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MODEL-BASED LIFE CYCLE COST AND ASSESSMENT TOOL FOR SUSTAINABLE BUILDING DESIGN DECISION

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ABSTRACT: There is a growing concern in reducing greenhouse gas emissions all over the world. The U.K. has set 34% target reduction of emission before 2020 and 80% before 2050 compared to 1990 recently in Post Copenhagen Report on Climate Change. In practise, Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) tools have been introduced to construction industry in order to achieve this such as. However, there is clear a disconnection between costs and environmental impacts over the life cycle of a built asset when using these two tools. Besides, the changes in Information and Communication Technologies (ICTs) lead to a change in the way information is represented, in particular, information is being fed more easily and distributed more quickly to different stakeholders by the use of tool such as the Building Information Modelling (BIM), with little consideration on incorporating LCC and LCA and their maximised usage within the BIM environment. The aim of this paper is to propose the development of a model-based LCC and LCA tool in order to provide sustainable building design decisions for clients, architects and quantity surveyors, by then an optimal investment decision can be made by studying the trade-off between costs and environmental impacts. An application framework is also proposed finally as the future work that shows how the proposed model can be incorporated into the BIM environment in practise.

Keywords: Building Information Modeling (BIM); Carbon emissions; Life Cycle Cost (LCC); Life Cycle Assessment (LCA)

1. INTRODUCTION

Over the past years, climate change has become a global focus. Many governments from all over the world take the initiatives on improving the energy efficiency of a building or built asset. Before 2020 the U.K. is mandated to achieve a 20% reduction of greenhouse gas emission over the current level in response to Kyoto commitments. The Climate Change Act 2008 targeted U.K.'s commitment to reduce greenhouse gas 26% by 2020 and not less than 80% by 2050 compared with 1990 as the baseline and it is now a matter of legal obligation [1]. Based on the Post Copenhagen Report, the U.K. revised targets to reduce 34% emission before 2020 and reduces 80% emission before 2050 compared to 1990 [2]. There are nine major categories energy and carbon dioxide (CO_2) emissions; water; materials; surface water run-off, waste, pollution; health and well-being; management and ecology to assess environment impact, out of these nine categories 'energy and CO2 emissions' is the most significant category which takes 36.4% of the total weighing [3].

Total carbon emission is the sum of embodied carbon emission and operational carbon emission. Embodied carbon emission is composed by creating, maintaining and demolishing a built asset. Creating carbon emission of a built asset may be taken as high as 62% of its whole life emission [4]. Further, cost is crucial to the success of a project. With up to 80% of project costs defined during design stage [5]. All these bring to the costing issues along the whole life of a built asset.

Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) tools are developed for assessing and monitoring sustainable buildings. The concept of LCC is not new. Whole LCC has been long used since the 1930s and has been introduced to the construction industry as a tool at 1960s [6]. Basically, Whole Life Cycle Cost (WLC) and Life Cycle Cost (LCC) are the same thing over time the terminology has changed from 'cost in use', then 'life cycle costing', then 'whole life costing' and till today 'whole life appraisal' used globally which consider costs, performance and impact to the environment. Owners, developers, architects, quantity surveyors, engineers, contractors, specialist contractors, equipment manufacturers, basically everybody involved in owning, developing, or managing a facility can use WLC or LCA to balance initial capital cost with WLC and life cycle carbon emissions [7]. Further, LCC is defined as the cost of an asset or its parts when fulfilling the performance requirement over its life cycle [8]. LCA is the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle [9]. It is a tool used for measuring and evaluating some aspects of all relevant costs, revenues, environmental impacts and performance associated in all stages of an asset over its life cycle [8].

The aim of this paper is to propose the development of a model-based LCC and LCA tool in order to provide sustainable building design decisions for clients, architects and quantity surveyors, by then an optimal investment decision can be made by studying the trade-off between different decision criteria costs and environmental impacts. The following sections of the paper are divided into 4 sections. Section 1.1 defines the research problem. Section 2 gives an overview of the current tools for LCC, LCA and BIM being used in construction industry. Section 3 gives an outline of the model-based LCC and LCA design and decision tools using BIM; Section 4 gives an overview on the further study and the last section, section 5, concludes the paper.

1.1 The Defined Problem

Both LCC and LCA share some similarities. First, both of them have the term 'life cycle' which defined as stages of a product's system from its raw material to final disposal stages [9] or can be understood by the entire 'cradle-to-grave' system. Further, 'life cycle' can be decided as an asset's physical, economic, functional, service or design life [7]. The study time spans vary accounted by different purpose of analysis. Second, both tools can be used to evaluate a single product, a component, a system or whole-buildings. Decision makers use them to analyze products' LCC and environmental impacts when making decisions. Third, both techniques are based on data collected from past projects in order to forecast future costs.

Although these two tools have been used for long but their popularity is still low mostly due to the lack of data and inaccurate future assumptions such as uncertainty in forecasting future market situation. Gathering data is thus a major problem to both LCC and LCA methods that largely affects the accuracy of the results. The weakness of LCC is that it is not a financial accounting tool and it purely based on economic analysis which may not be sensitive enough to catch up the project information. LCA study can then be very time and resource intensive. Moreover, LCA is not able to show the project or process that have better performance and cost efficiency [10].

Furthermore, construction industry has been given pressure from the government and the customer's expectation to be more innovated by using new ICTs such as BIM and smart materials in order to improve productivity during design and construction. Being an industry that is predominating comprised by Small and Medium Enterprises (SMEs) [11], most of the small firms are lack of organization skills and do not have the capacity in developing new technology for long term. Also, as a project-based industry; it is difficult to collect and restore high value information [12]. A new design and decision tool that integrates LCC and LCA in the BIM environment is therefore in an urgent needed.

2. REVIEW OF CURRENT LCC, LCA and BIM TOOLS IN THE CONSTRUCTION INDUSTRY

There are a range of tools being developed to assess the life cycle cost and environmental impacts of a built asset. They are illustrated as follows.

2.1 Life Cycle Cost (LCC) Tools

The Life Cycle Cost process involves simple but tedious costs calculations. In order to solve this problem, LCC associated I.T. tools have been developed that can facilitate cost quantification and decision making processes. There are few samples of LCC IT Tools:

- *Automated Cost Estimating Integrated Tools (ACEIT)*: It is a tool for analyzing, developing, sharing and reporting cost estimate by Research Inc. USA. This software provides a framework to automate key analysis tasks and standardizes the estimating process [14].
- *BLCC 5.3.* This software is developed by the U.S. Department of Energy. It works with Crystal Ball Simulation Software Ltd. The simulation contains the retail price, installation cost, total installed price, annual gas use, annual electricity use, equipment operating hours, household characteristics, annual maintenance cost, annual repair cost, and annual fuel cost results for each design option of the product class [14].
- *Kiinteistotieto:* It is a tool used for building stock and rent management, project annual budgeting programming. With additional use of data management, this tool normally is for making decision for investment, working out present values of the building and also to estimate rent levels. It can also be used for construction, renovation, restoration and continual building maintenance budget [14].
- *LCCW 3.0:* It is a tool developed in USA [13] that calculates Life Cycle Cost from products or component from inception to disposal stages. It can be used widely in building, a ship, a weapon system and infrastructure projects. This software defines Life Cycle Cost plus the number of man-hours multiplied by a cost rate. It use Cost Breakdown Structure (CBS) to divide total cost into sub-categories and represents it as a tree diagram [14].

2.2 Life Cycle Assessment (LCA) Tools

LCA is a methodology used to analyze the environmental impacts of a product or a building over its life cycle. It covers the 'cradle-to-grave' impacts which including the consideration of all inputs (raw materials, energy, water) and output (emissions to air, water, land and waste). Most of the existing LCA tools are based on qualitative and quantitative methods that can assess building environmental impacts from embodied energy, operational energy, CO2 emission and other emissions from buildings and these tools are categorized into five major classes of which some of the existing tools will be introduced as follows:

- *Detailed LCA Modeling Tools:* This category of LCA tools are based on materials used, building components and processes of the work to work out embodied energy and environmental impacts. This includes SimaPro, TEAM, Gabi, KCL-ECO, Boustead, GaBi, PEMS, Athena, BEES [14].
- *LCA CAD Design Tool:* Building Research Establishment (BRE) in the U.K. developed LCA design tool software called Envest. Designers for example input building design information such as building element choices, building height, number of storeys, window areas and building Gross Floor Area, calculation of their associated impacts and their comparisons against improvement options are then performed. Some LCA tools integrated with CAD design tools are able to read building component information and materials from CAD drawings and then to produce an environmental impact analysis. Others similar software include EcoScan, ECOit, LCAiTLCAid, ECOTECT, ENER-RATEE, Energy 10, EQUER, PAPOOSE, Legoe, Ecopro, OGIP, EPCMB [15].
- *Green Product Guides and Checklists:* Tools under this category are qualitative guides of environmental issues that help decision makers taking considerations when designing or selecting different options for building assets or products. Some famous guides include Environmental Preference Method (EPM), BREEAM, LEED, BEPAC, GREEN housing A-Z, ECDG, EcoSpecifier. [15].
- *Building Assessment Schemes:* These tools are used to predict or assess building performance during operational conditions. It can be used before or after building occupancy. Examples include GBTool, BEAVER/ESOII, BUNYIP, DOE2.2, GSL-Giselle, Okoprofile, NatHERS, SEDA, ECOPROFILE, E2000 and BEE 1.0. [15].

2.3 Challenges of Building Information Modeling (BIM) Tool

The changes in ICTs lead to a change in the way information is represented, often resulting in more complicated project information or knowledge management tools that generate vast amount of information. In particular, information is being fed more easily and distributed more quickly to individual recipients by the use of Building Information Modelling (BIM) [15].

> "BIM is a digital building model which generating, managing and sharing information during its entire life cycle" [17].

As an information container, it stores all kinds of information from product materials, specification, finishes, costs, 'carbon content' and any other special requirements. Figure 1 shows the usage of BIM and its functions. By using BIM to develop a 3D building model, it can detect clash allowing rapid reaction to be made for designers or clients to make decision at initial design stage. However, in some occasions, BIM has been mistaken as a design tool instead of information container for a project. With time factor implementing into BIM, BIM becomes a 4D modelling tool. The usage of BIM can then be maximised into planning, supply chain management, life cycle costing and assessment. BIM can therefore provide viability to integrate LCC with LCA to assess both economic viability and sustainability of buildings. Its availability lies in a central building component repository. Further, BIM can be seen as a 5D modelling tool with element/material cost information, together with time information stored in BIM, it can work out the project estimating cost and its cash flow along the project life cycle. Comprising assessment to the environmental information into the BIM, BIM can further become a 6D modelling tool that can calculate the environmental impacts from buildings. Eventually, it can become even nD model with other special information added in [18].

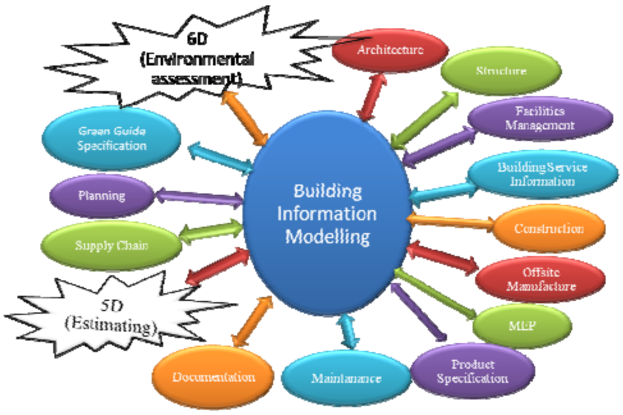

Figure 1. BIM Usage and its Functions

Performance-based design supported by product models is becoming stage-of-the-art practice [19]. Therefore, one of the key advantages of using BIM as an analysis tool allows multi-disciplines to simulate building performance in a virtual environment. The number of performance criteria can be analyzed that are depended on several aspects includes architectural, structural, mechanical, energy. Therefore, BIM tool is a feasible approach for multidisciplinary team members to access and collaborate effectively. Table 1 shows the potential benefits to different stakeholders (client, designer, estimator, contractor, and operator/maintainer) in a construction project team on using BIM tools.

Figure 2 shows the BIM Evolution. It further explains the ideas in this paper. It shows that BIM continues to develop from basic CAD system with 2D drawings, lines, arcs and texts move to higher level to a 3D building modelling with different aspects information be stored inside the model. As BIM technology further developing up to Level 3 with time factor implemented, a 4D

Table 1. Potential benefits to various stakeholders throughout the project life cycle on using BIM tools

Stakeholder	**Potential Benefits on using BIM**
Client	• Better understanding on managing and mitigating risk • More informed Life Cycle Cost estimation • Optimize the whole Life Cycle Cost • Lower capital cost • Greater supply chain efficiency • Improve management of safety • Better collaboration and communication • Provide visualisation of the project • Reducing waste by minimise costly drawings production and reproduction • Swift energy analysis • Able to estimate and optimize environmental impact • Deliver green solution • Informs future projects regarding life cycle fund management & long term environmental performance
Designer	• Improve clarity of requirements • Greater use of standard details • Better understanding of client's requirements and regulations. • Better communication with clients, contractors and manufacturers • Allow clash detection • Reduce waste by minimize costly drawings production and reproduction • Allow automatic checking against building codes • Swift energy analysis
Estimator	• Greater accuracy of tender prices • Less misunderstanding of design • More accuracy in estimating and in advising cash flow of the project • More informed Life Cycle Cost estimation • Better understanding on managing and mitigating risk • Optimization of whole Life Cycle Cost • Visualisation for both design and cost
Contractor	• Potential for 'defect free' • Improve change management • More efficient procurement process • Improve co-ordination on site • More standardization • Less rework and waste • Seamless communication with clients, designers, consultants and suppliers • Reduce construction wastes
Operator / Maintainer	• Consistent asset coding • Availability of records and operation management manuals • Supporting greater efficiency in the setting up of new projects • Rapid and accurate populating of Facility Management data base • Improve operational efficiencies

building modelling is able to show the process of a built asset's life cycle. A 5D model with cost information covers the cost of the built asset from 'cradle-to-grave' through the whole life cycle. Consisting of environment assessment information to build up a 6D model and the time dimension can indeed perform Life Cycle Assessment for the project. The majority BIM users in UK is still working within level 1 process [20] and to archiving maximized benefits on using BIM is not only to move to level 2 but also level 3 with the integration of time factor and further comprising LCC (5D) and LCA (6D) concepts into the model as suggested in this paper. As the usage of BIM moving up further beyond level 3, it reaches the level of data management or building information management.

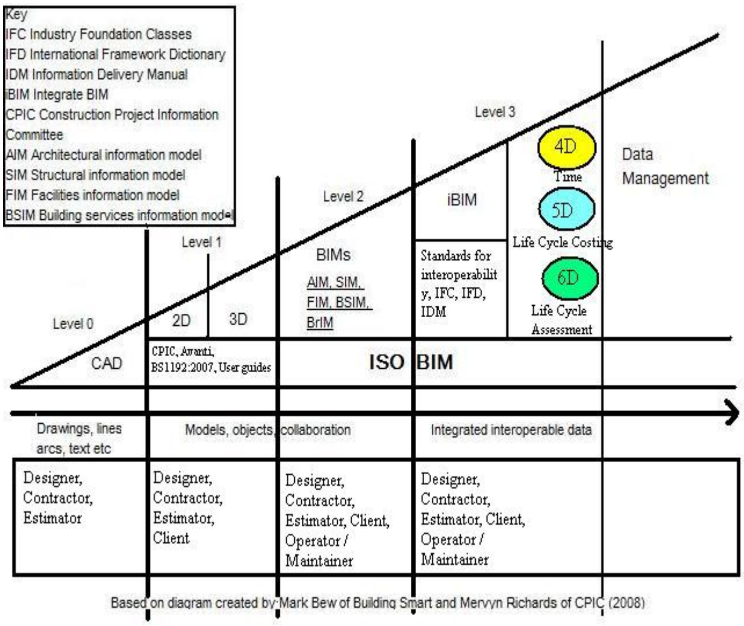

Figure 2. BIM Evolution

3. MODEL-BASED LCC and LCA SUSTAINABLE DESIGN DECISION

As mentioned in the previous section, adopting BIM technology into LCA can integrate LCC into a unified application framework. Similar concept has been considered for low impact building design decision in embodied carbon and waste (as shown in Figure 2). Following the same principle of BIM-based holistic modelling in the building lifecycle, LCA can be available in the design phase in the form of static visualization analysis whilst its dynamic simulation can be achievable from construction till demolish phase. In the design phase, associated sustainability issues like energy consumption, carbon emission, waste generation, involved in building design and materials can be accurately quantified on the basis of a unique visualized static 3D building model. Their costs hence can be estimated accordingly. From the phases of construction, to operation and demolition phases, LCC and LCA are a dynamic process where building sustainability and related costs are being embedded in those phases. For instance, carbon emission and waste production are likely to occur in the boundaries of manufacturing for building construction, maintaining for building operating and routine repairing, as well as recycling and disposing of building components and materials. These dynamic features are suggested to using a simulation approach for analyzing, while popular 4D/5D CAD techniques provide a viable approach to this dynamic simulation.

The BIM-based LCC and LCA tool is therefore being considered as an enabler for multidisciplinary collaboration across specialty boundaries throughout the building lifecycle. The viability of model-based collaborative work has been verified by an interactive approach targeting on 4D CAD [21]. Planners with different specialties can collaboratively perform planning and 4D simulation underpinned by the 3D model. Similarly, taking the advantage of integrating LCC and LCA into BIM can realize optimal design decisions from a holistic perspective in multidisciplinary coalition. Sustainability issues and related costs in HVAC, structure, for instance, in a building can then be examined using the same BIM environment. In this kind of design decision process, the central information repository provided by the BIM model can create a collaboration context for each potential stakeholder as shown in Table 1. Different specialties' information in the repository can be accessed not only by information owners but other collaborators. Therefore, sustainable design decisions on LCC and LCA can be made on the basis of informed rather than isolated approaches. The convenience of central information repository from the BIM model also brings the flexibility in applications. Given an online BIM model, distributed LCC and LCA applications can be available through network support for geographically dispersed stakeholders.

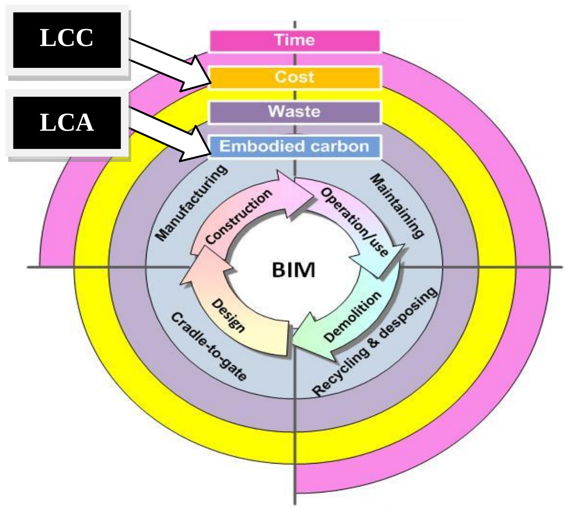

Figure 2. Holistic nD modeling in the building lifecycle [22]

4. FURTHER WORK

4.1 Bridging the gap between LCC and LCA through identification of their associated decision criteria

Developing a list of decision criteria related to cost and environmental impacts are needed in order to integrate these two tools within the BIM environment. This can be done by semi-structures interviews with the key stakeholders including clients, architects, and quantity surveyors. The next step is to develop a decision making model that analyze the tradeoff between these two lists of criteria, weighs among these criteria needs to be calculated as well. Eventually, a green cost model can be provided that shows sustainable design decision for decision makers when making investment decisions against different types of design options. This model can then be incorporated in the application framework in the following section.

4.2 Application framework

A distributed LCC and LCA application framework is able to satisfy multidisciplinary collaboration in LCC or LCA underpinned by a central BIM repository in the network condition. The framework takes the advantage of server-client software architecture to build server and client applications respectively (see Figure 3). In the server end, a building component repository is essential to gather building design information. All building component types and specifications are accumulated in this database. Current commercially available BIM toolkits like Autodesk Revit, Tekla, Digital Project provide mature authoring utilities to create BIM models. Hence architects and quantity surveyors can serve the repository with required building information to fill in. Leveraging database technologies, this repository can refer to other relevant databases like construction materials, energy consumption indices and cost indices. This compounded information in building components can provide required data when conducting cost and sustainability assessment for sustainable and optimal design decisions.

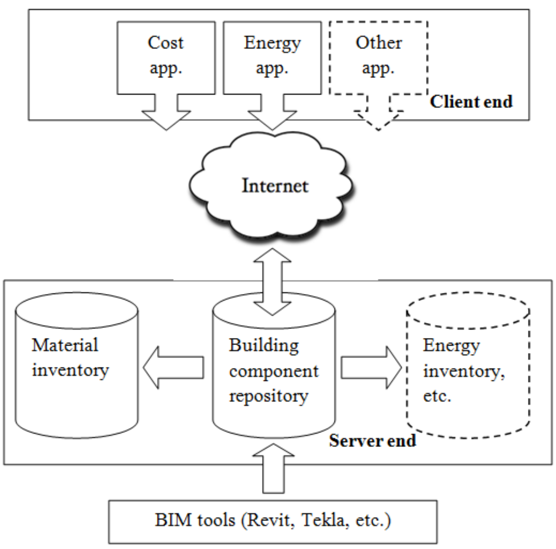

Figure 3. Server-client software architecture for LCC and LCA

In the client end, a range of applications can be created for LCC and LCA such as cost and energy and carbon emissions. In accordance with features for LCC and LCA, applications' functions need to provide users with both sta tic visualization and dynamic simulation analyses. These client applications are network enabled to access the server database via the Internet. Geographically dispersed multidisciplinary Architectural, Engineering and Construction (AEC) professionals therefore can apply these applications to perform any LCC and LCA work.

5. CONCLUSIONS

Time, cost and quality are traditional key factors to the success of projects. Cost is a crucial criterion to the whole life of the project. LCC is a tool purely based on economic analysis to a defined built asset or its parts when it meets the performance requirement over its life cycle. It is the most accurate costing tool to show stakeholders such as clients, architects and quantity surveyors the analysis of the investment to this asset. LCA based on input and output information to evaluation product potential impact to the environment over its life cycle. Both of them provided a whole picture of the assets life cycle information to decision maker, but there is a gap between cost and environment impacts (in particular, the zero or low carbon agenda). As environmental impact such as low carbon built asset draws more attention to governments nowadays and hence there needs trade off between the associated LCC and LCA costs and the environmental assessment. There are also challenges from the changes in ICTs lead to a change in the way information is represented, often resulting in more complicated project information or knowledge management tools that generate vast amount of information. In particular, information is being fed more easily and distributed more quickly to individual recipients by the use of BIM.

This paper proposes a model-based LCC and LCA tool that can be incorporated into BIM along the whole life (design, construction, operation/use and demolition) of a built asset. The ideas of 4D and 5D have to be incorporated into the BIM environment in order to provide sustainable design decisions and green costs that help decision makers to analyze the investment options based on the trade-off between cost and environmental impact. Further work includes the identification of decision criteria between LCC and LCA and putting the framework into application for multidisciplinary collaboration.

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