DETERMINATION AND COSTING OF SUTAINIABLE CONSTRUCTION PROJECTS: OPTION BASED DECISION SUPPORT

Anders Vennström, Senior Lecturer, Anders.Vennstrom@ltu.se
Thomas Olofsson, Professor and Head of Research Group, Thomas.Olofsson@ltu.se
Department of Civil, Mining and Environmental Engineering, Luleå University of Technology
William Fawcett, Doctor, william.fawcett@carltd.com
Cambridge Architectural Research Ltd
Attila Dikbas, Professor, dikbas@itu.edu.tr
Building Science and IT in Construction, TechnoBee
Esin Ergen, Assistant professor, esin.ergen@itu.edu.tr
Civil Engineering Department, Istanbul Technical University

ABSTRACT

The building stock in Europe accounts for over 40% of the final energy consumption in the European Union. Moreover, the construction sector is one of the largest producers of industrial waste contributing 40-50% of landfill in some EU countries. A common way of creating a forward planning for resource efficiency in construction project is to apply Life Cycle Cost (LCC – cost evaluation) and Life Cycle Assessment (LCA – environmental evaluation) procedures in the decision process. There are, however, difficulties in current LCC and LCA tools and it is challenging to combine data from those two types of tools since there are poor linkages between them. The EU funded 7th framework project CILECCTA sets out to develop a LCCA (Life Cycle Cost and Analysis) that combines life cycle cost with environmental affect and supports the determination of the costing and sustainability of project alternatives.

Current LCC software can assist the decision making process in simulating different alternatives for the design, construction, maintenance and demolition of assets – allowing the client, designer and builder to select the most favourable alternative. Through linking LCC and LCA methodologies, the CILECCTA project will go one stage further by enabling an assessment of the impact of the entire project on the environment and by estimating its sustainability. It will also include probabilistic analysis and the recently developed new generation methodology which applies real options principles analysis for construction industry decision making.

This paper sets out the strategic that should lead toward establishing a framework for developing a modular LCCA engine integrating asset-related data from price banks and life cycle inventories.

Keywords: Decision support, Life Cycle Cost, Life Cycle Assessment, real option analysis

1 INTRODUCTION

The European building industry is known to be fragmented, dominated by local standards and regulations, poorly organised and largely supply-driven with its main target being lowest cost of initial construction. Moreover, it is one of the largest producers of industrial waste contributing 40-50% of landfill in some EU countries. Recognising these problems, the industry has created the European Construction Industry Technology Platform (ECTP 2010) to lead the way in revolutionising construction products, processes and services. As a reaction to the fragmentation of the European building sector, the EC commissioned research into its status publishing its findings in the communication; *'The Competitiveness of the Construction Industry'*. Amongst its recommendations was *'the development of a common LCC methodology at European level, incorporating the overall sustainability performance of building and construction'* (Task group 4, 2003). Therefore Davis Langdon, a UK consultancy, was commissioned by the EC to develop a common methodology for Life cycle cost (LCC). Langdons proposed methodology was published in May 2007 along with an extensive review of the LCC and LCA literature and an outline framework for the development of LCC software tools to implement the methodology (Langdon 2007).

Buildings and construction infrastructure are long-lasting assets, so enlightened clients, designers and builders use Life Cycle Costing (LCC) to identify strategies that are cost-efficient over the whole life – aa fundamental requirement for sustainable design. However, this presents a problem because the future cannot be predicted with certainty. The standard method of LCC assumes that data about the future is available, so the method is of limited value. When there is high uncertainty, according to Ellingham and Fawcett (2006), an approach to whole-life costing which takes into account the future uncertainty is crucial. By applying an real options based approach future costs and benefits are discounted in proportion to the level of uncertainty; it also attaches value to 'lifecycle options' that allow future decisions to be made in response to unfolding events. Through linking LCC and LCA methodologies, the CILECCTA project will even go one stage further by also enabling an assessment of the impact of the whole project on the environment and estimating its sustainability.

2 CONCEPTUAL FRAMEWORK

2.1 Life cycle costing

The whole purpose of a common LCC methodology is to create a culture of forward planning to improve resource efficiency amongst the industry actors and their clients. For a long time the sector has aimed to build at the minimum cost without considering many other costs, such as the current cost of waste in the process, future energy costs, the costs of building maintenance and refurbishment, costs of change of use and costs of end-of-life determinations: demolition, re-cycling, new use, etc. Current LCC software can assist the decision making process in simulating different alternatives for the design, construction, maintenance and demolition of assets – allowing the client, designer and builder to determine the most favourable alternative for them.

The input required according to Schade (2009) for carrying out LCC analysis is categorised in Figure 1. These inputs influence the LCC outcome at different stages of the life cycle.

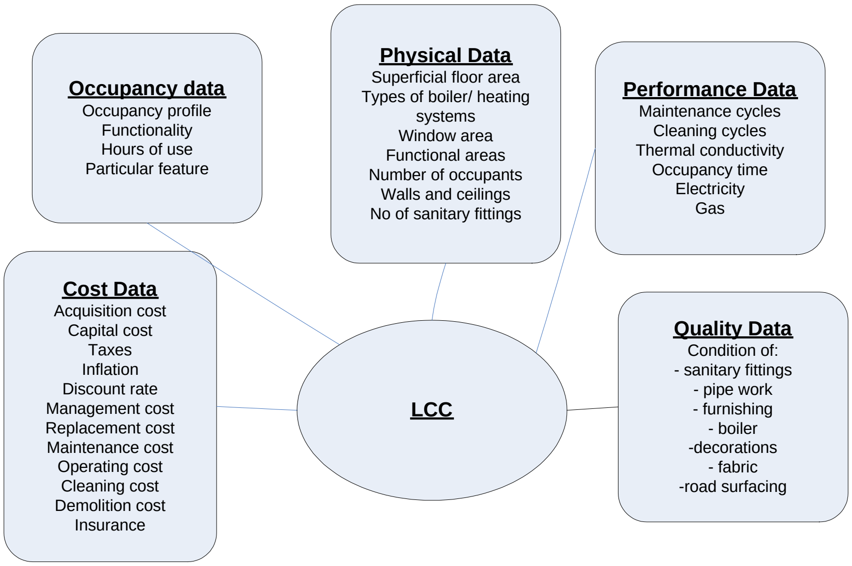

Figure 1: The required data categories for a life cycle cost analysis (Schade 2009)

The occupancy and physical data could be seen as the key factors at the early design stage. LCC estimation at this stage depends on data such as floor area and the requirements for the building. Performance and quality data are rather influenced by policy decisions such as how well it should be maintained and the degree of cleanliness demanded (Kishk et al., 2003). Quality data are highly subjective and less readily accountable than cost data (Flanagan et al., 1989). At the more detailed design stage, life cycle cost estimation is based more on performance and cost data of a building (Bakis et al., 2003). Timing is critical in LCC. Present valuing (discounting) of costs and benefits and specific time horizon scope is adopted. Any costs or benefits occurring outside that scope are ignored (Norris 2001).

The current cost data about labour, materials and equipment are the most essential data for LCC research. Mostly cost data are found in price banks (PB:s), at least for estimation of construction cost. However, this data needs to be seen in the context of other data categories (such as risk and uncertainties) to obtain a correct interpretation of them (Kishk et al., 2003). Since one of the big issues in LCC is the emphasis on data collection, in contrast to thinking about how to assess it, it might be misleading for the decision-maker were to put his/her emphasis. Accordingly, LCC compares the cost-effectiveness of alternative investments or business decisions from the perspective of an economic decision maker with data that is often/usually assumed, and that the policy decisions about maintenance are subject to change.

2.2 Life cycle assessment

Life cycle assesment (LCA) measures environmental impacts, both embodied and emitted, associated with all mass and energy flows over the whole life-cycle of the asset from raw materials, through production, use, end-of-life treatment, recycling and final disposal of the asset(Figure 2). In many cases, alternatives that are being compared have different characteristics so that it is problematic to use a single-criterion approach. Life cycle inventories (LCI) provide the quantified environmental information needed to make such assessments.

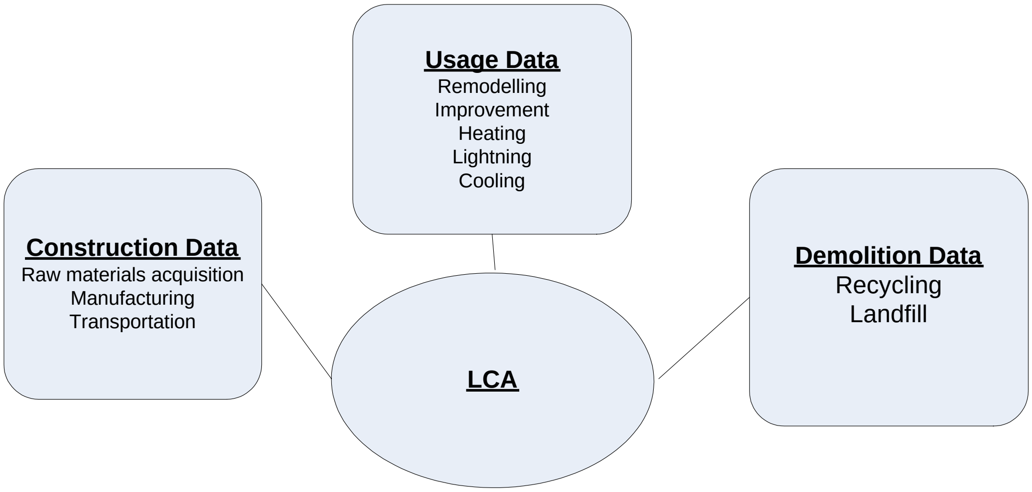

Figure 2: The required data categories for life cycle assessment (Norris 2001, Ochoa 2002)

A Life Cycle Inventory (LCI) describes a process in a physical way, by recording all mass and energy flows and their associated environmental impacts. All flows which enter and leave the process are counted as “Inputs” and “Outputs”. Mass flows may represent resources (e.g. 1 kg of water) or materials (e.g. 1 kg of brick or clay) used/produced, or emissions (e.g. 0,5 kg of CO_2), in a process. LCI databases contain this information for different processes. Their inputs and outputs reflect physical information on the processes themselves. By the help of so called “characterization factors” and by the method of “Impact Assessment” these flows are transferred into potential environmental impacts (e.g. 5kg GWP (global warming potential)-equivalent). These LCI datasets describe “aggregated dataset/process” that subsume the LCI data for all upstream processes. An example for an aggregated dataset may be “Brick” that includes the upstream processes “Raw material extraction” and “Moulding”. The timing of processes and their release or consumption flows are traditionally ignored; impact assessment may address a fixed time window of impacts (e.g., 100-year time horizon for assessing global warming potentials) but future impacts are generally not discounted. To conclude, LCA evaluates the relative environmental performance of alternative product systems that provide the same function. This environmental performance is assessed as holistically as possible, aiming to consider all important causally-connected processes, all important resource and consumption flows, regardless of whether or not they eventually impact anyone.

2.3 The relationship between LCC and LCA in decision making

A significant aspect of the CILECCTA project is the interface between LCC and LCA. Despite the similarity of their names, LCC and LCA have major methodological differences. These differences stem from the fact that LCC and LCA are each designed to provide answers to very different questions according to Norris (2000). One way of combining LCC and LCA is, according to Ciroth et al (2008) to add an economic dimension to LCA. LCC complements the LCA because elements that are not of interest for LCA are of high interest for LCC, such as costs for R&D and costs involved in the product design phase. Combining LCC and LCA also facilities eco-efficiency assessments which is easier to understand and further extend target audience for the use and interpretation of LCA.

The concepts behind both investigations deal with resource transfers, and they might be considered as sharing a common logical framework for counting and analysis, but with different units of measurement. A primary issue is whether LCA is an integral part of the decision-making process, or whether it provides additional data to reveal the environmental impact of decisions that are made on the basis of financial LCC. Managers constantly trade-off costs and benefits to achieve a project that maximize utility. In the current context, the trade-offs are between LCC and LCA. Different project alternatives can be mapped out on a two dimensional chart showing how each ‘scores’ on the two axes, one for LCC cost and the other for LCA environmental performance. Figure 3 shows a chart that a manager might use to evaluate a set of project alternatives.

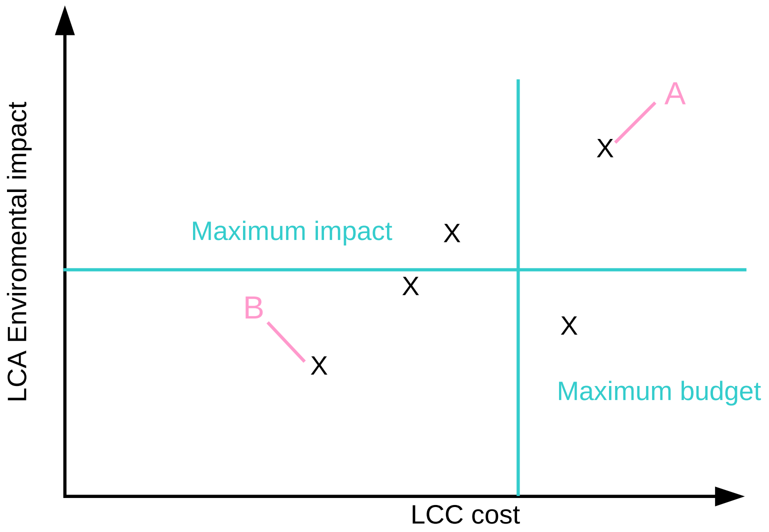

Figure 3: The trade of between LCC and LCA

It is clear that some alternatives dominate others, for example A is both more expensive and has a greater environmental impact than B. One might expect the realistic alternatives for one project to have a limited range of combinations of cost and environmental impact, with inexpensive projects performing less well environmentally and vice versa. Extremely good environmental performance (such as zero CO_2 design) is probably expensive, and the concept of decreasing marginal utilities implies increasing cost to extract each additional increment of environmental performance. The combinations of cost and environmental impact that are regarded as equivalent by an individual or organisation define indifference curves or contour lines, and the alternative on the highest contour is preferred. The indifference curves/contour lines vary for different people/organizations, depending on the relative weight given to cost and environmental impact.

Deterministic analysis yields single points for each alternative (as on Figure 3), whereas probabilistic analysis would yield areas rather single points. Alternatives with higher levels of uncertainty would be represented by larger areas on the graph, which may overlap. In this method LCC (including lifecycle options when appropriate), based on factors that are expressed in monetary terms, might be used to steer the initial stage of decision-making, with LCA information about environmental performance being taken into account before making the final decision. Presumably, when there is a significant difference between the alternatives in monetary terms, decisions are dominated by LCC; but when the difference between alternatives in LCC terms is small, the environmental performance derived from LCA might be decisive.

3 DECISSION MAKING UNDER UNCERTAINTY

Standard methods of life cycle analysis assume that it is possible to assemble complete information about the costs or environmental impacts that will occur during the service life of a building or infrastructure project; this can be called deterministic life cycle analysis. When this information is available, optimal decisions can be established – but in almost all realistic situations it is not available. Instead it is necessary to rely on uncertain estimates, with the amount of uncertainty increasing, for events taking place further in the future.

Using uncertain estimates, future costs or environmental impacts can be simulated probabilistically. Decision-makers can then take account of the range of possible outcomes, perhaps applying confidence-level tests to mitigate the risk of unfavourable outcomes. Probabilistic methods for analysing whole life costs are well-established in many industries, but not yet in construction. The CILECCTA project will provide tools for probabilistic analysis.

In standard methods of life cycle analysis it is normally assumed that all decisions about a building or infrastructure project are made at the time of construction, but in reality managers in the future make decisions that affect the evolution of their assets. In the language of real options theory, the owners have lifecycle options that allow them to respond in different ways, depending on the outcome of future events that are presently uncertain (Mun 2006; Ellingham & Fawcett 2006). Lifecycle option can be thought of as providing flexibility, which is highly desirable in situations of uncertainty, to mitigate the risk that a project will becoming worthless or require major adaptation in changing circumstances (Figure 4). For example, demountable partitions give the option to reconfigure an office quickly and economically if and when the layout requirements change.

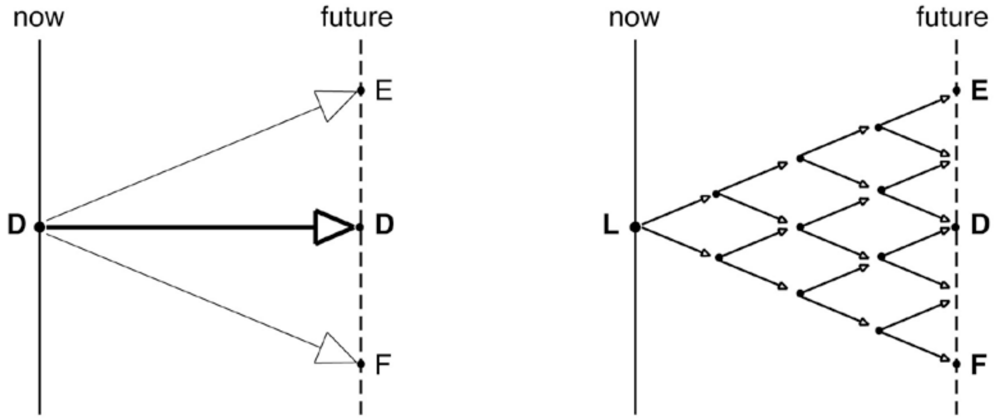

Figure 4: The benefit of lifecycle options when there is uncertainty about events during the service life of a building or infrastructure project.

The left side of Figure 4 shows that a deterministic decision D can only lead to outcome D. If external factors (eg. Price, technologies, regulations) change one may wish to have made a different decision leading to outcomes such as E or F- but there is nothing that can be done about it. With a lifecycle option (right side of Figure 4), today's decision L is followed by a sequence of later decisions that allow one to reach any of the outcomes D, E or F that turns out to be most favourable. It is impossible (and unnecessary) to predict how the later decision will be made.

If lifecycle options are overlooked, the project value will be underestimated. Although lifecycle options always add to project value, there is often an acquisition cost; in these cases it is necessary to compare option value with option cost in order to decide whether to acquire the option. Note that option value is greater when there is more uncertainty; in a case of deterministic information lifecycle options would have no value.

3.1 PROBABLISTIC DATA FOR LIFE CYCLE EVAUATION

Buildings are long-lived and are exposed to a range of uncertainties, principally in the value and timing of future costs and revenues. For reason, changes in costs and revenues attributable to a project over a specified planning period should be evaluated in LCC assessment process. Forecasts will be made regarding future escalation rates of these values, and estimate will be made of the probable service life of components. Clearly, the cash flows, escalation rates and component life cannot be known with certainty because of the variability in one or more of the estimated values or assumptions in the LCC process. This is the reason why the identification of causes of variability in the LCC analysis can have a significant influence on decision-making process. There exist a number of risk identification methods that can be employed for identifying causes of variability in LCC analysis. Examples are given below (Davis Langdon, 2007):

- Assessing relevant databases, where available
- Obtaining feedback from past projects
- Drawing out the knowledge and experience of individuals within the team
- Conducting interviews
- The Delphi method, gathering information from project participants

After identifying potential causes of variability in the LCC assessment, it becomes necessary to assess their potential likelihood and extent. Several techniques exist for the treatment of uncertainty for risk analysis.

Quantitative risk assessment generally use mathematically based analyses of statistical data, and may involve simulation. In practice, two techniques are likely to be of particular value in the LCC context and are identified as such ISO 15686 Part 5. At a simple level, *sensitivity analysis* measures the impact on project outcomes of changing one or more key input values about which there is uncertainty. Discount rate, future inflation assumptions, period of analysis, service life or maintenance, repair or replacement cycles and operational cost data are among key variables. Sensitivity analysis is used to set the 'expected value', a 'lower value' and a 'higher value' for each variable. A more complicated version of sensitivity analysis is to change several variables at once so that measures of worth can be computed for various combinations. Sensitivity analysis shows us how significant specific input values or combinations of input values are in determining the LCC outcomes. The major shortcomings of sensitivity analysis are that it gives no explicit measure of risk exposure, and it includes no explicit treatment of risk attitude. In other words, the findings of sensitivity analysis are ambiguous.

At a more sophisticated level, *Monte Carlo simulation* may be appropriate. It is the name given to a class of simulation approaches to decision making in which key input values are described by probability distributions. In the LCC context, it generates graphs that show the probabilities of total LCCs over the analysis period, which indicate the probability of exceeding various values. A set of Monte Carlo runs can identify the risks/ causes of variability that have the most impact on LCC.

Qualitative risk assessment is subjective because it relies largely on human judgment which will be influenced by the knowledge, skills and experience of the decision makers (Marshall, 1993). Qualitative tools which may be applicable in the LCC context include risk matrices and impact assessment matrices, SWOT analysis, brainstorming etc..

3.2 Decision process for LCC and LCA

The combination of LCC and LCA needs, however, to address the specific characteristic of the client's decision process in a construction process. The decisions to be made at a certain gate, called quality gate, require a specific level of information so that the performance of the proposed design solution can be evaluated (Figure 5).

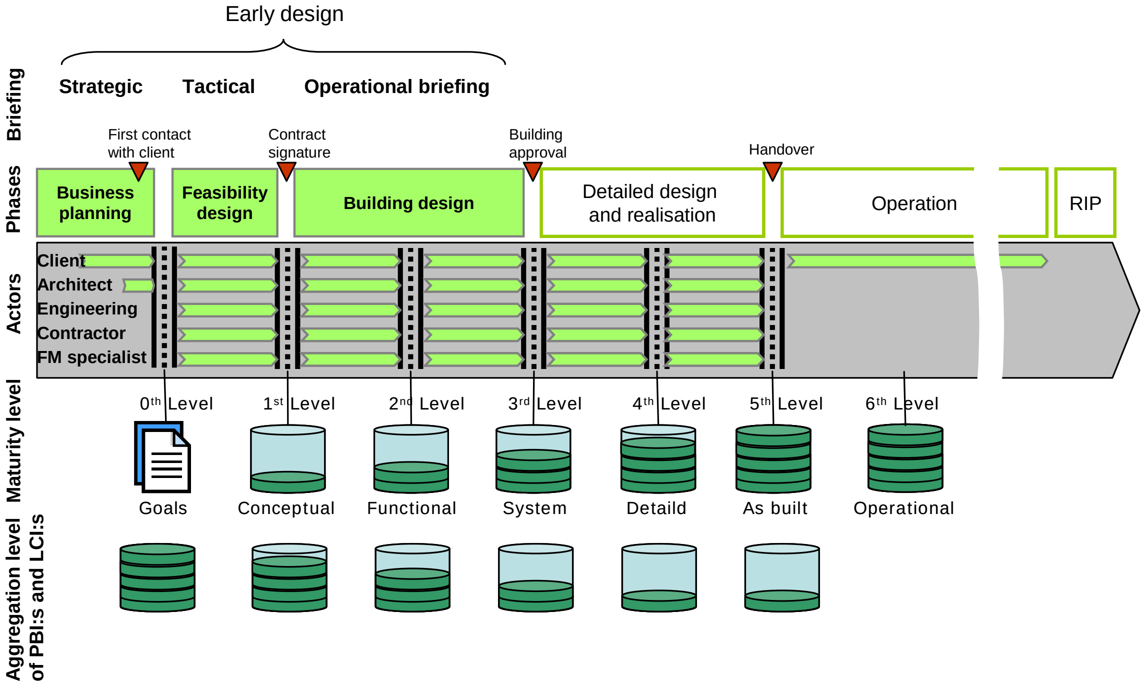

Figure 5: Default mapping of maturity levels versus building life cycle phases and aggregation level of PB:s and LCI:s (Based on Shade 2009)

A common approach is that the degree of detail, information level or model maturity is increasing through a number of phases from the early stages to detailed design and construction, where the required functionalities are gradually are mapped onto technical solutions. Similarly, Davis Langdon (2007) propose a stepwise approach methodology whereby proposals and solutions are identified initially and are then tested, validated and refined before becoming incorporated into the project. They further argue that an important feature of the LCC process is its essentially iterative nature since the process of construction design is itself highly iterative. The use and squence of LCC and LCA will depend on the priorities of the decison maker (Davis Langdon, 2007). The range of approaches might cover, for example, the use of LCC and LCA as two of the criteria in the evaluation of a number of investment alternatives or a single investment; the use of LCC to provide a financial/eceonomic evaluation of alternatives identified in a LCA assessment; the use of LCA as a means of identifying alternatives with a good environmental performance and then carrying out a LCC analysis; the use of LCC to select cost effective alternatives, then making a final decision in the light of a process of LCA carried out on those alternatives only.

Furthermore, there needs to be greater emphasis on assessment over the total life-cycle in the decision process. Accordingly, Ochoa et al (2002) investigated the construction, usage, and demolition of a residence and showed that the usage stage accounted for 95% of the total life-cycle energy consumption. Important therefore is to consider where in the construction processes the different aspects of LCC and LCA is determined. On average, by the time 1% of project costs are spent, roughly 70% of the lifecycle cost of the building has been committed (Romm, 1994). As stated by Kotaji et al. (2003) it is particularly important to show the relation between the design choices and the resulting life time cost (energy, maintenance and operation). As en example, an office building will cost about three times its initial cost to operate and maintain over a 25-year period (Flanagan and Jewell, 2005).

There are several tools that support the decision maker in the decision process (Kishk et al, 2003). However, when applying both LCC and LCA analyses in a complex context, such as contribution of a construction project his complexity can not be reduced to a simple set of universally applicable situations (Elghali et al 2008). A combined LCC and LCA tool will be used to select among alternative projects, designs or building components. Consequently LCC and LCA data should be presented in a way that enables effective comparison (Bakis et al., 2003). For that reason a modular LCC and LCA engine integrating asset-related data in PBs and life cycle inventories is an important concept. The information in PBs and LCIs, however, needs to be aggregated into building elements with all underlying costs and potential environmental impacts in order to be useful for decision making, especially in the early stage of the decision process. Furthermore, decision support needs to be capable of dealing with situations where system uncertainty is low but the decision stake are high, explicitly including consideration of decision stakes and uncertainty arising from incomplete information.

4 CONCLUSIONS

The purpose with this paper is to set out the strategic framework for developing a modular LCCA engine integrating asset-related data from price banks and life cycle inventories. Previous research shows that there are substantial benefit with a combination of LCC and LCA as a support to the decision process. By including probabilistic analysis in LCC and LCA methodologies, construction industry decision making that takes account of environment and cost is possible. The future decision tool needs to take in to account different level of decisions that are made in the construction process, from the first step of deciding the business case to the decision of rebuilding or demolishing. The uncertainty is higher in the beginning of the decision process, but these decisions have a bigger impact on the overall performance of an asset. There are three reasons for treating uncertainty as a central aspect of LCC:

- The take-up of LCC has been poor, perhaps because the unsatisfactory assumptions that have to be made in deterministic LCC undermine confidence in its results.
- The very long lifecycle of buildings compared to many other manufactured products increases uncertainty and makes it very difficult to assemble credible data for deterministic LCC
- Deterministic LCC is based on a method of investment appraisal that dates from the 1950s; since then many advances in investment appraisal that have emphasised the explicit modelling of uncertainty – it is appropriate to transfer these advances to the construction industry

There are also some important differences between LCC and LCA that need to be considered in the development of the decision tool. Unlike LCC, LCA does not include any time framework, which makes it difficult to discount future impacts. Probably the most suitable way of combining the two methods is to let LCA be a “passive passenger”, as Davis Langdon (2007) suggested, whereby LCC selects cost-effective alternatives, with final decisions being made in the light of a LCA. The time frame is essential also when applying life cycle option analysis which takes account of the range of possible outcomes. Further research needs to consider the difference in purpose between LCC and LCA; these differences have properly resulted in differences in their scope and methods.

The challenge, to develop aggregated PB:s and LCI to support the described decision process still remains. The previous described decision process, whereby a specific level of information is required so that the performance of the proposed design solution can be evaluated step by step, requires aggregated PB:s and LCI:s. The aggregation level decreases further down in the decision process whereby, in most case, the PB:s and especially LCI are more suitable today.

ACKNOWLEDGMENTS

The research leading to these results has received funding from the European Community's Programme FP7/2007-2013 under grant agreement no 229061.

REFERENCES

Allaby, E. M. (2006) A Dictionary of Ecology. Oxford University Press.

Curl, J. S. (2006) A Dictionary of Architecture and Landscape Architecture. Oxford University.

Bakis, N., Kagiouglou, M., Aouad, G., Amartunga, D., Kishk, M. & Al-Hajj, A. (2003) An Integrated Environment for Life Cycle Costing in Construction House. Taylor and Francis.

Ciroth A, Hunkeler D, Huppes G, Lichtenvort K, Rebitzer G, Rudenauer I, Steen B. (2008) *Environmental Life Cycle Costing*. SETAC Press, Pensacola, FL. Publishing House Taylor and Francis.

Davis Langdon (2007). *Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology*, Davis Langdon Management Consulting, UK.

Elghali,L., Clift R., Begg, KG and S McLaren., (2008): Decision support methodology for complex contexts. *Engineering Sustainability* 161, 2008, 1, 7-22

Ellingham, I. and Fawcett, W. (2006): *New Generation Whole-Life Costing*. Taylor and Francis

Flanagan, R. Kendell, A. Norman, G. and Robinsson, G., (1987): "Life Cycle Costing and Risk Management", *Construction Management and Economics*, 5, pp 53-71.

Flanagan, R. and Jewell, C. (2005) *Whole Life Appraisal for construction*, Oxford, Blackwell Publishing Ltd.

Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N. and Sun, M. (2003) *Whole lifecosting in construction – A state of the art review*. Research paper. London: RICS Foundation.

Kohler, N. (1999) The relevance of Green Building Challenge: an observer's perspective. *Building Research & Information*, 27**,** 309-320.

Kotaij, S., Schuurmans, A. and Edwards, S. (2003) *Life cycle assessment in building and Construction*, Denver, Society of Environmental Toxicology and Chemistry.

Langdon D (2007). *Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology*, Davis Langdon Management Consulting, UK.

Marshall, H.E. (1993) Uncertainty and Risk: Least-Cost Energy Decisions for Buildings, Video Training Workbook, National Institute of Standards and Technology, New York

Mun, J., (2006): *Real Options Analysis* (2nd edn.). Hoboken, NJ: Wiley

Norris G.A., (2000): Integrating Economic Analysis into LCA. *Environmental Quality Management* **10** (3) 59-64

Norris G.A., (2001): Integrating Life Cycle Cost Analysis and LCA. *The International Journal of Life Cycle Assessmen,* **6** (2) 118 – 120

Ochoa, L., Hendrickson C and Matthews H.S., (2002): Economic Input-output Life-cycle Assessment of U.S. Residential Buildings. *Journal of Infrastructure System*, **8** (4) 132-138

Romm, J. J. (1994) *Lean and clean management: how to boost profits and productivity by reducing pollution,* New York, Kodansha International.

Schade, J. (2009) *Energy simulation and life cycle costs: estimation of a building's performance in the early design phase.* Licentiatuppsats. 2009 Luleå: Luleå tekniska universitet.

Task Group 4 (2003): *Life Cycle Costs in Construction; Version 29 October 2003*, Enterprise Publications, European Commission. Endorsed during 3rd Tripartite Meeting Group (Member States/Industry/Commission) on the Competitiveness of the Construction Industry.