ITcon
www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

EMBEDDING LIFE CYCLE COSTING IN 5D BIM

SUBMITTED: August 2016
REVISED: July 2017.
PUBLISHED: September 2017 at http://www.itcon.org/2017/8
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SUMMARY: *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 clients are not requesting LCC. The research presented 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 limited research in this area to date. The research demonstrates the development of a 5D BIM based LCC solution, where LCC is integrated into the 5D BIM process by embedding an LCC calculation model structure within an existing 5D BIM technology. This process represents a change to the 5D BIM workflow, adding on a facility for LCC through post-processing BIM data. The research is carried out under a design science research methodology, to develop and then evaluate the solution proposed. An evaluation method known as 'Thinking Aloud cooperative evaluation' is used to gain feedback from a sample of QSs utilising the 5D BIM based LCC solution. The purpose of the evaluation is to gauge whether LCC can be effectively embedded in a 5D BIM platform. The contribution to knowledge is the articulation of a process which extends 5D BIM for LCC, by leveraging an existing 5D BIM technology. The findings outline that the primary benefits of the proposed process/system is that it allows for a link between the QSs cost plans/BOQ's and their LCC calculations in an integrated environment.*

KEYWORDS*: building information modelling, life cycle costing, whole life cycle costing, quantity surveyor.*

REFERENCE: *Dermot Kehily & Jason Underwood (2017). Embedding life cycle costing in 5D BIM. Journal of Information Technology in Construction (ITcon), Vol. 22, pg. 145-167, http://www.itcon.org/2017/8*

1. INTRODUCTION

Life Cycle Costing (LCC) is an area in Quantity Surveying (QS) practice that is concerned with the calculation of both construction CAPital Expenditure (CAPex) and OPerational Expenditure (OPex). 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 carryout LCC effectively in line with the relevant standards and guidelines.

Building Information Modelling (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 Quantity Take-Off (QTO) and free up time to concentrate on activities that would add further value for their clients. While LCC is identified as a value enhancing service, there has been limited research on how BIM could be leveraged to increase efficiency in facilitating this service.

The aim of the research is to investigate how BIM estimating software can be effectively utilised by QSs for LCC. In particular, the study develops a BIM based LCC technological solution, embedding an LCC calculation structure within an existing BIM estimating platform. This enables integrated CAPex and LCC analysis within the same system. This process represents a change to the CAPex estimating BIM workflow; adding on a facility for LCC through post-processing BIM data. The research is carried out under a design science research methodology, to 'develop' and then 'evaluate' the proposed BIM based LCC technological solution.

2. LITERATURE REVIEW

2.1 Life Cycle Costing

QS practice traditionally focused on construction CAPex, 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 LCC or occupancy costs of maintaining and managing the built asset after it was constructed (Cole & Sterner, 2000; Kirkham, 2012).

The Construction Best Practice Programme (CBPP 1998) 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), through ISO 15686-5, subsequently provided clarity on the scope of 'acquisition' and 'ownership' costs, further dividing LCC into 'construction'; 'operation'; 'occupancy'; 'maintenance' and 'end of life' costs (BS-ISO, 2008).

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).

Despite the benefits LCC can offer both the QS and the construction client, it is not widely carried out in the QS profession (Olubodun et al., 2010; Opoku, 2013). 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 LCC is not part of the standard cost management service. The reported reasons it has not been implemented into standard practice are; the perceived complexity of the LCC calculations; a lack of access and reliability of LCC data; a lack of standardisation and guidance documentation and that construction clients are not requesting it (Oduyemi, Okoroh, & Dean, 2014; Schaude, 2011)

2.1.1 Calculating LCC

To carry out LCC, QSs 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; RICS, 2015).

There are a number of methods of life cycle economic evaluation defined in Kishk et al. (2003), BS-ISO 15686-5 (2008) and NRM 3 (RICS, 2014). 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). 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.

Churcher (2008) and Schaude (2011) opine that NPV is the most powerful method and the most obvious choice in construction 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 analysis. ‘Discounting’ is the process of converting ‘future money’ to ‘present money’ (RICS, 2014). A stream of discounted future costs can be converted to a single sum NPV by adding together the discounted costs at the equivalent time base (BSI/BCIS, 2008; Clift, 2003). The total discounted NPV is a single figure that takes account of all relevant future incomes and expenditure (future cash flow) 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 for OPex certain additional data requirements are necessary such as discount rates, escalation rates and study periods.

2.1.2 Utilising Technology for LCC

The OGC (2007) and Kehily & Hore (2012) recommend the use of spreadsheet software such as MicroSoft (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. The BSI/BCIS (2008) and NRM 3 (RICS, 2014) appear to support their assertion, as they attach annex spreadsheets for presenting LCC based on NPV calculations.

There are a number of spreadsheet-based LCC applications that support LCC within the jusistictions they encompass and embed LCC calculations within their cells (Kishk et al., 2003; Pelzeter, 2007). The fact that these jursidictions use MS Excel rather than bespoke LCC applications adds credence to the claim that spreadsheet software is the most suitable software for LCC calulations. Examples include, Norway (Gundersen, 1998), Sweden (SEMC, 2011), Ireland (Kehily, 2011) and UK (Hunter et al. 2005), whom use customised LCC spreadsheets on publically funded projects. These spreadsheet applications are advantageoues to QSs because they include the necessary formulea to carry out LCC calculations (Kishk et al., 2003; OGC, 2007). However, incorporating the LCC estimate in separate spreadsheet software can disconnect the QSs measurement (carried out in estimating software) from the pricing and presentation of the LCC estimate (Eastman et al., 2011).

2.2 BIM and its Application for QS Practice

Fung et al. (2014) and Underwoord & Isikdag (2010) claim BIM has the potential to increase efficiency in the construction industry by changing traditional 2 Dimensional (2D) information exchange to a method of delivery that promotes collaboration and integration across the construction supply chain. Common to the definitions of BIM are BIM’s capabilities in delivering value throughout the whole building process including its operational life cycle (Eastman et al., 2011; Cheung et al., 2012). If this is accurate, harnessing the abilities of BIM may facilitate an LCC approach.

Boon (2009) and Ajibade & Venkatesh (2012) determine that by adding time and cost information to 3D BIM, a 4D time model and 5D cost model can be produced, respectively. 5D BIM offers capabilities to generate take-offs, counts and measurements directly from a model providing efficiencies for QSs carrying out CAPex estimating (Matipa et al., 2008; Monteiro & Martins, 2013: Smith, 2014). According to Barnes & Davies (2014), LCC is mainly provided for in 5D BIM by the QS when evaluating design decisions and thus, in this research it is referred to as an extension to the 5D BIM process.

2.2.1 BIM and Cost Management (5D BIM)

Sylvester & Dietrich (2010) and Crowley (2013) agree that with the 5D BIM process, practitioners can move from spending time on generating quantity and cost information, to validating the quantities and costs contained within their CAPex estimates. Wijayakumar & Jayasena (2013) note to carry out effective 5D BIM, QTO must be generated from the BIM to suit QS requirements and measurements rules. This is outlined in Eastman et al.

(2011) as 'associating the BIM quantities with assembly items', i.e. assembly of the estimate in accordance with QS Work Breakdown Structures (WBS). 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, so that when the quantities are extracted they are aligned to that code.

Given that model cost mapping is not yet ingrained in BIM objects, current practice is that QSs 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 (QS code in the objects of the model), this is the first stage of 'processing' the model where quantities are generated that are in a WBS and unit that makes it easier for the QS to populate in their cost plan (Drogemuller & Tucker, 2003). Mitchell (2012) states that the modern QS is carrying out 'post-processing' by utilising models within the 5D BIM environment to provide detailed and accurate estimates for what he deems 'living cost plans'. The living cost plan means that there is what Lovegrove (2014) deems a 'live link' between the quantities generated from the BIM and the cost plan. The living cost plan becomes the basis for providing quick updated estimates every time the model information is changed (Mitchell, 2012; Sylvester & Dietrich, 2010).

Crowley (2013) and Sabol (2008) maintain that by adopting and utilising 5D BIM the base skills of the QS can translate into enhanced skills providing more cost advice at the early stages of design and quicker cost advice on alternative design solutions. Sabol (2008) and Smith (2014) also point out that BIM makes it possible for QSs to provide alternative professional services such as LCC by leveraging BIM technology and freeing up time that would have been spent on labour intensive activities in traditional QS processes such as QTO. Post-processing BIM quantities to align with LCC WBSs could also add a further dimension to the estimating process.

2.2.2 BIM and Life Cycle Costing

Goucher & Thurairajah, (2012) and Whyte & Scott (2010) assert that construction clients will increasingly demand buildings with low operating costs, driving demand for technology that can quickly account for operational performance and then budget accordingly. However, Kirkham et al. (2004) and Whyte & Scott (2010) argue that there is much to be done in the development, promotion and utilisation of digital models that address LCC if productivity and environmental gains are to be realised.

Within the research field of BIM, many studies focus on the federated BIM environment by expanding capabilities within an integrated structure, i.e. carrying out 'what if' analysis in design software. Applying default LCC criteria to BIM object definitions by focusing on the data model itself could mislead the QS to use default criteria and not take account of the broader economic conditions in which a particular project may apply (Eastman et al., 2011; Sylvester & Dietrich 2010). Fundamentally, Shen et al. (2007) and Goucher & Thurairajah (2012) report that BIM authoring tools do not currently have the probabilistic capabilities to accommodate the variable conditions for LCC analysis. In this context, it can be seen from the Industry Foundation Classes (IFC) and Construction Operations Building Information Exchange (COBie) 'default parameters' that there are few LCC properties in BIM objects 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. A more flexible structure than BIM can provide is needed for the probabilistic nature of LCC calculations and the many variables necessary for 'what if' analysis (Eastman et al., 2011; Sylvester & Dietrich 2010; Whyte & Scott, 2010).

Kehily, McAuley & Hore (2012) propose utilising QS discipline specific 5D BIM software, which they state provides a suitable cost medium for LCC. The 5D BIM 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. A feature that is inherent in some of the leading 5D BIM estimating applications such as Exactal CostX and Nomitech CostOS is a customisation function which provides users with the ability to add columns and functions to the application's default workbook. 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 5D BIM system. Outlining a calculation methodology within a spreadsheet format that could be incorporated in 5D BIM would ground the system within current LCC methodologies, which suggest calculations and algorithms should be in a spreadsheet framework (OGC, 2007; BSI/BCIS, 2008; RICS, 2014).

3. RESEARCH METHODOLOGY

Design science was selected as the research strategy because there was significant participation from the researcher in designing a 5D BIM based LCC solution and subsequently evaluating it in action. Johannenson & Perjons (2012) state in design science a 'solution' to a field problem takes the form of what is known as an artificial construct ('artifact'), which they describe *"as an artificial object made by humans to solve practical problems*", i.e. a 'technological solution' that can affect change in human behaviour.

To contribute to new knowledge in design science an artifact should be developed and evaluated through an articulated formulated process to determine its effect on the environment to which it will be introduced (Kehily & Underwood, 2015; Johannenson & Perjons 2012). The contribution to knowledge in this research is the development of an artifact that embeds LCC within an existing 5D BIM technology to produce a 5D BIM based LCC artifact.

Hevner et al. (2004) state that when carrying out design science research it is important that the research process is well defined and articulated, so that if the researcher is interested in developing 'an artifact', that there is an explicit phased process to its development and evaluation. Hervner et al. (2004), Holmstrom et al. (2009) and Johannenson & Perjons (2012) all articulate well defined frameworks for design science, albeit using different terminology. These strategies outline four common phases; 1. diagnosing a problem; 2. proposing (developing) a solution; 3. implementing the solution & evaluating the process in action; and 4. specifying learning.

Hevner et al. (2004) explains that '1. 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. As discussed previously, BIM is identified as a holistic approach that could aid QSs in carrying out LCC, which as reported, is under-utilised in QS practice. Hevner et al. (2004) state that '2. developing a solution' is the process of constructing an artifact to provide a technological solution to the diagnosed problem. The 'development phase' in this research embeds an LCC calculation structure, created by the researchers, into an existing 5D BIM estimating platform – i.e. extending the 5D BIM workflow into LCC. This is discussed in further detail in section 4.

The utility, quality and efficiency of a design science artifact must be demonstrated via well executed evaluation methods (Hevner et al., 2004). '3. Evaluating the process in action' requires some way of determining how successful the proposed change is in its environment or simulated environment (Hevner et al., 2004; Johannesson & Perjons, 2012). A usability evaluation method known as 'Thinking Aloud (TA) cooperative evaluation' is proposed in this research. It enables a functional evaluation of the design science artifact, while also collecting data based on the subjective attitudes of the participants on the process they are engaged in (Monk et al. 1993; Nielsen, 1993; Dumas & Redish, 1999). 'TA cooperative evaluation' combines empirical usability evaluation with a qualitative research design by integrating interview type questions into the traditional TA method. Participants complete a number of tasks utilising the proposed artifact and data is generated through the completion (or non-completion) of the tasks and the attitudes and feedback from the participants throughout the evaluation. Kehily & Underwood (2015) contend the TA method is specifically suitable for BIM research, as participants using a proposed new BIM interface or process may not have utilised a similar technology previously and thus, will need to be guided on what to do.

This research proposes an extension to the 5D BIM process by embedding an LCC calculation structure in a 5D BIM technology (CostX). This solution represents the 'artifact' in design science research and thus, needs to be 'evaluated in action'. The primary research was carried out where sixteen QS participants engaged in a TA cooperative evaluation carrying out a number of tasks, which are outlined in greater detail in section 5. 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 thematic analysis was employed.

Hevner et al. (2004) note that design science research should contribute to knowledge by applying knowledge in a new or innovative way. Hevner et al. (2004) state that in design science research learning must be specified clearly. 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 (i.e. 5D BIM for LCC) and that the practice can have an effect on some of the barriers that prevent the widespread application of LCC (changing work practice). 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. EMBEDING LCC IN 5D BIM

4.1 Leveraging 5D BIM for LCC

As discussed previously, 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). When utilising a scientific calculator or financial tables each LCC variable must be input to determine the relevant result and each result must be accumulated to determine the total LCC. Kehily & Hore (2012) focused on constructing LCC spreadsheet templates and calculations within these templates to aid QSs carrying out LCC. Although the calculations in Kehily and Hore's template are more automated than the LCC spreadsheet applications mentioned in section 2.1, it does not represent a significant departure in methodology, as it ultimately uses MS Excel to carry out the calculations. In addition, similar to other spreadsheet applications and LCC methodologies outlined previously, their work does not leverage any Computer Aided Design (CAD) or BIM technology. Carrying out measurement must be done separately or in an alternative application and then manually input into the LCC spreadsheet.

As discussed in section 2.2.2, BIM authoring software does not currently have the capabilities to accommodate the variable conditions and probabilistic calculations necessary for LCC (Eastman et al., 2011; Whyte & Scott, 2010). In this research an LCC calculation structure is incorporated into a 5D BIM platform. The research adopted CostX 5D BIM software by Exactal. CostX was selected because it has a workbook that is similar to the functionality and capabilities of a spreadsheet, giving the user an opportunity to add new columns, rows and functions that can link calculations between them. Furthermore, CostX's spreadsheet functionality can be utilised to replicate the LCC calculation structures proposed in LCC methodologies, such as ISO 15686-5 (BS-ISO, 2008), BSI/BCIS 15686-5 (2008) and NRM 3 (RICS, 2014). This section outlines the design science artifact developed as part of this research.

4.2 Extracting Quantities by Utilising CostX

CostX enables you to quickly and accurately take off quantities from 2D drawings and BIMs using on-screen electronic measurement (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 a lower level of the workbook hierarchy will return summary details to the level 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.

Illustrated in Fig. 1, Wu et al. (2014) note that the CostX drawing viewer provides an excellent visualisation of the model similar to the navigation functionality in Revit, where the navigation features enable you to rotate, pan, zoom and spin the BIM. The drawing viewer gives the QS the opportunity to select items from the model (they are generating quantities for) and to view their object properties.

The power of CostX revolves around the integration between the electronic measurement tool (Fig. 1) and the workbook module of the software (Fig. 2). Mitchell (2012) describes that the user can take off quantities in BIM file formats such as DWFx and IFC in the electronic measurement tool and create automated 'live links' between their take off and their workbooks by switching from the 'dimension view' to a 'costing view', once the quantities are produced.

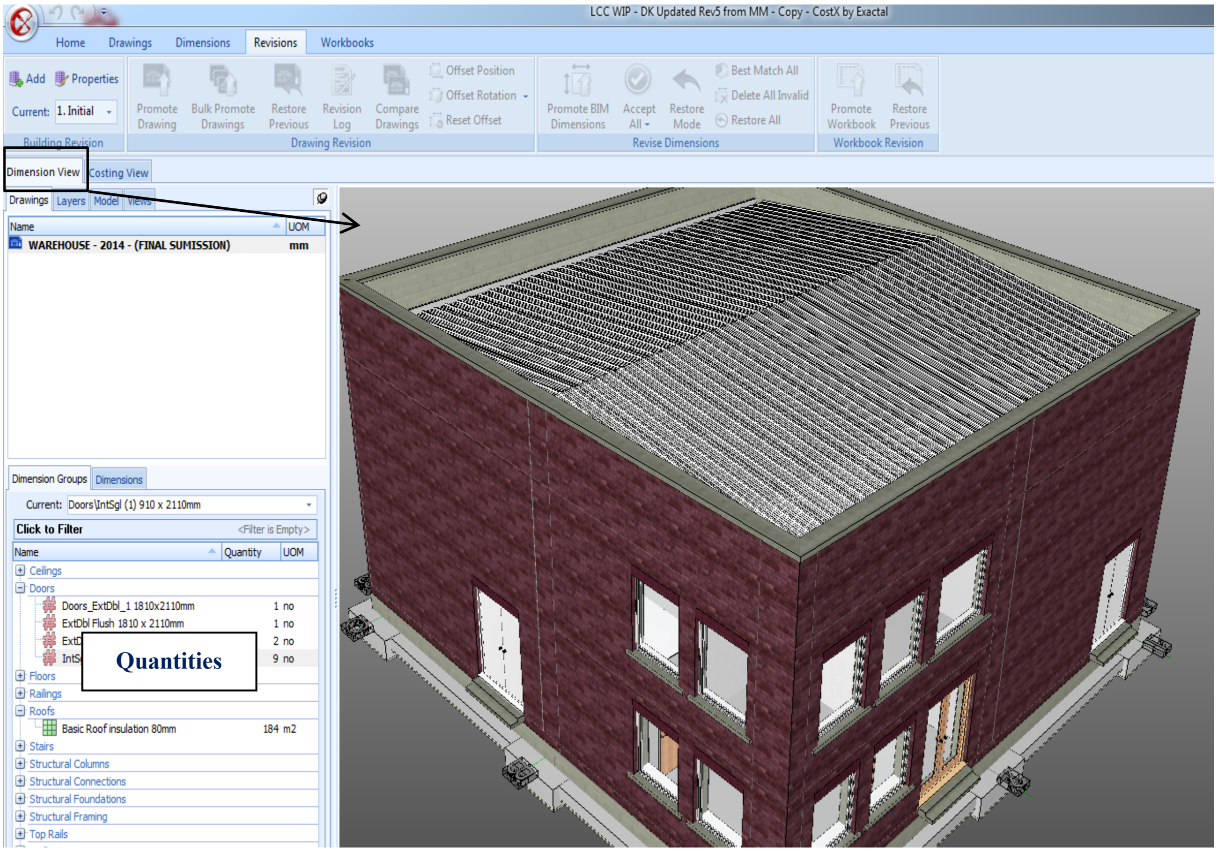

FIG. 1: CostX model visualisation

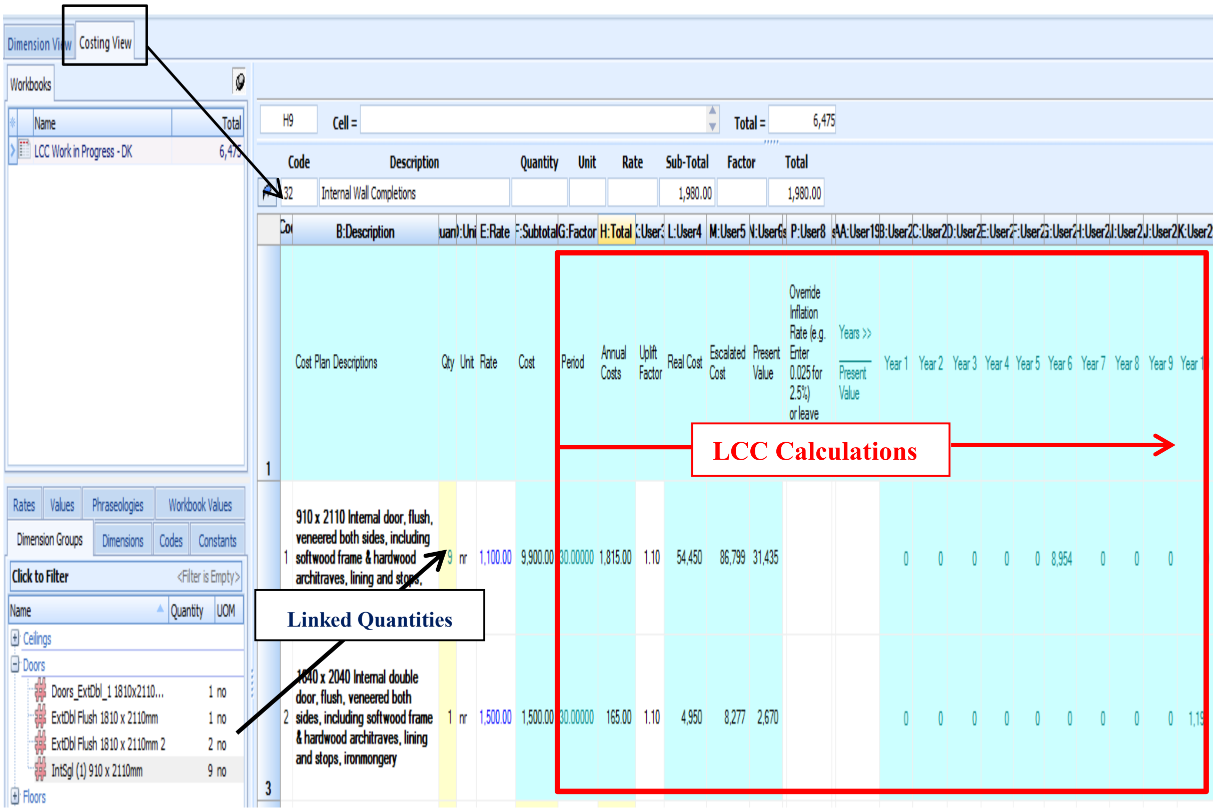

FIG. 2: CostX Workbook

To carry out 5D BIM QTO, CostX has a model definition tool that enables the user to configure a 'model map' to extract data and quantities from a BIM using any combination of object properties. Using this function, the 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 BIM authoring application. CostX also has a number of what they deem 'BIM import templates', which are pre-coded model maps (determined by CostX rather than the user) to quickly extract quantities based on the model schema of the authoring application. As demonstrated in Fig. 3, quantities can be extracted from the Revit model categorical structure based on the 'BIM Import Revit General' template and utilised for take-off as dimension groups.

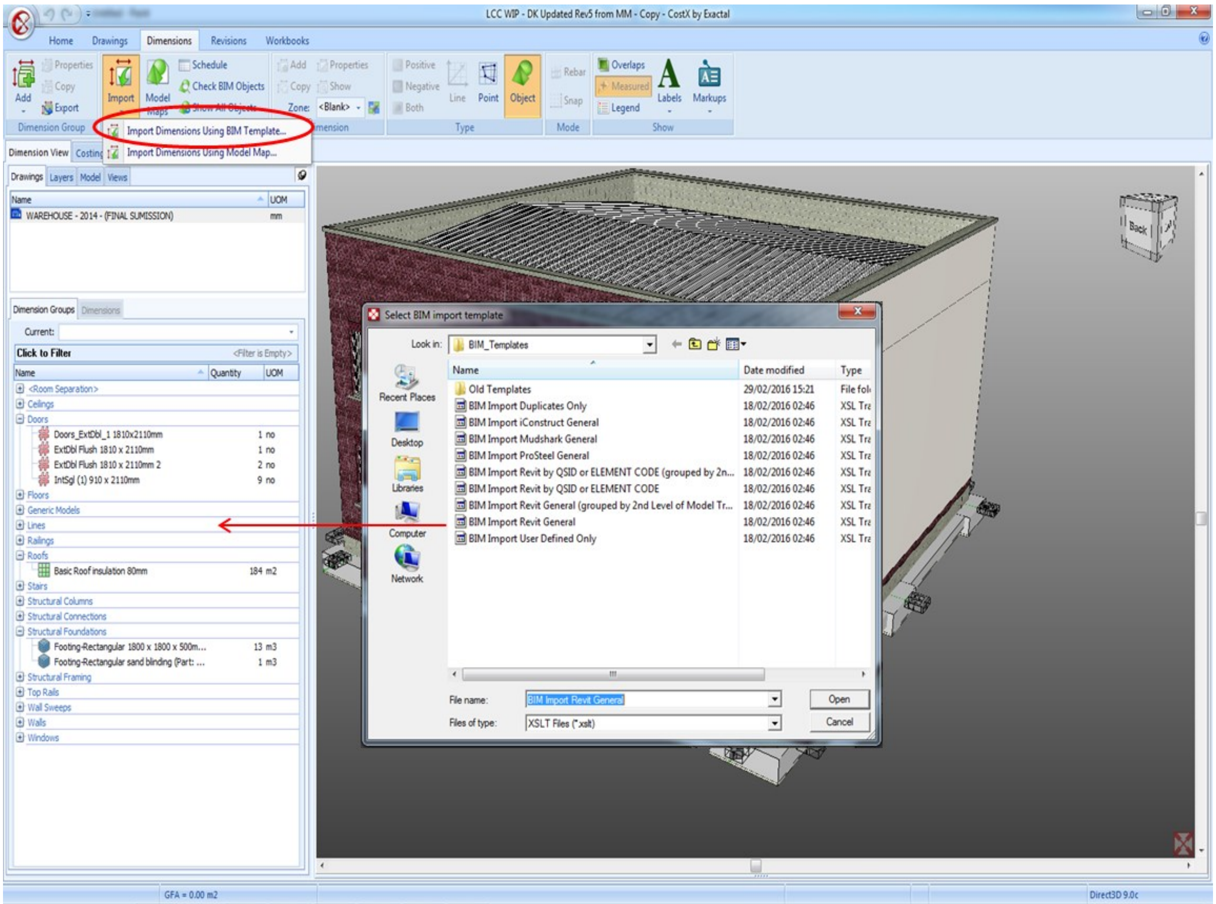

FIG. 3: BIM Import Template

The model map functionality and the use of pre-coded BIM templates provide the CostX 5D BIM platform with the ability to effectively generate quantities from the model and subsequently provide QSs with the ability to utilise these quantities in their estimates (Wu et al., 2014). This research specifically investigates CostX's capabilities to house the calculations and structures necessary to carry out and present LCC. This process leverages QTO extracted from the BIM for use in an LCC estimate leading to real-time LCC analysis in the same platform.

Noted in section 2.1, most LCC models are carried out in spreadsheet templates (leveraging spreadsheet formulae/functions) to carry out LCC calculations that require more complex computation than what is in your traditional cost estimate. The CostX workbook is similar to the functionality of a spreadsheet application providing the user with the ability to insert 'user defined columns' (like adding columns in an MS Excel spreadsheet). This enables the user to add LCC data and calculations to the CAPex cost items in their BOQ or cost plan. Fig. 2 illustrates the LCC calculation structure (red box) added in the user-defined columns of the CostX workbook. This embeds automated LCC calculations in the 5D BIM platform and links the QTO extracted from the model to the LCC calculations. The following sections outline in further detail the process of adding LCC capability to CostX's 5D BIM platform by extending its workbook functionality to calculate LCCs. This was carried out in collaboration with Exactal CostX.

4.3 Embedding LCC in CostX Workbook

LCC methodologies and guidance notes were discussed and it was agreed that embedding an LCC workbook in CostX would need to reflect relevant LCC 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. Collaboration with CostX gave rise to an artifact based on a summary page (Fig. 5) and three sub-sheets (Fig. 6, Fig. 7 and Fig. 8). The sub-sheets outline the LCC calculation structure for; [1] full replacement items (i.e. one off replacement); [2] minor replacement and repairs and [3] costs that occur on a yearly basis (occupancy and operations costs). This methodology is based on the WBSs and recommendations to calculating LCC contained in ISO 15686-5 (BS-ISO, 2008), its BSI/BCIS (2008) supplement and RICS (NRM 3) (2014).

The first step in producing an LCC model is to determine the data requirements (discount rate, escalation rate, and study period) used in the analysis. Data requirements need to be used in LCC calculations to determine present value and escalated LCCs. These calculations 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). For this research, this data is input in the 'calc' sheet of the LCC workbook, illustrated in Fig. 4, and utilised throughout the LCC calculations in the model. The LCC cash flows and total LCC costs (real, escalated and present value) in the sub-sheets are automatically calculated from these data requirements and the maintenance actions defined in the sub-sheets. If these data requirements are subsequently changed, the model will update and calculate outputs based on the new LCC criteria. This enables the user to variable test the model with different data requirements in real-time. This 'calc' sheet also defines the basis of the LCC display, i.e. whether the estimate will be presented as real costs, escalated costs or present values. In the example in Fig. 4, by inputting 'NPV' in row 4, the summary sheet will present total LCCs in 'present values' over a study period of 30 years.

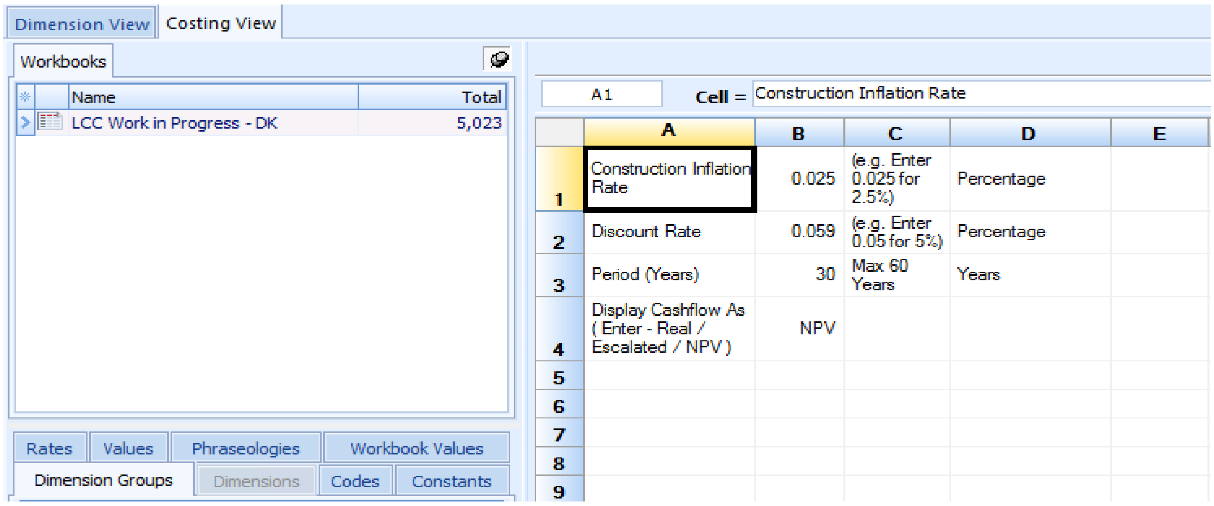

FIG. 4: Data Requirements

Fig. 5 represents the summary page and the total line items for the three relevant sub-sheet calculations. These three sub-sheets form the basis for any LCC calculations in an LCC estimate. In the example presented in Fig. 5, the summary structure is broken down per the WBS recommended in ISO 15686-5 (BS-ISO, 2008). Clicking on the line of the relevant element (WBS) in the summary, the user is able to access the applicable sub-sheet and LCC calculations to build up LCC costs within that element. These costs are then accrued and presented on the relevant line item in the summary page based on the values entered in the data requirements 'calc' sheet (Fig. 4).

	A:Code	B:Description	F:Subtotal	I:User1	J:User2	K:User3	A:User1	B:User2	C:User2	D:User2	E:User2	F:User2	G:User2	H:User2	I:User2	J:User2	K:User2
1	**2.0**	**Maintenance**	**Anuual Real Costs**	**Real Costs**	**Escalated Costs**	**Present Value**	Years >> Present Value	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
2	2.1	Major Maintenanace & Replacement (full replacement items) on elements below															
3		*Element*															
4		*Element*				[1]											
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		....															
9	2.2	Subsequent Refurbishment and Adaption Costs (Not in 2.1 or 2.4)															
10	2.3	Redecoration (Not in 2.1 or 2.4)															
12	2.4	Minor Replacement Repairs and PPM Costs (Routine)				[2]											
13		*Element*															
14	*32*	*Internal Wall Completions*	1,165	34,947	57,112	19,450		0	0	0	0	967	0	2,245	0	0	3,679
15		*Element*															
16		*Element*															
17		*Element*															
18		....															
19	2.5	Unscheduled Replacement Repairs and Maintenance (Reactive)															
20	2.6	Grounds Maintenanace															
22	**3.0**	**Operation costs (Annual)**															
23	3.1	Cleaning Costs (not in above)															
24	3.1.1	Windows and external surfaces															
25	3.1.2	Internal cleaning															
26	3.1.3	Specialist cleaning															
27	3.1.4	External works cleaning															
28	3.2	Utilities costs gas and electric															
29	3.2.1	Fuel Costs				[3]											
30	3.2.1	Fuel Costs (electricity)	3,330.00	99,900	212,295	81,820		3,286	3,243	3,200	3,157	3,116	3,074	3,034	2,994	2,954	2,915
31	3.2.2	Water and Drainage															
32	3.3	Administration Costs															

FIG. 5: Summary Sheet

4.3.1 Calculation Sub-Sheet [1]

The first sub-sheet (Fig. 6) deals with the calculation of full replacement cost items in an LCC estimate. User defined LCC columns are added to the CostX workbook (in this sub-sheet) to enable LCC calculations for major replacement items. The LCC cash flows throughout the analysis period and the total LCC costs (real, escalated and present value) are automatically calculated and populated from the LCC data requirements outlined in Fig. 4 and the replacement period and uplift factor entered in the LCC user defined columns in Fig. 6. The majority of cost plan items will also need an uplift factor, for preparation, demolition and making good to receive new work, over and above the basic installation cost (BSI/BCIS, 2008; RICS, 2014). To enable the LCC calculations expounded in Fig. 6, 'IF' scenario formulae are embedded in each of the yearly cash flow cells for every line item. These formulae are similar to Microsoft Excel functions and automate the calculation of cash flows by utilising 'IF' functions deriving data from the 'Replace Period' (column J), the 'Uplift Factor' (column K) and the data requirements input in Fig. 4. If any of these variables change the calculations, resultant cash flows and total LCCs (real, escalated and present value) will be updated. In this example, a 'Present Value' cash flow is generated for replacing the '910 x 2110 Internal door' every 6 years within the 30 year analysis period, input in the data requirements (i.e. year 6,12,18,24,30). The 'IF' functions dictate that any year that is not a multiple of the 'Replace Period' will have a value of '0'. Cash flows for 'Real' and 'Escalated' costs are calculated in the same manner (albeit with different formulae), but are not included in this screenshot as the expanded scope would limit the clarity of the illustration. As demonstrated in Fig. 5, these LCC totals (columns L, M and N) and the accumulated cash flows carry forward to the relevant element on the summary sheet. The same sub-sheet can be used to represent the relevant 'major maintenance and replacement costs' for every applicable elemental category in the LCC estimate.

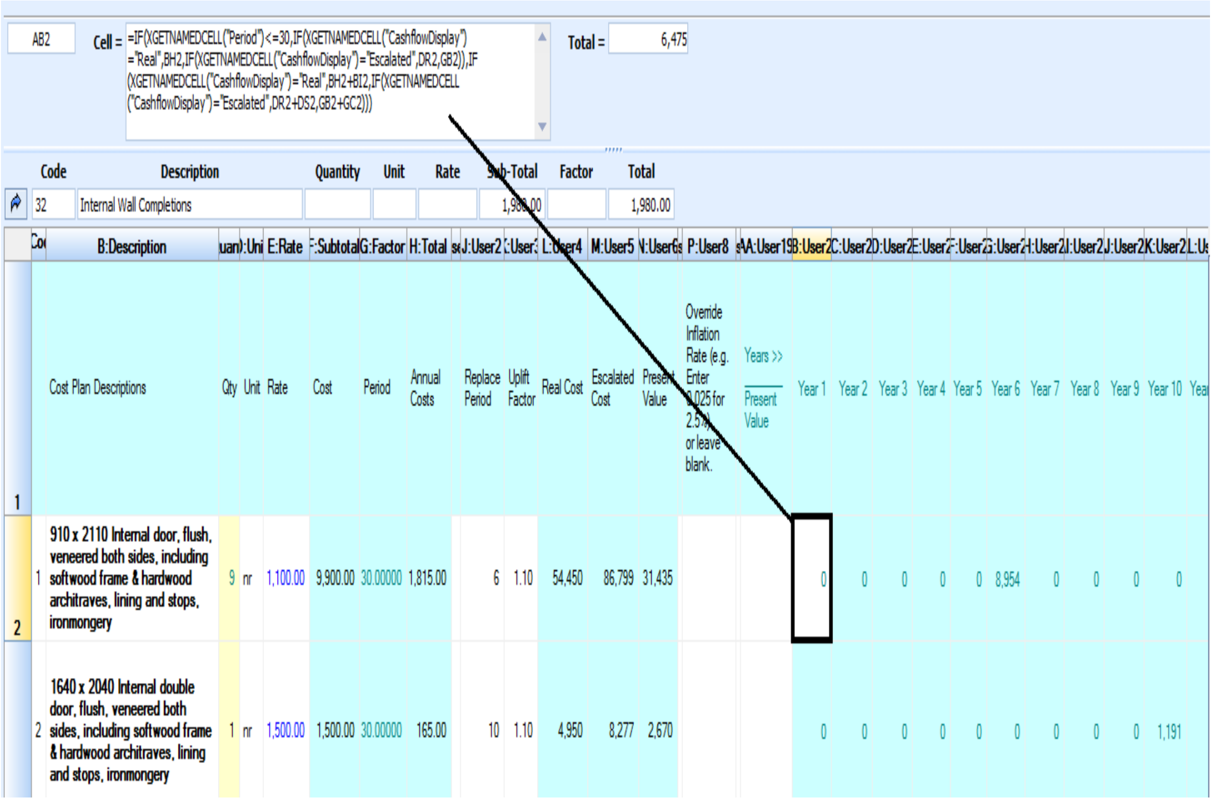

FIG. 6: LCC Calculation Sub-Sheet [1]

4.3.2 Calculation Sub-Sheet [2]

The second calculation sub-sheet [2] includes two types of calculations that can be preformed on 'minor replacement and repairs costs'. The first, illustrated on the top half of the sheet in Fig. 7, is based on a proportional breakdown of a cost plan item into a number of maintenance actions on the same line. For example, in the first line item for a '910 x 2110mm internal door' (row 2); door seals are replaced every 5 years (Maintenance Period 1 – column J) at an estimated cost of 5% (0.05) (Maintenance Factor 1 – column K) of the total cost of the door; ironmongery is replaced every 10 years (Maintenance Period 2 – column L) at 40% (Maintenance Factor 2 – column M) and the door is repainted every 7 years at 20% (Maintenance Period and Factor 3). Similar to the calculations explained in Fig. 6, 'IF' scenario formulea are embedded in the yearly cash flow cells. The automatic 'IF' functions in these cells allocate the appropriate costs throughout the 30 year study period into their relevant years for real, escalated and present value cash flows, while also calculating the total LCC costs. Within the frame of this screenshot (for the 910 x 2110mm internal door), present values are populated in year 5, year 7 and year 10, based on the 'Replace Periods' input in that line item. Year 10 is not evident in Fig. 7 because it is outside the scope of the illustration. Multiples of these periods are also populated within the 30 year analysis giving rise to an automated maintainence cash flow profile. Cash flows and total LCCs are also calculated in a similar manner for 'Real' and 'Escalated Costs'. This sub-sheet would be used in conceptual and schematic estimating in the early design stages. Similar to Fig. 6, these costs are accumulated and returned to the summary page (Fig. 5).

The second half of the sheet (Fig. 7) enables the user to carry out more detailed anaysis, breaking down the '910 x 2110mm Internal door' into its resepective minor maintenance items (such as seals, ironmongery and painting), on a line by line basis, rather than it accumulated on one line item. As demonstrated in Fig. 7, the seals of the door are replaced every 5 years (row 6, column J), the ironmongery replaced every 15 years (row 7, column J) and the door and frame repainted every 7 years (row 7, column J). This stucture would be used in the latter design stages and during FM, when there is more component detail available. Similar MicroSoft 'IF' functions to those outlined in Fig. 6 are embedded in the yearly cash flows to computate these line items and accumulate the LCCs. Both types of calculations are demonstrated in Fig. 7 for illustration purposes, but only one would be applicable depending on the level of detail in the LCC estimate.

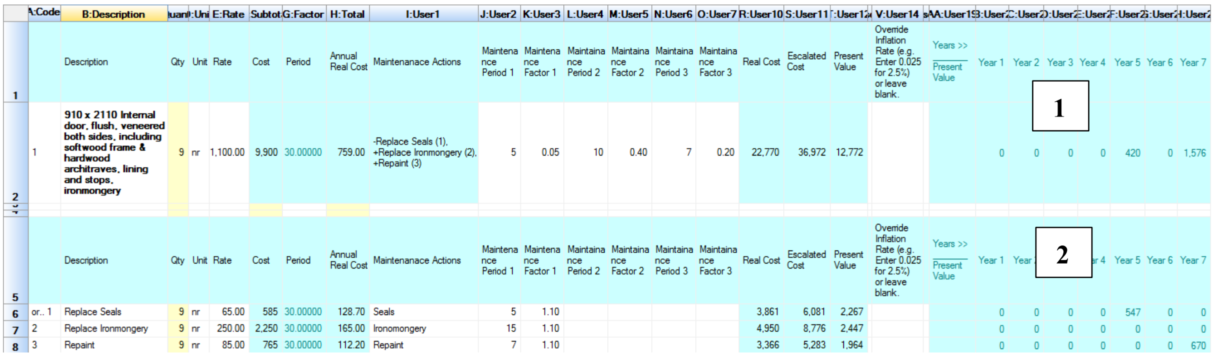

FIG. 7: LCC Calculation Sub-Sheet [2]

4.3.3 Calculation Sub-Sheet [3]

LCC calculation subsheet [3] is outlined in Fig. 8 and presents the annual costs calculation methodology for LCC items which recur on a yearly basis. This would include all items based on ISO 15686-5 (2008) for 3.0 operations costs and 4.0 occupancy costs.

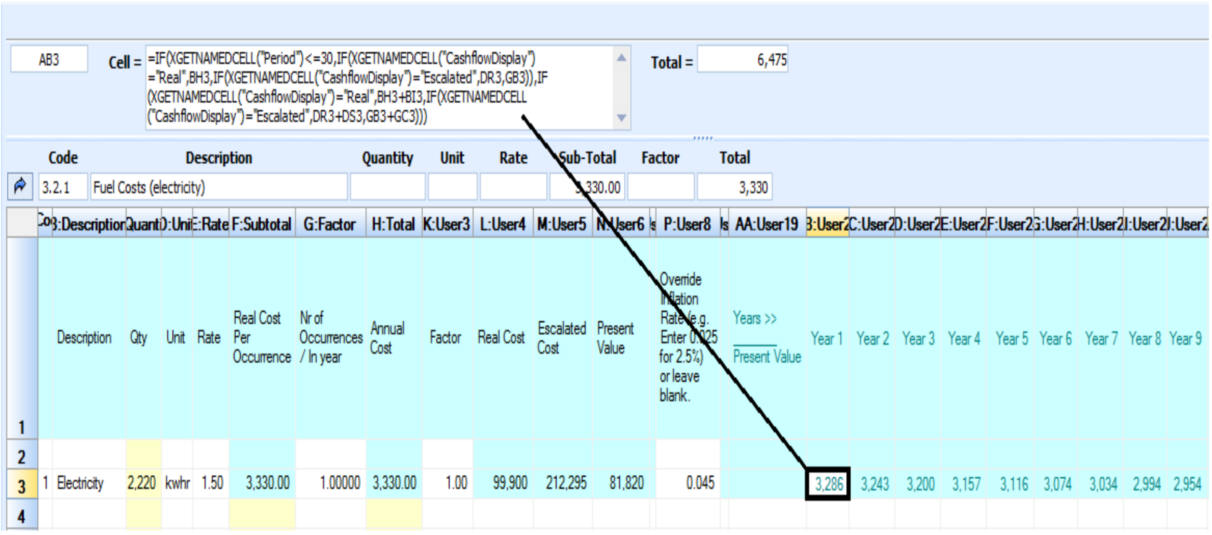

FIG. 8: LCC Calculation Sub-Sheet [3]

Fig. 8 provides an example of annual electricty costs which are automatically populated throughout the cash flow for the analysis period of 30 years (input in Fig. 4). The formulea to calculate these yearly LCC costs is evident in Fig. 8. They calculate the present values for each year based on the annual cost (column H) and the data requirements input in Fig. 4. The resultant total LCCs are returned to the summary page, similar to the sub-sheets outlined previously. There is also an opportunity in all sub-sheets to override the construction escalation rate, entered in the data requirements of the 'calc' sheet, and to apply an item specific rate. This would be particularly applicable for energy cost items that may escalate at a rate above the construction inflation rate. As demonstrated in Fig. 8, the project inflation rate of 2.5%, input in Fig. 4, is superseded by an energy specific escalation rate of 4.5% (column P). In this example, an annual 'Electricty' cost of 3,330 is calculated as a present value cash flow for every year of the analysis based at a discount rate of 5.9% (Fig. 4, data requirements) and an escalation rate of 4.5%. This gives rise to a discounted yearly cash flow over the analysis period and a total ‘Present Value’ of 81.820 (column N). This sub-sheet, similar to Fig. 6 and 7, also calculates cashflow values for real and escalated LCCs and returns them to the summary page illustrated in Fig. 5.

4.3.4 Contribution to the BIM Workflow

Current practice in the 5D BIM workflow is that LCC information is ‘pushed’ into the 5D process at the reporting end rather than ‘pulled’ from the BIM (i.e. LCC information is not embedded in the authored model because it is not usually in the domain of the designers and thus needs to added by the QS). Another issue, discussed in section 2.2, is that the 3D BIM environment is not semantically rich enough yet to accommodate the extent of LCC data and variable conditions for probabilistic calculations (Shen et al. 2007; Goucher & Thurairajah 2012) thus, creating LCC definitions in the authored BIM would be of no value. For these reasons, the technological process articulated in the previous section follows the methodology where LCC calculations are calculated in the 5D BIM platform rather than the authored BIM.

From a technological perspective, this approach highlights an innovative design science artifact, which leverages an existing 5D BIM tool and extends it for LCC. From a process perspective, it outlines a methodology that appends LCC to the 5D BIM workflow (Fig. 9). This process can take account of information that currently resides outside the 5D BIM workflow by post-processing BIM data.

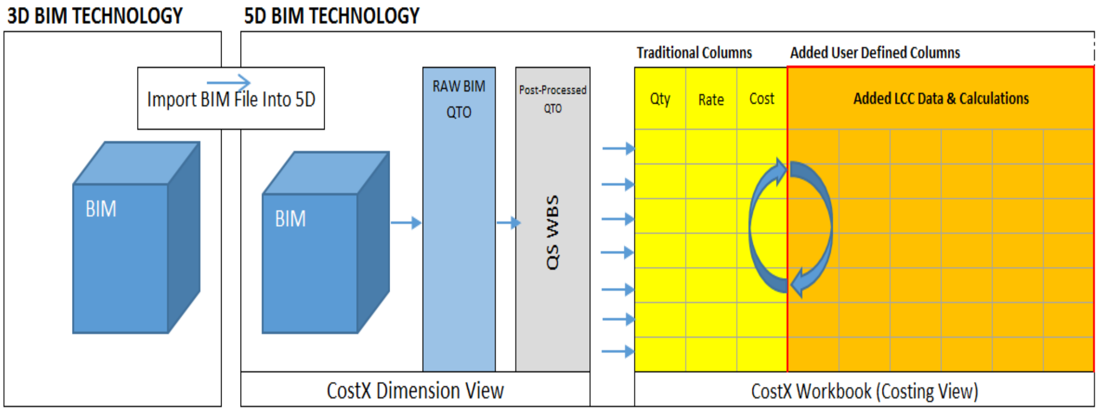

FIG. 9: 5D BIM LCC Extension

Fig. 9 illustrates the process of importing the BIM file into the 5D BIM platform, where quantities are extracted from the model by the QS to align to WBSs such as the BCIS in UK or the National Standard Building Elements (NBSE) in Ireland. These quantities are normally utilised in the traditional columns of the workbook (yellow columns) to generate a CAPex estimate. Fig. 9 indicates that by adding user defined columns (orange columns) containing automated LCC calculations the 5D BIM platform can be extended to carry out LCC. 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 in the reports.

5. EVALUATION

This section articulates the procedures employed to evaluate the artifact outlined in section 4. Data was collected per the formulated step by step structure to TA cooperative evaluation outlined in Monk et al. (1993) and Nielsen (1993). The fieldwork evaluated and collected data from sixteen participants whom engaged with the artifact discussed in the last section.

There were a broad range of participants (Fig. 10) from different companies and educational backgrounds with diverse experience in carrying out LCC calculations, QS software proficiency and BIM capability. What was necessary was that the participants had some experience of preparing cost plans and Bills Of Quantities (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.

Participant	Job Description	Level of Education	What do you do in your Job	How long have you being doing this work	Experience in Excel	QS software are you proficient	BIM Experience	LCC Experience	CostX Proficiency
Participant - 1	Professional QS	Hons Degree	Measurement for Cost Plans	12months - 2 Years	Advanced	Buildsoft	Advanced	Proficient	Advanced
			Measurement for BOQ's			Cost X			
			Cost & Prepare Cost Plans						
Participant - 2	Professional QS	Hons Degree & MRICS	Measurement for Cost Plans	10 - 20 years	Advanced	Buildsoft	Intermediate	Very little	Advanced
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans			CostX			
Participant - 3	Contractors QS	Hons Degree & MRICS	Measurement for Cost Plans	5 - 10 years	Advanced	Buildsoft	Intermediate	Very little	Novice
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans						
Participant - 4	Professional QS	Hons Degree	Measurement for Cost Plans	12months - 2 Years	Intermediate	Buildsoft	Novice	Some Knowledge	Novice
			Measurement for BOQ's			Cato			
			Cost & Prepare Cost Plans			CostX			
Participant - 5	Contractors QS	Hons Degree & MRICS	Measurement for Cost Plans	10 - 20 years	Advanced	Other: Estimation	Novice	Some Knowledge	Novice
			Measurement for BOQ's						
			Cost & Prepare Cost Plans						
			Life Cycle Costing						
Participant - 6	Professional QS	Hons Degree & MRICS	Measurement for Cost Plans	10 - 20 years	Intermediate	Buildsoft	Novice	Very little	Intermediate
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans			CostX			
Participant - 7	Contractors QS	Hons. Degree	Measurement for Cost Plans	20 - 30 years	Intermediate	Buildsoft	Novice	Some Knowledge	Novice
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans						
Participant - 8	Contractors QS	P.Grad	Measurement for BOQ's	10 - 20 years	Intermediate	Other: Estimate	Intermediate	Very little	Novice
			Cost & Prepare Cost Plans						
Participant - 9	Professional QS	Hons. Degree	Measurement for Cost Plans	20 - 30 years	Advanced	CostX	Advanced	Some Knowledge	Advanced
			Measurement for BOQ's			Autodesk QTO			
			Cost & Prepare Cost Plans						
Participant - 10	Professional QS	Hons. Degree & MRICS	Measurement for Cost Plans	5 - 10 years	Intermediate	Buildsoft	Advanced	Very little	Intermediate
			Cost & Prepare Cost Plans			BT2			
						CostX			
Participant - 11	Contractors QS	Hons. Degree & MRICS	Measurement for Cost Plans	10 - 20 years	Advanced	Buildsoft	Novice	Proficient	Novice
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans						
			Life Cycle Costing						
Participant - 12	Professional QS	Hons Degree & MRICS	Measurement for Cost Plans	20 - 30 years	Intermediate	Buildsoft	Intermediate	Some Knowledge	Novice
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans						
Participant - 13	Professional QS	Hons. Degree & MRICS	Measurement for Cost Plans	10 - 20 years	Advanced	Buildsoft	Intermediate	Some Knowledge	Novice
			Measurement for BOQ's			BT2			
			Cost & Prepare Cost Plans						
			Life Cycle Costing						
Participant - 14	Contractors QS	Hons Degree & MRICS	Measurement for Cost Plans	20 - 30 years	Intermediate	Buildsoft	Novice	Some Knowledge	Intermediate
			Cost & Prepare Cost Plans			CostX			
						Other: Vector			
Participant - 15	Professional QS	Hons Degree & FRICSI	Measurement for Cost Plans	30 - 40 years	Intermediate	Buildsoft	Novice	Very little	Novice
			Measurement for BOQ's						
			Cost & Prepare Cost Plans						
Participant - 16	Professional QS	Hons Degree	Measurement for Cost Plans	2 - 5 years	Advanced	Archicad	Intermediate	Some Knowledge	Novice
			Measurement for BOQ's						
			Cost & Prepare Cost Plans						
			Life Cycle Costing						

FIG. 10: User profile

There were three scenarios encompassing eight tasks to be completed by participants in the evaluation. Scenario 1 had one task and required the participant to extract BIM quantities from the model utilising the ‘BIM Import Revit General’ template available in CostX. Scenario 2 had five tasks and revolved around utilising/linking these BIM quantities for the LCC of an internal single door, in terms of its [1] full replacement and its [2] minor replacement, repairs and maintenance costs. Task 7 and 8 dealt with LCC of [3] annual recurring costs, in this case electricity. The participant was requested per the tasks to carry out a number of LCC inputs and calculations entering information in each of the sub-sheets discussed in section 4.

Directions for Task 1 are highlighted in Fig. 11 and encompassed extracting BIM quantities from the model, which were then utilised in further tasks using the sub-sheets. Fig. 3 illustrates the procedures in Task 1 where the user was requested to add a BIM drawing (DWFx) to the CostX dimension view. Subsequently, they were requested to automatically extract QTO from the model utilising the ‘BIM Import Revit General’ template discussed previously. By carrying out this task, quantities are automatically extracted from the DWFx file in the Revit categorical structure and listed as dimension groups. These dimensions are now available for linking to the LCC workbook.

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

FIG. 11: Scenario 1, Task 1

Task 2 required the participant to input the data requirements of the LCC analysis in the 'calc' sheet illustrated in Fig. 4. In Task 3 (Fig. 12) the user was directed to link the BIM quantities extracted in Task 1 to the LCC workbook by 'dragging and dropping' the quantity (InSgl 910 x 2110mm) from the dimension group into the LCC workbook. This forms a 'live link' between the BIM QTO and the LCC model. The calculations in the model automatically calculate the LCC costs in real costs, escalated costs and present value, which are checked by the participant against the answer in the task sheet.

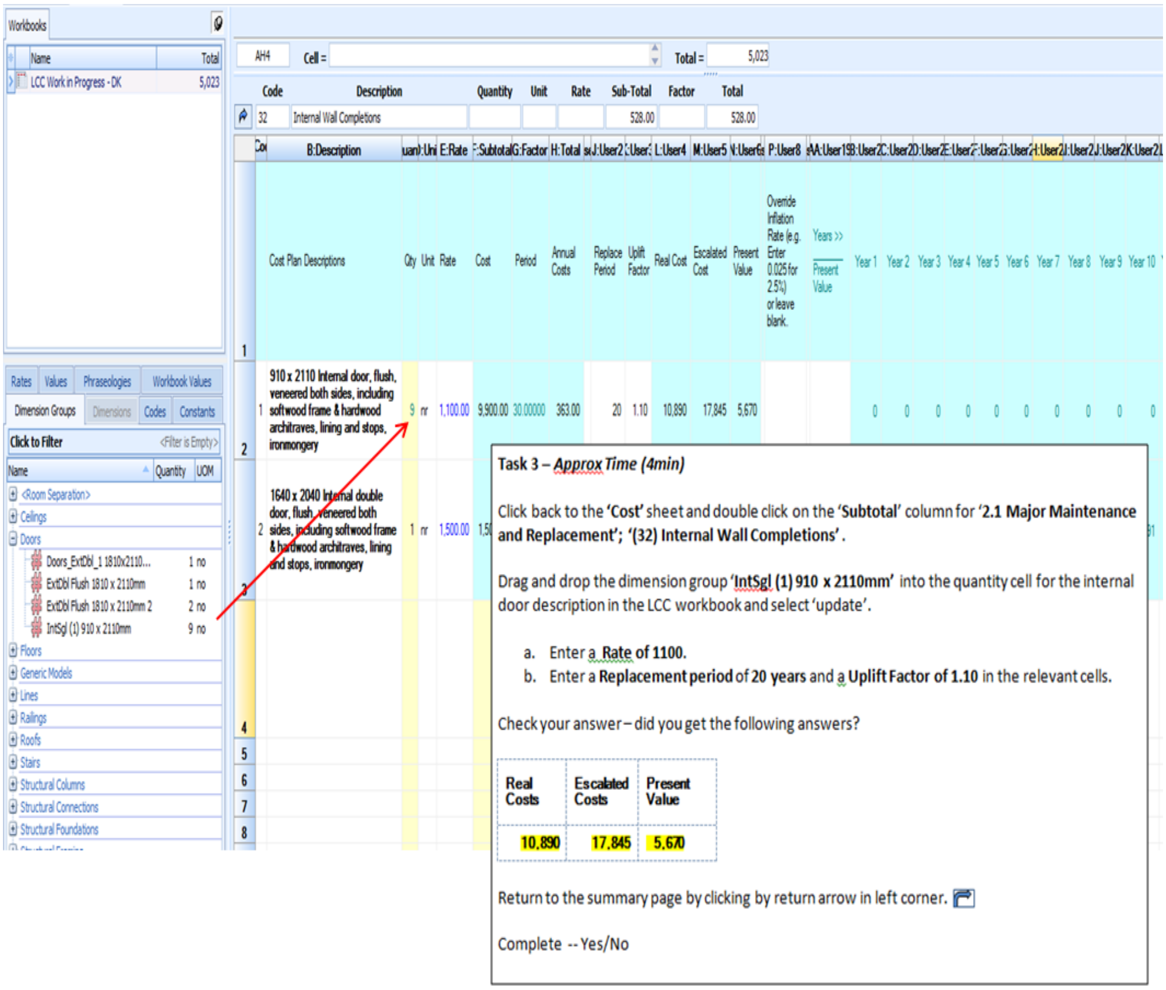

FIG. 12: Scenario 2, Task 3

Task 4, 5 and 6 entailed similar instructions to Task 2 but required the participant to utilise BIM QTO for the calculation of LCC for 'minor replacement, repairs and maintenance costs', which are illustrated in the sub-sheet in Fig. 7. The final two tasks, Task 7 and 8, dealt with the calculations in sub-sheet 3 (Fig. 8). Task 7 entailed the calculation of annual electricity costs, while Task 8 required participants to override the project inflation rate with an item specific escalation rate. As discussed in section 3, data is generated through the completion (or non-completion) of the tasks and the attitudes and feedback from the participants throughout the evaluation.

6. FINDINGS

6.1 Usability

In TA evaluation, one of the most important outputs of the research is the system's usability (Monk et al. 1993; Nielsen, 1993; Dumas & Redish, 1999). Extracts were coded in data analysis based on the five main criteria of usability, these are, satisfaction; ease of use; effectiveness; easy to learn and errors made. 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 will be outlined in the next 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.

Fig. 13 is a word cloud automatically generated from the data analysis software used in this research, presenting the most used words from the 'Feedback' category. It must be recognised that the context of use is not evident here, because the words are quantified based on one word, rather than a phrase or a sentence that may give a different context. However, it crudely encapsulates the views of the participants using the system and engaging in an integrated 5D BIM-LCC process. The word cloud was generated from the entire feedback category, discussed below, where words such as "easy", "automatic", "straightforward", "quickly" and "effective" represent words that align with usability criteria. This word cloud illustrates the potential advantages of the process but there were comments and suggestions from participants that proposed changes to the system, which may increase its effectiveness, these are outlined in the next section.

FIG. 13: Word Cloud

6.2 Feedback and Recommendations

As previously discussed in section 2.2, 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 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.

Section 4 described the development of LCC spreadsheet calculation structures, which were incorporated into the 5D BIM process by integrating LCC calculations into the workbook (sheets and sub-sheets) of CostX's 5D estimating software. The basis of following a post-processing methodology for integrating LCC, rather than creating LCC definitions in the authored model is based on the premise that 5D BIM offers a better environment for LCC. This reason being that 5D BIM software currently has greater computation capabilities over BIM design software (such as Revit and Archicad) and thus, can accommodate the variable conditions necessary in probabilistic LCC analysis. Integrating LCC functionality within the 5D BIM workflow enables the computation capabilities of spreadsheet software to be utilised in the production of LCC in BIM. Participants engaged in this process throughout the completion of the tasks of the evaluation. A number of these tasks are outlined in section 5.

Fig. 14 demonstrates an example of the output from data 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. The findings discussed in this section were generated from the analytical memos pertaining to the headings from the data analysis.

Nr	Code	Codes	Sources	Units of Meaning Coded	Analytical Memos
	6.0	**Recomendations 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	
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	

FIG. 14: Coding Feedback

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 a technology 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 integrated 5D BIM based LCC technology. Theoretically, this extends the existing 5D BIM process to accommodate LCC. Participants noted that this process is different from their current work practice because it enables an integrated workflow through the 5D BIM LCC process, which is facilitated by an integrated technology (design science - artifact) that was developed in this research. Ultimately, CAPex and LCC 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. Participants note that this advantage maintains transparency and links the workflows across the 5D BIM 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 were available to them. 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 LCC 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.

The findings also indicated that utilising this process has an effect on a number of the barriers to carrying out LCC, which were discussed in the review of literature. The findings outlined that this process provides a system that automates complex LCC calculations and offers a structure that standardises the format and presentation of the LCC 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.

Fig. 15 illustrates an example of the recommendations proposed by participants to improve the system and process.

Nr	Code	Codes	Sources	Units of Meaning Coded	Analytical Memos
	6.0	**Recommendations for Improvement and Feedback**	11	497	X
39	6.3	Recomendations 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	

FIG. 15: Scenario 2, Task 3

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 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 5D BIM LCC workflow. 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.

An issue that emerged from 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. 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. 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.

6.3 Conclusions

Spreadsheet capabilities are particularly advantageous for the probabilistic calculations in LCC due to their ability to accommodate multiple job conditions that enable the variable conditions for LCC calculations. 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 5D BIM LCC integrated environment. An LCC spreadsheet calculation structure produced in accordance with LCC WBSs was embedded in 5D BIM software. This was achieved through the customisation of the CostX workbook, by adding in user-defined columns. This essentially proposes an extension to the 5D BIM workflow that facilitates 'what if' analysis for LCC. Incorporating LCC calculations in a spreadsheet format in 5D BIM was seen as a benefit as 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 that brings an element of trust to the process. The findings outline that this process would aid QSs meeting requirements for LCC.

In the context of a design science research output, 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 design science, where the artifact proposed (5D BIM based LCC) is utilised in a context (LCC) that it was not originally designed for. The findings outline that the primary benefits of the proposed process is that it allows for a link between the QS's cost plans/BOQs 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 BIM LCC process. This process underscores the dynamic BIM process, where parametric adjustment attributes change throughout the outputs of the model simultaneously.

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.

6.4 Future Work

The current 5D workflow 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.

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 ingrained 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.

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