in Cost Estimating with Building Information Modeling*. Retrieved from Washington DC: http://www.dcstrategies.net/files/2_sabol_cost_estimating.pdf
- Sagor, R. (2005). *The Action Research Guidebook*. London: Corwin Press.
- Sattineni, A., & Bradford, R. H. (2011). *Estimating With BIM: A Survey of US Construction Companies*. Paper presented at the 28th ISARC, Seoul, Korea.
- Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research Methods for Business Students* (5 ed.). Essex, England: Pearson Education Limited.
- Saunders, M., & Tosey, P. (2012). The Layers of Research Design. *Rapport*, 30, 58-59.
- Savin-Baden, M., & Howell Major, C. (2013). *Qualitative Research: The Essential Guide to Research and Practice*. London & New York: Routledge.
- Sawhney, A. (2014). *International BIM Implementation Guide*. Coventry; United Kingdom: RICS.
- Schaude, J. (2011). *Life Cycle Cost Calculation Models for Buildings*. Retrieved from Lulea, Sweden: http://www.inpro-project.eu/media/lcc_juttaschaude.pdf
- Schön, D. A. (1991). *The reflective practitioner : how professionals think in action*. Aldershot: Arena, Ashgate.
- SCI-Network. (2011). *Whole Life Costing*. Retrieved from http://www.sci-network.eu/fileadmin/templates/scinetwork/files/Resource_Centre/Reports/State_of_the_Art_report_Whole_Life_Costing.pdf
- SCSI. (2015). Society of Chartered Surveyors Ireland. Retrieved from https://www.scsi.ie/about_us/about_us
- SEAI. (2015). Sustainable Energy Authority Ireland (SEAI). *Building Energy Rating (BER)*. Retrieved from http://www.seai.ie/Your_Building/BER/
- Seeley, I. H. (1996). *Building Economics* (4 ed.). New York: Palgrave MacMillan.
- SEMC. (2011). *Information Regarding Life Cycle Cost Calculation*. Swedish Environment Management Council.
- Shen, Z., Issa, R. A. A., & Gu, L. (2007). Semantic 3D CAD and Its Applications in the Construction Industry - An Outlook of Construction Data Visualization. *Lecture Notes in Computer Science*, 4781, 461-467.
- Shen, Z., & Issa, R. R. A. (2010). Quantitative Evaluation of the BIM-Assisted Construction Detailed Cost Estimates. *ITcon*, 15, 234-257.
- Shneiderman, B., & Plaisant, C. (2005). *Designing The User Interface: Strategies For Effective Human Computer Interaction* (4th ed.). United States: Addison Wesley.
- Smith, P. (2014). BIM and the 5D Cost Manager. *Procedia-Social and Behavioral Sciences*, 119, 475-484.
- Susman, G., & Evered, R. (1978). An Assessment of the Scientific Merits of Action Research. *Administrative Science Quarterly*, 24(4), 582-603.

- Swaffield, L. M., & McDonald, A. M. (2008). The Contractor's use of Life Cycle Costing on PFI Projects. *Engineering, Construction and Architectural Management*, 15(2), 132-148.
- Sylvester, K., & Dietrich, C. (2010). *Evaluation of Building Information Modelling (BIM) Estimating Methods in Construction Education*. Paper presented at the 46th ASC Annual International Conference, Wentworth Institute of Technology, Boston, Massachusetts.
<http://ascpro0.ascweb.org/archives/cd/2010/paper/CEUE221002010.pdf>
- Taylor, S., & Bailey, C. (2011). *Unlocking BIM Data*. Retrieved from
<http://questantinc.com/images/Articles%20and%20News%20Media/Articles/BIM%20Coding%20Paper%20Dec%202%20Final.pdf>
- TechontheNet (n.d). Tech on the Net. Retrieved from
<http://www.techonthenet.com/excel/index.php>
- TG4. (2003). *Task Group 4: Life Cycle Costs in Construction - Final Report*. Retrieved from
ec.europa.eu/DocsRoom/documents/5055/attachments/1/.../en/.../native
- Underwood, J., & Isikdag, U. (2010). *Building Information Modelling and Construction Informatics*. Hershey, New York: Information Science Reference.
- Vaishnavi, V., & Kuechler, B. (2007). Design Reserach in Information Systems. Retrieved from
<http://www.isworld.org/Researchdesign/drWoSSworld.htm>
- van Aken, J. E. (2005). Management Research as Design Science: Articulating the Research Products of Mode 2 Knowledge Production in Management. *British Journal of Management*, 16, 19-36.
- van Velsen, L., van der Geest, T., & Klaassen, R. (2007). *Testing the usability of a personalized system: comparing the use of interviews, questionairres and thinking aloud*. Paper presented at the Professional Communications Conference, Seattle, WA.
- van Manen, M. J. (1977). Linking Ways of Knowing with Ways of Being Practical. *Cirriculum Inquiry*, 6(3), 205-228.
- Voordijk, H. (2009). Construction Management and Economics: The Epistemology of a Multidisciplinary Design Science. *Construction Management and Economics*, 27(8), 713-720.
- Voordijk, H. (2011). Construction management research at the interface of design and explanatory science. *Journal of Engineering, Construction and Architectural Management*, 18(4), 334-342.
- Wahl, N. J. (2000). *Student Run Usability Testing*. Paper presented at the 13th Conference on Software Engineering Education and Training, Austin, Texas, USA.
- Whyte, A., & Scott, D. (2010). *Life-cycle costing analysis to assist design decisions: beyond 3D building information modelling*. Paper presented at the International Conference on Computing in Civil and Building Engineering, University of Nottingham.
- Wijayakumar, M., & Jayasena, H. S. (2013). *Automation of BIM Quantity Take-off To Suit QS Requirements*. Paper presented at the The Second World Construction Symposium 2013: Socio-Economic Sustainability in Construction, Colombo, Sri Lanka.

- Wong, I. L., Perera, S., & Eames, P. (2010). Goal Directed Life Cycle Costing as a Method to Evaluate the Economic Feasibility of Office Buildings with Conventional and TI-Facades. *Construction Management and Economics*, 28(7), 715-735.
- Wong, P. F., Salleh, H., & Rahim, F. A. (2014). The Relationship of Building Information Modelling (BIM) in Quantity Surveying Practice and Building Performance. *International Journal of Civil, Architectural, Structural and Construction Engineering*, 8(10), 977-982.
- Wu, S., Ginige, K., Wood, G., & Jong, S. W. (2014). *How Can Building Information Modelling (BIM) Support the New Rules of Measurement 1*. London; United Kingdom: RICS.
- Yin, R. K. (2009). *Case study research: design and methods* (4th ed.). Thousand Oaks, Calif.: Sage Publications.
- Zhou, L., Perera, S., Udeaja, C., & Paul, C. (2012). *SME Readiness of BIM: A Case Study of a Quantity Surveying Organisation*. Paper presented at the First UK Academic Conference on BIM, Newcastle upon Tyne, UK.

10 Appendices

10.1 Appendix 1 – TA Cooperative Evaluation Information

Appendix - 1a: USER PROFILE

DEVELOPING A USER PROFILE FOR THE EVALUATION – These are the characteristics of the user profile and the bounded case information of the participants selected for the user test. Item 3 states what characteristics the users must have to participate in the study. Item 4 outlines what characteristics are necessary while and item 5 outlines which of the characteristics can vary and how they might be defined. **The questionnaire on the subsequent page is derived from this user profile and will be administered before the test to determine whether the participant meets the user requirements.**

1. **Product Name: *LCC Application***
2. **General characterisation of user population:**
Quantity Surveyors carrying out Bills of Quantities and/or Cost Planning for Professional Quantity Surveying firms. (Suggested Sources – KSN, BruceShaw, Aecom)
3. **Characteristics of users that are relevant to the test:**
Takeoff & costing experience in the production of cost Plans & BOQ's
Third Level Honours Degree in Quantity Surveying
Life cycle costing experience
Excel (spreadsheet) experience
QS software experience
CostX Experience
4. **Which of the characteristics that you listed in 3. should all users in the test have in common and how will you define them?**

Experience with excel (spreadsheet) software
 basic level spreadsheet experience with inputting cost data, using basic formulae and formatting

Takeoff & costing experience in the production of cost Plans & BOQ's
 have been involved in taking off/measuring quantities and costing, cost plans or BOQ's for at least one year or more in a professional quantity surveying practice

Experience with QS software (not necessarily CostX)
 Experience using QS software for at least one year in a professional quantity surveying practice
5. **Which of the characteristics that you listed in 3. will vary in the test and how will you define them**

LCC experience
 “none” = never carried out calculations (no experience)
 “very little” = knowledge of the concept but no practical experience
 “some knowledge” = have carried out LCC calculations but no practical application
 “proficient” = carried out LCC estimates on construction projects

CostX experience
 “Novice” = No experience using CostX
 “Intermediate” = can take off 2D quantities and link them to the workbooks
 “Advanced” = can generate quantities from a BIM and use them in the workbook

Developed from - Dumas & Redish (1999) Monk et al (1993)

APPENDIX - 1b: PARTICIPANT INFORMATION SHEET

You are being invited to take part in a research study. Before you decide to do so, it is important for you to understand why the research is being done and what it will involve. Please take your time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. The information describes how you can make a contribution to the study and also ensures that you are aware of your rights as a research participant.

Thank you for reading this.

1. Background and aim of the project

The purpose of the author's overall doctorate research study is to address the requirements for Life Cycle Costing (LCC) by producing and evaluating an informed solution concept in recognition of LCC standards and methodologies, LCC calculations and leveraging BIM technologies. **The Project is being carried out as part of the researcher's doctoral studies in the University of Salford** The duration of the interview will take approximately 1 1/2hr. **The project proposal has been reviewed by the University of Salford Research Governance and Ethics Committee.**

2. Why you have been invited to participate

You will be one of a number of individuals whom have experience as a quantity surveyor and are proficient with QS software that have been invited to participate.

Taking part in the study will be entirely voluntary. It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. **To withdraw just let the researcher know by email or indicate to him verbally during the test that you wish withdraw.** A decision to withdraw at any time, or a decision not to take part, will not affect your work practice / standard of care by the health and social care services.

The way in which you are invited to participate is by attending and taking part in what is deemed a thinking aloud usability test on an LCC template that I have produced. The aim of the study is to find out how easy the system is to use? Does it calculate LCC calculations quickly and effectively and is it something that you would use if it was a QS software or embedded in QS software? Ultimately your feedback will be used to improve the system in its next iteration. This will take approximately 1 ½ hrs in DIT Bolton Street at a time that suits you. The testing method that will be used is known as cooperative evaluation thinking aloud and is addressed in more detail below.

3. Instructions for Cooperative evaluation

Thinking Aloud Cooperative Evaluation, asks you for a running commentary of what you are doing with the system and what you think is going on. The running commentary should

involve dialogue related to what you are thinking while trying to resolve each task. While you are doing this the researcher will be making notes from our discussions and other observations from your actions. The recording will be videotaped but your name will not be associated with any feedback.

You can ask questions or advise at any time. The response from me may involve a simple prompt or it may involve a more detailed explanation (coach) if necessary.

To ensure that there is a relatively continuous dialogue I may ask you appropriate questions (see examples outlined below) whenever possible. This is simply to find out what problems you are having and what you think of a certain feature. You may also give your opinions on the system or subjective satisfaction/dissatisfaction about the system or features of the system at any time.

Before the test is administered I will ask you a number of pre-test questions. The aim of these questions is to establish that each participant fits with the user profile. The response to these questions is not used as primary data but to gather background information from the participants to help me interpret data from the TA test session.

There are three scenarios in the prototype TA test. The first two scenarios revolve around the LCC of an internal single door in terms of its full replacement, minor replacement, repairs and maintenance costs. The third scenario deals with annual recurring costs; in this case electricity which is evaluated on a yearly basis. At the end of the test you will have an opportunity to ask any questions. I will also ask you a number of post-test interview questions to get your subjective feedback on the LCC tool and to garner your opinion and attitude to LCC.

I am interested in what you think so please do not treat this as an examination. If the system is not clear or anything misleads you. Any feedback is good feedback.

4. Taking part in the project –benefits

Through taking part in this project you are helping us to find answers which will be used to make recommendations in the development of a tool that can aid QS's to carry out complex timing consuming LCC calculations effectively and efficiently leveraging their cost plan or Bill of Quantities.

5. Confidentiality

If you consent to take part in this study we wish to assure you that all your details will be anonymised and all information will be stored in a secure, locked cabinet with access only to researchers in the project. Any video tape and interview material such as notes and transcripts will be destroyed once the project is completed. All information collected will be kept strictly confidential.

You do not have to take part. Even if you initially agreed to be interviewed you may withdraw at any point without giving reasons. If that is the case we thank you for considering the invitation and letting us know you no longer wish to be interviewed.

6. After the Project has finished – Results of the Study

This is a two year project. We will be making sure, at different intervals during this time that participants are kept informed of our progress. You are more than welcome to follow up with me on the project at any time. In addition I may publish reports and papers which focus on different findings from the tests. I wish to assure you that at no time will anyone be identified unless written permission has been given for us to do so.

7. Decisions

If you are happy to take part now you have read this information we would be grateful if you could sign the attached consent form and either return to the address below or bring with you to the interview. We would be grateful if you could let us know your intention to attend at the chosen time and date.

Thank you for your time and look forward to meeting you.

We welcome any suggestions or questions regarding both the content of this information sheet or the attached Project Summary document.

Signed: Researcher:

Date:.....

Address: Dermot Kehily
Dublin Institute of Technology
Bolton Street
dermot.kehily@dit.ie

Appendix – 1c: SCENARIO AND TASK LIST – Total Test Time Approx (8min 45sec)

SCENARIO 1 – Total Approx Time (5min)

The following cost plan item for a single door is to be replaced in full in 25years.

‘Internal single door, flush veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery, painting’

Task 1 – Approx Time (1min)

Open the excel file on the desktop and click on the first sheet tab **‘Project Details’**. Enter the following LCC project data requirements into the appropriate cells in yellow

Escalation Rate: 2.50%

Discount Rate: 5.90%

Project Period: 30

For 2.50% enter the fraction 0.0250 and likewise for the escalation rate.

Complete -- Yes/No

Task 2 – Approx Time (4min)

Click on the next sheet **‘Replacement’**, enter the description for the cost plan item in the relevant description cell for the item.

‘Internal single door, flush veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery, painting’

- a. Enter a **Qty of 25nr** and a **Rate of 1100**.
- b. Enter a **Replacement period of 20 years** and a **Maintenance Factor of 1.10** in the relevant cells.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
30,250	49,568	15,750

Complete -- Yes/No

SCENARIO 2 – Total Approx Time (6min)

The cost plan item for a single door is subject minor replacement, repairs and scheduled planned preventative maintenance (ppm) throughout the study period. These items are estimated based on when the actions will happen (years) and the percentage (factor) of the cost plan item that will apply in the calculation. The same project details will apply.

Task 3 – Approx Time (1min)

Click on the next sheet ‘Minor Repairs PPM’. Enter the following maintenance actions in the maintenance action description cell

(1) Replace Seals, (2) Replace Ironmongery, (3) Repaint.

Complete -- Yes/No

Task 4 - Approx Time (1min)

Enter in the following maintenance periods and maintenance factors in their appropriate cells.

Replace seals = Maintenance Period 1 ‘5’ years & Maintenance Factor **0.05** (5%)

Replace Ironmongery = Maintenance Period 2 ‘15’ years and Maintenance Factor **0.35** (35%)

Repaint = Maintenance Period 3 = ‘7’ years and Maintenance Factor **0.20** (20%)

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
49,500	81,650	27,196

Complete -- Yes/No

Task 5 – Approx Time (1min)

Change the following details and note how it changes the results

Replace Ironmongery = Maintenance Period ‘10’ years and Maintenance Factor **0.40** (40%)

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
63,250	102,700	35,478

Complete -- Yes/No

Task 6 – Approx Time (3min)

Instead of estimating the repairs and maintenance costs as a percentage costs from the cost plan item. The spreadsheet can be used to input and calculate the actual maintenance costs.

Input the following details in the description cells under the internal single doors cost plan item.

	QTY		Unit Rate
(1) Replace Seals	25	nr	65.00
(2) Replace Ironmongery	25	nr	250.00
(3) Redecorate	25	nr	85.00

Enter the same maintenance periods as in **task 4** (see below) in the ‘Maintenance Period’ column and enter an uplift factor of **1.10** in the ‘Maintenance Factor’ column to account for demolition and removal of the existing item.

Replace seals = Maintenance Period 1 ‘**5**’ years

Replace Ironmongery = Maintenance Period 2 ‘**15**’ years

Repaint = Maintenance Period 3 = ‘**7**’ years

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
10,725	16,892	6,297
13,750	24,378	6,797
9,350	14,674	5,456

Complete -- Yes/No

SCENARIO 3 – Total Approx Time (1min 30sec)

Many life cycle costs items are calculated based on the fact that they apply on an annual basis. These include occupancy costs such as insurance costs, postal costs and operations costs such as annual energy costs.

In this scenario the annual electricity cost is calculated and the total life cycle cost for electricity calculated over the study period. Energy costs often escalate at a greater rate than construction goods and services so a different escalation rate will be applied in the second task of the scenario.

Task 7 – Approx Time (1min)

Click on the last sheet 'annual'. Enter in the following details for electricity consumption:

Description: **Electricity**,
 Qty: **25000**,
 Unit: **kwhr**,
 Rate: **1.5**
 Number of Occurrence per year: **1**

Uplift factor; **1.00**

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
1,125,000	1,687,510	705,784

Complete -- Yes/No

Task 8 – Approx Time (30sec)

Override the project **escalation rate** of 2.5% by inputting **4.5%** (0.045) into the relevant cell.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
1,125,000	2,390,715	921,393

Appendix – 1d: INSTRUCTIONS & GUIDELINES FOR EVALUATION

INSTRUCTIONS FOR EVALUATOR/CHECKLIST – Instructions and procedures to be adhered to by the evaluator/tester when carrying out the test.

<p>1. Before the start of the investigation, ensure everything is in full working order. This must include:</p> <ul style="list-style-type: none"> • A properly working keyboard • A properly functioning browser • Home page displaying • Links are correct and functional • Log file is ready to be used • Camera/Tape recorder is working and audio/video is good quality • Task sheet, observation sheet and pre-test questionnaire are ready • Blank copy of consent agreement • Pen available for participant to sign necessary forms and for the evaluator to take notes during the test
<p>2. Introduce the user to the computer. Ensure that the user is fully comfortable with the seating, the positioning of keyboard and mouse, monitor and brightness.</p>
<p>3. Start Recording – Do this early as you might forget – it also validates that you are following correct procedures.</p>
<p>4. Once the user is comfortable, and not before, ensure that they aware of the purpose of the investigation, along with the task they are to do. Explain the nature of cooperative evaluation and what is involved relating to participant/tester dialogue.</p>
<p>5. Make sure the user has a copy of the scenarios, the tasks and anything else they need. Give them a period of time to read the tasks and ask any questions.</p>
<p>6. Once this is understood, the user will be asked to sign an agreement stating what is expected of them, plus a statement that the user can terminate the investigation at any time.</p>
<p>7. After all previous conditions have been satisfied, the investigation can begin.</p>
<p>8. Ask the participant to read and fill out the pre-test questionnaire.</p>
<p>9. Start the TA test with the first scenario and task</p>
<p>10. During the investigation, notes should be taken on the physical actions of the user. Check for signs of frustration or boredom, for example to drumming of fingers or yawning, and the time this happens. Observe and make notes on how the product is performing paying attention to how the user is feeling.</p>
<p>11. After the Cooperative evaluation carry ask Post Test Questions</p>
<p>12. When the user has completed the investigation, they must be thanked for their time and effort. The user should be made aware that the results obtained are to be made available on request.</p>
<p>13. Turn Off Video Camera.</p>

EVALUATOR BEHAVIOURAL GUIDELINES – Guidelines/protocols to be adhered to by the evaluator/tester when carrying out the test.
1. Introduce yourself and emphasise that you are testing the system and not the user
2. A friendly approach to the user should be adopted at all times. However care must be taken not to become over friendly – a degree of formality must be maintained. Refer to the user by their first name, or any other preferred name given by them.
3. The evaluator must be open and honest within reason. No question should be ignored, and the evaluator should treat the user with respect at all times.
4. The evaluator should avoid making the user feel uncomfortable in any way whatsoever.
5. If the user wishes to terminate the investigation, at any time, or for whatever reason the evaluator should not prevent this. The evaluator should not force the user to remain in the investigation if the user does not wish to continue.
6. During the investigation, the evaluator must resist all temptations to distract the user other than asking them questions. This will include, but not limited to, unnecessary or unavoidable noise, physical distraction, movement to excessive fidgeting consuming food or drink
7. The evaluator must keep the order of events (as defined in the INSTRUCTIONS FOR EVALUATOR section) the same for each participant – a divergence will ensure inconsistent results.
8. The evaluator should make clear to the user exactly what the task is to be performed. This will prevent the user from forming incorrect conceptualisations about the task in hand.

Faulkner (2000), Dumas & Redish (1999), Monk et al. 1993

Appendix 1e: Nature of dialogue in TA

Information for Cooperative evaluation: based on MONK et al. (1993)

Included hereafter are the instructions for the usability test. These instructions were included in the participant information sheet but will also be revisited on the day and verbally communicated to the participant prior to the test being administered.

This is what is called a *Thinking Aloud (TA) Cooperative Evaluation*, where I am asking you for a running commentary of what you are doing with the system and what you think is going on. The running commentary should involve dialogue related to what you are thinking while trying to resolve each task. While you are doing this I will be making notes from our discussions and possibly other observations from your actions. The recording will be videotaped but your name will not be associated with any feedback.

You can ask questions or advise at any time. The response from me may involve a simple prompt or it may involve a more detailed explanation (coach) if necessary.

To ensure that there is a relatively continuous dialogue I may ask you appropriate questions (see examples outlined below) whenever possible. This is simply to find out what problems you are having and what you think of a certain feature. You may also give you opinions on the system or subjective satisfaction/dissatisfaction about the system or features of the system at any time.

The aim of the study is to find out how easy the system is to use. Does it calculate LCC calculations quickly and effectively and is it something that you would use if it was a QS software or embedded in QS software. Ultimately your feedback will be used to improve the system in its next iteration.

Before I administer the test I will ask you a number of *pre-test questions*. The aim of these questions is to establish that each participant fits with the user profile. The response to these questions is not used as primary data but to gather background information from the participants to help me interpret data from the TA test session.

There are three scenarios in the prototype *Thinking Aloud Cooperative Evaluation*. The first two scenarios revolve around the LCC of an internal single door in terms of its full replacement, minor replacement, repairs and maintenance costs. The third scenario deals with annual recurring costs; in this case electricity which is evaluated on a yearly basis.

We are interested in what you think so please do not treat this as an examination. If the system is not clear or anything misleads you. Any feedback is good feedback.

****Note briefly each occurrence of unexpected behaviour and each comment on the usability of the system on the observation sheets. Do not let note taking interfere with the primary task of creating a dialogue.*

Monk et al. 1993 p81-82

Appendix - 1f: PRE-TEST QUESTIONS

Product Name: *LCC*

Participant # _____ Date of Test _____

- **Which description below would best define your job title**
 Professional Quantity Surveyor (PQS)
 Contractors Quantity Surveyor
 Junior Quantity Surveyor
 Other _____

- **Level of education/qualification**
 Ordinary Degree in Quantity Surveying
 Hons Degree in Quantity Surveying
 Hons Degree in Quantity Surveying & MRICS/MSCSI

- **What do you actually do in your job? (Check all that apply)**
 Takeoff/measurement of quantities for cost plans
 Takeoff quantities for Bills of Quantities
 Cost and prepare Cost Plans
 Carry out Life Cycle Costing Estimates

- **How long have you being doing this work**
 12 months – 2 years
 2 years – 5 years
 5 years - 10 years
 10 years or more

- **How would you describe your level of expertise in Excel or any other spreadsheet application**
 “novice” = basic data inputting skills and basic formatting of cells and sheets
 “intermediate” = using basic formulae, generating graphs from data, linking sheets
 “advanced” = can use excel functions such as advanced formulae and macros

- **Which Quantity Surveying programmes are you proficient in? (Check all that apply)**
 Buildsoft Global Estimating
 BT2
 CostX
 Autodesk QTO
 CATO
 Other: Please State _____

- **How would you describe your level of experience with BIM (check one)**
 "Novice" = no experiece using 2D or 3D take off for QS practices
 "Intermediate" = use 2D quatity take off from onscreen takeoff tools
 "Advanced" = can generate or extract quantities from a BIM 3D model

- **How would you describe your level of experience in Life Cycle Costing (check one)**
 “none” = never carried out calculations (no experience)
 “very little” = knowledge of the concept but no practical experience
 “some knowledge” = know how to carry out the calculations but no practical application
 “proficient” = Carried out LCC estimates on construction projects

- **If you have CostX experience, can you outline the extent of your proficiency (check one)**
 “Novice” = No experience using CostX
 “Intermediate” = can take off 2D quantities and link them to the workbooks
 “Advanced” = can generate quantities from a BIM and use them in the workbook

Appendix – 1g: DEBREIF/Post Test Questions

Product Name: LCC Prototype

Participant # _____ Date of Test _____

- Did you fully understand the pre-test instructions prior to test
- Did you find the recording equipment intrusive
- Did you find it easy to talk continuously
- Could you follow the tasks easily
- Was there anything about the test or tasks you did not like
- Have you used BIM in your work practices and if so to what extent
- If not - why are you not using BIM technology
- Have you ever carried out LCC estimates or calculations and to what extent
- If not - why do you not carryout LCC (what are the barriers)
- If so - What software have you used to carry out the calculations
- What do you believe are the benefits to LCC on construction projects
- Do you think LCC is a worthwhile practice for QSs
- Do you think you could develop this template or a similar version with necessary formulae to carry out LCC calculations on your own
- If you had this system or a similar application with LCC embedded, would you use it in your work
- Is it evident that you could use this template to do a complete whole life cycle cost estimate
- What do you think is the best thing about the system
- Do you have any recommendations/suggestions regarding the system
- Does this system effectively demonstrate how BIM can be used to carryout LCC
- After using this system and engaging in this process has it changed your attitude in any way to using BIM technologies for QS practices
- After using this system and engaging in this process has it changed your attitude in any way to carrying out LCC or providing this service for your clients

Appendix 1h: AGREEMENT/CONSENT FORM	Yes	No
<p>I confirm that I have read and understood the participant information sheet dated for the above study and what my contribution will be.</p> <p>Taking part in the project will include being interviewed and recorded (audio or video).</p> <p>I am physically comfortable with the use of this computer and its related facilities.</p> <p>I am aware of the task(s) expected of me, and find the instructions acceptable.</p> <p>I understand that my taking part is voluntary; I can withdraw from the study at any time and I do not have to give any reasons for why I no longer want to take part</p> <p>I am satisfied with the conduct of the evaluator thus far.</p> <p>I can ask questions at any time and I understand the evaluator can ask me questions at any time</p> <p>I understand my personal details such as phone number and address will not be revealed to people outside the project.</p> <p>I understand that my words may be quoted in publications, reports, web pages, and other research outputs but my name will not be used or associated with the data.</p> <p>I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of that data and if they agree to the terms I have specified in this form.</p> <p>I understand that other researchers may use my words in publications, reports, web pages, and other research outputs according to the terms I have specified in this form.</p> <p>I agree to assign the copyright I hold in any materials related to this project to Dermot Kehily</p> <p>Signed:</p> <p>_____participants signature</p> <p>_____date</p> <p>_____researcher/evaluators signature</p> <p>_____date</p>		

Appendix – 1i: SCENARIO AND TASKS LIST – Total Test Time Approx (8min 45sec)**SCENARIO 1 – Total Approx Time (2min)**

This scenario extracts quantities from the model using quantities defined from the Revit families in the Revit model.

Task 1 – Approx Time (1min)

Click '**Drawings**' tab and click on '**Add**' icon and select '**Warehouse 2014**'; '**Open**' and '**Insert**'.

Click '**Dimensions**' tab and click on '**Import**' icon and select '**Import Dimensions using BIM Template**' select '**BIM Import Revit General**' and '**Open**'.

Un-collapse the '**Doors**' dimension group folder to see the 9no Internal Doors

Complete -- Yes/No

SCENARIO 2 – Total Approx Time (5min)

The following cost plan item for a single door is to be replaced in full in 25years.

‘Internal single door, flush veneered both sides, including softwood frame & hardwood architraves, lining and stops, ironmongery, painting’

Task 2 – Approx Time (2min)

Open the LCC workbook by clicking the ‘**Costing View**’ tab. Enter the following LCC project data requirements into the appropriate cells in the ‘**Calc**’ sheet.

Construction Inflation Rate: 0.025 (2.5%)

Discount Rate: 0.059 (5.90%)

Period (Years): 30

Display Cash Flow as: NPV

Complete -- Yes/No

Task 3 – Approx Time (4min)


Click back to the ‘**Cost**’ sheet and double click on the ‘**Subtotal**’ column for ‘**2.1 Major Maintenance and Replacement**’; ‘**(32) Internal Wall Completions**’ .

Drag and drop the dimension group ‘**IntSgl (1) 910 x 2110mm**’ into the quantity cell for the internal door description in the LCC workbook and select ‘update’.

- c. Enter a **Rate of 1100**.
- d. Enter a **Replacement period of 20 years** and a **Uplift Factor of 1.10** in the relevant cells.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
10,890	17,845	5,670

Return to the summary page by clicking by return arrow in left corner. 

Complete -- Yes/No

SCENARIO 3 – Total Approx Time (6min)

The cost plan item for a single door is subject **minor replacement, repairs and scheduled planned preventative maintenance (ppm)** throughout the study period. The same project details will apply.

Task 4 – Approx Time (2min)

Double Click on the ‘**Subtotal**’ column of ‘**2.4 Minor Replacement Repairs and PPM Costs**’ – ‘**(32) Internal Wall Completions**’.

Drag and drop again the dimension group ‘**IntSgl (1) 910 x 2110mm**’ into the quantity cell for the internal door description in the LCC workbook and select ‘update’.

Enter in the following maintenance periods and maintenance factors in their appropriate cells.

Replace seals = Maintenance Period 1 ‘**5**’ years & Maintenance Factor ‘**0.05**’ (5%)

Replace Ironmongery = Maintenance Period 2 ‘**15**’ years and Maintenance Factor ‘**0.35**’ (35%)

Repaint = Maintenance Period 3 = ‘**7**’ years and Maintenance Factor ‘**0.20**’ (20%)

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
17,820	29,394	9,791

Complete -- Yes/No

Task 5 – Approx Time (1min)

Change the following details and note how it changes the results

Replace Ironmongery = Maintenance Period 2 ‘**10**’ years and Maintenance Factor **0.40** (40%)

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
22,770	36,972	12,772

Complete -- Yes/No

Task 6 – Approx Time (3min)

Staying on the same sheet

Instead of estimating the repairs and maintenance costs as a percentage cost from the cost plan item. The spreadsheet can be used to input and calculate the actual maintenance costs.

Input the following details in the description cells under the internal single doors cost plan item and drag and drop dimension group door qty into qty cells in the workbook.

	Unit Rate
(4) Replace Seals	nr 65.00
(5) Replace Ironmongery	nr 250.00
(6) Repaint	nr 85.00


Replace seals = Maintenance Period - **'5' years**, & Uplift Factor – **1.1**

Replace Ironmongery = Maintenance Period - **'15' years** & Uplift Factor – **1.1**

Repaint = Maintenance Period - **'7' years** & Uplift Factor – **1.1**

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
3,861	6,081	2,267
4,950	8,776	2,447
3,366	5,283	1,964

Return to the summary page by clicking by return arrow in left corner. 

Complete -- Yes/No

SCENARIO 4 – Total Approx Time (1min 30sec)

Many life cycle costs items are calculated based on the fact that they apply on an annual basis. These include occupancy costs such as insurance costs, postal costs and operations costs such as annual energy costs.

Task 7 – Approx Time (1min)

Double click on ‘Subtotal’ Column for ‘3.0 Operations Costs (Annual)’ – 3.2.1 Fuel Costs (electricity).

Drag and drop ‘GFA’ dimension group into the Qty cell and click update.

Enter in the following details for electricity consumption:

Rate: **3.50**

Number of Occurrence per year: **1**

Factor; **1.00**

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
25,109	37,663	15,752

Complete -- Yes/No

Task 8 – Approx Time (30sec)

Override the project **escalation rate** by inputting **4.5%** (0.045) into the relevant cell.

Check your answer – did you get the following answers?

Real Costs	Escalated Costs	Present Value
25,109	53,358	20,564

Complete -- Yes/No

10.2 Appendix 2 – Data Analysis Phases

APPENDIX 2a: PHASE 1 - OPEN CODING				
Nr	Code	Name	Sources (Transcripts & Video)	Units of Meaning Coded
	1.0	Debriefing	12	85
1	1.1	Carried out LCC calculations	6	6
2	1.2	What software did you use	6	13
3	1.3	Develop LCC template on your own	9	15
4	1.4	If you had would you use it in work	6	6
5	1.5	Built into QS software	6	9
6	1.6	Evident to do WLCC using template	9	10
7	1.7	Best thing about Prototype	6	6
8	1.8	Worst Thing about Prototype	8	13
9	1.9	Any recommendations	6	7
	2.0	Emergent Codes	12	407
10	2.1	Applications & uses of LCC template	8	22
11	2.2	Barriers to LCC	9	22
12	2.3	BIM	6	13
13	2.4	Cash Flows	9	24
14	2.5	Check Validity & Calculations	7	8
15	2.6	Client demand willing to pay	3	4
16	2.7	Collaboration between FM and QS to produce estimate	1	1
17	2.8	Confusion with Task	11	32
18	2.9	Educational Tool	11	43
19	2.10	Fluidity and Changeability	5	8
20	2.11	Graphical representation	4	5
21	2.12	Inaccuracies-deficiencies in template	12	51
22	2.13	Like a tool in itself	1	2
23	2.14	Marketing Tool	1	1
24	2.15	Notes or guidance for user	1	1
25	2.16	Prefers separate line items for maintenance costs	2	3
26	2.17	Professional Experience with LCC	7	11
27	2.18	Study Period	1	1
28	2.19	Summary Tab	11	19
	2.20	Understanding of LCC	12	123
29	2.20.1	Confusion of LCC terminology	9	19
30	2.20.2	Full replacement Sheet	5	5
31	2.20.3	Item Specific Escalation	12	21
32	2.20.4	Occurrences in annual Costs	9	11
33	2.20.5	Periodic Maintenance Replacement & Factor	11	27
34	2.20.6	Setting up similar Template	4	4
35	2.20.7	Taking information from cost plan	7	15
36	2.20.8	Uplift Factor	10	19
37	2.20.9	Where in supply Chain LCC is used	1	1
38	2.21	Use of Excel Experience	8	11
39	2.22	Value Added Service	1	1
40	2.23	Would this be already developed	1	1
	3.0	Evaluation of Test	6	38
41	3.1	Understanding of pretest instructions	6	6
42	3.2	Recording Equipment Intrusive	6	6
43	3.3	Easy to Talk Continuously	6	7
44	3.4	Follow Tasks Easily	6	13
45	3.5	Anything did not Like	5	6
	4.0	Scenarios	12	117
46	4.1	Task 1	12	15
47	4.2	Task 2	12	18
48	4.3	Task 3	12	12
49	4.4	Task 4	12	15
50	4.5	Task 5	12	13
51	4.6	Task 6	12	16
52	4.7	Task 7	12	13
53	4.8	Task 8	12	15
	5.0	Thinking Aloud	12	148
54	5.1	Ease of Use	12	48
55	5.2	Easy to Learn	7	11
56	5.3	Effectiveness	12	47
57	5.4	Low Error Rate	5	7
58	5.5	Satisfaction	8	35

Appendix 2b: PHASE 2 - CATEGORISATION OF CODES				
Nr	Code	Name	Sources (Transcripts & Video)	Units of Meaning Coded
	1.0	Debriefing	12	78
1	1.1	Carried out LCC calculations	6	6
1	1.1.1	No have not carried them out	2	2
2	1.1.1.1	Only in Collage	3	3
3	1.1.2	Yes Professionally	1	1
4	1.1.2.1	Discussed them but no calculations	1	1
2	1.2	What software did you use	6	13
5	1.2.1	Custom	5	11
6	1.2.2	Excel	6	13
3	1.3	Develop LCC template on your own	9	15
7	1.3.1	No	7	7
8	1.3.2	Yes	5	8
4	1.4	If you had would you use it in work	6	6
9	1.4.1	Yes	4	4
10	1.4.1.1	Comparative Analysis	1	1
11	1.4.1.2	Depends on client demand	2	2
5	1.5	Built into QS software	6	9
12	1.5.1	Easier - More Likely to do LCC	5	6
13	1.5.2	QS don't do it because systems aren't there	2	2
14	1.5.3	Spreadsheet can be imported into other packages	3	4
15	1.5.4	Yes - Value added Service	1	1
6	1.6	Evident to do WLCC using template	9	10
13	1.6.1	Use Cost Plan & or Bill - Copy & Paste	9	10
7	1.7	Best thing about Prototype	6	6
14	1.7.1	Automation of Calculations	3	3
15	1.7.2	Getting user to think of life cycle	1	1
16	1.7.3	Leveraging the cost plan	1	1
17	1.7.4	Spreadsheet Form	2	2
8	1.8	Worst Thing about Prototype	8	13
15	1.8.1	Appearance - Layout could be enhanced	7	11
16	1.8.2	Hide information you don need	1	2
17	1.8.3	Lock down Cells	5	5
18	1.8.4	Separate tabs for cash flows	5	5
19	1.8.5	Some sort of prompt Guidance initially	5	6
20	1.8.6	Some Terminology needs to be explained	1	2
	2.0	Emergent Codes	11	689
9	2.1	Applications & uses of LCC template	11	57
21	2.1.1	Applicable to concept and detailed estimates	3	5
22	2.1.2	As a Contractors VE Tool	1	1
23	2.1.3	Holistic Client Service	2	2
24	2.1.4	LCA	1	1
25	2.1.5	Like a tool in itself	2	3
26	2.1.6	Marketing Tool	1	2
27	2.1.7	Operations	1	1
28	2.1.8	PPPs	2	2
29	2.1.9	Sensitivity Analysis	3	3
30	2.1.10	To address to alternative items	7	15
10	2.2	Barriers to LCC	9	59
31	2.2.1	Calculations	7	15
32	2.2.2	Client requirements	3	5
33	2.2.3	Get LCC info from Supplier	1	2
34	2.2.4	Its More a Design Issue	1	1
35	2.2.5	Link with LCA	0	0
36	2.2.6	Overlapping of services	1	1
37	2.2.7	Presentation of the LCC estimate	1	2
38	2.2.8	Technology	6	6
39	2.2.9	Time Intensive	1	2
40	2.2.10	What life Spans to Use	2	3
11	2.3	BIM	6	22
41	2.3.1	Enhance Visual Presentation	2	3
42	2.3.2	Getting information from the object	2	4
43	2.3.3	Save time for other activities	1	1
44	2.3.4	Where spreadsheet can be linked to BIM	1	1
12	2.4	Cash Flows	9	58
45	2.4.1	Auto fills Cash Flows	1	2
46	2.4.2	Cash flows under each other - in the same frame	5	6
47	2.4.3	Drill down detail	5	5
48	2.4.4	Graph Cash Flows	1	1
49	2.4.5	Hide Information you don't need	7	15
50	2.4.6	Lock cells	5	5
51	2.5	Check Validity & Calculations	7	10
52	2.6	Collaboration between FM and QS to produce estimate	1	1
13	2.7	Confusion with Task	11	51
53	2.7.1	Task 1 - Project Details Label items	4	4
54	2.7.2	Task 3 - Separate Lines or in One Cell	1	1
55	2.7.3	Task 3 - Starts with lower half of sheet	1	1
56	2.7.4	Task 4 - Calculations Working on One Line	1	2
57	2.7.5	Task 6 - Enters same factors as Task 4	3	4
58	2.7.6	Task 7 - Input Years in Occurrences	1	1
59	2.7.7	Task 8 - wrong sheet to override escalation	4	4
14	2.8	Educational Tool	11	101
60	2.8.1	Capital vs. LCC	1	1
61	2.8.2	Demonstrates how you can leverage Cost Plans	5	12
62	2.8.3	Helps think about usage in a facility	2	2
63	2.8.4	Highlights process of LCC	5	11
64	2.8.5	Understand how cyclical LCC affects cash flows	4	11
65	2.8.6	Understand how escalation & discount affect LCC	4	8
66	2.8.7	Uses the tool to explain PV	3	4
67	2.8.8	Uses to explain terminology	4	8
68	2.9	Fluidity and Changeability	6	9
15	2.10	Graphical representation	4	10
69	2.10.1	Demonstrate Graphs	2	2
70	2.10.2	Visual link to options	1	2
16	2.11	Inaccuracies-deficiencies in template	13	115
71	2.11.1	Drill down detail	6	9
72	2.11.2	How do I know calculations are correct	1	1
73	2.11.3	Input Prompts - Guidance	7	9
74	2.11.4	Label as project details	2	4
75	2.11.5	Lock - hide content of cells so they cant be change	5	7
76	2.11.6	More Specific Column Titles	2	4
77	2.11.7	More than four replacement items	1	1
78	2.11.8	On replacement items in one cell	3	4
79	2.11.9	Percentages vs. Factors	3	4
80	2.11.10	Project Specific Escalation	3	4
81	2.11.11	Study Period	1	1
82	2.11.12	Too much scrolling for cash flows	6	16
83	2.12	Prefers separate line items for maintenance costs	2	3
17	2.13	Professional Experience with LCC	7	20
84	2.13.1	Alternatives	5	8
85	2.13.2	PPP	1	1
18	2.14	Summary Tab	11	37
86	2.14.1	Filter information	2	2
87	2.14.2	Overall summary	3	4
88	2.14.3	Show level of detail in a drill down	7	10
19	2.15	Understanding of LCC	12	125
89	2.15.1	Confusion of LCC terminology	9	19
90	2.15.2	Full replacement Sheet	5	6
91	2.15.3	Item Specific Escalation	12	21
92	2.15.4	Occurrences in annual Costs	9	11
93	2.15.5	Periodic Maintenance Replacement & Factor	11	27
94	2.15.6	Setting up similar Template	4	4
95	2.15.7	Taking information from cost plan	7	16
96	2.15.8	Uplift Factor	10	19
97	2.15.9	Where in supply Chain LCC is used	1	1
20	2.16	Use of Excel Experience	8	11
98	2.16.1	Advantage to be familiar with Excel	8	10
99	2.16.2	Due to experience with Excel it will quicken learning	8	11
100	2.16.3	Validates calculations - transparent and understandable	4	5
	3.0	Evaluation of Test	6	38
101	3.1	Understanding of pretest instructions	6	6
102	3.2	Recording Equipment Intrusive	6	6
103	3.3	Easy to Talk Continuously	6	7
104	3.4	Follow Tasks Easily	6	13
105	3.5	Anything did not Like	5	6
	4.0	Scenarios	12	115
106	4.1	Task 1	12	13
21	4.2	Task 2	12	18
107	4.2.1	Label Replacement 'Years'	1	1
22	4.3	Task 3	12	12
108	4.3.1	Confused entering text task 3 in one cell	2	2
109	4.3.2	Could put on 3 different rows	2	2
110	4.3.3	Starts with lower half of sheet for Task 3	1	1
23	4.4	Task 4	12	15
111	4.4.1	Confused inputting	2	3
112	4.4.2	Corrects input error	1	1
113	4.4.3	Demonstrates understanding of Task 4 cyclical map	1	1
114	4.4.4	What if we had four items	1	1
115	4.5	Task 5	12	13
24	4.6	Task 6	12	16
116	4.6.1	Input error	1	1
117	4.6.2	Why do we have 1.1 uplift here and not in task 4	1	1
25	4.7	Task 7	12	13
118	4.7.1	Easy to do and understand because its every year	1	1
26	4.8	Task 8	12	15
119	4.8.1	Goes back to first sheet	3	3
	5.0	Thinking Aloud	12	150
27	5.1	Ease of Use	12	48
120	5.1.1	Automatic calculations	8	18
121	5.1.2	Ease Inputting Information	11	22
122	5.1.3	Familiar	1	1
123	5.1.4	Handy	1	3
124	5.1.5	Intuitive	3	5
125	5.1.6	Simplifies	3	4
126	5.1.7	Straightforward	6	17
127	5.1.8	Useful	1	1
128	5.1.9	User Friendly	3	3
28	5.2	Easy to Learn	7	11
129	5.2.1	Intuitive	0	0
130	5.2.2	Learning Curve	2	3
29	5.3	Effectiveness	14	47
131	5.3.1	Applications of use	1	1
132	5.3.2	Facilitate LCC	1	2
133	5.3.3	Facilitates more informed decision making	1	1
134	5.3.4	Populates Cash Flows	6	6
135	5.3.5	Very Clever	1	1
136	5.4	Low Error Rate	5	7
30	5.5	Satisfaction	9	37
137	5.5.1	Beneficial	1	1
138	5.5.2	I like the way	1	1
139	5.5.3	Interesting	1	1
140	5.5.4	That's great - Very Good - Perfect - Excellent - Brilliant	3	10
141	5.5.5	There is a lot on information there	1	2
142	5.5.6	Thought put into it	1	1
143	5.5.7	Well laid out	1	1

Appendix 2c: PHASE 3 - CODING ON				
Nr	Code	Name	Sources (Transcripts & Video)	Units of Meaning Coded
	1.0	Debriefing	12	46
1	1.1	Carried out LCC calculations	6	6
2	1.1.1	No have not carried them out	2	2
1	1.1.1.1	Only in College	3	3
3	1.1.2	Yes Professionally	1	1
2	1.1.2.1	Discussed them but no calculations	1	1
4	1.2	What software did you use	6	13
3	1.2.1	Custom	5	11
4	1.2.2	Excel	6	13
5	1.3	Develop LCC template on your own	9	15
5	1.3.1	No	7	7
6	1.3.2	Yes	5	8
6	1.4	If you had would you use it in work	6	6
7	1.4.1	Yes	4	4
7	1.4.1.1	Comparative Analysis	1	1
8	1.4.1.2	Depends on client demand	2	2
8	1.5	Advantages of Template - EFFECTIVENESS	6	6
9	1.5.1	Advantage of it in Spreadsheet	8	11
9	1.5.1.1	Advantage to be familiar with Excel	8	10
10	1.5.1.2	Check Validity & Calculations	7	10
11	1.5.1.3	Demonstrate Graphs	2	2
12	1.5.1.4	Link to BIM	1	1
13	1.5.1.5	Spreadsheet can be imported into other packages	3	4
14	1.5.1.6	Universal Medium for QS so Validates calculations - transparent	5	6
15	1.5.2	Applicable to concept and detailed estimates	3	5
16	1.5.3	Autofills Cash Flows	8	14
10	1.5.4	Automation of Calculations	8	25
17	1.5.4.1	Saves user time	6	6
18	1.5.5	Collaboration between FM and QS to produce estimate	1	1
19	1.5.6	Ease of input	11	24
11	1.5.7	Ease of Use Words	12	48
20	1.5.7.1	Easy to do and understand because its every year	1	1
21	1.5.7.2	Familiar	1	1
22	1.5.7.3	Handy	1	3
23	1.5.7.4	Intuitive	3	5
24	1.5.7.5	Simplifies	3	4
25	1.5.7.6	Straightforward	6	17
26	1.5.7.7	Useful	1	1
27	1.5.7.8	User Friendly	3	3
28	1.5.6	Easier - More Likely to do LCC	5	7
29	1.5.7	Facilitates more informed decision making	1	1
30	1.5.8	Fluidity and Changeability	6	9
31	1.5.9	Getting user to think of life cycle	2	2
32	1.5.10	Input Cells are highlighted	1	2
33	1.5.11	Leverages IT for LCC	1	1
34	1.5.12	Leveraging the cost plan to do WLCC	9	12
35	1.5.13	Quick Learning Curve	8	13
	2.0	Emergent Codes	22	492
12	2.1	Applications & uses of LCC template	11	57
36	2.1.1	Applicable to concept and detailed estimates	3	5
37	2.1.2	As a Contractors VE Tool	1	1
38	2.1.3	Holistic Client Service	2	2
39	2.1.4	LCA	1	1
40	2.1.5	Like a tool in itself	2	3
41	2.1.6	Marketing Tool	1	2
42	2.1.7	Operations	1	1
43	2.1.8	PPP's	2	2
44	2.1.9	Sensitivity Analysis	3	3
45	2.1.10	To address to alternative items	7	15
13	2.2	Barriers to LCC	10	58
14	2.2.1	Calculations help do LCC & Save Time	7	15
46	2.2.1.1	Its Still Time Intensive	2	3
15	2.2.1	Client requirements	3	5
47	2.2.1.1	Can facilitate a more Holistic Client Service	0	0
48	2.2.1.2	Depends on Client Type (Short Term)	1	1
49	2.2.1.3	Easier to Sell Service to Client	0	0
50	2.2.1.4	Might not be requested & Not Paid	1	1
51	2.2.2	Get LCC info from Supplier	1	2
16	2.2.3	Lack of Understanding of LCC process and Terminology	1	1
52	2.2.3.1	Confusion of LCC terminology	9	19
53	2.2.3.2	Demonstrates understanding of Task 4 cyclical maintenance	1	1
54	2.2.3.3	Full replacement Sheet	5	6
55	2.2.3.4	Item Specific Escalation	12	21
56	2.2.3.5	Its More a Design Issue	1	1
57	2.2.3.6	Occurrences in annual Costs	9	11
58	2.2.3.7	Periodic Maintenance Replacement & Factor	11	27
59	2.2.3.8	Setting up similar Template	4	4
60	2.2.3.9	Taking information from cost plan	7	16
61	2.2.3.10	Uplift Factor	10	19
62	2.2.3.11	Where in supply Chain LCC is used	1	1
63	2.2.4	No applicable Technology so this helps	7	7
64	2.2.5	Overlapping of services - who specifies	1	1
65	2.2.6	Presentation of the LCC estimate	1	2
66	2.2.7	What life Spans to Use	2	3
17	2.3	BIM		
67	2.3.1	Enhance Visual Presentation		2
68	2.3.2	Getting information from the object		2
69	2.3.3	Save time for other activities		1
70	2.3.4	Where spreadsheet can be linked to BIM		1
18	2.4	Confusion with Task		11
71	2.4.1	Task 1 - Project Details Label items		4
72	2.4.2	Task 3 - Separate Lines or in One Cell		2
73	2.4.3	Task 3 - Starts with lower half of sheet		1
74	2.4.4	Task 4 - Calculations Working on One Line		1
75	2.4.5	Task 6 - Enters same factors as Task 4		4
76	2.4.6	Task 7 - Input Years in Occurrences		1
77	2.4.7	Task 8 - wrong sheet to override escalation		4
19	2.5	Educational Tool		11
78	2.5.1	Demonstrates how you can leverage Cost Plans		5
79	2.5.2	Gets Qs thinking of LCC		3
80	2.5.3	How cyclical LCC affects future cash flows		4
81	2.5.4	How escalation & discount are used in LCC to show Real Nominal		4
82	2.5.5	Uses to explain terminology		6
20	2.6	Graphical representation		4
83	2.6.1	Demonstrate Graphs		2
84	2.6.2	Visual link to options		1
85	2.7	Prefers separate line items for maintenance costs		3
21	2.8	Professional Experience with LCC		7
86	2.8.1	Alternatives		5
87	2.8.2	PPP		1
22	2.9	Suggestions for Improvement and Feedback		13
88	2.9.1	Appearance - Layout could be enhanced		7
89	2.9.2	Cash flows under each other - in the same frame		5
90	2.9.3	Drill down detail		7
91	2.9.4	Hide information you don need		8
92	2.9.5	How do I know calculations are correct		1
93	2.9.6	Input Prompts - Guidance		7
94	2.9.7	Label as project details		2
95	2.9.8	Label Replacement 'Years'		1
96	2.9.9	Lock - hide content of cells so they cant be changed		5
97	2.9.10	More Specific Column Titles		2
98	2.9.11	More than four replacement items		1
99	2.9.12	On replacement items in one cell		3
100	2.9.13	Overall summary		3
101	2.9.14	Percentages vs Factors		3
102	2.9.15	Project Specific Escalation		3
103	2.9.16	Separate tabs for cash flows		5
104	2.9.17	Some Terminology needs to be explained		2
105	2.9.18	Study Period		1
106	2.9.19	Too much scrolling for cash flows		6
	3.0	Evaluation of Test		6
107	3.1	Understanding of pretest instructions		6
108	3.2	Recording Equipment Intrusive		6
109	3.3	Easy to Talk Continuously		6
110	3.4	Follow Tasks Easily		6
111	3.5	Anything did not Like		5
	4.0	Tasks Complete		13
112	4.1	Task 1		12
113	4.2	Task 2		12
114	4.3	Task 3		12
115	4.4	Task 4		12
116	4.5	Task 5		12
117	4.6	Task 6		12
118	4.7	Task 7		12
119	4.8	Task 8		12
	5.0	Usability - Thinking Aloud		16
23	5.1	Ease of Use Words		12
120	5.1.1	Easy to do and understand because its every year		1
121	5.1.2	Familiar		1
122	5.1.3	Handy		1
123	5.1.4	Intuitive		3
124	5.1.5	Simplifies		3
125	5.1.6	Straightforward		6
126	5.1.7	Useful		1
127	5.1.8	User Friendly		3
128	5.2	Low Error Rate		5
24	5.3	Satisfaction		9
129	5.3.1	Beneficial		1
130	5.3.2	I like the way		1
131	5.3.3	Interesting		1
132	5.3.4	That's great - Very Good - Perfect - Excellent - Brilliant		3
133	5.3.5	There is a lot on information there		1
134	5.3.6	Thought put into it		1
135	5.3.7	Very Clever		1
136	5.3.8	Well laid out		1

Appendix 2d: PHASE 4 - DATA REDUCTION 1				
Nr	Code	Name	Sources (Transcripts & Video)	Units of Meaning Coded
	1.0	Debriefing	6	6
1	1.1	Addressing Barriers - Advantages of Template - EFFECTIVENESS	6	6
2	1.1.1	Advantage of it in Spreadsheet	8	11
1	1.1.1.1	Advantage to be familiar with Excel	8	10
2	1.1.1.2	Check Validity & Calculations	7	10
3	1.1.1.3	Demonstrate Graphs	2	2
4	1.1.1.4	Link to BIM	1	1
5	1.1.1.5	Spreadsheet can be imported into other packages	3	4
6	1.1.1.6	Universal Medium for QS so Validates calculations - transparent	5	6
7	1.1.2	Applicable to concept and detailed estimates	3	5
3	1.1.3	Collaboration	0	0
8	1.1.3.1	Collaboration between FM and QS to produce estimate	1	1
9	1.1.3.2	Overlapping of services - who specifies	1	1
10	1.1.4	Ease of input	11	24
4	1.1.5	Ease of Use Words	12	48
11	1.1.5.1	Easy to do and understand because its every year	1	1
12	1.1.5.2	Familiar	1	1
13	1.1.5.3	Handy	1	3
14	1.1.5.4	Intuitive	3	5
15	1.1.5.5	Simplifies	3	4
16	1.1.5.6	Straightforward	6	17
17	1.1.5.7	Useful	1	1
18	1.1.5.8	User Friendly	3	3
19	1.1.6	Easier - More Likely to do LCC	5	7
19	1.1.7	Facilitates more informed decision making	1	1
19	1.1.8	Fluidity and Changeability	6	9
19	1.1.9	Getting user to think of life cycle	2	2
19	1.1.10	Input Cells are highlighted	1	2
19	1.1.11	Leverages IT for LCC	1	1
19	1.1.12	Leveraging the cost plan to do WLCC	9	12
19	1.1.13	Longwinded Calculations	0	0
19	1.1.14	Quick Learning Curve	8	13
19	1.1.15	Auto fills Cash Flows	8	14
5	1.1.16	Automation of Calculations	8	25
20	1.1.16.1	Saves user time	6	6
	2.0	Emergent Codes	21	332
6	2.1	Applications & uses of LCC template	11	57
21	2.1.1	Applicable to concept and detailed estimates	3	5
22	2.1.2	As a Contractors VE Tool	1	1
23	2.1.3	Holistic Client Service	2	2
24	2.1.4	Like a tool in itself	2	3
25	2.1.5	Link to LCA	1	1
26	2.1.6	Marketing Tool	1	2
27	2.1.7	Operations	1	1
28	2.1.8	PPP's	2	2
29	2.1.9	Sensitivity Analysis	3	3
30	2.1.10	To address to alternative items	7	15
7	2.2	Barriers to LCC	14	153
8	2.2.1	Calculations help to do LCC & Save Time	7	15
32	2.2.1.1	But Its Still Time Intensive	2	3
9	2.2.2	Client requirements	3	5
33	2.2.2.1	Can facilitate a more Holistic Client Service	2	2
34	2.2.2.2	Depends on Client Type (Short Term)	1	1
35	2.2.2.3	Easier to Sell Service to Client	1	2
36	2.2.2.4	Might not be requested & Not Paid	1	1
10	2.2.3	Educational Tool - Addresses Barriers	11	98
37	2.2.3.1	Demonstrates how you can leverage Cost Plans	5	12
38	2.2.3.2	Gets Qs thinking of LCC	3	3
39	2.2.3.3	How cyclical LCC affects future cash flows	4	11
40	2.2.3.4	How escalation & discount are used in LCC to show Real Nom	4	9
41	2.2.3.5	Uses to explain terminology	6	19
42	2.2.4	Get LCC info from Supplier	2	3
11	2.2.5	Lack of Understanding of LCC process and Terminology	1	1
12	2.2.5.1	Indicates Confusion of LCC terminology & Process	9	19
43	2.2.5.1.1	Its More a Design Issue	1	1
43	2.2.5.1.2	Occurrences in annual Costs	9	11
43	2.2.5.1.3	PPM	2	2
43	2.2.5.1.4	Uplift Factor	10	19
43	2.2.5.1.5	Where in supply Chain LCC is used	1	1
13	2.2.5.2	User Demonstrates Understanding of LCC Terminology & Process	0	0
44	2.2.5.2.1	How to Calculate cyclical LCC Maintenance Costs	11	27
45	2.2.5.2.2	How you calculate full replacement	5	6
46	2.2.5.2.3	How you can take information from cost plan	7	16
47	2.2.5.2.4	Item Specific Escalation	12	21
15	2.2.6	LCC calculations	6	6
16	2.2.6.1	No have not carried them out	2	2
48	2.2.6.1.1	Only in College	3	3
17	2.2.6.2	Yes Professionally	1	1
49	2.2.6.2.1	Discussed them but no calculations	1	1
50	2.2.7	Overlapping of services - who specifies	1	1
51	2.2.8	Presentation of the LCC estimate is important	1	2
18	2.2.9	Technology	0	0
19	2.2.9.1	BIM could be used to	6	24
52	2.2.9.1.1	Enhance Visual Presentation	2	3
53	2.2.9.1.2	Getting information from the object	2	4
54	2.2.9.1.3	Save time for other activities	1	1
55	2.2.9.1.4	Visual link to options	1	2
56	2.2.9.1.5	Where spreadsheet can be linked to BIM	1	1
20	2.2.9.2	Could you Develop LCC template on your own	9	15
57	2.2.9.2.1	No	7	7
58	2.2.9.2.2	Yes	5	8
21	2.2.9.3	Graphical representation	4	10
59	2.2.9.3.1	Demonstrate Graphs	2	2
60	2.2.9.3.2	Visual link to options	1	2
61	2.2.9.3	No applicable Technology so this helps	7	7
22	2.3	Professional Experience with LCC	9	39
62	2.3.1	Alternatives	5	8
23	2.3.2	If you had would you use it in work	6	6
24	2.3.2.1	Yes	4	4
63	2.3.2.1.1	Comparative Analysis	1	1
64	2.3.2.1.2	Depends on client demand	2	2
65	2.2.3	PPP	1	1
25	2.2.4	What software is used	6	13
66	2.2.4.1	Custom	5	11
67	2.2.4.2	Excel	6	13
26	2.4	Suggestions for Improvement and Feedback	13	83
27	2.4.1	Appearance - Layout could be enhanced	7	11
68	2.4.1.1	Drill down detail	7	10
69	2.4.1.2	Hide information you don't need	8	17
70	2.4.1.3	Overall summary	3	4
28	2.4.2	On replacement items in one cell	3	5
71	2.4.2.1	Explain how Calculations work on one Line	3	5
72	2.4.2.2	Prefers separate line items for maintenance costs	3	5
73	2.4.2.3	What if there is more than four replacement items	1	1
29	2.4.3	Questions	0	0
73	2.4.3.1	Explain Calculations Working on One Line	3	6
74	2.4.3.2	How do I know calculations are correct	1	1
75	2.4.3.3	What if Study Period is greater than 30	1	1
30	2.4.4	To avoid Making Mistakes	0	0
76	2.4.4.1	Input Prompts - Guidance	7	10
31	2.4.4.2	Label for project details	6	10
77	2.4.4.2.1	Breakdown Escalation maybe into a number of items for en	1	1
78	2.4.4.3	Lock - hide content of cells so they cant be changed	5	11
79	2.4.4.4	More Specific Column Titles	3	6
80	2.4.4.5	Percentages vs. Factors	3	4
32	2.4.4.6	Project Specific Escalation	3	4
81	2.4.4.6.1	E for escalation	1	1
82	2.4.4.6.2	Hide formulae in cell for escalation	3	4
83	2.4.4.7	Some Terminology needs to be explained	2	3
33	2.4.5	Too much scrolling for cash flows - too much information	6	16
84	2.4.5.1	Cash flows under each other - in the same frame	5	6
85	2.4.5.2	Drill down detail	7	10
86	2.4.5.3	Hide information you don't need	8	17
87	2.4.5.4	Overall summary	3	4
88	2.4.5.5	Separate tabs for cash flows	5	5
	3.0	Evaluation of Test	6	38
89	3.1	Understanding of pretest instructions	6	6
90	3.2	Recording Equipment Intrusive	6	6
91	3.3	Easy to Talk Continuously	6	7
92	3.4	Follow Tasks Easily	6	13
93	3.5	Anything did not Like	5	6
	4.0	Tasks Complete	13	115
94	4.1	Task 1	12	13
95	4.2	Task 2	12	18
96	4.3	Task 3	12	12
97	4.4	Task 4	12	15
98	4.5	Task 5	12	13
99	4.6	Task 6	12	16
100	4.7	Task 7	12	13
101	4.8	Task 8	12	15
	5.0	Usability - Thinking Aloud	16	99
35	5.1	Ease of Use Words	12	48
102	5.1.1	Easy to do and understand because its every year	1	1
103	5.1.2	Familiar	1	1
104	5.1.3	Handy	1	3
105	5.1.4	Intuitive	3	5
106	5.1.5	Simplifies	3	4
107	5.1.6	Straightforward	6	17
108	5.1.7	Useful	1	1
109	5.1.8	User Friendly	3	3
110	5.2	Low Error Rate	6	14
36	5.3	Satisfaction	9	37
111	5.3.1	Beneficial	1	1
112	5.3.2	I like the way	1	1
113	5.3.3	Interesting	1	1
114	5.3.4	That's great - Very Good - Perfect - Excellent - Brilliant	3	10
115	5.3.5	There is a lot on information there	1	2
116	5.3.6	Thought put into it	1	1
117	5.3.7	Very Clever	1	1
118	5.3.8	Well laid out	1	1

Appendix 2e: PHASE 4a & 5 - DATA REDUCTION 2					
Nr	Code	Codes	Sources (Transcripts & Video)	Units of Meaning Coded	Analytical Memos
	1.0	Addressing Barriers - Advantages of Template - EFFECTIVENESS	6	6	
1	1.1	Access to Information	2	5	X
2	1.1.1	Collaboration	2	2	
1	1.1.1.1	Collaboration between FM and QS to produce estimate	1	1	
2	1.1.1.2	Overlapping of services - who specifies	1	1	
3	1.1.2	Get LCC info from supplier	2	3	
3	1.2	Client requirements	5	21	X
4	1.2.1	Depends on Client Type (Short Term)	2	3	
4	1.2.1.1	Might not be requested & Not Paid	1	1	
5	1.2.2	Easier for QS - More Likely to do LCC	5	7	
6	1.2.3	Easier to Sell Service to Client - Marketing	1	2	
5	1.2.4	Facilitate Holistic Service & Informed Decisions	2	4	
7	1.2.4.1	Applicable to concept and detailed estimates	3	5	
8	1.2.4.2	As a Contractors VE Tool	1	1	
9	1.2.4.3	Link to LCA	1	1	
10	1.2.4.4	PPP's	2	2	
11	1.2.4.5	Sensitivity Analysis	3	3	
12	1.2.4.6	To address to alternative items	7	15	
6	1.3	LCC Time & Calculations	12	106	X
7	1.3.1	Calculations	12	37	
8	1.3.1.1	Automation of Calculations	8	25	
13	1.3.1.1.1	Auto fills Cash Flows	8	13	
14	1.3.1.1.2	Calculates PV, Escalated Costs	9	13	
15	1.3.1.1.3	Saves user time	6	6	
16	1.3.1.2	Leveraging the cost plan to do WLCC	9	12	
9	1.3.2	Calculations help to do LCC & Save Time	11	21	
17	1.3.2.1	But Its Still Time Intensive	2	3	
18	1.3.3	Ease of input	11	24	
10	1.3.4	Easier - QS More Likely to do LCC	5	7	
19	1.3.4.1	Input Cells are highlighted	1	2	
20	1.3.5	Quick Learning Curve	8	13	
11	1.4	Methodology - Understanding LCC process and Terminology	13	207	X
12	1.4.1	Educational Tool - Addresses Confusion	11	99	
21	1.4.1.1	Demonstrates how you can leverage Cost Plans	5	12	
22	1.4.1.2	Gets Qs thinking of LCC	3	4	
23	1.4.1.3	How cyclical LCC affects future cash flows	4	11	
24	1.4.1.4	How escalation & discount are used in LCC to show Real Nominal & P	4	9	
25	1.4.1.5	Uses to explain terminology	6	19	
13	1.4.2	Indicates Confusion - Questions on LCC terminology & Process	9	19	
26	1.4.2.1	Its More a Design Issue	1	1	
27	1.4.2.2	Occurrences in annual Costs	5	5	
28	1.4.2.3	Uplift Factor	10	19	
29	1.4.2.4	What is PPM	2	3	
30	1.4.2.5	Where in supply Chain LCC is used	1	1	
14	1.4.3	Presentation of the LCC estimate is important	4	7	
31	1.4.3.1	Applicable to concept and detailed estimates	3	5	
15	1.4.4	User Demonstrates Understanding of LCC Terminology & Processes	13	81	
32	1.4.4.1	How to Calculate cyclical LCC Maintenance Costs	11	27	
33	1.4.4.2	How you calculate full replacement	5	6	
34	1.4.4.3	How you can leverage cost plan	7	16	
35	1.4.4.4	Item Specific Escalation	12	21	
36	1.4.4.5	Occurrences in annual Costs	9	11	
16	1.5	Technology - Leverages IT for LCC	11	60	X
17	1.5.1	Advantage of it in Spreadsheet	8	11	
18	1.5.1.1	QS already familiar with Excel - increases learnability	8	10	
37	1.5.1.1.1	Demonstrate Graphs	2	2	
38	1.5.1.1.2	Fluidity and Changeability - can manipulate	6	9	
39	1.5.1.1.3	Like a tool in itself	3	4	
40	1.5.1.1.4	Quick Learning Curve	8	13	
41	1.5.1.1.5	Similar to a Cost Plan - so easily understood	3	3	
42	1.5.1.1.6	Universal Medium for QS so Validates calculations - transparent and	7	12	
19	1.5.1.2	Spreadsheet can be imported into other packages	3	4	
43	1.5.1.2.1	So potential Link to BIM	2	3	
20	1.5.2	Could you Develop LCC template on your own	9	15	
44	1.5.2.1	No	7	7	
45	1.5.2.2	Yes	5	8	
21	1.5.3	Link to BIM could be used to	6	20	
22	1.5.3.1	Enhance Visual Presentation	2	3	
46	1.5.3.1.1	Visual link to options	1	2	
47	1.5.3.2	Getting information from the object	2	4	
48	1.5.4	No applicable Technology so this helps	7	7	
	2.0	Evaluation of Test	6	38	X
49	2.1	Understanding of pretest instructions	6	6	
50	2.2	Recording Equipment Intrusive	6	6	
51	2.3	Easy to Talk Continuously	6	7	
52	2.4	Follow Tasks Easily	6	13	
53	2.5	Anything did not Like	5	6	
	3.0	Experience with LCC	9	66	X
54	3.1	Alternatives	5	8	
23	3.2	If you had would you use it in work	6	10	
24	3.2.1	Yes	4	4	
55	3.2.1.1	Comparative Analysis	1	1	
56	3.2.1.2	Depends on client demand	2	2	
25	3.3	LCC calculations	6	9	
26	3.3.1	No have not carried them out	2	2	
57	3.3.1.1	Only in College	3	3	
27	3.3	Yes Professionally	1	1	
58	3.3.1	Discussed them but no calculations	1	1	
28	3.4	What software is used	6	28	
59	3.4.1	Custom	2	2	
60	3.4.2	Excel	6	13	
	4.0	Recommendations for Improvement and Feedback	16	272	X
29	4.1	Appearance - Too much scrolling for cash flows - too much information	9	59	
30	4.1.1	Cash flows under each other - in the same frame	5	6	
61	4.1.1.1	Separate tabs for cash flows	5	5	
62	4.1.2	Drill down detail	7	10	
63	4.1.3	Hide information you don't need	8	17	
64	4.1.4	Overall summary	8	10	
31	4.2	Questions	3	8	
65	4.2.1	Explain Calculations Working on One Line	3	6	
66	4.2.2	What if Study Period is greater than 30	1	1	
67	4.2.3	What if there is more than four replacement items	1	1	
32	4.3	Tasks Complete	13	115	
68	4.3.1	Task 1	12	13	
69	4.3.2	Task 2	12	18	
70	4.3.3	Task 3	12	12	
71	4.3.4	Task 4	12	15	
72	4.3.5	Task 5	12	13	
73	4.3.6	Task 6	12	16	
74	4.3.7	Task 7	12	13	
75	4.3.8	Task 8	12	15	
33	4.4	To avoid Making Mistakes	9	39	
76	4.4.1	Input Prompts - Guidance	7	10	
77	4.4.2	Lock - hide content of cells so they cant be changed	5	11	
34	4.4.3	Project Specific Escalation	3	4	
78	4.4.3.1	Hide formulae in cell for escalation	3	4	
35	4.4.4	Some Terminology needs to be explained	3	4	
79	4.4.4.1	More Specific Column Titles	4	8	
36	4.4.5	Unit of Measure	6	10	
80	4.4.5.1	Percentages vs. Factors	3	4	
	5.0	Usability - Thinking Aloud	16	152	X
37	5.1	Ease of Use Words	12	83	
81	5.1.1	Easy to do and understand because its every year	1	1	
82	5.1.2	Familiar	1	1	
83	5.1.3	Handy	1	3	
84	5.1.4	Intuitive	3	5	
85	5.1.5	Simplifies	3	4	
86	5.1.6	Straightforward	6	17	
87	5.1.7	Useful	1	1	
88	5.1.8	User Friendly	3	3	
89	5.2	Low Error Rate	6	14	
38	5.3	Satisfaction	9	55	
90	5.3.1	Beneficial	1	1	
91	5.3.2	I like the way	1	1	
92	5.3.3	Interesting	1	1	
93	5.3.4	That's great - Very Good - Perfect - Excellent - Brilliant	3	10	
94	5.3.5	There is a lot on information there	1	2	
95	5.3.6	Thought put into it	1	1	
96	5.3.7	Very Clever	1	1	
97	5.3.8	Well laid out	1	1	

Appendix 2f: PHASE 6 - OPEN CODING				
Nr	Code	Name	Sources (Transcripts & Video)	Units of Meaning Coded
	1.0	Addressing Barriers	8	296
1	1.1	Access to Information	7	14
2	1.2	Client requirements	8	46
3	1.3	Lack of Knowledge	8	34
4	1.4	LCC Time & Calculations	8	51
5	1.5	Methodology - Understanding LCC process and Terminology	9	88
6	1.6	Resistance to Change	8	21
7	1.7	Technology - Leverages IT for LCC	6	42
	2.0	Benefits of LCC	8	246
8	2.1	Addressing Alternatives - optioneering	8	28
9	2.2	Another service for the QS	6	12
10	2.3	Assessing Maintenance Programmes	3	9
11	2.4	Banks and pension funds	1	1
12	2.5	Benefits to Property Managers	4	11
13	2.6	Better value for client - more holistic service	8	26
14	2.7	Contract evaluation-calculation	1	1
15	2.8	Contractors Value Engineering tool	4	7
16	2.9	Could use it for WLLC	4	5
17	2.10	Evaluation of LCC tenders - what your being offered esp Design & Build	5	7
18	2.11	Evaluation of sustainability measurers - measure os sustainability	4	10
19	2.12	Extra Fees	3	3
20	2.13	Graphical Representation	3	4
21	2.14	LCC durations might not be actually used	1	1
22	2.15	Marketing tool	3	6
23	2.16	More awareness now on LCC	4	9
24	2.17	More informed Design Decisions - effect on future expenditure	8	37
25	2.18	PPP	1	2
26	2.19	Tendering	1	2
27	2.20	To educate clients with hard data	5	14
28	2.21	Useful for Calculating Prelims	2	3
	3.0	BIM	8	267
29	3.1	3D BIM needs to have spreadsheet function	1	2
30	3.2	Add parameters in Authoring application	4	7
31	3.3	Architects not using BIM	3	8
32	3.4	Ask architect to set up model a certain way	4	7
33	3.5	Benefits in Optioneering	2	3
34	3.6	Benefits of BIM Visualisation	4	11
35	3.7	Benefits of quantification	2	3
36	3.8	Benefits of Revisoning	5	9
37	3.9	BIM not used as BIM	4	8
38	3.10	Checked BIM qtys with traditional 2D measure	3	6
39	3.11	Clients not aware of BIM capabilities	1	1
40	3.12	Contractor not prepared to agree BIM Quantities	1	2
41	3.13	Cost of using BIM	3	7
42	3.14	Differences in measurement practices	2	5
43	3.15	Easier to do LCC	6	11
44	3.16	Fees	2	2
45	3.17	Got to ask for the Model	4	6
46	3.18	Have LCC rate libraries in your system	2	3
47	3.19	Have you used BIM	8	14
48	3.20	But would like to use it	2	3
49	3.21	I don't have the training or knowledge of 3D BIM	1	1
50	3.22	Included in project brief	1	2
51	3.23	Larger companies using BIM	1	1
52	3.24	Link between Quantities & LCC	8	22
53	3.25	Great to have LCC info in Model - getting infor	2	5
54	3.26	In the same system - extension	3	3
55	3.27	One Quantity link to a number of Cost Plan Items	1	1
56	3.28	Live link in CostX	7	14
57	3.29	Needs to be collaborative	3	6
58	3.30	Not everything in the model - details, schedules	1	1
59	3.31	Not in the correct QS format	4	7
60	3.32	Pitch it to Client - demonstrate its use	4	5
61	3.33	Pushed with government work		2
62	3.34	Puts pressure on QS to offer more services		3
63	3.35	Request for BIM driven by FM		4
64	3.36	Saves QS time		2
65	3.37	Software we use cant accommodate BIM		2
66	3.38	Used as a Trial - Own Initiative		4
67	3.39	Validation of quantities		4
	4.0	Evaluation of Test	8	42
68	4.1	1 Understanding of pretest instructions		7
69	4.2	2 Recording Equipment Intrusive		8
70	4.3	3 Easy to Talk Continuously		8
71	4.4	4 Follow Tasks Easily		8
72	4.5	5 Anything did not Like		7
	5.0	Experience with LCC	8	80
73	5.1	Alternatives		5
74	5.2	Could you develop template		8
75	5.3	Evident you could use it to do WLLC		7
76	5.4	If you had would you use it in work		7
77	5.5	LCC calculations		8
78	5.6	What software is used		6
	6.0	Scenarios	8	70
79	6.1	Task 1		8
80	6.2	Task 2		8
81	6.3	Task 3		8
82	6.4	Task 4		8
83	6.5	Task 5		7
84	6.6	Task 6		7
85	6.7	Task 7		8
86	6.8	Task 8		6
	7.0	Suggestions for Improvement and Feedback	12	371
87	7.1	Access to LCC databases or LCC information		3
88	7.2	An integrated Cost - LCC System		6
89	7.3	Automation of Cashflows		6
90	7.4	Automation of the calculations		8
91	7.5	Benefits of visualisation		2
92	7.6	Better link to the object properties		3
93	7.7	Brings FM into the decision making process		6
94	7.8	Can follow this as a methodology to do LCC		3
95	7.9	Can reuse it		2
96	7.10	Can show level of detail you want		5
97	7.11	Clear inputting data		2
98	7.12	Compare components based on LCC		2
99	7.13	Does three forms of LCC calculations		1
100	7.14	Dropdown menu for data requirements		1
101	7.15	Easy to learn - looks and feels like excel & other QS software		8
102	7.16	Export to excel		6
103	7.17	Generate manipulate your own LCC reports		3
104	7.18	Get LCC info from the object properties		2
105	7.19	Graphical representation		1
106	7.20	Highlight in colour where you need to input		1
107	7.21	Leveraging Cost Plan - BOQ		4
108	7.22	Like the live link		7
109	7.23	Likes the specific escalation rate		2
110	7.24	Likes uplift factor		1
111	7.25	Link between BIM and LCC is great		8
112	7.26	Link cells so you only have to drag qty once		1
113	7.27	More automation in linking LCC data to BIM quantum		2
114	7.28	More explicit on link between Maintenance Periods & Actions		1
115	7.29	More likely carry out LCC using this system		6
116	7.30	Not the same level of excel functionality		1
117	7.31	Prefers the detailed maintenance LCC calculations		3
118	7.32	Protect non input cells		1
119	7.33	QS Getting more from your software		4
120	7.34	Quick Learning curve - user friendly		8
121	7.35	Real time Sensitivity Analysis on Inflation etc		1
122	7.36	Standard uplift factor		1
123	7.37	Storing LCC information for client FM		4
124	7.38	Transparent because you can see in workings - formulae		1
125	7.39	What if there was more than 4 maintenance actions		2
126	7.40	Would save us outsourcing LCC work		1
127	7.41	You can manipulate system for use		3
	8.0	Usability - Thinking Aloud	8	97

Appendix 2g: PHASE 7 - CATEGORISATION & CODING ON				
Nr	Code	Name	Sources (Transcripts & Video)	Units of Meaning Coded
	1.0	Addressing Barriers	8	264
1	1.1	Client requirements	8	41
2	1.1.1	Client has not requested it	8	14
1	1.1.1.1	Client capital and facilities budgets not integrated	1	1
2	1.1.1.2	Client not aware of how useful it is - lack of awareness - wouldn't	4	6
3	1.1.1.3	Some clients not concerned with future expenditure	2	4
3	1.1.2	Government requirement - will be and already is	4	6
4	1.1.2.1	But unclear exactly what they want	1	1
5	1.1.2.2	Will be more specific in the future	1	1
4	1.1.3	Growing awareness-recognition of LCC	1	1
6	1.1.3.1	BIM will push clients into LCC space	1	2
7	1.1.3.2	Indirectly looking for it through sustainability & energy efficiency	1	3
8	1.1.3.3	Will be driven by more FM related decisions & involvement	3	3
5	1.2	Complex & Time Intensive LCC Calculations & Formulae	7	18
9	1.2.1	Burns companies fees- don't get paid for it	2	2
10	1.2.2	No standardisation-everyone does a different spreadsheet	2	2
6	1.3	Lack of Access & Knowledge on LCC information	7	14
11	1.3.1	Especially M&E costs are difficult to get access too - cost advice	2	2
12	1.3.2	Using information when you get it - Experience	1	1
7	1.4	Lack of Knowledge - know how	7	28
13	1.4.1	We had to outsource to get capabilities	3	3
8	1.5	Methodology - Understanding LCC process and Terminology	9	84
9	1.5.1	Demonstrates a lack of understanding during exercises	0	0
14	1.5.1.1	Asked for the difference between percentage calc and detailed calc	1	1
15	1.5.1.2	Doesn't understand cost plan percentages	6	7
16	1.5.1.3	Nr of occurrences	3	3
17	1.5.1.4	What is ISO	1	1
18	1.5.1.5	What's minor replacement repair	1	1
19	1.5.1.6	What's uplift factor	6	6
20	1.5.1.7	Why higher rate of escalation	1	1
10	1.5.2	Demonstrates understanding of process & terminology	7	36
21	1.5.2.1	Is uplift factor taken into account in percentage calculation	2	2
22	1.5.2.2	Understands cost plan percentages	2	3
23	1.5.2.3	Understands cyclical maintenance	4	4
24	1.5.2.4	Understands theory of NPV & LCC calculations	1	5
11	1.6	Resistance to Change	8	23
25	1.6.1	Diversity to survive	1	1
26	1.6.2	Q's need to change attitude	2	2
27	1.6.3	Too small to use it	1	1
28	1.6.4	Training	1	1
12	1.7	Technology	7	56
29	1.7.1	Ability-Training to leverage latest technology	4	8
30	1.7.2	Cost of the technology	1	2
31	1.7.3	Lack of visualisation	2	2
32	1.7.4	No information from model on LCC	1	2
33	1.7.5	Separate applications for LCC & Capital Cost	3	8
34	1.7.6	Trusting the technology	1	1
	2.0	Benefits of LCC	6	49
13	2.1	To Clients	0	0
35	2.1.1	Addressing Alternatives - optioneering	8	30
36	2.1.2	Assessing Maintenance Programmes	6	13
37	2.1.3	Banks and pension funds	1	1
38	2.1.4	Benefits to Property Managers	5	12
39	2.1.5	Better value for client - more holistic service	8	30
40	2.1.6	Brings FM into the decision making process	6	27
41	2.1.7	Could use it for WLLC	5	6
42	2.1.8	Evaluation of LCC tenders - what your being offered esp Design & Cost	4	7
43	2.1.9	Evaluation of sustainability measures - measure of sustainability	5	11
44	2.1.10	More informed Design Decisions - effect on future expenditure	8	38
45	2.1.11	PPP	2	5
46	2.1.12	Promotes collaboration	2	2
47	2.1.13	To educate clients with hard data	8	18
14	2.2	To Contractors	0	0
48	2.2.1	Contract evaluation-calculation	1	2
49	2.2.2	Contractors Value Engineering tool	4	7
50	2.2.3	Marketing Tool-get work	2	5
51	2.2.4	PPP	2	4
52	2.2.5	Tendering	2	5
53	2.2.6	Useful for Calculating Prelims	2	3
15	2.3	To Quantity Surveyors	1	1
54	2.3.1	Another service for the QS	8	15
55	2.3.2	Extra Fees	3	3
56	2.3.3	Marketing tool-get work	5	9
57	2.3.4	Needs to educate client on LCC	5	15
58	2.3.5	Would give me the ability possibly to offer as normal service	2	2
	3.0	BIM	8	62
16	3.1	Barriers	8	45
17	3.1.1	Architects not using BIM	6	10
59	3.1.1.1	BIM not used as BIM but just for design	4	8
60	3.1.1.2	Not giving model	2	4
61	3.1.2	BIM in concept but then not used after	1	1
62	3.1.3	Clients not aware of BIM capabilities	3	3
63	3.1.4	Cost of using BIM	4	8
64	3.1.5	Extra charge - fees	2	2
65	3.1.6	Larger companies using BIM	3	3
18	3.2	Benefits	8	18
66	3.2.1	Benefits in Optioneering	2	2
67	3.2.2	Benefits of BIM Visualisation	4	11
68	3.2.3	Benefits of quantification	3	4
69	3.2.4	Benefits of Revisioning	5	9
70	3.2.5	Easier to do LCC	6	10
71	3.2.6	Get FM info off design team	1	2
72	3.2.7	Puts pressure on QS to offer more services	3	5
73	3.2.8	Saves QS time	3	12
19	3.3	Have you used BIM	8	14
20	3.3.1	No	4	7
74	3.3.1.1	But is in our plans	2	4
21	3.3.2	Yes	4	4
75	3.3.2.1	But not full measurement - partially used	1	1
76	3.3.2.2	But on a trial basis	2	3
77	3.3.2.3	Majority of work is BIM	1	1

22	3.4	Problems in 3D BIM	8	16
78	3.4.1	BIM not used as BIM - geometry & efficiency in design	4	8
79	3.4.2	Contractor not prepared to agree BIM Quantities	1	2
80	3.4.3	Cost of using BIM	4	9
81	3.4.4	I don't have the training or knowledge of 3D BIM	3	3
82	3.4.5	Incorrectly categorised	2	2
83	3.4.6	Not everything in the model - details, schedules	2	3
84	3.4.7	Not in the correct QS format - lot of interpretation	6	16
85	3.4.8	Software we use cant accommodate BIM	2	3
86	3.4.9	Validation of quantities- check with 2D	5	11
23	3.5	Promoting Use	4	5
87	3.5.1	Request for BIM driven by FM	4	5
24	3.6	Recommendations by QS	8	14
88	3.6.1	3D BIM needs to have spreadsheet function	1	2
89	3.6.2	Add parameters in Authoring application	4	7
90	3.6.3	Ask architect to set up model a certain way	4	7
91	3.6.4	Got to ask for the Model	4	6
92	3.6.5	Included in project brief	1	2
93	3.6.6	Needs to be collaborative	3	7
94	3.6.7	Pitch it to Client - demonstrate its use	4	6
95	3.6.8	Pushed with government work	2	8
96	3.6.9	Training	2	2
97	3.6.10	Used as a Trial - Own Initiative	5	9
	4.0	Evaluation of Test	8	44
98	4.1	1 Understanding of pretest instructions	8	8
99	4.2	2 Recording Equipment Intrusive	8	9
100	4.3	3 Easy to Talk-Continuously	8	8
101	4.4	4 Follow Tasks Easily	8	11
102	4.5	5 Anything did not Like	8	8
	5.0	Experience with LCC	8	98
25	5.1	Carrying out LCC calculations	8	38
103	5.1.1	Educational exposure	4	5
104	5.1.2	No	3	3
26	5.1.3	Yes	5	7
105	5.1.3.1	But we outsourced	1	1
106	5.1.3.2	Component Evaluation - option appraisal	5	8
107	5.1.3.3	Created our own spreadsheet with calculations	3	5
108	5.1.3.4	Using Bespoke software	1	1
109	5.1.3.5	Yes but only once twice - but not consistently using it	3	5
110	5.1.3.6	Yes numerous times	2	2
27	5.2	Could you develop template	8	11
28	5.2.1	No - not like that with automation	7	10
111	5.2.1.1	But some type of dumbed down version	6	6
112	5.2.3	Yes	1	1
29	5.3	If you had would you use it in work	7	18
113	5.3.1	But not Daily	1	1
114	5.3.2	If its a standard template like this	1	1
30	5.4	It is evident you could use it to do WLLC - item by item in your estimate	8	9
115	5.4.1	But access to information	3	3
116	5.6	More awareness now on LCC	5	11
117	5.7	What software is used - Excel	6	11
	6.0	Scenarios	8	71
118	6.1	Task 1	8	10
119	6.2	Task 2	8	8
120	6.3	Task 3	8	10
121	6.4	Task 4	8	11
122	6.5	Task 5	7	7
123	6.6	Task 6	7	9
124	6.7	Task 7	8	9
125	6.8	Task 8	6	6
	7.0	Suggestions for Improvement and Feedback	11	76
31	7.1	Feedback	0	0
32	7.1.1	Advantages	0	0
126	7.1.1.1	An integrated Cost - LCC System	8	14
127	7.1.1.2	Benefits of visualisation	2	2
128	7.1.1.3	Can follow this as a methodology to do LCC - standardised structure	6	13
129	7.1.1.4	Live Link between BIM and LCC is great	8	17
130	7.1.1.5	More likely carry out LCC using this system	6	14
131	7.1.1.6	QS Getting more from your software	6	10
33	7.1.2	Different to other LCC systems	0	0
132	7.1.2.1	Likes the specific escalation rate	2	4
133	7.1.2.2	Likes uplift factor	1	1
134	7.1.2.3	Live link in CostX	7	15
34	7.1.3	Presentation & Reporting	0	0
135	7.1.3.1	Can show level of detail you want - manipulate system to show	5	18
136	7.1.3.2	Does three forms of LCC calculations	1	2
137	7.1.3.3	Export to excel	6	12
138	7.1.3.4	Generate manipulate your own LCC reports	3	5
139	7.1.3.5	Graphical Representation	3	4
140	7.1.3.6	Real time Sensitivity Analysis on Inflation etc	2	4
141	7.1.3.7	Storing LCC information for client FM	4	5
142	7.1.3.8	Transparent because you can see in workings - formulae	1	1
35	7.1.4	Quick Learning curve - user friendly	8	28
143	7.1.4.1	Clear & easy inputting data	5	10
144	7.1.4.2	Looks and feels like excel & other QS software	8	20
36	7.1.5	Speed Efficiency Automation	0	0
145	7.1.5.1	Automation of Cashflows	6	14
146	7.1.5.2	Automation of the calculations	8	43
147	7.1.5.3	Can reuse it	3	3
148	7.1.5.4	Leveraging Cost Plan - BOQ	4	7
149	7.1.5.5	Would save us outsourcing LCC work	1	1
37	7.2	Suggestions for improvement	0	0
150	7.2.1	Access to LCC databases or LCC information	4	6
151	7.2.2	Default Uplift	1	1
152	7.2.3	Double check calcs - sanity check	2	2
153	7.2.4	Dropdown menu for data requirements	1	2
154	7.2.5	Get LCC info from the object properties	4	6
155	7.2.6	Graphical representation	1	1
156	7.2.7	Great to have LCC info in Model - getting info	2	5
157	7.2.8	Have LCC rate libraries in your system	2	3
158	7.2.9	Highlight in colour where you need to input	1	3
159	7.2.10	Link cells so you only have to drag gly once	1	1
160	7.2.11	More automation in linking LCC data to BIM quantum	4	7
161	7.2.12	More explicit on link between Maintenance Periods & Actions	1	2
162	7.2.13	Not the same level of excel functionality	1	2
163	7.2.14	Pay for information - outsource work	2	3
164	7.2.15	Prefers the detailed maintenance LCC calculations	3	3
165	7.2.16	Protect non input cells	1	1
166	7.2.17	Standard uplift factor	1	1
167	7.2.18	Still will be time intensive exercise even with this	1	1
168	7.2.19	What if there was more than 4 maintenance actions	2	2
	8.0	Usability - Thinking Ahead	8	97

Appendix 2h: PHASE 8 - DATA REDUCTION					25	3.4	Recommendations by QS	9	59	
Nr	Code	Codes	Sources (Transcripts & Video)	Units of Meaning Coded	Analytical Memos					
		1.0 Barriers to LCC		248	X					
1	1.1	Client requirements - Client not requested it	10	59		25	3.4	Recommendations by QS	9	59
1	1.1.2	Client not aware of how useful it is - lack of awareness - wouldn't know how to read it	4	6		26	3.4.1	The Client	5	29
2	1.1.3	Some clients not concerned - budgets not integrated	4	8		64	3.4.1.1	Include in project brief	1	2
2	1.2	Complex & Time Intensive LCC Calculations & Formulae	9	23		65	3.4.1.1	Needs to be collaborative	3	8
3	1.2.1	Burns companies fee- don't get paid for it	2	2		66	3.4.1.1	Pitch it to Client - demonstrate its use	4	6
4	1.3	Lack of Access & Knowledge on LCC information	9	16		67	3.4.1.1	Pushed with government work	2	8
4	1.3.1	Especially M&E costs are difficult to get access too - cost advice on energy savings	3	4		68	3.4.1.1	Request for BIM driven by FM	4	5
5	1.3.2	Using information when you get it - Experience	1	1		27	3.4.2	The Model	6	18
5	1.4	Lack of Knowledge - know how	7	28		69	3.4.2.1	Add QS related parameters in authoring application	6	11
6	1.4.1	Separate department specialising	2	2		70	3.4.2.2	Ask for the Model	5	7
7	1.4.2	We had to outsource to get capabilities	3	3		28	3.4.3	Use it	6	12
6	1.5	Methodology - Understanding LCC process and Terminology	8	83		71	3.4.3.1	Training	2	2
7	1.5.1	Demonstrates a lack of understanding during exercises	8	20		72	3.4.3.1	Used as a Trial - Own Initiative	5	10
8	1.5.1.1	Asked for the difference between percentage calc and detailed calc	1	1				4.0 Evaluation of Test - everything ok	10	22
9	1.5.1.2	Doesn't understand cost plan percentages	6	7				5.0 Experience with LCC	10	57
10	1.5.1.3	Nr of occurrences	3	3		29	5.1	Experience carrying out LCC calculations	10	55
11	1.5.1.4	What is ISO	1	1		73	5.1.2	Educational exposure	4	5
12	1.5.1.5	What's minor replacement repair	1	1		74	5.1.3	No	3	3
13	1.5.1.6	What's uplift factor	6	6		75	5.1.4	What software is used - Excel	8	14
14	1.5.1.7	Why higher rate of escalation	1	1		80	5.1.5	Yes	7	9
8	1.5.2	Demonstrates understanding of process & terminology	9	38		76	5.1.5.1	But we outsourced	2	3
15	1.5.2.1	Is uplift factor taken into account in percentage calculation	2	2		77	5.1.5.2	Component Evaluation - option appraisal	5	8
16	1.5.2.2	Understands cost plan percentages	4	5		78	5.1.5.3	Created our own spreadsheet with calculations	4	7
17	1.5.2.3	Understands cyclical maintenance	6	7		79	5.1.5.4	Using Bespoke software	1	1
18	1.5.2.4	Understands theory of NPV & LCC calculations	1	5		80	5.1.5.5	We have a separate FM department	1	1
19	1.5.2.5	No standardisation-everyone does a different spreadsheet	2	2		81	5.1.5.6	Yes but only once twice - but not consistently using it	4	6
9	1.6	Technology	7	53		82	5.1.5.7	Yes numerous times	2	2
20	1.6.2	Cost & Training to leverage latest technology	4	10				6.0 Recommendations for Improvement and Feedback	11	497
21	1.6.3	Separate applications for LCC & Capital Cost	3	8		31	6.1	Feedback on template	10	300
22	1.6.4	Trusting the technology - checking LCC calcs	2	2		32	6.1.1	Could you develop template	8	11
		2.0 Benefits LCC	11	304	X	83	6.1.1.1	No - not like that with automation	7	10
10	2.1	Changing attitudes to LCC	7	32		84	6.1.1.2	Yes	3	3
11	2.1.1	Government requirement - will be and already is	4	6		85	6.1.2	Different to other LCC systems	10	72
23	2.1.1.1	But unclear exactly what they want	1	1		86	6.1.2.1	An integrated Cost - LCC System v links between quantum & cost & LCC	10	48
24	2.1.1.2	Will be more specific in the future	1	1		87	6.1.2.2	Likes the specific escalation rate	2	4
12	2.1.2	Growing awareness-recognition of LCC	5	11		88	6.1.2.3	Looks and feels like excel & other QS software - familiarity	8	20
25	2.1.2.1	BIM will push clients into LCC space	3	5		89	6.1.3	Presentation & Reporting	10	55
26	2.1.2.2	Indirectly looking for it through sustainability & energy efficiency	1	1		90	6.1.3.1	Can follow this as a methodology to do LCC - standardised structure - leads to more	7	14
27	2.1.2.3	Will be driven by more FM related decisions & involvement	4	7		91	6.1.3.2	Can show level of detail you want - generate your own reports	6	22
28	2.1.3	QS needs to educate client on LCC	5	15		92	6.1.3.3	Export to excel	6	12
13	2.2	To Clients	11	170		93	6.1.3.4	Graphical Representation	3	4
29	2.2.1	Addressing Alternatives (optioneering) Demonstrate with hard data	11	48		94	6.1.3.5	It is evident you could use it to do WLLC - item by item in your estimate	10	13
30	2.2.2	Benefits to Property Managers & FM - future expenditure	8	29		95	6.1.3.6	But access to information	3	3
31	2.2.3	Better value for Client - more collab. holistic service	11	58		96	6.1.3.7	Real time Sensitivity Analysis on Inflation etc	4	6
32	2.2.4	Evaluation of sustainability measures - measure of sustainability	6	14		97	6.1.4	Quick Learning curve - user friendly	10	31
33	2.2.5	To calculate and evaluate tenders with FM element	7	21		98	6.1.4.1	Clear & easy inputting data	7	15
14	2.3	To Contractors	5	19		99	6.1.4.2	Looks and feels like excel & other QS software	11	23
34	2.3.1	Contractors Value Engineering tool	4	7		36	6.1.5	Result of using	10	65
35	2.3.2	To calculate and evaluate tenders with FM element	5	9		97	6.1.5.1	If you had this would you use it in work	9	25
36	2.3.3	Useful for Calculating Prelims	2	3		98	6.1.5.2	But not Daily	1	1
15	2.4	To Quantity Surveyors	10	35		99	6.1.5.3	If its a standard template like this	1	1
16	2.4.1	Another service for the QS	10	19		100	6.1.5.4	No - I wouldn't need it	1	1
37	2.4.1.1	Extra Fees	3	3		101	6.1.5.5	Yes great for PPP	2	3
38	2.4.1.2	Would give me the ability possibly to offer as normal service	3	3		102	6.1.5.6	More likely carry out LCC - easier to do LCC	10	25
39	2.4.2	Marketing tool-get work	6	11		103	6.1.5.7	QS Getting more from your software - built on existing system	6	10
40	2.4.3	QS's need to change attitude - Diversity to survive	4	5		104	6.1.5.8	Use it for building database	2	4
		3.0 BIM	10	266	X	105	6.1.5.9	Would save us outsourcing LCC work	1	1
17	3.1	Benefits to QS - in efficiency - can offer more services	9	52		37	6.1.6	Speed Efficiency-Automation	10	66
41	3.1.1	Benefits in Optioneering	2	2		106	6.1.6.1	Automation of the calculations & population of cash flows	10	50
42	3.1.2	Benefits of BIM Visualisation	6	17		107	6.1.6.2	Can reuse it - forms template	5	5
43	3.1.3	Benefits of Quantification & saves QS time	4	13		108	6.1.6.3	Leveraging Cost Plan - BOQ	5	8
44	3.1.4	Benefits of Revisioning	7	12		38	6.2	Scenarios	10	86
45	3.1.5	Fabrication	1	3		109	6.2.1	Task 1	10	12
18	3.2	Have you used BIM	8	14		110	6.2.2	Task 2	10	10
19	3.2.1	No	5	8		111	6.2.3	Task 3	10	12
46	3.2.1.1	But is in our plans	4	6		112	6.2.4	Task 4	10	13
20	3.2.2	Yes	6	11		113	6.2.5	Task 5	9	9
47	3.2.2.1	But not full measurement - partially used	1	1		114	6.2.6	Task 6	8	10
48	3.2.2.2	But on a trial basis	2	3		115	6.2.7	Task 7	10	11
49	3.2.2.3	Just for qty's - export them out	1	5		116	6.2.8	Task 8	8	8
50	3.2.2.4	Majority of work is BIM	3	5				6.3 Recommendations for improvement	10	49
51	3.2.2.5	We see ourselves as leaders	1	1		39	6.3	Appearance	6	10
21	3.3	Problems & Barriers in 5D BIM	10	93		40	6.3.1	Graphical representation	1	1
22	3.3.1	Hardware & Software	8	18		117	6.3.1.1	Prefers the proportional breakdown	1	2
52	3.3.1.1	Cost of using BIM - Training, Software, Hardware	6	11		118	6.3.1.2	Prefers the detailed maintenance LCC calculations	5	5
53	3.3.1.2	I don't have the training or knowledge of 5D BIM	3	3		119	6.3.1.3	What if there was more than 4 maintenance actions	2	2
54	3.3.1.3	Software we use cant accommodate BIM	2	3		120	6.3.1.4	Avoid making errors	6	11
23	3.3.2	Problems with the model	9	61		121	6.3.2.1	Double check calcs - sanity check	2	2
55	3.3.2.1	Architects not using BIM & not giving it	6	12		122	6.3.2.2	Dropdown menu for data requirements	1	2
56	3.3.2.2	BIM not used as BIM - used for geometry & efficiency in design	5	9		123	6.3.2.3	Highlight in colour where you need to input	1	3
57	3.3.2.3	Contractor not prepared to agree BIM Quantities	3	4		124	6.3.2.4	More explicit on link between Maintenance Periods & Actions	2	3
58	3.3.2.4	Not everything in the model - details, schedules	4	6		125	6.3.2.5	Protect non input cells	1	1
59	3.3.2.5	Not in the correct QS format - lot of interpretation & validation	7	30		42	6.3.3	Efficiency	7	28
24	3.3.3	Process	6	14		126	6.3.3.1	Access to LCC databases or LCC information - within system	6	9
60	3.3.3.1	Clients not aware of BIM capabilities	3	3		127	6.3.3.2	Get LCC info from the object properties - more automation in linking LCC to Object	5	11
61	3.3.3.2	Extra charge - fees	3	3		128	6.3.3.3	Link cells so you only have to drag qty once	2	2
62	3.3.3.3	Larger companies using BIM - im too small	3	4		129	6.3.3.4	Not the same level of excel functionality	1	2
63	3.3.3.4	Wont give you Bim when pricing	1	3		130	6.3.3.5	Smoothing cash flows	1	2
						131	6.3.3.6	Standard uplift factor	1	1
						132	6.3.3.7	Still will be time intensive exercise even with this	1	1
								7.0 Usability - Thinking Ahead	10	117

10.3 Appendix 3 – Glossary of Terms

LCC

Base Rate - the interest rate selected as the basis of the discount rate. This could be the current bank rate or client's opportunity cost of capital. The base rate is commonly adjusted by the inflation rate to give the discount rate.

Capital Cost - initial construction costs and costs of initial adaptation where these are treated as capital expenditure.

Constructed Asset - whole building or structure, system or a component or part

Discount Rate – the interest rate used for bringing future costs to a comparable time base (time zero).

Escalation Rate - positive or negative rate reflecting an estimate of differential increase/decrease in the general price level for a particular commodity, or group of commodities, or resource

External Costs - costs associated with an asset that are not necessarily reflected in the transaction costs between provider and consumer and that, collectively, are referred to as externalities.

Inflation/Deflation - a sustained and measurable increase/decrease in the general price level.

Life Cycle Cost - cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements.

Life Cycle Assessment - method of measuring and evaluating the environmental impacts associated with a product, system or activity, by describing and assessing the energy and materials used and released to the environment over the life cycle

Maintenance Cost - total of necessarily incurred labour, material and other related costs incurred to retain a building or its parts in a state in which it can perform its required functions

Net Present Value - sum of the discounted future cash flows

Nominal Cost - expected price that will be paid when a cost is due to be paid, including estimated changes in price due to, for example, forecast change in efficiency, inflation or deflation and technology

Nominal Interest Rate - the actual interest rate applied not adjusted for inflation. Note Fisher equation (real interest rate = nominal interest rate – inflation).

Operation Cost - costs incurred in running and managing the facility or built environment, including administration support services

Period of Analysis - period of time over which life-cycle costs or whole-life costs are analysed

Period of analysis/period of study - the length of time over which the life cycle cost assessment is analysed.

Physical Life of a component - the time at which a component fails to meet the performance criteria required of it and has to be removed and replaced.

Real Cost - cost expressed as a value at the base date, including estimated changes in price due to forecast changes in efficiency and technology, but excluding general price inflation or deflation

Real Interest Rate – the rate adjusted for inflation.

Risk - likelihood of the occurrence of an event or failure and the consequences or impact of that event or failure

Sensitivity Analysis - test of the outcome of an analysis by altering one or more parameters from initial value(s)

Service Life - period of time after installation during which a building, or its part, meets or exceeds the performance requirements.

Time Value of Money - measurement of the difference between future monies and the present-day value of monies

Time Zero - the point in time from which the study period commences. All relevant costs accrued prior to time zero are deemed to be capital costs.

Treasury Discount Rate - the rate specified as the discount rate by the Government Treasury to be used as the discount rate for public-sector whole life costing calculations.

Unit of Time - The time interval used in life cycle cost calculations. It may be any unit of time measurement (day, week, month, year). However, in the calculations the time period and interest rate per time period must be synchronised.

Whole Life Cycle Cost - all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements

BIM

As Built - As built is defined as the record drawings and documentation that capture changes to the design in the finally constructed facility.

BEP BIM Execution Plan - Written plan to integrate the BIM tasks and information with all stakeholders and processes.

BIM Implementation Plan - the blueprint for integrating BIM into an organisation's working practices.

bSI - buildingSMART International - non-profit international organisation formerly known as International Alliance for Interoperability (IAI) focused on improving the exchange of information between software applications used for the built environment sector.

Building Information Management - Used in place of building information modelling to highlight the requirement to explicitly manage the information in a BIM environment.

Building Information Model - digital representation of the physical and functional characteristics of a facility using a collection of elements or information that serves as a shared knowledge resource for design, construction, operation and retrofit/demolition of a built environment asset.

Building Information Modelling - used to both describe the process and the philosophy that enables the input, sharing, maintenance and output of (electronic) information used in the built environment sector.

Clash detection - process of identifying or detecting possible collisions between elements in a building information model generally from two different disciplines (sometimes all referred to as collision detection or coordination).

Classification - systematic arrangement of headings and sub-headings for aspects of construction work including the nature of assets, construction elements, systems and products.

Client - the construction client whom is an individual or organization commissioning a built asset.

COBie Construction Operation Building information exchange - A structured facility information for the commissioning, operation and maintenance of an asset.

Federated Model - Building information model consisting of linked but distinct component/disciplinary models.

Information Exchange - structured collection of information at one of a number of pre-defined stages of a project with defined format and fidelity

Information Management - tasks and procedures applied to inputting, processing and generation activities to ensure accuracy and integrity of information

Interoperability - The ability of two or more (computer or software) systems or components to exchange information and to use the information that has been exchanged.

Lean - production focused on delivering value for the employer or client and eliminating all non-value-adding activities using an efficient work-flow

Model Author - originator of model files, drawings or documents

NRM 1 - RICS new rules of measurement 1: Order of cost estimating and cost planning for capital building works.

NRM 2 - RICS new rules of measurement 2: Detailed measurement for building works.

Off-Site Construction - Refers to structures built at different locations than the location of use or installation.

Parametric Objects - A digital representation of a physical object using set of parameters.

PAS 1192 Parts 2 and 3 - Publicly Available Specification sponsored by the Construction Industry Council (CIC) in support of BS 1192:2007 – also includes excellent glossaries of terms.

Project Delivery Team - group of organizations or individuals contracted either directly or indirectly to deliver services or products to the project

Soft Landings - graduated handover of a built asset from the design and construction team to the operation and maintenance team to allow structured familiarization of systems and components and fine tuning of controls and other building management systems

UniClass - Unified classification for the Construction Industry classification system used in the UK and owned by CPIC.

10.4 Appendix 4 – List of Publications

- Kehily, D. (2011). *Guide to Life Cycle Costing*. Society of Chartered Surveyors. Dublin; Ireland: SCSl.
- Kehily, D., & Hore, A. (2012). *Life Cycle Cost Analysis Under Ireland's Capital Works Management Framework*. Paper presented at the Joint CIB W070, W092 & TG72 International Conference on Facilities Management, Procurement Systems And Public Private Partnership, Capetown, South Africa.
- Kehily, D., McAuley, B., & Hore, A. (2012). Leveraging Whole Life Cycle Costs When Utilising Building Information Modelling Technologies. *International Journal of 3-D Information Modeling*, 1(4), 40-49.
- Kehily, D., McDonnell, F., & Woods, T. (2013). Linking Effective Whole Life Cycle Cost Data Requirements to Parametric Building Information Models Using BIM Technologies. *International Journal of 3-D Information Modeling*, 2(4), 1-11.
- Kehily, D., Underwood, J. (2015). *Design Science: Choosing an appropriate methodology for research in BIM*. Paper presented at CITA BIM Gathering: An Integrated Future. Dublin. Ireland.

10.5 Appendix 5 – Research Ethical Approval

Academic Audit and Governance Committee

College of Science and Technology Research Ethics Panel (CST)

To Dermot Kehily (and John Hudson)
cc: Prof Charles Egbu, Acting Head of School of SOBE
From Nathalie Audren Howarth, College Research Support Officer
Date 19 May 2014

Subject: Approval of your Project by CST
Project Title: LEVERAGING BUILDING INFORMATION MODELLING
TECHNOLOGIES FOR LIFE CYCLE COSTING
REP Reference: CST 14/19

Following your responses to the Panel's queries, based on the information you provided, I can confirm that they have no objections on ethical grounds to your project.

If there are any changes to the project and/or its methodology, please inform the Panel as soon as possible.

Regards,

A handwritten signature in black ink, appearing to read 'N. Audren', with a long horizontal flourish underneath.

Nathalie Audren Howarth

College Research Support Office