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Linking Effective Whole Life Cycle Cost Data Requirements to Parametric Building Information Models Using BIM Technologies

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Abstract – This paper demonstrates the capabilities of BIM (Building Information Modeling) in leveraging Whole Life Cycle Cost (WLCC) data requirements to perform WLCC calculations and produce WLLC estimates. The research determines the extent to which WLCC data, such as time, interest rates, escalation rates and real costs can be attached to parametric BIM data to be used effectively to create speedier and more accurate real-time WLLC analysis. Without incorporating WLCC data in the BIM, a complete picture of a construction project's WLCC cannot be formed from the default outputs of the model. BIM 5D applications such as CostX utilise the parametric properties of the model, providing users with the ability to generate information and quantities from the BIM to be used in a formatted cost plan. The benefit of the 5D process is that selected quantity surveying information in the BIM can be live linked from the model to the cost plan providing a real-time analysis of WLLC. The authors demonstrate in this paper how they leverage BIM, by incorporating WLCC data and calculations in a customised CostX workbook, thus providing the authors with the ability to live link the output values from the model to the values in the workbook to perform WLCC. This paper demonstrates the practical application of this process on a pilot project in order to complete a WLCC analysis.

Keywords – life cycle, whole life cycle costs, whole life cost analysis, building information model

I INTRODUCTION

Cole & Sterner [1] define Whole Life Cycle Costing (WLCC) as the consideration of all 'relevant' costs and revenues associated with the 'acquisition' and 'ownership' of an asset. The scope of what is considered a 'relevant cost' is set out by Cole & Sterner as initial capital cost, occupation costs, operating costs and the costs incurred or benefited from its disposal.

Cole & Sterner [1] state that WLCC has been in existence since the 1970's but has not been implemented into standard practice. There are a number of barriers to adoption that have been mentioned over the last twenty years in academic and practice based publications. Those that are mentioned frequently are the lack of historical WLCC data, the complexity of the calculations and the lack of standardisation across the industry [2].

Due to the amount of variables that exist in WLLC, the Office of Government Commerce [3] in the United Kingdom recommends the use of standard spreadsheet software, which they state can be adapted to perform the required tasks, building in a facility for key variables. The OGC state that specialist WLCC software is not adaptable and cannot process variable data as efficiently as generic spreadsheets. The annex's of BSI/BCIS [4] seem to support this, as the recommended WLLC templates are outlined in spreadsheet form.

Another factor to take into account is the emergence of Building Information Modelling (BIM). BIM automates many of the technical procedures involved in the traditional disciplines of the construction industry including design and take-off [5, 6]. BIM, though sophisticated can find itself restricted in incorporating the data requirements for WLLC and without an external application cannot produce a complete WLCC Analysis (WLLCA). The authors will investigate the possibility of developing

a solution concept for WLCC leveraging the benefits of BIM.

II REPRESENTING WLLC

a) *How to Carry Out The Calculations*

The complexity of the calculations and the time consuming nature of WLCC calculations are mentioned frequently as reasons for WLCC slow development [2]. Pelzeter [7] states that WLCC has been slow to catch on because there is a lack of practical knowledge in relation to 'how to' carry out the calculations. The complexity of WLLC calculations is often viewed as a barrier to its implementation.

Some publications such as Eurovent [8] and Fuller & Petersen [9] express the scope of WLCC as a formula. This formula is generally outlined as follows;

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

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 [10, 4]. Construction costs are priced and paid for immediately at the construction stage and therefore an escalation/discount time based adjustment is not applied. These costs can be directly applied from cost plan or Bill of Quantities (BOQ) cost items. Operation, Maintenance and Replacement (OMR) costs, represent the costs incurred over the study period of the asset [9]. Disposal (D) costs represent the cost incurred, or price benefitted, from the disposal or sale of an asset. Evaluating operation, maintenance, replacement and disposal costs is an exercise in predicting the future costs of these events over the study period of the WLCC, so that economic evaluation can be applied not just to the construction cost but to the entire scope of the life cycle of the project. This is the essence of WLCC and is ingrained in the definitions outlined in all eminent standards [10, 4, 11, 9].

b) *Representing WLLC*

According to the BSI/BCIS [4] the most prevalent methods in calculating WLCC in the United Kingdom and Ireland is a representation of the WLLC as a cash flow over a study period. However,

comparing different building or component options through cash flow forecasting is difficult as different costs take place at different time frames. Thus these costs need to be evaluated at a comparable time base so that options may be evaluated in equivalent terms. The BSI/BCIS [4] state that the comparable time base is usually present day, noted as year zero (0) on the WLLC estimate.

The process of converting 'future money' to 'present money' is called discounting [12]. A stream of discounted future costs can be converted to a single sum Net Present Value (NPV) by adding together the discounted costs of future expenditure at the equivalent time base, year 0 [4, 13, 9, 14]. Gluch & Baumann [15] state that the NPV's of different buildings (or components within buildings) over a certain study period can be compared to assess the most economically viable alternative.

c) *Using the Formulae*

Kehily [16] states that a scientific calculator can be used to carry out the Present Value (PV) calculations but this method can be quite time consuming as each variable must be inputted to determine the relevant factor. Financial tables allow for PV calculations to be performed without the use of calculators. Financial tables greatly simplify the computational requirements of WLCC [16]. Even though financial tables take the number crunching out of the process it is still quite time consuming as a factor has to be looked up for each item in the estimate and if a cost item has a number of different intervals, factors need to be calculated for each year the item is replaced in the study period.

A recommended approach by the OGC [3] is to use standard software such as 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. The BSI/BCIS [4] and RICS [12] include annex spreadsheets for presenting WLCC costs based on PV calculations. Pelzeter [7] states that methodologies in WLCC provide the tabulated framework to present an WLCC estimate but do not explicitly outline the calculations in the model. The OGC [3] states that specialist software does exist but is not adaptable to different jurisdictions and different methodologies.

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	Qty Rep	Unit	Uplift Factor	Replace Rate	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
				CUR			%																
	Cost Plan Items																						
xxx	Painting	184	m2	8.50	1,564	Remove make good and replace painting	100%	184	m2	1.10	9.35	1,720	4.00	6.00	1.00	6.00	6,882	2.00%	6.65%	2.14	5.43	9,344	3,686
xxx	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	1.00	625,000	2.00%	6.65%	14.74	32.67	816,773	368,471

Fig. 1: Template Spreadsheet

III TEMPLATE SPREADSHEET

a) Introduction

The authors have produced a template to aid construction professionals producing WLCC models in line with the standard methodologies and WLCC calculations. This template provides a suggested column layout in spreadsheet form (figure 1) to be used on its own when completing WLCC estimates, or imported into estimating software through the software’s column customisation function. The template is a development on the authors previous work on WLCC [16]. The calculation methodology does not represent a complete WLCC template but rather a calculation methodology that can be used in conjunction with BIM technologies. The spreadsheet calculations can be easily transferred into estimating software through the customisation function of the software adding WLCC criteria and data requirements to the existing quantity/cost function.

It is difficult to see and explain the figures outlined in figure 1 because of the number of columns and level of detail on the spreadsheet. For the purposes of explaining the calculations and linkages between the calculations the author has broken figure 1 into sections which are outlined below in figure 2, 3 and 4.

The first row in figure 1 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 of your estimating software’s workbook.

b) Utilising the Cost Plan

The first number of columns outlined in figure 2 (1-6) represent the typical data included in a cost plan or a BOQ including the reference number (code); item description; quantity; unit; rate and total cost. These items can be copied or imported from the itemised cost plan and should represent all those items that will be replaced within the total life (years) of the building or the study period. The advantage of using the cost plan as a basis of evaluating WLCC is that the items provide a real cost basis for estimating replacement costs.

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 Rep	Unit	Uplift Factor	Replace Rate	Factored Replace Cost
				CUR			%					
	Cost Plan Items											
xxx	Painting	184	m2	8.50	1,564	Remove make good and replace painting	100%	184	m2	1.10	9.35	1,720
xxx	Energy	1	LS	25,000.00	25,000	Yearly Energy Cost	100%	1	LS	1.00	25,000.00	25,000

Fig. 2: Utilising Construction Cost Plan

The subsequent columns (7-13) in figure 2 represent the replacement action to take place on the cost plan item. These columns follow the guidelines for calculating replacement costs in the NRM 3 [12].

c) Adding WLCC Characteristics

The columns (14-17) outlined in figure 3 provide the inputs for calculating the nominal costs and present value. The ‘Interval’ (14) outlines the number of times the item will be replaced in the life cycle. The ‘Design Life’ (15) is the published reference life for the item being replaced [17, 4, 12]. A ‘Lifting Factor’ (16) can be applied to the design life to take

account of the conditions of the item in a project specific context.

13	14	15	16	17	18
Factored Replacement Cost	Interval	Design Life	Lifting Factor	Factored Life	Real (base) LCC
1,720	4.00	6.00	1.00	6.00	6,882
25,000	25.00	1.00	1.00	1.00	625,000

Fig. 3: WLCC Characteristics

d) *Life Cycle Cost Formulae and Factors*

The total ‘Real’ WLCC represented in column 18 in figure 3 is a result of the ‘Factored Replacement Cost’ (13) multiplied by the number of times the item will be replaced (Interval) (14).

Single Compound Amount (SCA) (22) and Single Present Value (SPV) (21) in figure 4 are used to calculate the total ‘Nominal’ cost (23) and the total ‘Present Value’ (24) and are generated from the data inputted in columns (14-17) and the escalation and discount rate inputted in column 19 and 20. The formulae include the links, which extract the variables from the relevant preceding cells to include them in the calculation.

13	14	15	16	17	18	19	20	21	22	23	24
Factored Replacement 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%	2.74	5.43	9,344	3,686
25,000	25.00	1.00	1.00	1.00	625,000	2.00%	6.65%	4.74	12.67	816,773	368,471

Fig. 4: Representing WLCC

The second row of figure 1 shows a cost for ‘Energy’. These costs will not necessarily be linked to a cost plan item. Energy costs are an operational cost and differ from the examples outlined above as they are costs that recur on a uniform basis rather than at certain intervals. Uniform costs are usually calculated as costs for the year and replicated over the relevant study period.

The spreadsheet is not fully intended as a standalone template to carry out WLCC estimates. However it is useful in its own right, as a calculation

tool and also for evaluation of component options. The eminent standards and methodologies in WLCC such as BSI/BCIS [4], Fuller & Petersen [9] and the NRM 3 [12] provides a coded Work Breakdown Structure (WBS) for carrying out WLCC in their applicable jurisdictions. The classification categories in the WBS provide a framework for presenting the WLCC estimate. It is important to note that without the implementation of a standard WBS or methodology for WLCC, the process would live up to its documented failings of not following a standard approach [1].

The calculations outlined in the spreadsheets above are based on a spreadsheet application that does not leverage any Computer Aided Design (CAD) technology or BIM. 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 excel that can capture cost information to be reused in another exercise or on another project.

In order to successfully generate an accurate WLCC, it is recommended that the spreadsheet template, be incorporated alongside BIM estimating software (with the ability to customise columns and add formulae) to provide a more detailed WLCCA. This will in turn provide the client with the financial tools required to select the most economical advantageous solution and eliminate the need for investing in new estimating software to carry out WLCCA.

In order to leverage BIM when producing WLCC estimates it is necessary to outline what BIM is and how it can be harnessed by construction cost professionals to supplement their services.

IV BUILDING INFORMATION MODELLING

a) *Introduction*

One of the key aspects of BIM is its ability to provide cost estimators with detailed 3D project views that combine vital information from tools within the BIM model. The BIM model though sophisticated is not extensively used to provide estimation software with the data requirements for WLCC, such as escalation rates, discount rates and study periods. Without incorporating WLCC 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.

b) *Dimensions in BIM*

The BIM authoring tool and design tool produces a 3D visualisation of the building and is generally used by architects to produce the design. Ajibade &

Venkatesh [18] and Boon [19] state by adding time and cost information to the model, a 4D time model and 5D cost model can be produced. The 4D process links the 3D objects to a time frame which can be used to produce a schedule of works [2]. The 5D application recognises materials used within the model and where available assigns the associated cost to these components. 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 BOQ or cost plan. The BIM authoring tool has some functionality in respect to producing reports based on 4&5D data but in practice construction managers and cost consultants use their own programmes to interrogate and extract 4 & 5D information from the model [6]. Fu et al. [2] state that it has been proved that 4D & 5D BIM has improved communications in the construction process and reduced the duration and cost of a building project. In recent years 'infinite dimensions' (nD) is becoming a term in BIM to describe the expanding application to include the broader aspects of built environment, these attributes include sustainability, acoustics, maintenance, lighting and buildability [2]. Fu et al. [2] outline these considerations are primarily used in "what if" analysis throughout the whole life cycle of a building project, rather than just focusing primarily on 3, 4 & 5D, which is on design and construction. In this context WLCC falls within the life cycle analysis of nD modelling.

Mitchell [20] states 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 states for BIM to be truly successful then all the D's need to be embraced.

c) Limitations of BIM for Cost Management

Traditionally Quantity Surveyors (QS) carry out manual take off from the architects paper drawings or import 2D CAD drawings into an estimating software package and carry out onscreen take off [18]. This process is described by Sabol [17] and Ajibade & Venkatesh [18] as a time consuming and costly process, which is prone to human errors, that often lead to inaccuracies in the estimates. The benefit of cost planning through BIM as outlined by Sabol [17] 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.

One of the issues with placing the cost management function in the BIM authoring tool is that the model properties are not put together to a cost management methodology and thus creating a formal cost plan within the BIM design tool per a Standard Method of Measurement (SMM) is difficult [21, 22, 5].

Despite agreement among a number of authors that the advantages of BIM revolves around a single model, Howell & Batcheler [23] and Taylor & Bailey [24] dispute the use of a single model in practice. In practice these authors have found that design team members use separate models and applications for 3D design, structural steel fabrication, energy analysis and the 4th and 5th dimensions of sequencing and construction cost planning. In the case of cost management a 5D QS may not find the architect's BIM tool sufficient for cost plan modelling because architectural BIM data structures are not compatible with the elemental or trade code structure required under classification structures and SMM methodologies [5]. Cost databases and units of measurement are based on traditional standards of measurement and are not applicable to BIM objects. Goucher & Thurairajah [25] states that without a fundamental change from costs per standard methods to costs per BIM objects, problems synchronizing the two systems will likely arise.

According to Eastman et al. [26] QS's still rely on the functionality and computation capabilities of the spreadsheet. Most QS's produce their estimates and cost reports in spreadsheet applications such as Microsoft Excel and Open Office, while many others use estimating applications that contain workbook and spreadsheets similar to standard spreadsheet applications.

Traditional estimating applications have not been designed specifically for BIM but many of the leading software estimating manufacturers have added a BIM interface or BIM plugin to their existing application as an updated extra. This integrates the outputs of the model with the cost database and workbook functions of the existing software [5].

Mitchell [20] states that the modern QS is taking the traditional QS role to the next level, by utilising models within the 5D environment to provide detailed and accurate estimates for what he deems 'living cost plans'. The living cost plan means that there is what CostX [27] deems a 'live link' between the 3D quantities generated from the model and the cost plan. The living cost plan becomes the basis for providing quick updated estimates every time the model information is changed [20, 6].

d) BIM and WLLC

Sabol [5] points out in her research that BIM makes it possible for QS's to provide alternative professional services by leveraging BIM technology and freeing up time that would have been spent on time consuming activities in traditional QS processes. Traditionally WLLC put QS's out of their comfort zone [19], which is demonstrated by the low

levels of the service as outlined by Hourigan [28] in Ireland. The use of technology and software brings with it efficiencies and speed of process, that enables practitioners to carry out activities that were once very time consuming and complicated.

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 WLCC perspective [29]. One of the major limitations, as explained by Shen et al. [30], is that the current model properties are not semantically rich enough, to cover all the construction process data and job conditions. To carry out WLCC 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 these WLCC attributes are job specific and are subject to variation depending on the location, market conditions and client requirements of the project and these conditions are not applicable to BIM objects in every instance.

A feature which is inherent in some of the leading 5D estimating applications such as CostX, CostOS and Buildsoft is a customisation feature which provides users with the ability to add columns and functions to the applications default workbooks and settings. In these applications users can customise cost data to include adjustments for the additional variables of life cycle costing that cannot be extracted from the model.

e) Integrating WLCC Spreadsheet Template in BIM

The authors have created a spreadsheet template which allows cost professionals to add their own domain-specific judgments through the customisation of traditional estimating packages with a BIM and cost database interface, in order to complete a WLCCA. The functionality of the spreadsheet gives users the ability to carry out risk and sensitivity analysis on the variables and present the WLCC estimate in a format that will align with current standards in WLCC.

Incorporating the spreadsheet into BIM enables the user to utilise the automated calculations of the spreadsheet while leveraging the data contained within the model and linking it where applicable to the spreadsheet. The reporting function of the application can then be used to generate a report, presenting the WLCC cost plan in a format that is

applicable to one of the standard methodologies in WLCC.

VI COSTX

The authors have used CostX® estimating software by Exactal Technologies to demonstrate how the template outlined above can be imported into suitable estimating software.

CostX® enables you to quickly and accurately take off quantities from 2D drawings and 3D/BIM models using on-screen electronic measurement [27]. At its core CostX comprises of a spreadsheet based workbook and an electronic measurement tool/drawing viewer. 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. CostX also provides the user with the ability to add user defined columns to the workbook – enabling the authors to add additional columns for WLCC to the existing 'quantity' 'unit' 'rate' and 'total' columns.

The power of CostX revolves around the integration between the electronic measurement tool and the workbook module of the software. The user as outlined by Mitchell [20] can take off quantities from either 2D or 3D/BIM drawings in the electronic measurement tool and create live links between their take off and their workbooks. Subsequently changing any of the dimensions in the measurement tool will in turn change those dimensions in the workbook where the dimensions were linked. The live links keep the workbook updated with relevant quantities and leads to easy revisions.

Outlined in figure 5 the authors have imported the WLLC spreadsheet template (figure 1) into CostX's workbook by adding user defined columns creating a customised WLLC CostX workbook based on the BSI/BCIS [4] WBS. The workbook is live linked both to the original construction cost plan and to the dimension group quantities in the measurement tool. The power of the WLLC template is embedded in the formulae of the cells. The cell calculations and formulae in the WLCC 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. When the user returns from this spreadsheet level to the level above, WLLC information such as real costs, nominal costs and present value is returned into the relevant coded breakdown structure and overall hierarchy of the BSI/BCIS [4]. The coded WBS applicable to a WLLC item or items can be selected from the 'Phraseology' tab in CostX, which contains an user imported CSV file of the BSI/BCIS [4] WBS. In this manner WLLC estimates can be constructed from

Name	Total
LCC	2,919
LCC - Input	0
LCC - original	382,544
LCC - Replacement	195,592

Code	Description	Quantity	Unit	Rate	Sub-Total	Factor	Total
3.1.1	Windows and External Surfaces	3,120	m2	15.13	2,919		2,919

A.Code	B.Description	C.Quantity	D.Unit	E.Rate	F.Subtotal	G.Factor	H.Total	User1	User2	User3	User4	User5	User6	User7	User8	User9	User10	User11	User12	User13		
1	Code	Description		Cost Per Occurance	Annual Cost	Inter val	Expe cted	Fact or	Factor ed	Real Costs	Escala tion	Disc out	SPV	SCA	Nominal Cost	Present Value	1	2	3			
2	3.1.1.1	External works; cleaning building envelope; curtain walling	3,892	m2	0.75	2,919	1.00000	2,919	30	1.00	1.00	1.00	87,570	0.020	0.067	16,177	41,379	120,287	47,220	2,919	2,919	2,919

Fig. 5: CostX WLLC Workbook

the information in the WLLC 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 WLLC but any level of detail can be catered for including early cost planning and conceptual life cycle costing.

The authors have carried out a pilot study of a notional building designed by the Construction Information Technology Alliance (CITA) in Ireland. The quantities were extracted from an IFC model for the production of a construction cost plan. The WLLC workbook was linked to the cost plan and the relevant replacement items and quantities were extracted from the cost plan and priced based on their relevant life spans. The multidimensional links between the dimensions, the cost plan and the WLLC workbook harnesses the power of CostX to produce a WLLC template that can effectively create speedier and more accurate real-time WLLCA. 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.

V CONCLUSIONS

Bringing the complex WLLC calculations into suitable estimating software such as CostX provides the user with the tools to generate quantities, cost them and calculate the WLLC in real costs, nominal costs and PV costs. This BIM model though sophisticated can find itself restricted to provide estimation software with the data requirements for WLLC. The authors have demonstrated a generic template that can be incorporated within the CostX workbook. This template through a series of column and function customisations can help provide the estimator with a greater level of construction process data and job conditions without requiring numerous software packages to create viable and usable

results. The key benefits to cost professionals are; the ability to complete an WLLCA without having to do any of the time consuming PV calculations within a customised CostX workbook; using the BIM interface to generate quantities and internal or external databases to cost them

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