life-cycle costing in the construction sector

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Summary
The construction sector is a major consumer of natural resources. Inability to predict performance reliably can result in unsustainable waste (through over-design) or costly premature deterioration. Life-cycle costing makes it possible for the whole life performance of buildings and other structures to be optimized. Its value is highlighted by the increasing use of private finance initiative type procurement, in which a developer/builder operates and maintains the structure over an agreed period. This article introduces the concept of life-cycle costing as used in the construction sector. It briefly explains how LCC is carried out and some of the barriers to its adoption. Initiatives seeking to tackle these barriers are presented. A case study illustrates payback on investment to reduce energy consumption. For this exercise, two design options were developed: the original client-compliant design and an energy efficient option.

Résumé
Le secteur de la construction est un gros consommateur de ressources naturelles. L'incapacité de prévoir avec justesse les performances des constructions peut se traduire par des volumes de déchets contraires au concept même de développement durable (design trop recherché) ou par une détérioration prématurée coûteuse. L'évaluation du coût du cycle de vie permet d'optimiser les performances des bâtiments et autres constructions pendant toute leur durée de vie. L'intérêt de cette évaluation a été démontré par le recours de plus en plus fréquent à des projets menés par financement privé dans lesquels le promoteur ou le maître d’œuvre exploite et entretient la construction pendant une durée déterminée. L'article présente le concept d'évaluation du coût du cycle de vie tel qu’il est appliqué dans le secteur de la construction. Il explique comment est effectuée l'évaluation et quels obstacles freinent son adoption ; il présente quelques initiatives visant à lever ces barrières. Une étude de cas illustre le retour sur investissement des efforts de réduction de la consommation d'énergie. Deux options architecturales ont été élaborées à cet effet : le projet initial conforme aux vœux du client et un projet basé sur l'efficacité énergétique.

Resumen
El sector de la construcción es un gran consumidor de recursos naturales. La incapacidad de prever el rendimiento con seguridad puede resultar en desechos insostenibles (por planificación excesiva) o en un deterioro prematuro costoso. La determinación del costo del ciclo de vida permite optimizar el rendimiento de edificios y otras estructuras durante toda su vida. Su valor ha salido a relucir por la utilización creciente de una especie de iniciativa privada de financiación en la que el promotor o constructor se encarga del funcionamiento y mantenimiento de la estructura durante un periodo acordado. El artículo presenta el concepto de costo del ciclo de vida según se utiliza en el sector de la construcción, explica brevemente como se determina el costo del ciclo de vida y algunos de los obstáculos para su utilización, y describe iniciativas para superar estos obstáculos. Un estudio de caso ilustra el rendimiento de la inversión para reducir el consumo de energía. Para ello, se desarrollaron dos opciones de diseño: el diseño original según el pedido del cliente y una alternativa de eficiencia energética.

Use of the designation “life-cycle costing” has changed over number of years. It has also variously been called whole-life costing, terotechnology, through-life costing, costs-in-use, total-cost-of-ownership, total-life costing, ultimate life cost and total cost. Life-cycle costing (LCC) and whole life costing (WLC) are commonly used terms today. The difference between the two is often taken to be that LCC is a sub-set of WLC and represents the period of interest that the cost analysis is aimed at.

A building owner will be interested in the costs of a built asset over its whole life, which could be measured in hundreds of years, whereas tenants will only be concerned with the costs they will have to bear during their tenancy – say 25 years. Public finance initiative (PFI) contractors will also be more interested in the life-cycle costs of the building for the 25- to 30-year contract period than in the residual life after it has been handed back.

In this article the term life-cycle costing (LCC) will be used because it reflects the majority of those who are interested in the technique. It is also used by the International Organization for Standardization. Not surprisingly, given the history of the term, there are a number of definitions. “BS ISO 15686 Buildings and Constructed Assets – Service Life Planning Part 1:2000 General Principles” defines LCC as: the total cost of a building or its parts throughout its life, including the costs of planning, design, acquisition, operations, maintenance and disposal, less any residual value.

The UK’s Construction Best Practice Programme (CBPP) provides another useful definition:
...the systematic consideration of all relevant costs and revenues associated with the acquisition and ownership of an asset.
As its most fundamental level, it includes consideration of all costs and revenues associated with the acquisition, use, maintenance and disposal of a built asset.

Life-cycle costing (LCC) is an estimation of the monetary costs of the funding, design, construction, operation, maintenance and repair, component replacement, and sometimes demolition of a building. It may be applied to new designs or to existing structures, in the latter case enabling residual life and value to be estimated. As different maintenance and repair and replacement operations take place at different times, incremental costs are converted to present-day value using a discounted cash flow approach.

LCC relies on predicting when elements of the building and its services will deteriorate to a condition where intervention is needed, and what the discounted cost of each intervention will be. LCC calculations therefore depend on numerous assumptions, all subject to a degree of uncertainty.

Why use LCC?
Achieving excellence in design is essential for a construction project to deliver best value. Design is both a creative and a technical process. It should include the following components, each of which must be addressed appropriately:

Functional design of the facility to meet the needs of users and operations. This should result from a detailed assessment of the needs of the users and operations and how they may change over time, as well as how the facility will need to be altered to meet these changing needs.

Design of the complete facility to address the environment for those who use, enjoy, operate, maintain or are otherwise affected by it, including aspects that impact on their health and safety. The design should address impact on the external global environment, as well as the facility’s aesthetic, cultural and civic values.

Design of each assembly and component, whether manufactured on-site or in a factory, and whether it is a standard product or purpose-made or adapted for the facility.

Design of the entire construction process, addressing how each component will be manufactured, transported and assembled to complete the facility. Maintenance of the facility (including details of how components can be replaced and/or repaired) should be addressed, as well as its ultimate disposal.

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Costing of projects. This should include full life-cycle costs of the facility, as well as more immediate construction and project costs. The quality of both design and construction has the potential to greatly reduce life-cycle costs, including costs in-use and eventual disposal of the built facility.

Decisions made early in the design process can have a considerable influence on life-cycle costs. Building orientation will influence the amount of solar heat gain and level of cooling required and the degree of shading; floor plate depth will influence the decision on whether the building needs to be air-conditioned as opposed to naturally ventilated; levels of insulation and air tightness will affect heat loss and energy costs; the number of floors will impact on costs of access for cleaning and maintenance; the number of entrances influences levels of security; and so on.

The earlier life-cycle costing can be considered in the procurement process, the more effective the outcome will be (Figure 1).

LCC is used in particular to:
- determine whether a higher initial cost is justified by reductions in future costs (for new build or when considering alternatives to “like for like” replacement);
- identify whether a proposed change is cost-effective against the “do nothing” alternative, which typically has no initial investment cost but higher future costs.

Taking a life-cycle cost approach to procurement of buildings provides better certainty about future costs and the risks associated with them. Until recently, lending institutions have considered that most financial risk occurs during the construction period. Costs during construction can be affected by unexpected ground conditions, inclement weather, labour and materials shortages, time overruns, defects and poor budgeting. Financial institutions are now in the market for funding long-term PFI projects (lasting over 25 years) and they realize that there is even greater uncertainty during this period. Lack of understanding of how buildings perform, and when the need for intervention should occur to prevent failure, makes predicting future costs a long way ahead an unreliable exercise.

Owner-occupier clients are also coming to realize that the costs of building ownership can be a significant drain on company profits. They are looking for greater predictability of future costs before embarking on a construction project.

### What needs to be considered when carrying out LCC?

The time-dependent stages of the life of a facility that need to be considered during the decision and procurement processes are: acquisition (including pre-construction and construction); operation (maintenance, replacement or refurbishment); and disposal (sale or demolition).

At each stage consideration must be given to the basic elements of the facility such as structure, envelope, mechanical and electrical services, finishes, and fixtures and fittings (Table 1).

The most important aspect when considering a facility’s whole life is how it will enhance the core business operations that will take place in, on or around it. A very clear understanding of what those business operations currently are and how they might change in the future is necessary as a starting point, before it is

### Table 1: LCC Considerations

<table>
<thead>
<tr>
<th>Stage of building life</th>
<th>Considerations for life-cycle costing</th>
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</thead>
<tbody>
<tr>
<td>1. Acquisition by construction (new or refurbishment) – which would include costs of:</td>
<td>Land for the building, its clearance and related groundwork for new build; design, although this may often be included in the cost of construction with use of design and build type procurement; planning, regulatory and legal fees; construction, commissioning, fitting out and handover; in-house administration; interest or cost of money</td>
</tr>
<tr>
<td>Or Acquisition by purchase or rental – which would include costs of:</td>
<td>Purchase price; planning, regulatory and legal fees; adaptation to suit needs of the business; in-house administration; interest or cost of money</td>
</tr>
<tr>
<td>2. Operation (use and maintenance) – which would include costs of:</td>
<td>Maintenance, repairs, replacements of components and systems; cleaning; utilities and energy; churn (regular reconfiguration to suit changes in business or process operation – internal layouts of office buildings typically change every five to seven years); security and management; rate's (and rent if required)</td>
</tr>
<tr>
<td>Income from use of asset</td>
<td>Income that may be generated through subletting of planned or surplus space</td>
</tr>
<tr>
<td>3. Disposal – which would include costs of:</td>
<td>Demolition; site clean-up</td>
</tr>
<tr>
<td>Income from disposal</td>
<td>Sale of interest in asset; sale of land; sale of materials from demolition</td>
</tr>
</tbody>
</table>

Source: Client’s Construction Forum, Whole Life Costing: A client’s guide, 2000
possible to determine the facility's output performance requirements.

The life-cycle cost model for a specific project will be developed and subsequently updated by different parties according to the project stage reached and the form of procurement adopted. At project inception, the model might be developed in-house or by an external cost consultant. At tender stage, the bidder should take on or prepare the model if tenders are to be evaluated based on life-cycle costs. Where a framework contract is already in place, the framework supplier might be the most appropriate organization to develop the model from the outset.

A great deal of time can be spent going through lots of historical data from numerous sources in an attempt to get the most accurate information. This process is time consuming and normally shows that there are enormous gaps in the data available for creating life-cycle cost models. Where historical data is available, this may well reflect past mistakes in the industry such as lowest price. Irrespective of whether or not historical cost information is available, it is always preferable to estimate the costs from first principles and use historical cost and performance information only as a check.

To account for different operations taking place at different times, incremental costs are converted to current costs using a discounted cash flow method that incorporates interest rates and inflation. This is particularly important when comparing options that have different replacement cycles.

The discounted cost rate, \( r \), enables calculation of the discounted costs based on the future value of money as follows:

\[
\text{Discounted cost rate, } r = \frac{1 + \text{interest rate}}{1 + \text{inflation rate}}
\]

If the cost in year \( t \) is \( C_t \) and the discount rate is \( r \), the life-cycle cost for a facility with a design life of \( N \) years, expressed as the cost at current value, is:

\[
\text{Present cost} = \sum_{t=0}^{N} \frac{C_t}{(1 + r)^t} \times 100
\]

The application of the principle of present cost (PC) is similar to net present value (NPV) and can cause difficulties in the analysis of WLC. Even at a low discount rate, the NPV decreases rapidly over time, as illustrated in Figure 2. This makes capital investment for long-term performance unattractive to a developer in monetary terms.

The discount rate is used to calculate the present value of a future income stream or cost - that is, the sum of money to be invested today in order to accumulate the amounts by the time they are needed. It is set by the client and includes the degree of risk on return required in a commercial context, or the rate of interest payable where loans are required to finance the construction work. If it is set too high, future costs will appear insignificant and will be favourably calculated. If it is set too low, higher capital costs will be discouraged but high operational costs may result. If inflation is taken into account in the discount rate and if rates are substantially different in practice, the calculation may lead to inappropriate choices.

**Figure 4**

**EuroLifeForm: main features of life-cycle cost and performance model**

- **Performance data**
- **Deterioration models**
- **Statistical quantification of parameters**
- **Probabilistic analysis of performance**
- **Life-cycle performance analysis**
- **Financial models**
- **Real cost data**
- **Indirect repair costs**
- **Direct repair costs**
- **Planned maintenance**

**Cost**

- **Capital costs**
- **Demolition**

**Time**

- **Environmental impact, sustainability, social impact**

### Barriers to take-up of LCC

Life-cycle costing has often been dismissed because of lack of clear methodology and absence of data. A study in 1999 carried out by BRE on behalf of the Construction Research and Innovation Panel (CRISP) found that these were the main reasons only 25% of clients used life-cycle costing. The lack of universal methodology and standard formats for calculating life-cycle costs, the difficulty integrating operating and maintenance strategies at the design phase, along with meaningless results, were considered barriers to the use of life-cycle costing.

"BS ISO 15686 Buildings and Constructed Assets – Service Life Planning, Part 1: General Principles" provides an overall framework that addresses the design of a building or construction with a view to its operation through the whole of its operational life. The approach requires long-term performance and overall operating costs to be addressed early in the design stage. It enables the design to be assessed against the client’s long-term needs for the service life of the building.

A major impetus for producing this new ISO standard has been concern over the industry need to forecast and control the cost of ownership, as a high proportion of the life-cycle costs will have been set by the time of hand-over (Figure 1). It encourages involvement of all parties in the decision process for selection of components and systems, based on performance (durability) appropriate to the function and expected life of the asset. It focuses on the lack of data on durability, and provides a methodology for assessing and recording decisions on estimating the service lives of components where there is a lack of robust scientific and certified product data.

Service life planning is an integral aspect of life-cycle costing. The replacement cycles of sub-components that are expected to last less time than the overall service life of the main component, or the life of the building, are very sensitive to the calculation of life-cycle costs. Reliable forecasting of future replacements against the functional requirements of the building will reduce the possibility and costs of disruption to the business or processes being carried out in (or being supported by) the building or...
This will compliment the work that has been undertaken by the Economically Most Advantageous Tender (EMAT) Task Group set up in July 2001 to develop a methodology for awarding construction contracts. This is an important step towards encouraging tender assessments and awards based on best value. The award criteria being recommended by the EMAT Task Group are:

- quality and life-cycle cost;
- the relationship (ratios) between quality, life-cycle costs and initial construction cost (the tender price);
- weightings for quality and life-cycle cost criteria; and
- mandatory thresholds.

Procurement routes such as prime contracting and PFI lend themselves more readily to being assessed on the basis of life-cycle costing, but involve lengthy and costly tendering processes.

Probabilistic approach for predicting life-cycle costs and performance of buildings and civil infrastructure (EuroLifeForm)

Some LCC thinking currently attaches a risk factor to interventions for replacements, but the risk is not usually time dependent. It may be assumed that there is a 1% chance of leakage through a cladding system over a 30-year life, but there is no indication of when the leaks may occur. To estimate the changing risk with time, a probabilistic approach is needed.

EuroLifeForm is a European funded research project. The principal objective of the EuroLifeForm project is the development of a generic model for predicting life-cycle costs and performance. This will be applicable initially to the design of buildings and structures to optimize life-cycle costs and latterly to optimize interventions through maintenance and repair. The approach will be essentially the same, the principal difference being the input data for predicting performance. For existing structures decisions can be based on observed performance, while the design of a new structure must rely on background information.

The project primarily addresses technological and cost issues, but other factors such as environmental impacts are becoming increasingly important. Some of these factors are difficult to value in monetary terms, but qualitative methods of assessment are being investigated. Methods for multi-criteria decision making are being investigated in this context, to enable the client to optimize in relation to his own hierarchy of priorities and the weighting between them. The main features of the proposed EuroLifeForm life-cycle cost and performance model are shown in Figure 4.

The principal benefit of this project will be improved predictability in relation to the cost and performance of an asset. Uncertainties will always exist, but the intention is to enable these to be identified and quantified using a risk-based approach. By making possible more transparent and better-informed decisions at the design stage, this will lead to better value and more efficient use of resources.

References
1. www.iso.ch/iso.

Prime contracting

Historically, the UK Ministry of Defence has used the term "prime contracting" to describe single point responsibility. Although this originally referred to weapons and equipment procurement, the term is equally valid for construction procurement.

Prime contracting recognizes that industry is best placed and best qualified to manage the complete task.

The prime contractor will be responsible for:
- sub-contract selection;
- procurement management;
- design, coordination and overall system engineering and testing;
- planning, programming and cost control;
- total delivery, fit for purpose and in line with life cost predictions.

6. These reports are available on the European Commission's website (http://europa.eu.int/comm/enterprise/construction/index.htm).
Case study on comparative life-cycle costs: client-compliant bid versus energy efficient design (barrack accommodation for the UK Ministry of Defence)

The client wanted to build low-energy sleeping accommodation for soldiers, but needed assurances that any additional initial capital cost would be justified. Building Research Establishment (BRE) used life-cycle costing to demonstrate value for money by adopting a sustainable construction approach. For the exercise, two design options were developed: the client-compliant (original) design and an energy efficient option. The overall project value is in the order £4.0 million.

The results of the analysis show that initial additional capital spending of £72,648 on the energy efficient option produces an LCC saving of over £236,945 (discounted at 6%) at current prices. The additional costs mainly cover redesigning the building to reduce air exfiltration (leakage) and to increase wall and roof insulation and building mass. Savings were made to the heating system by adopting a heat recovery approach, taking advantage of occupancy patterns, and realizing the passive environmental control from utilizing the additional building mass and the effect of increased insulation.

<table>
<thead>
<tr>
<th>Energy/ utility costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>The following costs have been estimated using CYPAM, an industry recognized energy use software. All energy and water consumption figures are based on calculations carried out by the design team services engineer. Costs are based on local rates provided by the utility providers.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy/utility costs</th>
<th>Client-compliant option £</th>
<th>Alternative energy efficient option £</th>
<th>Saving/extra £</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial capital cost of elements analyzed</td>
<td>1,623,199</td>
<td>1,695,848</td>
<td>-72,648</td>
</tr>
<tr>
<td>Life-cycle cost (LCC) over 60 years</td>
<td>4,272,398.85</td>
<td>2,870,913</td>
<td>1,401,485</td>
</tr>
<tr>
<td>Net present value (NPV) of life-cycle cost over 60 years</td>
<td>2,608,191</td>
<td>2,371,245</td>
<td>236,945</td>
</tr>
</tbody>
</table>

Energy efficient design appraisal for barrack accommodation payback period at NPV (6% discounted)

The gas cost takes account of an estimated additional £1000 per year saving in hot water heating cost through use of low water flow showers.

<table>
<thead>
<tr>
<th>Total energy/ utility cost (non-discounted over 60 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client-compliant option £</td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Gas</td>
</tr>
<tr>
<td>Electricity</td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partnering principles are key to the process</th>
</tr>
</thead>
<tbody>
<tr>
<td>The pricing model is a target cost incentive fee arrangement. This is a simple arrangement under which the parties share, on a pre-determined basis, any excess or savings of actual costs, thus providing a strong financial incentive to improve performance. It is an underlying premise of prime contracting that the contracting parties will buy into the principles of shared goals and will receive a fair profit for delivering what the client wants, when it wants it, at the agreed price. To make this concept work to the maximum advantage of both parties, long-term contractual relationships should be considered.</td>
</tr>
</tbody>
</table>

The UK National Health Service has adopted a similar approach, calling it ProCure21.