SCSI
Chartered property, land and construction surveyors

GUIDE TO LIFE CYCLE COSTING

2nd Edition, Information Paper

RICS

OLLSCOIL TEICNEOLAÍOCHTA BHAILE ÁTHA CLIATH
TU DUBLIN
TECHNOLOGICAL UNIVERSITY DUBLIN

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Information Paper

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Document status defined

SCSI and RICS produces a range of standards . These have been defined in the table below. This document is an information paper.

Document status defined

Type of document	Definition	Status
Standard International standard	An international high level principle based standard developed in collaboration with other relevant bodies	Mandatory
Professional statement SCSI/RICS professional statement (PS)	A document that provides members with mandatory requirements or a rule that a member or firm is expected to adhere to. This term also encompasses practice statements, Red Book professional standards, global valuation practice statements, regulatory rules, SCSI/RICS Rules of Conduct and government codes of practice.	Mandatory
Guidance and information SCSI/RICS code of practice	Document approved by SCSI/RICS, and endorsed by another professional body/ stakeholder, that provides users with recommendations for accepted good practice as followed by conscientious practitioners.	Mandatory or recommended good practice (will be confirmed in the document itself). Usual principles apply in cases of negligence if best practice is not followed.
SCSI/RICS guidance note (GN)	Document that provides users with recommendations or approach for accepted good practice as followed by competent and conscientious practitioners.	Recommended best practice. Usual principles apply in cases of negligence if best practice is not followed.
SCSI/RICS information paper (IP)	Practice-based information that provides users with the latest technical information, knowledge or common findings from regulatory reviews.	Information and/or recommended best practice. Usual principles apply in cases of negligence if technical information is known in the market.
SCSI/RICS economic/ market report	A document usually based on a survey of members, or a document highlighting economic trends.	Information only.
SCSI/RICS consumer guide	A document designed solely for use by consumers, providing some limited technical advice.	Information only.
Research	An independent peer-reviewed arm's length research document designed to inform members, market professionals, end users and other stakeholders.	Information only.

Life Cycle Costing

1.1 Introduction

Traditionally within the construction industry, design professionals provide advice to clients based on the economic aspects of building development proposals, but tend to primarily concern themselves with the initial Capital Expenditure (CAPex) [1, 2]. Techniques such as Life Cycle Costing (LCC) provide end users with a longer term view, which includes maintenance and operating costs over a building's life, in addition to the initial construction CAPex [3]. This information paper discusses the meaning and applicability of LCC, focusing mainly on how the calculations are carried out and how Quantity Surveyors (QSs) could apply them to a construction project. A practice-based approach to LCC calculations are addressed, beginning with the fundamental financial formulae in LCC; application of LCC financial calculations to construction projects; and the use of spreadsheet software to carry out an LCC estimate. The benefits to utilising a LCC approach and the challenges in the approach are addressed, particularly in the context of sustainability and green procurement. Currently within sustainability in construction there are a proliferation of terminology with many of these terms and acronyms having similar meanings. This information paper starts with the definitions and meaning around a whole life cost approach to construction.

1.2 Whole Life Cycle Costing and Life Cycle Costing

Several definitions exist for **Life Cycle Costing**:

> *an economic evaluation in which all costs arising from owning operating and maintaining a building over a certain study period or building life cycle are considered to be potentially important* [4].

The functions of LCC are for decisions in option appraisal, informing design decisions; and importantly providing an enriched cash flow forecast for the client over an extended period [4, 5].

Another term which encompasses a broader evaluation of LCC is **Whole Life Cycle Costing**:

> *all significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements.* [6]

Figure 1 illustrates the hierarchical breakdown structure for WLCC in the International Standard Organisation (ISO) 15686 Part 5 [6]. As seen in the definitions above, WLCC includes a broader economic matrix, encompassing not only construction costs and LCC but also 'non-construction costs' such as site purchase; letting or selling agent fees; procurement costs and the cost of finance **(2nd tier, Figure 1)** [6, 3].

Figure 1 BS-ISO 15686-5 [6]

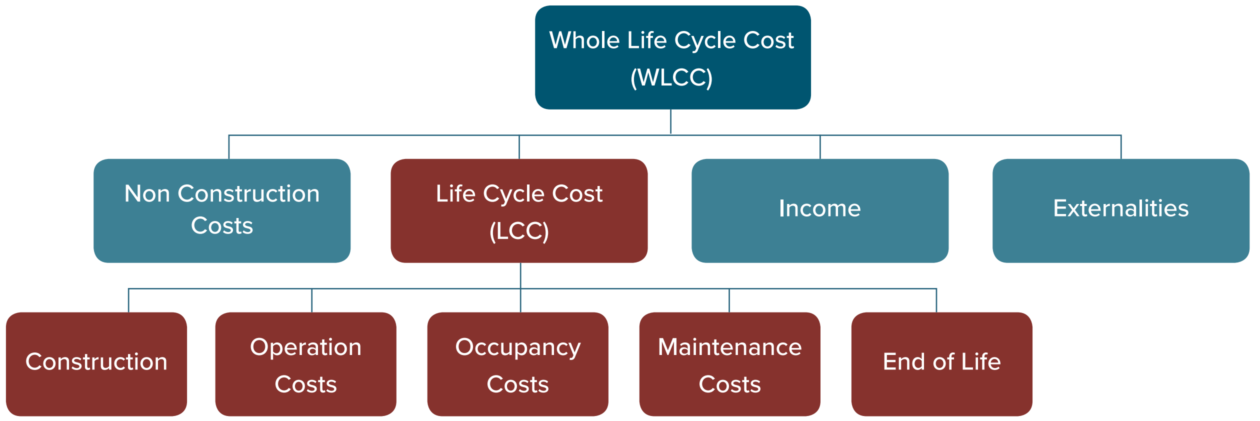


Figure 1 also illustrates that WLCC includes 'income' from the built asset and any defined 'external' costs. The ISO 15686-5 [(6)] describes external costs as 'externalities', which are costs not necessarily reflected in the transaction between provider and consumer, giving examples such as business staffing, productivity and user costs [(6)]. Another externality which is very relevant today, is the wider impact on the environment which could possibly be assessed through a Life Cycle Analysis (LCA) and Green Building Ratings. Externalities could also be expanded to take account of the social impact on the built asset.

1.3 Standardisation of LCC

In 2008, the ISO published [1]**'ISO EN 15686 Part 5'** [(6)]. ISO 15686-5 was, in turn, adopted almost immediately by the British Standards Institute (BSI) for 'BS-ISO 15686-5' [(6)]. BS-ISO 15686-5 forms part of the ISO's wider standards giving guidance on various aspects of planning the service life of buildings and constructed assets. Part 5 'provides guidelines, definitions, principles and informative text on the application of LCC techniques in the context of service-life planning' [(6)]. As discussed previously, **Figure 1** represents the cost breakdown structure applicable to the ISO document.

1.3.1 LCC in Public Procurement

The Irish Government introduced the Capital Works Management Framework (CWMF) in August 2009 to achieve greater cost certainty and better value for money on publicly funded projects. Guidance notes on [2]**'The Planning and Control of Capital Costs – GN 2.2'** published in support of the CWMF, states that 'whole life costs are an important consideration throughout the design process, and should be integrated at each stage in cost plan development' [(7, p. 54)].

In the UK, The Office Government Commerce (OGC) has developed an established suite of guidance notes and tools encompassing project management and sustainability through the 'Achieving Excellence in Construction Procurement Guides'. [3]**'A guide for 'Whole-life costing and cost management'** [(8)] forms part of the OGC suite.

The OGC and the CWMF documents are guides rather than methodologies; in order to carry out a detailed LCC you would have to consult one of the relevant international standards. These standards, such as BS-ISO 15686-5 [(6)], are very informative publications, but they are theoretical, with little in the way of practical examples. In the recent past there have been several guidance documents published that outline LCC in greater detail, providing examples, and presenting a format for carrying out the LCC.

1.3.2 BSI/BCIS: Supplement to ISO 15686-5 (2008)

In 2008, the British Standard Institute (BSI) and the British Cost Information Service (BCIS) in the UK, jointly published a document which put forward a standardised method for producing LCC applicable to the UK construction industry [(3)]. The document addresses some of the failings discussed previously, where the BS-ISO 15686-5 [(6)] does not provide adequate clarity or guidance. The [4]**BSI/BCIS 15686-5** [(3)] provides a cost data structure and a method of measurement for LCC, which aligns with BS-ISO 15686-5 [(6)] and the UK's BCIS cost structure conventions. It delivers further detail in LCC calculations; provides templates and spreadsheets to carry out LCC estimates; outlines worked LCC examples; adds additional classifications to the BS-ISO 156868-5 [(6)] WBS; and furnishes clarity on what type of costs are attributed to each ISO category.

1.3.3 SCSI: Guidance Notes on Life Cycle Costing (2010) (Updated 2016A)

In 2010, the SCSI working group published a '[5]***Guide to LCC'*** [(9)], which provided practical guidance and assistance for the SCSI members and QSs in Ireland carrying out LCC and producing LCC estimates in line with Ireland's CWMF. The document was different from other guidance notes, as it provided detailed worked examples using financial tables to carry out the calculations and also provided guidance on how LCC calculations can be written as formulae into Microsoft (MS) Excel cells. This document represents a new version of that original publication, but given the time since its publication it represents a significant update and should be considered on its own merit.

1.3.4 RICS: New Rules of Measurement 3 (NRM 3) (2014)

In March 2014, the RICS introduced [6]**New Rules of Measurement 3 (NRM 3)** (10). NRM are a suite of documents that has been developed to provide standard measurement rules for all construction projects in the UK. While NRM 1 and NRM 2 deal with cost management for CAPex, NRM 3 provides consistent rules and guidelines for the quantification and measurement of building maintenance and renewal works. NRM 3 is more than a guidance document, in that it provides a detailed set of rules (much like what you see in the ARM4) and best practice procedures, for different stages of the procurement process aligned to both BS-ISO 15686-5 (6) and the BSI/BCIS (3) ISO supplement.

1.3.5 RICS Guidance Notes: Life Cycle Costing (2016)

[7]**The RICS guidance notes on LCC** (11) follows the guiding principles outlined in ISO 15686-5 (6) and the BCIS/BSI Supplement (3). These guidance notes provide excellent information for QSs carrying out LCC exercises throughout the design period and providing LCC option appraisal and sensitivity analysis. The RICS guidance notes outline similar content to what is contained in the original SCSI (9) guidance notes, outlining standard definitions for LCC and WLCC; describing the different metrics for LCC calculations; explaining the different stages that LCC calculations can be carried out; linking with other aspects of sustainable evaluation and; providing practical examples of LCC models.

1.3.6 International Construction Management Standard (ICMS) 3rd Edition.

The International Construction Management Standard (ICMS) was published in 2017 and focused on capital costs. The first edition of the ICMS establishes a basis for the comparison of international construction measurement costs, across the various construction sectors on a “side by- side” basis. The standard is backed by the United Nations (UN), International Monetary Fund (IMF) and the European Union (EU). The ICMS will most likely replace the National Standard Building Elements (NSBE) in Ireland in the near future.

The ICMS 2nd edition was published in 2019 and expands the ICMS for LCC. The [8]**ICMS 3rd Edition** (12) was published in November 2021 adding carbon emissions (LCA) to the ICMS framework, making it a whole life assessment. The LCC breakdown structure in ICMS 3rd edition is consistent with ISO 15686-5, comprising of WLCCs which are broken into 4 categories, (1) non-construction costs, (2) LCC, (3) income and (4) externalities. LCC is further divided into (A) acquisition, (C) construction, (R) renewal, (O) operation, (M) maintenance and (E) end-of-life costs (i.e. ACROME), which represents a slight departure from ISO 15686-5 at this level **(Figure 2)**.

The ICMS (12) has four levels of codes in comparison, to two in the NSBE, starting with a project level coding structure, through a number of sub-groups **(Figure 3)**. Each of the LCC level 2 (ACROME categories) have cost groups (level 3) and cost subgroups (level 4). Section 1.14.3 outlines an example of how the ICMS work breakdown could be utilised to carry out and present an LCC estimate.

1.3.7 Summary List of Important Documents

1. BS-ISO EN 15686 Part 5 (2008)
2. CWMF: The Planning and Control of Capital Costs – GN 2.2 (2007)
3. OGC: A guide for Whole-life costing and cost management (2007)
4. BSI/BCIS: Supplement to 15686-5 (2008)
5. SCSI: Guidance Notes on Life Cycle Costing (2010)
6. New Rules of Measurement 3 (NRM 3) (2014)
7. RICS: LCC Guidance Note (2016)
8. International Construction Management Standard, 3rd edition (2021)

Figure 2: ICMS Framework [12]

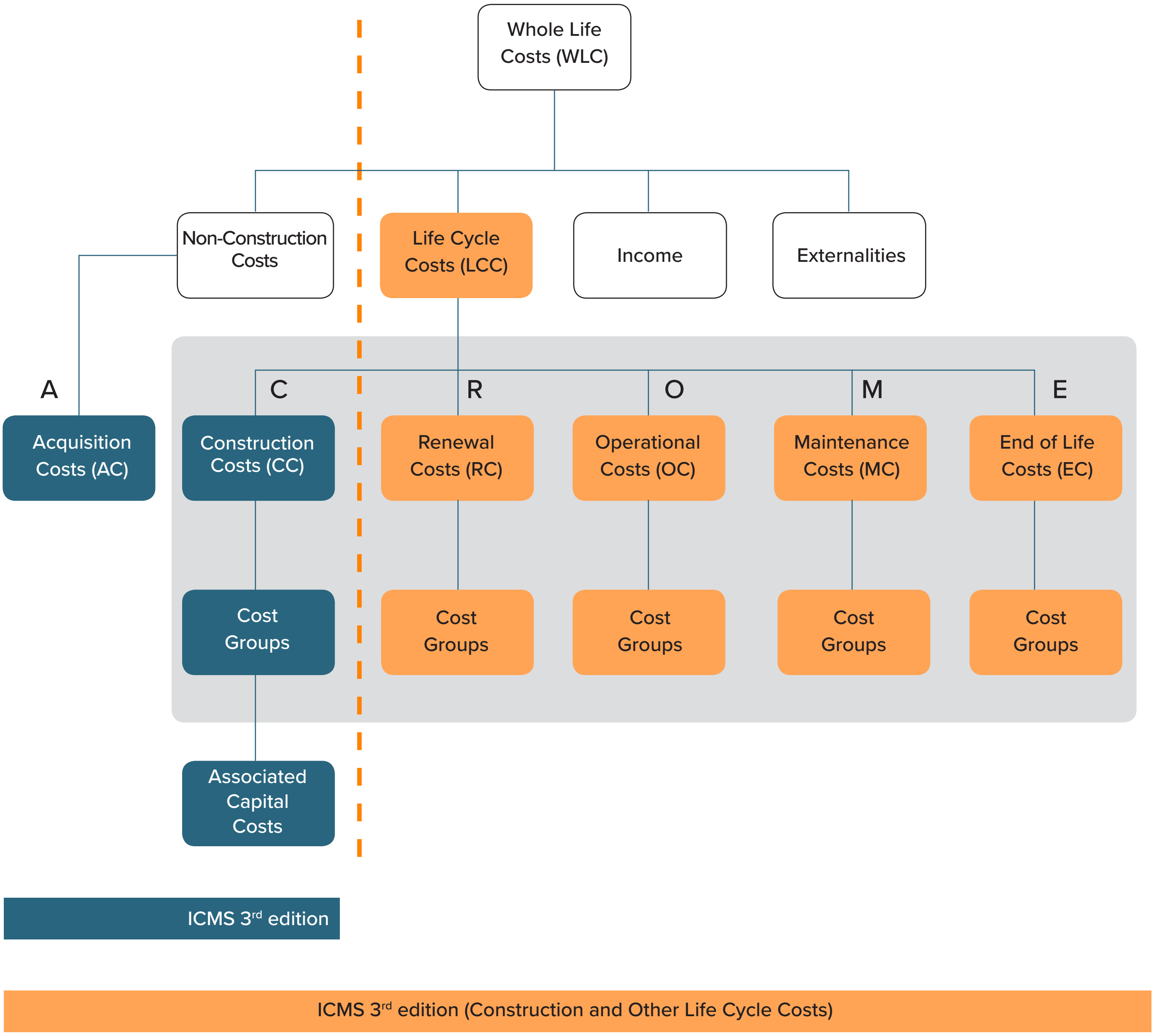
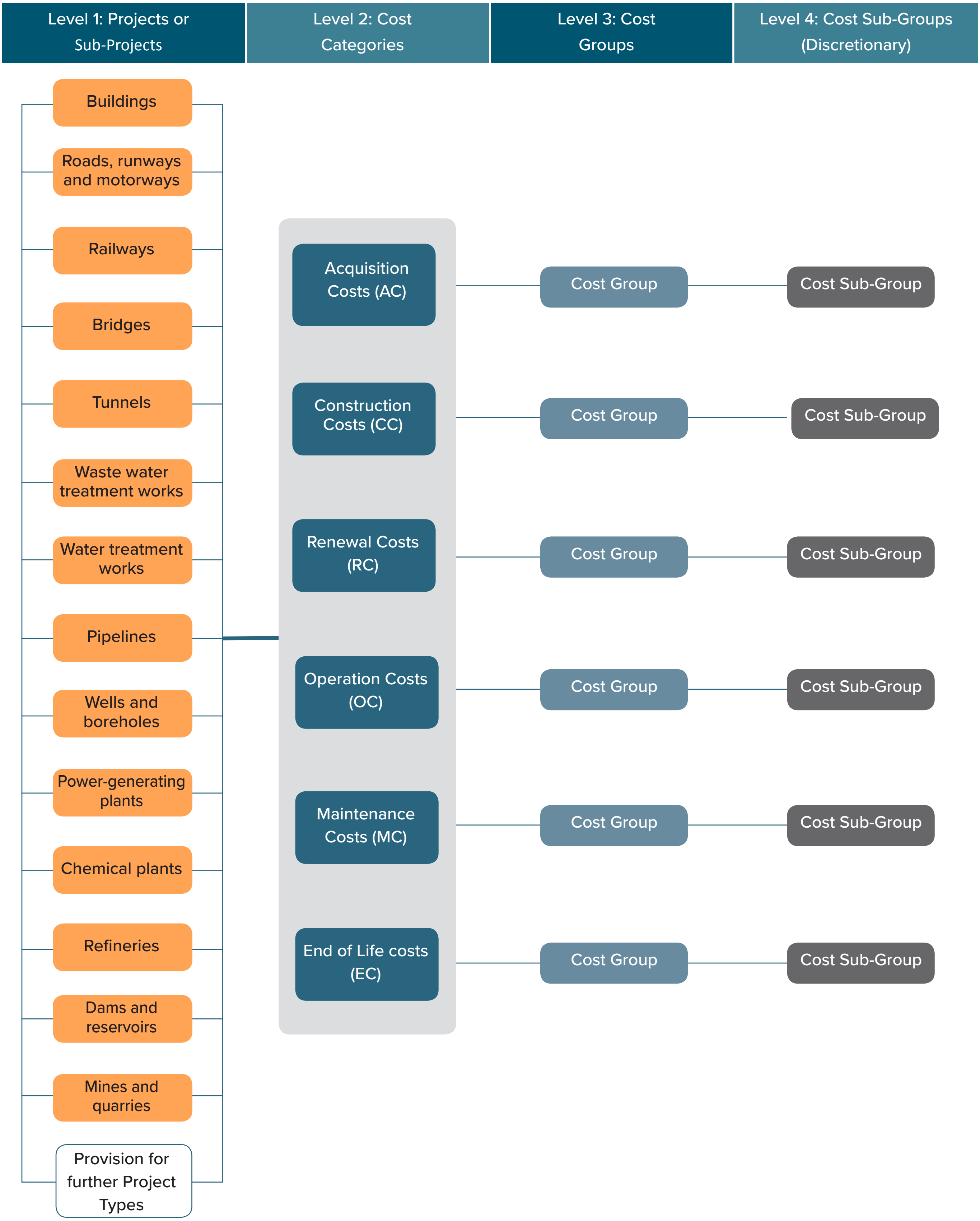


Figure 3: Level 1 Projects and Sub-Project - ICMS Framework [12]



1.4 Benefits of LCC

The central benefit of LCC is that it enables a whole cost approach to the acquisition of a capital asset, giving the client a total cost view of the project rather than only considering the initial CAPex. LCC facilitates more effective and economically sound decision making enabling the client to view current and future cost demands and use this to assist in their financial management [12]. The central benefit outlined here can be analysed into a number of themes based on the function of its application.

1.4.1 Evaluating Design

One of the main purposes of LCC is to compare several design options from a number of competing proposals [13, 14, 15]. LCC should be used to inform decisions during design and to reassure clients that the overall performance of the building, for the entire life cycle, is taken into consideration through alternative design solutions [15].

LCC is beneficial when it is used to compare how one built asset monetarily performs against a competing alternative design. The competing designs could be a traditional design to a more sustainable option; or refurbishment versus new construction [3].

1.4.2 Life Cycle Costing as a Measure of Sustainability

Sustainable construction presumes a whole systems approach, which considers the environmental, social and economic consequences of any decision made within the construction industry [10, 16]. It is becoming increasingly important that clients use an investment appraisal technique that uses a whole life approach, to examine how better environmentally performing buildings could be built for a cost that can be evaluated and justified in commercial terms [10, 17]. The BSI/BCIS [3] define WLCC as a methodology for assessing the economic effects of sustainability, which allows for more comprehensive decision making based on sustainable evaluation rather than initial costs alone.

The LCC estimate cannot fully represent a measure of sustainability as environmental considerations cannot only be expressed in monetary terms [13, 16]. LCC can be used in tandem with Life Cycle Analysis (LCA), which is a better determinant of environmental performance, as it focuses on embodied carbon emissions rather than an exclusive monetary analysis [16]. LCC complements LCA because many of the calculation metrics, such as maintenance and replacement profiles, for the calculation of LCC, are also necessary in LCA [18]. Noted in section 1.3.6, the ICMS 3rd Edition now expands the ICMS framework for Carbon Emissions.

LCC can be used to assess the increased value of energy conservation on projects, hence adding to the sustainability of the asset [4]. This is evaluated by payback analysis carried out through LCC calculations (outlined in Section 1.9) and allows for different energy solutions to be selected based on their LCC [1].

The application of LCC in sustainable construction is evident in green building rating methodologies, such as, Building Research Establishment Environmental Assessment Methodology (BREEAM) and Leadership Energy Efficient Design (LEED). These systems provide a scaled rating based on a building's sustainability in the UK and US respectively. Both LEED and BREEAM provide rating points for the application of LCC [11]. Section 1.5.1 outlines how sustainable considerations can be engrained in public procurement to promote the procurement of environmentally friendly goods, services and works.

1.4.3 LCC and Facilities Management

LCC can also be used to determine the maintenance and replacement cost of a component or system over a study period. This information can inform design decisions on Facilities Management (FM) issues such as cleaning, maintenance, energy efficiency, durability and disposal [6]. Cost consultants can build sophisticated maintenance plans and profiles, ideally consulting with facilities managers, to devise a life cycle strategy and carry out maintenance and replacement works in accordance with the expenditure set out in the strategy [6, 9]. This essentially provides a budget and template for cost control during the life of the building [13, 9]. In addition, the framework can be used to collate actual operational data during the operational phase, providing a mechanism of recording LCC [15]. Information obtained from the building 'in use' should be utilised for future operational decision making [15]. With early stakeholder involvement, a building which is 'end use orientated' can be achieved [19].

1.4.4 Procurement & Tendering

Traditional

The majority of construction work in Ireland is procured through the traditional procurement and tender process. The traditional tender process does not lend itself to a meaningful evaluation of LCC, as the design is already completed prior to the tenderer receiving the tender documents [9]. Thus, once the contractor builds to the standards set out in the design documents, they have no real input in how the building performs in use. There are ways the contractor's expertise and experience could be harnessed to improve quality in design and construction, which would enable them to have a meaningful contribution on the sustainability and the whole life of the project. These mostly incorporate earlier contractor involvement in the design/construction process, so that their construction expertise can be harnessed in the design, where specification proposals can be investigated that have a bearing on the costs in use. These practices and processes include, employing a contractor as a consultant for a fee; parallel tendering; constructability/sustainability reviews; value engineering workshops; risk (and reward) sharing agreement; two stage tendering (where LCC is in selection criteria of the 1st Stage). The utilisation of alternative procurement processes is also another way to facilitate meaningful LCC in design.

Design and Build

In Design and Build (D & B) procurement the contractor has an input into the design process and thus has a significant influence on how the building will perform during the occupancy stage [20, 21]. In D & B procurement and tendering the contractor should be asked to prepare a detailed WLCC evaluation of their design and construction cost estimate, so that their proposal can be considered based on Most Economically Advantageous Tender (MEAT) criteria.

Management Contracting and Construction Management

Management Contracting and Construction Management, where works are constructed by a number of different contractors, are other procurement strategies which could be utilised for more effective operational expenditure. These strategies give the contractor an opportunity to be involved earlier in the design process, which brings construction expertise into early decision making.

Private Finance Initiatives (PFIs).

Private Finance Initiatives (PFIs) and Public Private Partnerships (PPPs) are based on a long term contract, where the company employed provides public services after construction of a project has been completed [18]. The long term nature of these investments, means that there is increased client interest in operational and maintenance costs, as they have to pay the contractor staged payments over an agreed period, typically twenty-five to thirty years [22]. The contractor bidding on a PFI or PPP project should submit a tender that includes both construction costs and LCC. If LCC is not considered as part of the award criteria in a PFI or PPP, due consideration is not given to the buildings cost in use. One tenderer may propose a design/construction which is more expensive than some of his competitors, but costs significantly less to run and maintain. Thus, the conveyance fee (the monthly/yearly payment to the contractor) may be less throughout the conveyance period than that of the tenderer with a lower CAPex bid. LCC is viewed as the most effective method of analysing long-term costs on PFI and PPP projects and without careful LCC analysis, tenders could be exposed to significant risk [2, 8, 22].

1.5 Green Procurement

Irelands's public authorities such as the Office of Public Works (OPW), the Department of Education (DoE) and County Councils, are major consumers of goods and materials. By using their purchasing power to choose environmentally friendly goods, services and works, they can make an important contribution to sustainable consumption and production. Green Public Procurement (GPP) is defined by the European Commission (EC) as 'a process whereby public authorities should seek to procure goods, services and works with a reduced environmental impact throughout their life-cycle when compared to goods, services and works with the same primary function that would otherwise be procured' [23]. As a result, member states that pursue GPP can significantly contribute to the adoption of sustainable consumption and production patterns, and the promotion of regional green growth through their contracting authorities [24]. The main techniques availabe to contracting authorities, for GPP in construction, are;

- The specification of sustainable production processes and materials in the design;

- Evaluation of tendering companies for their green track record and proposed sustainability practices;
- **LCC and LCA** evaulation in design cost planning
- Project tender evaulation utilisng sustainability metrics such as **LCA and LCC** to select the most sustainable option.
- Discounting abnormally low tenders on the grounds of compliance of environmental law.

Every European country has to incorporate into its national law, the EU directives 2014/24/EU and 2014/25/EU, which promote GPP. In Ireland this is outlined in the EPA's **'Green Public Procurement Guidance for the Public Sector'** [(23)]. This document very clearly outlines that the selection of tenders and bids must move beyond lowest cost, taking into account whole life and sustainability of the building. As can be seen from the bullet points above, LCC is a large compenent of GPP. Green Public Procurement Guidance for the Public Sector [(23)] is a must read for contracting authorities setting out their evaulation criteria on tenders.

1.5.1 LCC in Green Public Procurement

Through the GPP directives, the EU has decided to strongly promote LCC in practice. In Ireland this has been promoted throught the GPP guidance notes [(23)], where LCC is explicitly outlined as an approach to evaualte competing bids. As outlined in section 1.3.1, MEAT is currently been utilised in Ireland to assess bids in construction [(7)]. MEAT is a tender arrangement which meets the current economic needs of the Government and also their economic needs of the future, by evaluating a tender that considers more than just the lowest price [(7)]. However, rarely is MEAT used as it was intended, and the lowest cost tender in many cases is still selected. This is due to the fact that contracting authorities envisage that the MEAT may be found only on the basis of the purchase price of the good. The EU (2014/24/EU) [(25)] sets out that MEAT should be expanded to take account of LCC and sustainability, to encourage GPP. This is now evident in Ireland's GPP guidance and MEAT criteria, which the EPA [(23)] note should be used to evauate tenders taking into account the life cost of the building and even its sustainability [(23)]. The GPP [(23)] has set out that Ireland will commit to implementing green public procurement in all tenders using public funds by 2023. The CWMF will need to be updated to take account of this particularly in the context of Guidance Notes 2.2.

1.5.2 MEAT and LCC

LCC is a criterion which can be included in the MEAT award, thus it encourages contractors to develop, and clients to evaluate, a tender which will reduce the future maintenance and operational costs of an asset. However, if a traditional procurement process is used, an LCC evaluation by the tenderer provides no real value, as the design and specification is fixed based on full design and specifications. Other issues, are outlined in **Figure 4**, where LCC calculations take a significant amount of time for the tenderer and is open to variation due to different interpretations which makes evaluation difficult [(26)].

Figure 4: LCC in BId Award [(26)]

"There are two possible ways of assessing lifecycle costs in building planning services:

1. Calculation of the life cycle costs of the submitted architectural contests by independent experts appointed by the client. [...].

2. Calculation of the life-cycle costs of the building design by the bidders themselves. For this purpose, the client must provide normative specifications for the calculation methodology as well as provide the predefined normatively determined data for the calculation to all bidders.

The second approach is found to be unsuitable in practice for the following reasons:

- *The additional expenditure per participant for the calculation is disproportionate, apart from the often lacking know-how.*
- *The scope for interpretation when applying predefined data pools is too great for participants.*

Consequently, results can easily be falsified and the meaningfulness for the client is diminishing."

Source: Lebenszykluskostenrechnung in der Vergabe. Leitfaden r die ake er abe on Planungsleistungen (IG Lebenszyklus Bau, 2016).

The most beneficial use of LCC is throughout the design process, in terms of evaluating cost/benefits to sustainable materials and processes, versus more traditional approaches [26]. Thus, logically, sustainability is already ingrained in the design prior to selection of a tender. If LCC is to be included in traditional procurement tender evaluation, a mechanism should be utilised where contractors can make proposals to the design and specification, which can be considered in their tender evaluation.

However, GPP and MEAT can be used effectively on 'alternative procurement strategies', such as those outlined in section 1.4.4. Award criteria on these projects could consider the following;

1. Contractors must comply with applicable environmental obligations set out in Irish law and EU law; abnormally low tenders must be rejected where this is due to breach of any of the above laws;
2. Evidence of the environmental management measures which a supplier will be able to apply in the execution of any contract may be requested at selection stage;
3. An LCC evaluation of the operational cost throughout the conveyance period, with a proposal of an annual payment (bid) to contractor;
4. Third-party ecolabels or certifications can be requested to demonstrate compliance with technical specifications;
5. Award criteria could be expanded to include social or environmental characteristics of the goods, services or works being purchased evaluated through LCC and LCA.

Item 3 and 5 outlines the use of LCC as a means of tender evaluation and award, for both whole life cost and externalities (i.e. social and sustainability criteria). The EPA [23] outlines that contracting authorities are allowed to award a contract in line with the optimum price-quality ratio assessed on the basis of criteria which may even include environmental considerations. The EU [25] stresses that if this stratgety is pursued, it is critically important that the award criteria is transparent to all tenderers prior to the bid. Where a national LCC methodology exists, this should be used as a common methodology to all tenders, much like the NSBE and ARM4 in CAPex evaluation (at the moment no national methodology exists in LCC).

Specific rules should also apply regarding methods for assigning costs to environmental externalities, which aim to ensure that these methods are fair and transparent [25]. Assigning an economic matrix to sustainability is difficult to achieve, as noted in section 1.4.2, because LCC is not a complete measure of sustainability and social criteria. Issues could arise in widespread variation and interpretation in practice, making it very hard to compare bids. Adding sustainability and social criteria to MEAT remains very rare across the EU within public sector procurement. However, increasingly strict environmental legislation and ambitious targets will likely change this situation and a meaningful procurement evaluation of these metrics will need to be established. [27]. Other barriers to the widespread use of LCC are addressed in the following section.

1.6 Barriers to adoption

Although the significance of LCC has been recognised on construction projects, as early as the 1980s, together with substantial amounts of research into the field, the application has not been consistently implemented on construction projects [28, 29]. Some of these issues are perceived issues and the most relevant solution to these problems is knowledge and training, which hopefully this information paper addresses. The following sections are discussed not to discourage practitioners but to make them aware of the issues and limitations with carrying out LCC.

1.6.1 Client Requirements

One of the most significant barriers, is that LCC 'is not requested by the client' [21, 30]. Clients are unwilling to pay for an additional service, especially if they are not familiar and not convinced of its value [20]. Many clients have a limited understanding of the process and are not informed about the benefits [30, 31]. This is reflected in the lack of 'contractual incentives' or 'fiscal encouragement' for QSs carrying out LCC, as there is usually no additional fee for doing so [20, 21, 5].

There is also a separation between capital and running budgets on most construction projects [30]. This is particularly an issue with public authorities who may be restricted in their ability to transfer funds between capital and revenue budgets [20]. One authority will often accept the lowest cost on a project and hand the project off to another department to maintain. Due to the limited life of public agencies and legislative programmes there is a short-term emphasis on costs associated with the term of the public administration. Thus, they are less likely to accept longer term benefits at the expense of increased CAPex. However, it is clear this issue is changing with a focus on sustainability and a whole building attitude.

1.6.2 Obtaining Relevant LCC Data (Using Historical Data)

Obtaining reliable, appropriate and relevant cost information to use in LCC studies is often ranked by respondents as a primary barrier to LCC [20, 28 21]. Historical LCC data may be inaccurate when used in the context of a new project [14, 28]. The reason historical data is inaccurate is that it is often incomplete, outdated and misunderstood, making it unreliable for third parties to analyse and apply to a new situation [10, 14].

There are many dimensions and aspects in LCC data which often make it unreliable and not applicable to another asset [14]. Some of these issues are; different maintenance policies; unplanned maintenance or failures; the use of alternative replacements; hidden costs; timing distortions and the effects of delayed work. In this context, how long a building component lasts and when it becomes obsolete is based on how the component is used or what type of traffic/wear and tear it is subjected too. For example, a linoleum floor finish in the corridor of a school will need to be replaced earlier than that in a domestic kitchen, due to the extent of traffic on it. Thus, using 'expected life expectancies', without interrogation with respect to its use, would be misleading.

Historical databases are not essential to the implementation of LCC because as technology advances, new technologies will render the material obsolete and associated costs redundant when applied to a future cost [14]. There is difficulty in applying theoretical life expectancies to a material that may be more durable as technology advances in the future [14]. In fact, an entirely different material or technology may be used when the material is replaced.

A particular difficulty with access to LCC data is that there is a lack of any framework or mechanism for collecting LCC information in use [15]. Efforts have been made to address this issue, but the extent of data collection, inconsistencies across data, and the various levels of detail required, make collating historical data a problem [21]. Given these difficulties, there is merit to question the application of LCC as a mechanism for evaluating future expenditure, however, LCC should not be utilised as an absolute reflection of future expenditure but rather a means to make informed decisions. Due to these issues it is preferable to estimate the cost from first principles and to use historical cost information as a check [10, 14].

1.6.3 Lack of a Standard Method of LCC

One of the main reasons that LCC has not gained more widespread acceptance is a lack of standardisation in carrying out and presenting LCC [20, 28, 31, 21]. However, over the last ten years there have been a number of publications addressing various barriers to adoption and presenting a standard method of measurement for LCC. These standards were discussed in section 1.3. However, no single standard has been accepted internationally or even at a European level [32].

Although significant efforts have been made to remove this barrier, 'lack of a common methodology' is still mentioned by QSs as one of the most significant barriers to greater implementation of LCC [20, 31]. The ICMS 3, discussed in section 1.3.6, may tackle this perceived barrier. As noted previously the ICMS 3 outlines an international standard for LCC which aligns to the BS-ISO 15685-5 [6].

1.6.4 LCC and the QS (The calculations – Time Consuming and Longwinded)

Another reported barrier is that QSs 'do not have sufficient time to carry out LCC', 'the calculations are complex and time consuming', and 'there is a perceived lack of confidence in the results' [29, 31, 5]. These issues accentuate a time-consuming process which is compounded by the barrier outlined in section 1.6.1, where 'QSs are not reimbursed by the client' for the additional time to carry it out. LCC calculations such as net present value, nominal costs, and internal rate of return are not traditional computations in cost management [9]. The following sections outline in detail the calculations and how to apply them.

1.7 Representing Life Cycle Costs

When expenditure is analysed over a period of time, cost items give rise to cost/time profiles that consist of a single occurrence or costs that are repeated at regular or irregular intervals [6]. LCC calculations take account of these cost/time profiles and therefore depend on numerous assumptions, all subject to a degree of uncertainty [14].

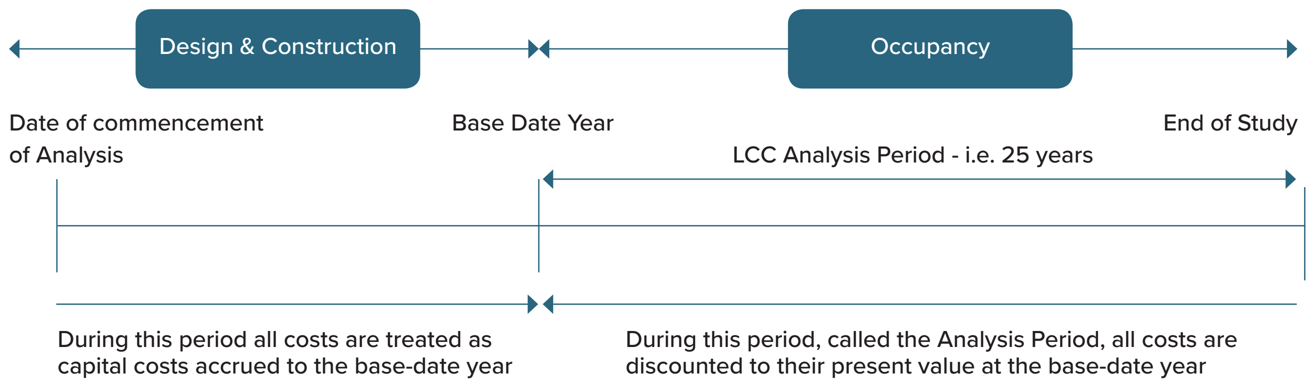
There are a number of methods of life cycle economic evaluation defined in the publications discussed above. These are Real Cash-Flow, Net Present Value (NPV), Annual Equivalent Cost (AEC), Payback Period (PB), Net Savings (NS), Savings to Investment Ratio (SIR) and Internal Rate of Return (IRR). The Real Cash-Flow forecast establishes future expenditure based on todays (Real) costs (not including inflation or discounting), AEC converts all future expenditure to an equivalent annual cost, so that LCC can be evaluated based on a single figure that represents an average yearly cost over a given study period. The PB represents the time required for the expected annual savings to pay back the initial investment. The NS is a simple technique that represents the difference between the income generated from the investment and the initial CAPex of that investment. The IRR and SIR are traditional financial appraisal techniques, which provide a calculation in a percentage and ratio respectively, on how the initial investment performs over a certain period based on income to investment [18, 2]. The plethora of calculations and the context in which they should be applied can lead to confusion on which one should be utilised. It also gives rise to inconsistency in applying a standard approach.

NPV is the most powerful method and the most obvious choice because it focuses on cash flow analysis, which is beneficial in the evaluation of design decisions, rather than a single percentage or ratio that oversimplifies the cash flow [2].

The NRM 3 [10] and the BSI/BCIS [3] and the ICMS 3 use the NPV method as the main method for presenting costs in their recommended template/summary pages and annexes at the back of their documentation. However, the calculation utilised should be applicable to the circumstance of what is required [4]. For example, NPV cash flow analysis may be suitable for WLCC, but if you require a simple calculation to evaluate the benefit of investing in a renewable technology, a PB or IRR may be more applicable.

Calculating the NPV starts with the representation of the life cycle costs as a Real Cash-Flow over a study period [3]. However, comparing different buildings or component options through cash-flow forecasting is difficult, as particular costs occur at different time frames [3, 14]. Thus, these costs need to be evaluated at a common time base, so that options may be evaluated in equivalent terms. The comparable time base is usually present day, noted as 'year zero (0)' (base date) on the LCC estimate [3]. 'Base date' can be set at the point where services or operations are commenced [11]. Therefore, as illustrated in **Figure 5**, all expenditure on fees, construction and financing and all overhead charges from the 'Date of Commencement of Analysis' until the 'Base Date Year', are added together and treated as CAPex. OPex commences when the service is provided, starting at the 'Base Date Year' up to the 'End of Study' period. This encompasses an 'LCC Analysis Period' (i.e. 25 years) which includes operations, occupancy, renewal, maintenance and end of life costs associated with BS-ISO 15686-5 [6] and ICMS 3[12] LCC categories, illustrated in **Figure 1**. These costs are discounted back with NPV calculations to the base date to add to the CAPex [3, 11].

Figure 5: Representation of key dates in LCC [11]



'Discounting' is the process of converting 'future money' to 'present money' [11]. A stream of discounted future costs can be converted to a single sum Net Present Value (NPV) by adding together the discounted costs at the equivalent time base [3]. The NPV of different buildings or components within buildings over a certain study period can be compared to assess the most economic effective alternative [11]. To calculate NPV certain additional data requirements are necessary, such as interest rates and study periods.

1.8 Data Requirements for LCC

Certain data requirements (factors) need to be applied to carry out the NPV calculations in LCC. These factors enable the cost consultant to evaluate different systems and building options over a selected study period, even though their replacement and maintenance profiles may be significantly different [15].

1.8.1 Escalation/Inflation Rates

When LCCs are expressed in 'nominal' costs, the costs are adjusted for inflation, representing the 'current costs' at the time the cost is incurred [3, 33, 13]. To do this, LCC calculations incorporate an escalation rate to take account of the rise in the general price level of the item that is being analysed, to the future date the cost will be incurred. Assessing inflation becomes harder when the rise differs across products. Different products and services escalate at different levels, even though a general inflation rate in the construction sector may be reported and applied. Taking account of different escalation rates adds complexity to the calculations as a single rate cannot be applied to the entire LCC assessment [18]. Nominal (escalated) costs can be presented in an LCC estimate and represent the future costs prior to them being discounted for NPV [6, 9].

1.8.2 Discount Rates

The discount rate, on the other hand, is usually a universal rate applied to the LCC analysis. A discount rate takes account of the time value of money [4, 13]. The principle of time value, means that cash available now has a greater value than the same quantity of cash in the future [13]. For example, the spending power of a quantity of cash will be less in ten years' time. LCC discounts future sums with a discount rate into present day (base date/year0) money for evaluation purposes.

Discount rates can be expressed as 'real' and 'nominal' depending on whether escalation is included in the rate [3]. Real discount rates are already adjusted for inflation and assume that a standard rate of inflation applies equally to all items in the estimate [6, 3]. Nominal discount rates do not include the escalation rate in the discount rate, thus escalation rates are applied as a separate rate in calculations that include nominal discount rates [33] .

In Ireland discount rates and inflation rates are listed on the Department of Public Expenditure and Reform's website (DPER) [9]. The rates are listed as nominal discount rates, which indicate a separate treatment of inflation. The website advises that on public construction projects a government technical adviser will quote a prescribed inflation rate based on the context of a particular project.

1.8.3 Study Period (Period of Analysis)

The 'study period' is that period of time for which the investor has an interest in the building's life [4]. The ISO define this as the 'period of analysis', which they state is the length of time over which the LCC is calculated [6]. These time periods can vary. The study period on a WLCC analysis could be the estimated physical life of the building or alternatively the estimated period of use [6]. In PFIs, the study period is determined by the hand over date which is usually twenty to thirty years. The study period may also be determined by the investor's expected payback period on their initial investment [4].

Various definitions exist to define the length of time during which the building satisfies specific requirements. These can be described as:

- economic life – a period of occupation which is considered to be the least cost option to satisfy a required functional objective
- functional life – the period until a building ceases to function for the same purpose as that for which it was built
- legal life – the life of a building, or an element of a building until the time when it no longer satisfies legal or statutory requirements

- physical life – life of a building or an element of a building to the time when physical collapse is possible
- social life – life of a building until the time when human desire dictates replacement for reasons other than economic consideration
- technological life – life of a building or an element until it is no longer technically superior to alternatives. (14, 3)

1.9 Basis of the Calculations

1.9.1 Calculating Factors.

To calculate the NPV, financial PV factors must be calculated with the data requirements outlined previously, were 'r' represents the discount rate and 'n' the study period. The standard PV factor in **Equation 1** is expressed as:

$$\frac{1}{(1+r)^n} \qquad r = \text{discount rate},\ n = \text{study period (usually years)}$$

Equation 1: PV Factor (6)

This formula gives rise to a factor which can be multiplied by the relevant cost to calculate it's PV. There is no separate treatment of inflation in this formula, thus if escalation is to be factored into this equation, a real discount factor must be used.

If inflation is to be taken into account there must be a two-stage process, firstly calculating the real discount rate and then secondly to use it in the PV calculation outlined in Equation 1. The stages are outlined in **Equation 2** and **Equation 3** where 'i' represents the nominal discount rate and 'e' is the escalation rate:

1st Stage

$$\text{Real Discounted Rate (r)} = \left[\frac{(1+i)}{(1+e)}\right] - 1$$

Equation 2: Real Discount Rate (13)

The calculated real discount rate (r) is then incorporated into the PV calculation in **Equation 3** to calculate the relevant factor based on the year (n) the cost is incurred.

2nd Stage

$$\text{PV Factor} = \frac{1}{(1+r)^n} \qquad r = \text{real discount rate}$$

Equation 3: PV Factor 2 (6)

The factor calculated in stage two, is then multiplied by the current (known) cost to calculate the PV. Ultimately, the two stage PV process outlined here represents the current cost of the item today escalated to a future date and then discounted back to present day. This calculation would be used for a one-off replacement item such as replacing a door or repainting skirting.

1.9.2 Recurring Costs

If the same cost is incurred in another year, such as annual electricity costs, then the calculation must be performed again and added to the previous PV cost. **Equation 4** (13) outlines this calculation for a recurrent cost every year, over a study period, whereby the factors are calculated every year and the results are added together to calculate an accumulated factor. The accumulated factor is then multiplied by the recurring cost to calculate the NPV.

$$\text{PVFactor} = \frac{1}{(1+r)^1} + \frac{1}{(1+r)^2} + \frac{1}{(1+r)^3} + \frac{1}{(1+r)^4} + \frac{1}{(1+r)^5} + \cdots$$

Equation 4: Accumulated PV Factor (13)

Instead of calculating the factors every year for those costs that accrue on an annual basis, **Equation 5** (4) provides a Uniform PV (UPV) calculation, which incorporates a cumulative calculation.

$$\text{UPV Factor} = \frac{(1+r)^n - 1}{r(1+r)^n}$$

Equation 5: UPV Factor (4)

An issue with the UPV calculation, is it assumes that the payments are made at the beginning of each period, while SPV calculates its factors at the end of the year. Thus, if you were to check the factor against performing it by adding the single factors together you would get a different result. To correct the effects of this anomaly you must add one (+1) to the number of years and deduct the first payment in the UPV calculation. It is recommended, for this reason, that you use **Equation 4** above.

1.9.3 Incorporating Escalation Separately

Equation 6 (4) outlines 'modified*' PV calculations that take account of the escalation rate in the formulae, incorporating the two-stage process outlined above in a single calculation. These calculations are identified by an 'astrix', ie SPV* and UPV* to account for the inclusion of an escalation rate in the calculation. In this case, there would be no need to carry out a pre-calculation for a real discount rate, as it is considered in the formulae.

$$\text{UPV Factor} = \frac{(1+r)^n - 1}{r(1+r)^n} \qquad \text{SPV* Factor} = \left[\frac{[1+e]}{[1+i]}\right]^n$$

Equation 6: SPV*/UPV* Factor [4]

However, although these calculations greatly simplify the LCC PV factors, by utilising the escalation rate and discount rate in the same formulae, and in the case of the UPV* Factor, embedding the recurrent cost calculation each year in one formulae, they are not recommended in this information paper. The formulae doesn't always equate to the equivalent calculation in the long version (which calculates them individually). This is because of the assumption of where these factors are applied, at start or end of the year. Again the simple PV factors outlined in the calculations in **Equation 1** and **Equation 4** are recommended. However, this makes the calculation of LCC factors very time consuming and longwinded, and thus utilisation of automation is necessary.

1.10 Using the formulae

1.10.1 Scientific Calculator

A scientific calculator can be used to carry out the PV calculations, but this method is quite time consuming, as each variable must be inputted to determine the relevant factor. This calculation must be repeated for each LCC calculation to determine the cumulative present value LCC [9, 29].

1.10.2 Calculating PV factors with financial tables

Financial tables allow for PV calculations to be performed without the use of calculators. Financial tables contain pre-calculated PV factors covering a wide range of discount rates, escalation rates and time periods. Financial tables are available for UPV and SPV calculations [13, 4, 9]. Even though this takes the number crunching out of the process, it still remains quiet time consuming, as a factor has to be looked up and applied for each item in the estimate.

Table 1 presents an extract from financial tables [34]. The financial tables, although significantly quicker than by scientific calculator, have some limitations. For example, calculating PV factors becomes problematic if the study period (in years) is not an integer of 5, between 30 and 50 years. The tables in this example do not provide factors for those study periods.

Table 1: 8% Table [34]

d= 8% **d= 8%**

DISCOUNT FACTORS

Discount Rate d = 8%

Year	Single Compound Amount SCA	Single Present Value SPV	Uniform Capital Recovery UCR	Uniform Present Value UPV	Uniform Sinking Fund USF	Uniform Compound Amount UCA
1	1.0800	0.9259	1.0800	0.9259	1.0000	1.0000
2	1.1664	0.8573	0.5608	1.7833	0.4808	2.0800
3	1.2597	0.7938	0.3880	2.5771	0.3080	3.2464
4	1.3605	0.7350	0.3019	3.3121	0.2219	4.5061
5	1.4693	0.6806	0.2505	3.9927	0.1705	5.8666
6	1.5869	0.6302	0.2163	4.6229	0.1363	7.3359
7	1.7138	0.5835	0.1921	5.2064	0.1121	8.9228
8	1.8509	0.5403	0.1740	5.7466	0.0940	10.637
9	1.9990	0.5002	0.1601	6.2469	0.0801	12.488
10	2.1589	0.4632	0.1490	6.7101	0.0690	14.487
11	2.3316	0.4289	0.1401	7.1390	0.0601	16.645
12	2.5182	0.3971	0.1327	7.5361	0.0527	18.977
13	2.7196	0.3677	0.1265	7.9038	0.0465	21.495
14	2.9372	0.3405	0.1213	8.2442	0.0413	24.215
15	3.1722	0.3152	0.1168	8.5595	0.0368	27.152
16	3.4259	0.2919	0.1130	8.8514	0.0330	30.324
17	3.7000	0.2703	0.1096	9.1216	0.0296	33.750
18	3.9960	0.2502	0.1067	9.3719	0.0267	37.450
19	4.3157	0.2317	0.1041	9.6036	0.0241	41.446
20	4.6610	0.2145	0.1019	9.8181	0.0219	45.762
21	5.0338	0.1987	0.0998	10.017	0.0198	50.423
22	5.4365	0.1839	0.0980	10.201	0.0180	55.457
23	5.8715	0.1703	0.0964	10.371	0.0164	60.893
24	6.3412	0.1577	0.0950	10.529	0.0150	66.765
25	6.8485	0.1460	0.0937	10.675	0.0137	73.106
26	7.3964	0.1352	0.0925	10.810	0.0125	79.954
27	7.9881	0.1252	0.0914	10.935	0.0114	87.351
28	8.6271	0.1159	0.0905	11.051	0.0105	95.339
29	9.3173	0.1073	0.0896	11.158	0.0096	103.97
30	10.063	0.0994	0.0888	11.258	0.0088	113.28
35	14.785	0.0676	0.0858	11.655	0.0058	172.32
40	21.725	0.0460	0.0839	11.925	0.0039	259.06
45	31.920	0.0313	0.0826	12.108	0.0026	386.51
50	46.902	0.0213	0.0817	12.233	0.0017	573.77

Note : All amounts end-of-year

When utilising financial tables, the user must firstly select the appropriate discount rate (i.e. 8%) in **Table 1** [34]. The correct SPV factor is located at the intersection between the SPV column and the relevant year. The selected factor is then multiplied by the relevant cost to establish the discounted PV. A similar process is carried out for UPV, SPV* and UPV* calculations. There are numerous publications of financial tables, albeit they work slightly different with different emphasis on calculations and study periods [13].

In **Table 1** the years stop at year 50, certain LCC exercises require study periods in excess of 50 years. Another issue is that the rates are only expressed as a whole numbers. Calculating a factor based on a fraction of a percentage is not possible, which is how they are represented in most cases.

1.10.3 Spreadsheet Application of Factors

A recommended approach by the OGC [8] is to use standard software such as MS 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. MS Excel has a number of PV functions that could be utilised to calculate LCC calculations without having to construct them from scratch. These are discussed in the following section.

The advantage of using the PV functions is that the same formulae can be used to calculate a discounted lump sum or the PV for a recurring cost, i.e., it can calculate both the SPV and the UPV cost depending on which is applicable. Whether the factor is to be calculated at the start or end of the end of year can be established in the function. The syntax for the PV function is outlined in **Equation 7** as;

=PV (interest_rate, number_payments, payment, [FV], [Type])

Equation 7: PV Function MS Excel

Inputting the relevant data allows the user to apply it to a single or recurring sum.

> If an item in the formulae is not applicable to either SPV or the UPV it should be left as 0. The 'interest_rate' is the interest rate or discount rate for the investment. The 'number_payments' is the number of payments for the annuity or the year the payment needs to be made. 'Payment' is the amount of the payment made each period. If this parameter is omitted it assumes the calculation is based on a single payment. If the calculation is based on a single payment the user must enter that sum in 'FV'. FV is the 'Future Value' of the payment or cost to which the discount factor is applied. If this parameter is omitted, the PV function assumes FV to be 0 and the calculation is based on the recurring cost. 'Type' is optional; it indicates when the payments are due, '0' for the end of the period or '1' for the beginning of the period. If the 'type' parameter is omitted, the function assumes a type value of 0 [13].

Equation 8 demonstrates an example of an SPV calculation of €325, in 8 years, at a discount rate of 3%; in which the data would be inputted into the formulae as follows [13, p. 22];

=PV(0.03,8,0,325,0) = 256.56

Equation 8: PV Function Example (1)

In this case, the third number in the calculation is 0, as only one payment applies. Alternatively, **(Equation 9)** if the formula was used to calculate the PV of a recurring cost of €325, every year for 8 years, at a 3% discount rate; the following would be inputted into the function bar in MS Excel (f_x);

=PV(0.03,8,325,0,0) = 2281.40

Equation 9: PV Function Example (2)

These MS Excel functions are advantageous when calculating SPV and UPV discussed above, but they are not applicable in every instance of LCC calculations. They do not account for a separate treatment of escalation and thus an additional calculation would have to be utilised. When producing LCC estimates many calculations are utilised which could require a combination of the calculations discussed above. The QS must use their judgment and experience to apply the right calculation to the right scenario.

1.11 Risk Analysis

Computing LCC calculations based on formulae, outlined above, gives an indication that the resultant values are absolute. This is not the case, there are so many variables and factors in LCC calculations that the product of the calculation can only give an indication of LCC based on a number of assumptions [3, 11]. LCC modelling must incorporate a facility whereby a change in any of the variables can be easily accommodated [11]. This is referred to in the majority of LCC standards as 'Risk Analysis' [6, 3, 10]. Risk analysis is utilised in LCC in two ways, through 'sensitivity analysis' or 'monte-carlo' simulation [6, 3].

In sensitivity analysis a calculation structure must be developed that can accommodate 'what if' questioning of the results by changing variables such as the unit rates, discount rate, escalation rate, life expectancy or study period. Spreadsheet software is used to carry out sensitivity analysis because it offers a medium to set up LCC variables (data requirements) and link them through formulae. Ideally models should be set up so that a change to a single-entry acts across all affected calculations, providing a framework where presenting different scenarios can be easily carried out [9, 11].

Monte Carlo simulation is a statistical technique which can be used in LCC to model a range of possible costs based on probability distributions. Rather than a finite whole number for LCC, this would allow the identification of a distribution of possible costs based on a range of confidence levels [6].

The utilisation of spreadsheet software can provide a structure for either sensitivity analysis or monte carlo, with simulation software [3, 8]. Basic use of spreadsheets to calculate and present LCC is outlined in section 1.13.1. The other main ingredient in LCC is the Data. QSs are proficient in quantity take off and construction costs but LCC cost data such as product life cycle data and maintenance and operations costs are less readily available. However, there are a number of different ways to access LCC time and cost data.

1.12 Sources of LCC Data*

extract from RICS Life Cycle Costing Guidance Note[11]

Sourcing reliable data in a readily usable form relevant to LCC studies for a variety of purposes and at different levels of detail is commonly regarded as an area of weakness in supporting life cycle costing calculations. This weakness, once recognised, can be addressed by understanding data type and variability characteristics in the data set. There are four categories of LCC data.

1.12.1 Unstructured historical data

Estate managers, office managers, facilities managers and others whose job concerns the running and managing buildings are in the best position to record historic data. If recorded properly, this is a good source of LCC data. Similarly, account departments and energy managers also have all the necessary cost and consumption data, although it is rarely in a form that is readily usable for LCC calculations. Early involvement of key stakeholders in the design process is key in this regard. If personnel which will be using and managing the building are involved in the design process their knowledge and data can be communicated to the design team and specifically utilised by the quantity surveyor in the LCC.

1.12.2 Structured historical data

The Building Cost Information Service (BCIS) is best known for its database of elemental building costs. The BCIS's Building Running Costs Online service is the UK's largest and oldest database of running cost analyses (see www.bcis.co.uk) and provides. The database is an online service which provides cost data on building maintenance, decorations, fabric and operations, cleaning, utilities and administration costs for a wide range of building functions. It also outlines Figures for the life expectancy of over 300 common building components. The BCIS also creates a framework in which the property manager or surveyor may systematically collect data year by year.

Other examples of structured data are:

- HAPM Component Life Manuals published by Spons: list the typical operational life of components commonly used in housing.
- RS Means Facilities Construction Cost Data (published annually) by RS Means in USA. While priced in US dollars and based on data from US facilities managers, it does contain a wealth of labour constants that may be relevant to maintenance and cleaning operations internationally. Data, in the form of constants, are invaluable in building up rates from first principles.
- The Society of Construction and Quantity Surveying in the Public Sector (SCQS) Whole Life Cost Service has a database that is populated by subscribers. The assumptions made and the source of the data used are described by the contributors and appended to database items.

1.12.3 Data from modelling

Modelling techniques yield predictive calculations. The technique requires an approach for variable analysis and are best used with software such as spreadsheets, which provide fluidly to appease the unique considerations of the project and the data being utilised. The following stages outlines the incremental steps in model calculations.

- Define precisely the activity to be modelled. This could be cleaning curtain walling; modelling of energy consumption; or calculating the LCC for two building components for comparative analysis (i.e. Timber windows vs PVC). It could extend to a whole life cycle analysis across a 60 year period.
- Build your model including any necessary formulae – automate the calculations across the model, where changing any of the variables changes the overall costs. This may require the use of 'logical' and 'lookup' functions which requires a more advanced proficiency in spreadsheets.
- Run the programme, inputting values for the variables.
- Observe the outcome and, if required, run the programme again with different values for the variables to test for sensitivity.
- Extract graphs for visual aid.

1.12.4 Data from manufacturers, suppliers and specialist contractors

Although logically the best source of data for systems and components, the quality of data from manufacturers, suppliers and specialist contractors tends to be compromised by caveats aimed at restricting liability. Technical sales staff are the best people to approach, although a general statement along the following lines can be expected: 'these fans work for years; they come with a 2-year guarantee but providing they are well maintained should run for 8 to 12 years. Some fans are still going after 16 years.' From this comment you could assume that the fan is unlikely to fail in the first 2 years, is unlikely to last 16 years, and probably has an average life of about 10 years.

1.13 Utilising Technology

While manual methods of calculations are still defined in relevant standards they are no longer being used in the production of LCC estimates. These methods are generally included to provide the methodology underpinning the calculations, but most examples of LCC are now calculated and presented in computer software [32].

There are two categories of computer-based LCC programs, which can be described as glass box or black box systems [11]. A glass box computer-based LCC program is characterised by the visibility of the process, such that each step in the LCC process can be seen by the operator. Conversely, a black box computer-based LCC program is characterised by the input of data and the output of results with each step in the process being invisible to the operator. The most common glass box systems are based on spreadsheets and are developed within an organisation for their specific needs and on specific projects. Black box systems are usually propriety software bought from a software company.

The primary advantage of developing in-house LCC models is that the build-up and calculation steps are visible and tailored to your organisation and project characteristics. As outlined in section 1.11, considering the variable nature of LCC calculations, a spreadsheet approach to sensitivity and risk analysis is recommended in this information paper. The primary disadvantage is the time it takes to build in your calculations and construct the LCC spreadsheet template [11].

1.13.1 LCC in Spreadsheets

Spreadsheet software such as MS Excel can be effectively used in LCC as a basis for calculating and presenting costs by building a facility for key variables [8]. Specialist software is not adaptable and cannot process variable data as efficiently as generic spreadsheets [8]. The BSI/BCIS [3] and NRM 3 [10] seem to support this assertion, as they attach annex spreadsheets for presenting LCC based on NPV calculations. While standards and methodologies in LCC provide the tabulated framework to present an LCC estimate they do not explicitly outline the calculations in the model [5].

There are a number of spreadsheet-based LCC applications that support LCC within the jusistictions they encompass and embed LCC calculations within their cells [2, 5]. The fact that these jursidictions use MS Excel rather than black-box LCC applications adds credence to the claim that spreadsheet software is the most suitable software for LCC calulations. Examples include, Norway, Sweden and the United States (NIST) whom use customised LCC spreadsheets on publically funded projects. These spreadsheet applications are advantageoues to QSs because they include the necessary formulea to carry out LCC calculations but they are not adaptable to other jursidictions and/or different methodologies [8]. Now the ICMS 3 provides a template for presenting LCC estimates, however this template does not include the calculations.

1.13.2 LCC and BIM

A Building Information Modelling (BIM) approach to construction procurement is being increasingly utilised as a collaborative set of procedures and associated technologies that assist design and construction professions in conceiving, designing, constructing and operating the built environment. Although 5D BIM (Cost Modelling) is currently being used in QS practice, BIM is not extensively used in the application of LCC and there has been limited research in this area to date. Kehily [35] demonstrates the development of a 5D BIM based LCC solution in iTWO CostX, where LCC is integrated into the 5D BIM process by embedding an LCC calculation model structure within an existing 5D BIM technology. This process represents a change to the 5D BIM workflow, adding on a facility for LCC through post-processing BIM data. The primary benefit of this proposed process/system is that it allows for a link between the QSs cost plans/BOQ's and their LCC calculations in an integrated environment. This is a novel approach, but it is not a dedicated BIM/LCC system and was not developed further after the research was carried out in 2016. The workbook in CostX has some excellent functionality but it is designed for construction cost estimating and cannot completely replicate the variability inherent in a spreadsheet. 5D automated measurement can still be utilised in the 5D application, but this paper recommends exporting these quantities to MS Excel and then carrying out the LCC estimate.

1.14 Tutorials LCC Formula

The following section provides a number of videos, workbooks and solutions for the QS to get started with carrying out LCC estimates. The intention is that the user will develop the building blocks of proficiency in LCC calculations and start applying them to an LCC estimate. The tutorial content here does not address carrying out a full LCC estimate, but once the user becomes proficient in the main calculations, for one off costs or for recurring costs, the calculations are repeditive and thus they should have the skills to add LCC calculations to an existing cost plan. This will give the user the ability to build there own template in LCC and thus they will not have to replicate these calculations again. It must however be stressed, that LCC is so variable in nature and not applied uniformly in terms of presententation, format and in line with measurement rules, such as in BOQ production. No two LCC estimates are similar.

1.14.1 LCC Formulea in Excel

Developing proficiency in using LCC functions in spreadsheets is essential when constructing an LCC model. The spreadsheet functions outlined in section 1.10.3 are the DNA of each item in an LCC analysis. Once the QS understands and is able to apply these financial calculations to each cost plan item (for replacement) and add then calculations for annual operations and occupancy management costs, they will be able to construct an LCC model. The following two training videos used in conjunction with the Excel spreadsheet provided developes the QSs profiency in using the basic formulae first. Utilising these formulea in a meaningful LCC estimate will be addressed in the following sections.

Life Cycle Costing in Excel 1 – Video
LCC Excel Template - 1
LCC Excel Solution - 1

Life Cycle Costing in Excel 2 – Video
LCC Excel Template - 2
LCC Excel Solution - 2

1.14.2 LCC Excercises

The excercises shown in the following videos, outline a number of senarios where the calculations demonstrated in the videos above are used in some simple LCC models. These videos outline the pliability of spreadsheets and how the various LCC data requirements and cost plan items can be presented in a number of different ways.

Life Cycle Costing Exercise 1 - Video
LCC Excel Template - 1
LCC Excel Solution - 1

Life Cycle Costing Exercise 2 - Video

LCC Excel Template - 2

LCC Excel Solution - 2

Life Cycle Costing Exercise 3 - Video

LCC Excel Template - 3

LCC Excel Solution - 3

Life Cycle Costing Exercise 4 - Video

LCC Excel Template - 4

LCC Excel Solution - 4

1.14.3 LCC in ICMS

The following video and associated spreadsheet template demonstrate an example of how LCC calculations can be embedded in the ICMS taxonomy, which was briefly discussed in section 1.3.6. It must be noted that this process is not absolute in terms of how to carry out LCC using the ICMS schema, but provides an example of how calculations could be embedded in a spreadsheet which accommodates the ICMS taxonomy. It does not constitute a full ICMS LCC cost report, but rather outlines an example of how one item is calculated within the ICMS schema.

This example outlines how columns are added to rows in an ICMS template to calculate LCC costs for real costs, nominal costs and present values. The example also outlines some tips in the excel functions to carry out these calculations quickly.

LCC with ICMS – Video

LCC ICMS Template

LCC ICMS Solution

1.15 Summary

LCC is used to assess the costs associated with the wider implications of operation, maintenance and disposal, in addition to, the more traditional CAPex view of the asset. This allows for a number of applications such as option appraisal; measuring sustainability; evaluation for procurement and tendering and utilsation for FM. Although these benefits are well documented, there are a number of barriers that prevent LCC being more widely practiced by QSs in the construction industry. The principle barriers reported are; lack of client demand; availability and reliability of quality data upon which to base calculations; lack of standards or guidance notes and the perception that calculations are complex and time consuming. Standard methodologies and LCC guides are over theoretical with little in the way of practical examples and lack process implementations to guide a cost professional through the procedures calculating and presenting LCC. The achievement of greater success implementing the requirements of the CWMF and now the principles set out in Ireland's GPP, depends on a process that would allow for easier calculation, preparation and analysis in a uniform method. The process must also become more adaptable to apply to different standard LCC methodologies and to apply to different projects. This guidance document outlines the calculations in both manual form and spreadsheets. In addition, a number of videos with exercises and solutions are included to help QSs gain the knowledge and proficiency carrying out LCC.

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Glossary

LCC – Life Cycle Cost
WLCC – Whole Life Cycle Cost
ISO – International Standard Organisation
LCA – Life Cycle Analysis
BSI – British Standard Institute
CWMF – Capital Works Management Framework (Ireland)
OGC – Office of Government Commerce (UK)
BS – British Standard
BCIS – British Cost Information Service
SCSI – Society of Chartered Surveyors Ireland
NRM – New Rules of Measurement (UK)
RICS – Royal Institute of Chartered Surveyors
ICMS – International Construction Management Standard
NSBE – National Standard Building Elements (Ireland)
ACROME – Acquisition Construction Renewal Operations Maintenance End of Life
LEED – Leadership in Energy Efficiency and Design
FM – Facilities Management
PFI – Public Finance Initiative
PPP – Public Private Partnership
MEAT – Most Economically Advantageous Tender
OPW – Office of Public Works (Ireland)
GPP – Green Public Procurement
NPV – Net Present Value
PV – Present Value
IRR – Internal Rate of Return
NS – Net Savings
PB – Pay Back
AEC – Annual Equivalent Cost
SIR – Savings to Investment Ratio
DOE – Department of Education
DPER – Department of Public Expenditure and Reform (Ireland)
UPV – Uniform Present Value
SPV – Single Present Value
FV – Future Value
RICS – Royal Institute of Chartered Surveyors
SCQS – Society of Construction and Quantity Surveying in the Public Sector (UK)
NIST – National Institute of Standards and Technology
BIM – Building Information Modelling
BOQ – Bill of Quantities

SCSI Chartered property, land and construction surveyors

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