LIFE CYCLE COST ANALYSIS

AIQS INFORMATION PAPER

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This Information Paper was prepared on behalf of the Australian Institute of Quantity Surveyors (AIQS) by Stephen Ballesty and as such the AIQS acknowledges that Stephen, as author, retains the moral rights for this work.

AUTHOR'S NOTE

This Information Paper has been produced in Australian English, except for quotes from and references to other publications produced in American English, such as ISO standards. Please also refer to the enclosed Glossary of Terms that sets out the terminology and definitions used within this paper.

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EXECUTIVE SUMMARY

Life Cycle Cost (LCC) analysis aims to achieve best value for money rather than lowest cost solutions for our Built Environment.

LCC analysis provides a valuable comparative and management tool that can influence the design, specification, construction, operations, and sustainability performance. In adhering to the architectural principle of "form follows function", it should be noted that appropriate LCC analysis modelling provides practical insights into the future implications of current decisions.

As an economic evaluation technique, LCC analysis provides for identifying and quantifying all costs, initial and ongoing, associated with a project or an asset over its anticipated life. Applications include as a:

- **comparative tool** to evaluate different options, design solutions, components, or materials in support of strategic planning and investment decisions typically applied during the constructed assets or facilities delivery or Design and Construction project life cycle phases
- **management tool** following project delivery, facility occupation, or asset acquisition against which actual performance can be monitored and maintained. This also provides a basis for improved budget planning and expenditure forecasts.

The LCC process requires a level of due diligence from all interested parties and stakeholders and involves assessing costs incurred and evaluating alternatives that have impacts on the total costs of the constructed asset or facility throughout its life cycle phases.

LCC analysis does have its limitations. It can be complex, time-consuming and often bespoke in addressing the number of variables involved and a large amount of data to aggregate throughout the process.

Effective LCC analysis combines the following key components:

1. Context or purpose as determined by interested parties and stakeholders' objectives.
2. Design inputs, construction deliverables, and operational variables; should be reflected progressively through the facility life cycle or project phases.
3. 'Service life' and life expectancies of the components and the whole constructed asset or facility when all the objectives, inputs, and variables are considered.
4. Costs associated with the components and period of analysis to achieve and maintain outcomes meeting the required function, specified performance, and desired quality.

Successfully applying LCC analysis requires knowledge and understanding of many key factors including; stakeholder requirements, end-user objectives, project scope, life expectancy, LCC analysis techniques, and a consistent application of standards and calculation methodology.

Whole Life Cost (WLC), and particularly LCC analysis is an area that Quantity Surveying Professionals are uniquely positioned to influence improved outcomes in contributing to a more sustainable, productive, and liveable Built Environment.

1.0 INTRODUCTION

Increasing clients seeking to apply responsible management principles and take into account ESG criteria, the acronym for Environmental, Social, and Governance (economic and corporate issues) for three (3) broad areas of interest. These are clients who consider it important to reflect their corporate values and concerns into their projects instead of merely considering the potential profitability and/or risk presented by an investment opportunity.

According to ISO 15686-5: 2017, *"Life-cycle costing is relevant at portfolio/estate management, constructed asset and facility management levels, primarily to inform decision-making and for comparing alternatives. Life-cycle costing allows consistent comparisons to be performed between alternatives with different cash flows and different time frames. The analysis takes into account relevant factors from throughout the service life, with regard to the client's specified brief and the project-specific service life performance requirements".*

LCC analysis has been long established as a valuable comparative and management tool for improved decision-making processes during the design, delivery, and operation of significant facilities and strategic asset acquisitions.

"The practice of costing a building or a piece of plant or equipment over its life is not new. …The larger and more complex an asset, the more difficult it is to consider or calculate all the possible options and trade-offs, and the cost-effectiveness of each design decision. … Life-cycle costing is concerned with the 'cost of ownership"
Management Aspect of Terotechnology, 1976

There is currently no comprehensive resource for life expectancy data due to the number and complexity of the LCC variables. The risks and assumptions involved with undertaking LCC analysis can directly contribute to unrealistic expectations and/or failure to achieve desired outcomes. While the digitisation of the delivery (design and construction) and management of the Built Environment holds great promise, the application of professional judgement does and will remain a determining factor in successful LCC analysis.

However, experience has shown life-cycle data to be notoriously scant and that the nature of LCC analysis can be more complex than appears at first glance. Hence, the application of the analytical skills of Quantity Surveying Professionals is invaluable in achieving successful outcomes.

For this Information Paper (paper), LCC analysis 'Service Life' of a constructed asset or facility has generally been considered as having the same meaning as economic, design, useful or effective life. Other terms or published definitions could be used. It is recommended that when using life expectancies that the relevant terms and conditions that are used are well defined.

Additionally, there are other standards, guides, textbooks, and reference materials that have been published before and since. This paper provides a summary of some resources and attempts to provide practical consensus on the key LCC issues. For example, a unique inclusion in the paper is Cost Management Life Cycle Table (page 14): This combines for the first time the *AIQS' Australian Cost Management Manual: Volume 1*, (4th edition, 2021) and the ICMS' CROME acronym (2nd edition, 2019) to describe concisely the required scope across ten (10) project stages of the Quantity Surveying Professionals' LCC outputs and deliverables for the life cycle phases of design, construction and asset/facilities management.

1.1 PURPOSE

The purpose of this paper is to:

1. inform members and their clients on factors impacting Life Cycle Costs
2. establish a common approach to undertaking the provision of Life Cycle Costs
3. inform members and their clients of the scope, inclusions, and exclusions relating to Life Cycle Costs
4. guide members and their clients on Life Cycle Cost analysis applications in achieving whole of life objectives.

This paper does not purport to address all issues that should be considered, nor is it a comprehensive description of the topic at law, the industry standards, or regulatory requirements. Members should obtain independent legal advice as required.

1.2 STATUS

This paper is intended to embody recognised current good practice and therefore may provide some professional support if properly applied. It should be noted that quantity surveying techniques and tools continue to evolve.

While this paper is regarded as accurate at the time of publication, readers are advised to confirm relevant legislation and client requirements before providing LCC analysis services as these may change from time to time.

1.3 APPLICATION

This paper is pertinent to members providing advice on life-cycle costing and the related whole of life advisory services. It provides guidance only which could be reasonably applicable to any organisation that wishes to establish, implement, maintain and improve its life-cycle systems and outcomes. It should be noted that there are many publications and approaches.

Members should always consider their client's brief and, where appropriate, obtain specialist technical advice in the delivery of such professional services.

Consistent with the AIQS Code of Conduct, a member must operate within the limits of their qualifications and experience and must not accept instructions in a field of practice in which they possess insufficient knowledge and skill to provide competent services to the client unless the member obtains fully informed consent from the client to undertake the services in conjunction with a person having the required competence. Members undertaking life-cycle costing services for design, construction, and asset/facilities management purposes require a broad range of professional skills and experience, including an understanding of:

- the whole life costs for the constructed assets or facilities of a similar sector, size, complexity, and utility
- demand and supply of materials, labour, and plant; professional services; and planning and building approval processes
- installation and commissioning costs and cycles for plant and machinery; and operational considerations such as maintenance and systems life expectancy
- planning scheme provisions could affect the utilisation of the constructed assets or facilities

- net present value and cost escalation allowances
- heritage, obsolescence, depreciation, utilisation, resilience, and sustainability issues
- risk assessment and sensitivity analysis.

There are limitations on LCC analysis. It can be time-consuming due to its complexity and often bespoke nature addressing the number of variables involved and a large amount of data to aggregate throughout the process. It is worth noting that, in some cases, particular cost estimate components may need to be drawn from disparate sources and differentially adjusted throughout the process. This may introduce an additional level of uncertainty into the analysis as well as complexity to reporting.

Life Cycle Cost analysis provides a valuable comparative and management tool that can influence the design, specification, construction, operations, and sustainability performance.

1.4 EXCLUSIONS

Life-cycle approach issues not covered within this paper include embodied energy and carbon emissions related to the Built Environment in terms of processing, manufacturing, transport, and project delivery.

This paper refers to the ICMS Coalition's *International Construction Management Standard: Global Consistency in Presenting Construction Life Cycle Costs and Carbon Emissions 3rd edition,* November, 2021 (ICMS 2021). However, this paper does not specifically deal with the issue of the measurement and presentation of carbon emissions.

Beyond the scope of this paper is the practice of Life Cycle Assessment (LCA) which extends to the total environmental impact of a material or product through every step of its life. LCA can consider a range of environmental impacts such as resource depletion, energy and water use, greenhouse emissions, waste generation, and so on. LCA can be applied to the whole constructed asset or facility or individual components of the same. It is necessarily complex and the details are beyond the scope of this paper. *AS ISO 14040: 2019 Environmental Management life cycle assessment, principles, and framework provides* more detail on LCA methodologies and protocols.

Additionally, this paper does not consider the life-cycle aspects of sustainability rating tools such as GreenStar, NABERS, LEED, etc.

2.0 LIFE CYCLE COST (LCC)

2.1 RELATIONSHIP BETWEEN WLC AND LCC

The terms Whole Life Cost (WLC) and Life Cycle Cost (LCC) are commonly used interchangeably, leading to confusion when their meanings are different. Furthermore, the approach to life-cycle management has traditionally been seen as a specialist pursuit or something additional to mainstream construction cost management services. This has meant that the basis and interpretation of life-cycle costing exercises have varied between stakeholders such as clients, consultants, and contractors; and is regarded differently across our industry sectors.

WLC is a technique for determining both the direct and indirect financial costs resulting from the design, construction, operations and disposal of a building or facility throughout its entire service life, also referred to as the 'total cost of ownership'.

Historically, LCC has been defined as "*an economic assessment of competing design alternatives, considering all significant costs of ownership over the economic life of each alternative, expressed in terms of equivalent dollars*" Dell'Isola & Kirk (1981).

The establishment of ISO 15686-5: 2008 *Buildings and constructed assets - Service life planning - Part 5: Life-cycle costing* (current edition 2017) set out definitions for these two (2) terms:

- **Whole Life Cost (WLC):** All significant and relevant initial and future costs and benefits of an asset, throughout its life-cycle, while fulfilling the performance requirements. (ISO 15685-5: 2017).
- **Life Cycle Cost (LCC):** Cost of an asset or its parts throughout its life-cycle, while fulfilling the performance requirements. (ISO 15685-5: 2017).

Subsequently, other definitions have been published, such as appears in the:

- *International Construction Management Standards: Global Consistency in Presenting Construction Life-Cycle Costs and Carbon Emissions, 3rd edition* (ICMS 2021).
- *AS ISO 41011: 2019 Facility Management - Vocabulary* (identical adoption by Standards Australia of ISO 41011: 2017).

These have been provided in Section 4: Glossary of Terms, as current and relevant alternatives.

ICMS (2019 and 2021) defines LCC is an economic evaluation method that takes into account all relevant costs over a period of analysis and provides a high-level structure and format for classifying, defining, measuring, recording, analysing, and presenting construction and other life cycle costs. It defines LCC's scope as covering construction, renewal, operation, maintenance and end-of-life (CROME) costs.

Under the ICMS 2021, LCC is a key component of WLC for building, facility, and infrastructure projects alike, which the ICMS 2021 defines as 'constructed assets'. As illustrated in Figure 1, WLC includes for LCC defined by the CROME acronym along with non-construction costs, income and externalities, as it relates to the systematic economic consideration of all costs and benefits over a period of analysis, and a defined scope.

WLC, and particularly LCC, is an area that Quantity Surveying Professionals are uniquely positioned to influence improved outcomes.

The presentation of costs should make clear the scope of those costs included or excluded as defined within the ICMS framework and the relevant level of costs for the purpose, as well as deal with the 'time value of money'. This concept provides that money available at present is worth more than the identical sum in the future due to its potential earning capacity.

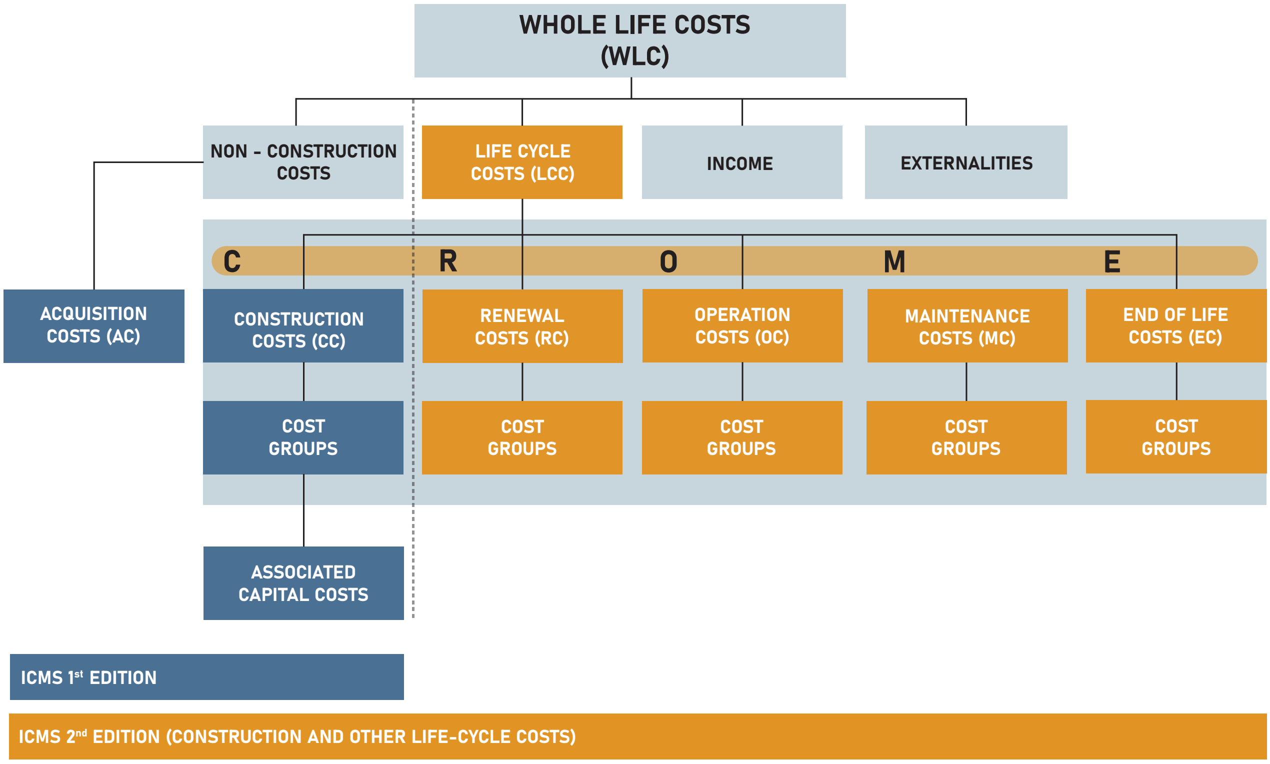

Figure 1: The relationship between LCC and WLC as depicted within the ICMS framework on page 9 of the ICMS 2019. *This graphic has been appropriated from ICMS 2019 by Stephen Ballesty (2022).*

LCC analysis provides a valuable comparative and management tool that can influence the design, specification, construction, operations, and sustainability performance. In adhering to the architectural principle of 'form follows function', it should be noted that appropriate LCC analysis modelling provides practical insights into the future implications of current decisions.

Historically, cost planning and cost management have focused only on the initial capital costs relating to a facility's design and delivery, or asset acquisitions. Project budgets through to bids or tender stage have tended to reflect these capital costs alone, and the traditional planning and control processes rarely extended beyond project completion and handover in any consistent or structured form, if at all.

For the true 'value for money' to be realised, the total costs of ownership throughout the facility life cycle need to be understood. The WLC methodology provides a basis for systematic economic evaluation and can be used to establish the total cost of ownership. This structured approach should address all costs in connection with a constructed asset or facility. The WLC concept is sometimes referred to as terotechnology or a 'cradle-to-grave' approach.

WLC provides a basis for assessing the 'value for money' beyond initial capital costs alone. While short-term savings may be achieved via value analysis or similar techniques, these savings can result in higher ongoing costs being incurred through the constructed asset or facility life cycle.

This upfront savings principle can also apply to professional fees. When aggressive savings on fees are pursued at the outset of a project these savings can be far outweighed by poor design and construction quality impacting on the experience of end-users and long-term operational costs.

To achieve optimum WLC outcomes improved data consistency and performance monitoring is required. The ICMS 2019 provides a global high-level cost classification system, as a basis for classifying, defining, measuring, recording, analysing, presenting, and comparing LCC of construction projects at a regional, state, national or international level. Also, the adoption of other standards (ISO 15686: 2017, AS ISO 41001: 2019, AS ISO 55001: 2014, etc.) and increased use of available technologies and data analytics in asset and facilities management will provide for better understanding of life-cycles and life-expectancies.

Additionally, ICMS 2021 recognising the impact of our activities provides a common reporting framework allowing the interrelationship between construction life cycle costs and carbon emissions to be explored, and providing enhanced opportunities to make decisions about design, construction, operation, and measurement of the Built Environment that optimise sustainability.

2.2 CROME EXPLAINED

ICMS 2019 incorporates the CROME acronym (construction, renewal, operation, maintenance, and end-of-life costs), and provides the opportunity for integrated thinking across some traditional industry silos.

As a tool, LCC analysis can be used to evaluate the optimum cost and economic merits across competing options and/or alternative design solutions considering the total cost of ownership over the service life of each alternative, expressed in equivalent dollars.

Taking into account the 'Service Life' of a constructed asset or facility, LCC analysis generally considers terms like economic, design, useful or effective 'life' as having the same meaning. The 'Service Life' should also consider the commercial aspects such as the revenue generated, taxation concessions, and salvage value. Although many definitions exist, for this paper, 'Service Life' is defined as the "period of time after practical completion that a constructed asset or facility, or its component parts, meet(s) or exceed(s) the performance requirements" (ISO 15686 11: 2014 and ISO 21930: 2017, AIQS modified, 2022).

Design options and alternatives can offer differential opportunities concerning future maintenance requirements, component replacement cycles, environmental performance, and operating costs. Evaluation by simply adding up all the costs (both initial capital costs and subsequent operational costs) for competing design options and alternatives is not sufficient, as this ignores both the effects of time and the future 'value of money'.

LCC analysis should involve bringing all project costs considered to their present value or equivalent future cost. This allows interested parties, stakeholders, and decision-makers to be better informed as to the merits of design options and alternatives on an 'apples to apples' basis. LCC analysis may use comparative techniques such as value analysis, economic evaluation, cost-benefit analysis, sensitivity analysis, and/or net present values.

LCC analysis is a vital tool, during informal or formal value engineering/management, where a project/facility solutions may involve multiple alternatives to satisfy end-user requirements and performance specifications. Consideration of design options beyond their initial capital costs alone provides the opportunity to achieve improved economic outcomes over time without compromising function and quality.

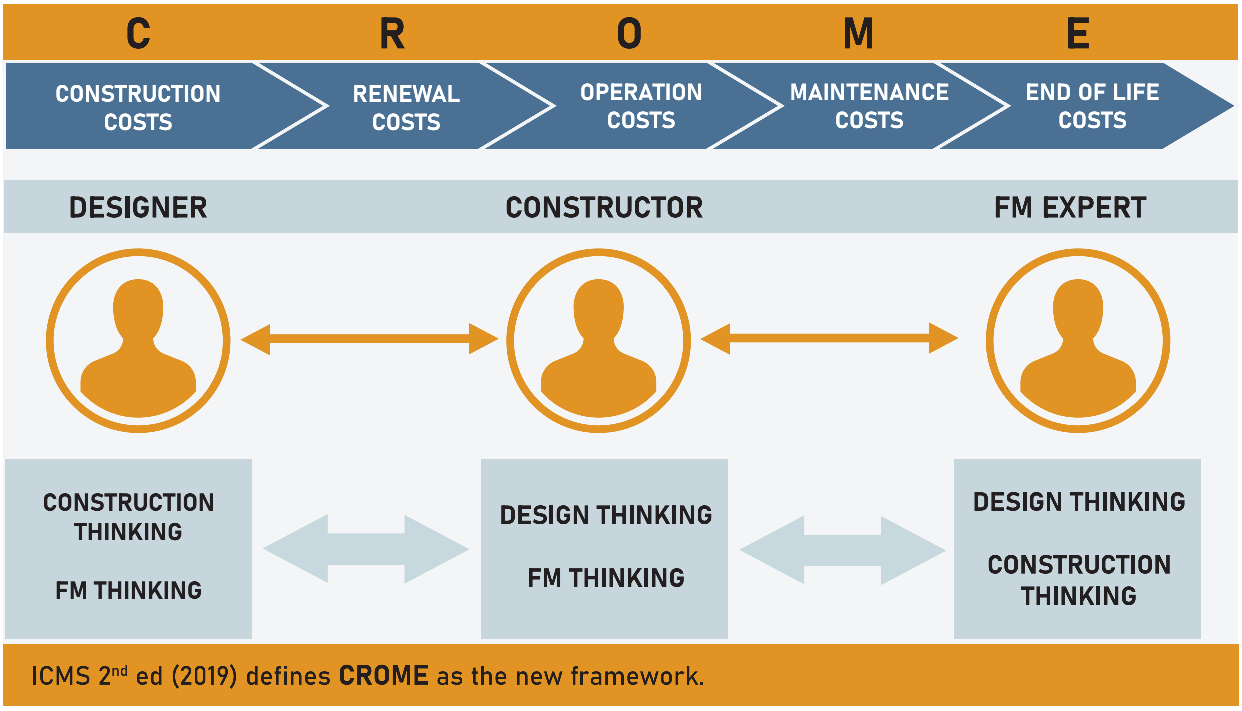

Figure 2: The relationship between significant contributors to the facility life cycle (Designer, Constructor and Facility Management (FM) Expert) across the CROME approach within ICMS 2019. Courtesy of Anil Sawhney, *Construction Journal* (November-December 2019) article. *This graphic has been created by Stephen Ballesty (2022).*

Beyond its use as a comparative tool, LCC analysis also serves as a management tool providing a basis for decisions such as the optimum time for performance-based upgrades, refurbishments, major adaptations, and replacement projects. LCC analysis is also key in making the right informed decisions regarding functionality, sustainability, resilience and adaptability.

2.3 BENEFITS OF LCC ANALYSIS

There are two (2) main applications of LCC analysis:

1. As a comparative tool to evaluate different options, design solutions, components, or materials in support of strategic planning and investment decisions.

   Typically applied during the constructed assets or facilities delivery or **Design** and **Construction** project life-cycle phases.

2. As a management tool following project delivery, facility occupation, or asset acquisition against which actual performance can be monitored and maintained. This also provides a basis for improved budget planning and expenditure forecasts.

   More commonly applied via the longer-term operational and management procedures during the **Asset/Facilities Management** project life-cycle phases.

However, LCC analysis should always endeavour to contribute to improved communication and informed decision-making.

Figure 3: LCC analysis as part of the cost management process can be iterative, allowing for improved communication and a data-driven improvement cycle, sometimes referred to as a DMAIC (an acronym for Define, Measure, Analyse, Improve and Control) for optimising and stabilising and design processes contributing to better outcomes. *This graphic has been appropriated from Wikipedia by Stephen Ballesty (2022).*

Given that initial capital cost alone can be misleading as a value metric, the benefits of LCC analysis for both public and private sector organisations, and the broader community are:

- recognition of 'total costs' and demonstration of the delivery value for the money to stakeholders to support defined objectives, requirements, and priorities
- a better understanding of the life-cycle consequences of Built Environment decisions with a greater focus on quality-of-life objectives and strategic planning for the future
- identification and analysis of all significant costs of ownership and occupancy
- improved communication, transparency, and accountability throughout the project or facility life cycle in terms of the requirements and methodologies resulting in enhanced service consistency and cost:benefit outcomes
- improved productivity, service, safety, and well-being in terms of more effective and efficient allocation of resources
- improved assessment of design alternatives and their full impacts in terms of maintenance and operational costs for newly constructed assets and facilities
- improved assessment of life-cycle periods and when to best consider refurbishment, major adaptation, change of use, or end-of-life events for existing constructed assets and facilities.

In conjunction with other evaluation tools (e.g. value analysis, cost:benefit analysis, sensitivity analysis, etc.) the above can be further enhanced to optimise a range of outcomes.

2.4 THE ROLE OF ISO STANDARDS

First published in 2008, *ISO 15686-5: 2017 Buildings and constructed assets, Service Life Planning - Part 5: Life-cycle costing*, deals directly with LCC methodologies.

Further, the ISO 41000 series of Facilities Management (FM) standards, aimed at improving the quality of life of people and the productivity of the core business of organisations, recognise the need to optimise life-cycle performance and costs, specifically citing LCC analysis as an appropriate means. This ISO 41000 series of FM standards, as published in 2017-20, has to date been identically adopted by Standards Australia.

The acknowledgment of LCC analysis extends to AS ISO 41001: 2019 which states the scope of the FM management system involves the "totality of the activities … ensuring that the system addresses long term (whole life cycle) needs" as a basis for planning of objectives for:

- *"establishing the method and criteria for decision making*

- *prioritising activities and resources to achieve the objectives*
- *understanding and documenting the processes to be used in managing facilities over their full life cycles."*

Sustainability objectives are integral to achieving optimal LCC across design, construction and maintenance, and operation costs.

In terms of strategic level FM, it is important to consider the LCC of each activity and investment. *"This may include the principles of sustainability, by considering not only the financial costs but also the social and environmental impacts and their associated costs. These costs can then be carried forward to the life cycle analysis to provide an enhanced financial assessment. In doing so for all supporting assets, FM creates additional value for the organization and the society as a whole". (*AS ISO 41013: 2019).

Within *AS ISO 55000:2014 Asset Management overview, principles and terminology*, states that to provide value to the organization and its stakeholders includes:

1. *"a clear statement of how the asset management objectives align with the organizational objectives*
2. *the use of a life cycle management approach to realize value from assets*
3. *the establishment of decision-making processes that reflect stakeholder need and define value."*

An organisation's strategic asset management plan (SAMP) should set out its asset management goals, and describe the role of the asset management system in meeting these objectives. The SAMP can have a timeframe that extends beyond the organisation's own business planning timeframe, requiring the asset management system to address the life of the constructed assets or facilities.

Further, *AS ISO 55000: 2014 states: "The creation of an asset management system is usually cross-functional and based on life cycle considerations; this can provide a focal point for addressing the issues of functional integration of the organization and life cycle planning."*

Improved longevity, performance, sustainability, and resilience are possible through the implementation of LCC analysis for newly constructed assets and existing facilities.

2.5 COMPONENTS OF LCC ANALYSIS

Effective LCC analysis combines the following key components:

1. Context or purpose as determined by interested parties and stakeholders' objectives.
2. Design inputs, construction deliverables, and operational variables; should be reflected progressively through the facility life cycle or project phases.
3. 'Service Life' and life expectancies of the components and the whole constructed asset or facility when all the objectives, inputs, and variables are considered.
4. Costs associated with the components and period of analysis to achieve and maintain outcomes meeting the required function, specified performance, and desired quality, per the ICMS including:
    - **Real Costs:** The cost expressed as a value at the common date, including estimated changes in price due to forecast changes in efficiency and technology, but excluding general price inflation or deflation. (ISO 15686-5)
    - **Nominal Costs:** The expected price that will be paid when a cost is due to be paid, including estimated changes in price

- due to, for example, forecast change in efficiency, inflation or deflation, and technology. (ISO 15686-5)
- **Discounted Cost:** The resulting cost when the real cost is discounted by the real discount rate or when the nominal cost is discounted by the nominal discount rate. (ISO 15686-5).

LCC analysis is an economic evaluation technique, for identifying and quantifying all costs, initial and ongoing, associated with a project or an asset over its anticipated life.

For this paper 'Service Life' is defined as: *the period of time after practical completion that a constructed asset or facility, or its elements and component parts, meet(s) or exceed(s) the performance requirements.*

Service Life cycles can be represented graphically by component or elemental life expectancy

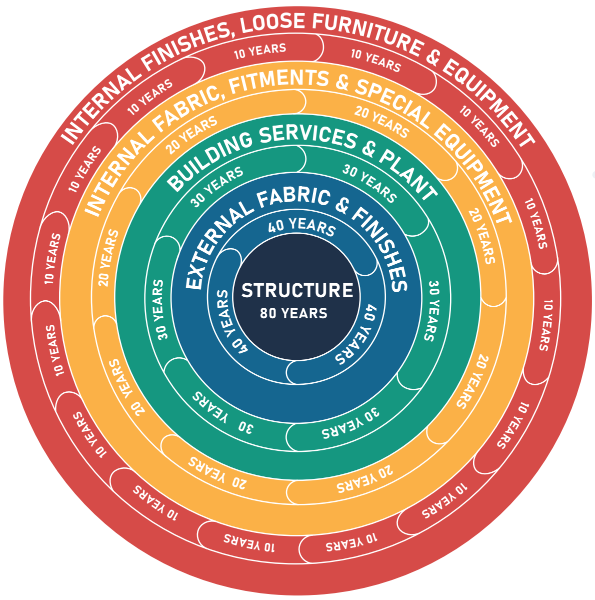

Figure 4: The life cycle 'onion' is only a graphical representation of the concept of differential life expectancy of building elements and the component parts within a constructed asset or facility. *This graphic has been created by Stephen Ballesty (2022).*

bands, using the definitions included within AIQS' Australian Cost Management Manual: Volume 2 - Elemental and Sub-elemental Definitions, 2001 (reprinted 2006), grouped by nominal 10-year life expectancy bands can be used to explain the concept of differential life expectancy the *component parts* within a *constructed asset or facility*. The practice of LCC analysis is no simple matter, as significantly more details, variables and inputs are required to achieve accurate forecasts.

'Service Life' is now the preferred term within AS/NZS 4536, ISO 15686-5, and the ICMS (2019 and 2021).

While not strictly within the conventional realm of LCC, the Australian Taxation Office (ATO) website provides an insight on the definition of 'Service Life':

"The decline in value of a depreciating asset is generally based on its effective life; that is, how long it can be used to produce income, taking into account:

- *whether it's subject to wear and tear at a reasonable rate*
- *whether it's maintained in reasonably good order and condition*
- *the period within which it is likely to be scrapped, sold for no more than scrap value, or abandoned.*

The effective life is used to work out the asset's decline in value (or depreciation) for which an income tax deduction can be claimed".

Details of the ATO's effective life of depreciating assets (applicable from 1 July 2021) in terms of life years for defined assets for income tax deduction purposes in accordance with Tax Ruling TR 2021/3 can be found at TR 2021/3 as published on 30 June 2021 - https://www.ato.gov.au/law/view/document?DocID=TXR/TR20213/NAT/ATO/00001.

In addition to these ATO schedules, other valuable life expectancy data can be found with design specifications, manufacturer product guides, research papers, industry publications, operational manuals, asset reliability and facility performance data analytics and reporting.

The ICMS provides a useful basis to classify, define, measure, record, analyse, present, and compare historical, current, and future construction and other life cycle costs of newly constructed assets and major adaptation and projects. This can be applied throughout the various facility life cycle or project phases through to the end-of-life or a shorter period of analysis.

Wherever possible, existing facilities can similarly adopt the standardised cost classifications and elements to ensure compatibility of valuable maintenance and operational cost data for LCC analysis and benchmarking purposes. Likewise, this practice will enhance the understanding of actual life expectancies and the conditions under which these were achieved.

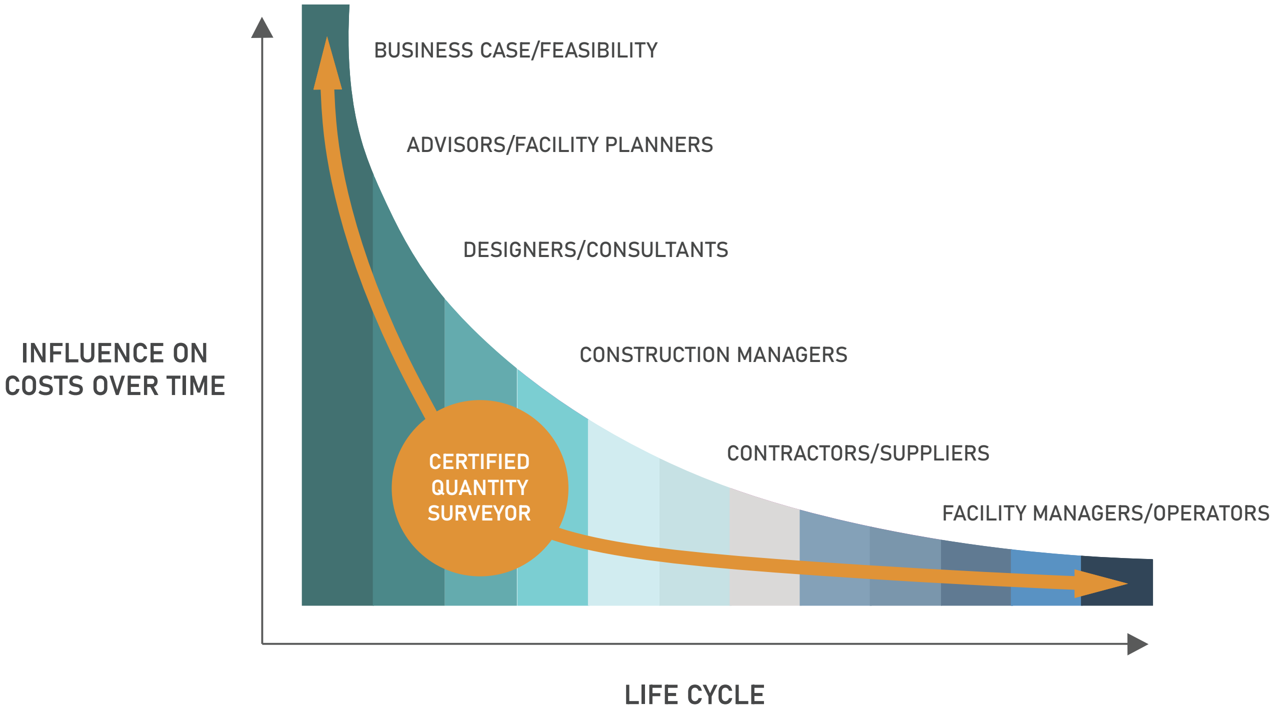

Figure 5: Across the various project or facility life cycle phases a range of participants have the opportunity to influence the form, function, and performance of our Built Environment. Predominately the long-term capacity and flexibility being determined in the conceptual phases. Certified Quantity Surveyors' inputs are crucial to supporting informed decision-making throughout. *This graphic has been created by Stephen Ballesty (2022).*

COST MANAGEMENT LIFE CYCLE TABLE

FACILITY LIFE PHASES ★	PROJECT STAGES PER ACMM & ICMS COMBINED	BASIS & DOCUMENTS REQUIRED	COST MANAGEMENT ACTIVITIES	LCC INTERFACE & DELIVERABLES
DESIGN	1. Brief ★	Study Brief, sketches or relevant information.	Brief Stage Cost/Indicative Cost.	Business Case or Feasibility Study inputs based on facility policy and functional objectives.
	2. Outline Proposals ★	Scope of works (size, type, location, plan, building shape, etc.) and functional areas.	Outline Proposal Cost/ Preliminary Estimate.	Life Cost Budgets related to project planning horizons and life expectancy targets.
	3. Sketch Design ★	Dimensioned sketch plans, elevations and sections, structural sketches and specifications.	Sketch Design(Limit of Cost Estimate) Cost Plan.	Life Cost Planning with comparative analysis and option selection.
	4. Documentation ★	Final working drawings and specifications prior to tender.	Tender Cost Plan (Tender Estimate).	Life Cost Plan per design.
	Project planning: reflective of current policies, standards, strategic objectives and understanding of risks and target LCC requirements.			
CONSTRUCTION	5. Tender ★	Priced Bill or Schedule of Prices.	Tender Report/contract administration and analysis.	Life Cost Plan per tender.
	6. Construction ★★	For construction documents.	Final Account/contract administration and evaluation.	Project Monitoring management review and option refinement.
ASSET / FACILITIES MANAGEMENT	**Performance Evaluation:** reflective of facility plans, standards, monitoring, benchmarking and meeting target LCC requirements.			
	7. Renewal ★	Costs of replacing a Facility, Constructed Asset and/ or major components once they reach the end of their life, and which the client decides are to be included in the capital rather than the revenue budget.		CAPEX budget to support the service delivery plan.
	8. Operation ★	Costs of running and managing a Facility, Constructed Asset, including administrative support services, rent, insurances, energy and other environmental/regulatory inspection costs, taxes and charges.		OPEX budget to support the service delivery plan.
	9. Maintenance ★	Costs of corrective, responsive and preventative maintenance on a Facility, Constructed Asset or its parts and all associated management, cleaning, services, repainting, repairing or replacing of parts.		Maintenance Plan to support the service delivery plan.
	10. End of Life ★	Net costs or fees for disposing of an asset at the end of its service life after deducting the salvage value and other income due to disposal, including costs resulting from disposal inspection, decommissioning and decontamination, demolition and reclamation, reinstatement, asset transfer obligations, recycling, recovery, disposal of components and materials, and transport and regulatory costs.		Business Case or Feasibility Study inputs based on facility policy, functional objectives, performance status and applicable regulatory and statutory requirements.

★ **Facility Life Cycle Phases shown here are nominal, the groupings are not exclusive or confined. By definition design, construction and asset/ facilities management should co-exist, overlap & integrate.**

★ **AIQS' Australian Cost Management Manual: Volume 1, 4th edition (2021)**

★ **International Construction Measurement Standards (ICMS), 2nd edition (2019)**

Table 1: Combining the AIQS' *Australian Cost Management Manual: Volume 1* (4th edition, 2021) and the ICMS' CROME acronym (2019) is required to span the full scope of the Quantity Surveyors' and Cost Management Professionals' LCC outputs and deliverables. *This graphic has been created by Stephen Ballesty (2022).*

2.6 LCC APPLICATIONS DURING DESIGN, CONSTRUCTION AND ASSET/ FACILITIES MANAGEMENT

From a terotechnology perspective (or the pursuit of the optimum technical and economic cost of ownership or lease of a facility over its whole life span from conception through acquisition to operation and finally disposal), LCC should be of interest to all stakeholders: investors, owners, designers, constructors, asset/facility managers, and end-users/occupants/visitors. The use of LCC analysis is reflective of longer-term thinking: early consideration of future requirements, reliability, flexibility and functionality in the development of solutions appropriate utilisation and adaptation strategies will promote the sustainability and resilience of the Built Environment.

Increasingly, clients are seeking to apply responsible management principles and take account of Environmental, Social, and Governance (ESG) criteria when measuring the sustainability, ethical, corporate and economic impact of an investment decisions. These are clients who consider it important to reflect their corporate values and concerns into their projects.

The application of LCC analysis throughout the project or facility life cycle is often expressed as the impact on the cost that can be achieved over time. At every project or life cycle phase, it is about ensuring that the WLC criteria and longer-term requirements are addressed instead of merely considering the potential profitability and/or risk presented by an investment opportunity.

Fundamentally there can be little argument that initial policy and design decisions influence future outcomes and performance. Equally design and construction phase decisions can be costly to change during the asset/facilities management phase. But it should be noted that the application of LCC analysis should be seen as beneficial at all project or facility life cycle phases.

Generally, the application of LCC analysis covers the entire life cycle and can be grouped here into three (3) principal facility life cycle phases, and further categorised into but not limited to the following 10 project phases.

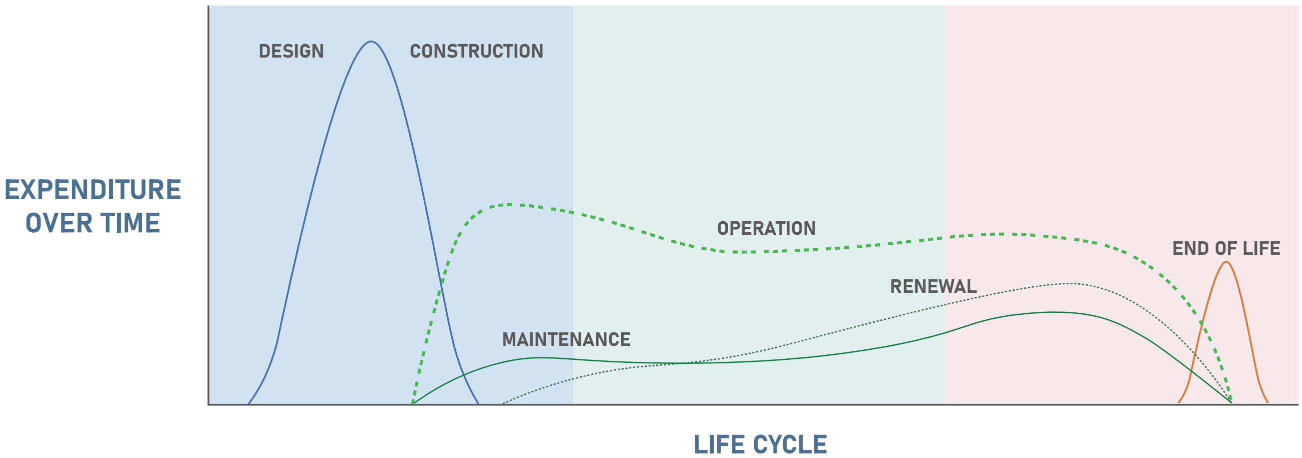

Figure 6: Across the various project or facility life cycle phases the nature of expenditure changes over time as determined by facility type, and factors such as age, condition, utilisation, etc. The challenge for Quantity Surveyors and Cost Management Professionals is to provide consistent, accurate, and reliable cost predictions to support informed decision-making throughout. *This graphic has been created by Stephen Ballesty (2022).*

For this paper, Project phases 1-6 are expressed per the AIQS' *Australian Cost Management Manual: Volume 1*, (4th edition, 2021), and Project phases 7-10 reflect the ICMS' CROME acronym (2nd edition, 2019). Additionally, the Cost Management Life Cycle Table on page 14 outlines the typical basis and documentation, along with Quantity Surveying Professionals' service responses and likely LCC interfaces and deliverables.

The LCC process requires a level of due diligence from all interested parties and stakeholders and involves assessing costs incurred and evaluating alternatives that have impacts on the total costs of the constructed asset or facility throughout its life cycle phases.

During the Design phase, and specifically in the earlier project stages 1-3 some interested parties and stakeholders may seek LCC budgeting and benchmarking based on a percentage of capital costs or $/m2. In the absence of relevant benchmarks, either from published or corporate databases, the appropriate data may not exist in sufficient quantity or quality for such significant decisions.

It is worth noting that the Australia Department of Finance requires a 'business case' application to consider options, analyses costs, benefits, and risks, and ultimately support investment decision-making. Further, the business case should be continually updated throughout the development and decision-making process to include the best information available, while taking into account WLC considerations.

Hence, Quantity Surveying Professionals providing early project or high-level LCC advice should consider adopting a parametric estimating approach with client agreed assumptions and specialist consultant input LCC variables. Early LCC advice could be expected to produce an estimate range with a stated level of accuracy for an appropriate LCC contingency allowance until further design development has been progressed. Not taking such precautions fails to appreciate the complexity and inter-relationship of LCC variables that are required to deliver accurate LCC analysis putting at risk a range of planning and performance outcomes.

Type of ownership may influence property decision-making, and life-cycle obligations will vary between freehold to leasehold. The latter having defined obligations to be met under an agreement for lease. The Strata Title ownership option, originally introduced to Australia in 1961, and in accordance with the Owners Corporations Acts in various States circa 2006, brings with it specific LCC applications. An Owners Corporation (formerly known as a Body Corporate) is responsible for maintenance, repair and overall management of the common property, and can include sustainability upgrades and capital works.

The terminology and requirements may vary between State jurisdictions, and from time to time, and should be checked when considering LCC analysis on Strata Titled properties.

Generally, an Owners Corporation will be required to maintain a Capital Works Fund (previously called a 'sinking fund', 'reserve fund forecast' or 'maintenance plan') to ensure there are sufficient funds available to pay for capital expenses when works are scheduled or required.

The Capital Works Fund can include for:

- painting or repainting the common property
- acquiring, renewing or replacing personal property for the scheme
- renewing or replacing fixtures and fittings that are part of the common property
- to replace or repair the common property.

Currently in New South Wales, *"the Owners Corporation is required to prepare a plan of expected major expenditure to be met from the capital works fund. The plan is for a 10-year period commencing on the first AGM of the Owners Corporation, and must be reviewed at least every five years. Items of major expenditure could include, for example, replacing the roof of a building.*

The amount required for the 10-year plan may vary between schemes, for instance, newer schemes may require relatively less money than the plans for older schemes with more repair work due. Each capital fund 10-year plan should reflect the individual needs of its scheme.

The 10-year plan must be approved by owners at an annual general meeting (AGM)".

Refer NSW Strata Schemes Management Act 2015 and https://www.fairtrading.nsw.gov.au/.

Similar requirements currently exist for strata schemes in most other Australian locations.

3.0 PROCESS OF LCC ANALYSIS

3.1 GETTING STARTED

At its core, LCC analysis is life expectancy based.

The future life expectancy of component items is intrinsically linked with the life expectancy of the whole constructed asset or facility life-cycle. Hence, LCC analysis, and determining the appropriate period of analysis, is part of the strategic decision-making process.

Successfully applying LCC analysis requires knowledge and understanding of the:

- interested parties and stakeholders' ownership objectives
- end-users' operational objectives
- design intent, functional requirements, and variables
- project scope, status, and available relevant data/documentation
- life expectancy concept and the related impacts which affect facility performance
- LCC analysis techniques, databases, the necessary inputs, and risk assessments
- LCC analysis formulation, presentation, and interpretation.
- consistent application of established terminology, standards and calculation methodology.

For comparison and analysis purposes all costs should be discounted and dealt with at present value for constructed asset or facility alternatives. In addition, allowances should be made for matters of finance, inflation, taxation, profit, and risk to deal with future costs in 'real' dollars.

LCC analysis techniques may vary through the facility life cycle or project phases to cover the progressive evaluation of the costs, risks, and benefits associated with project alternatives, new designs, construction delivery, and completed or existing facilities. The level of detail and required accuracy for a specific LCC analysis will be determined by the project objectives, scope, status, and available data. LCC analysis applications may range from business case inputs per the Commonwealth Investments, Resource Management Guide, January 2020 to maintenance budget within a strategic asset management plan (SAMP) per AS ISO 55001: 2014.

Beyond the requirement for access to relevant and appropriate databases, there will invariably be the need to apply a degree of professional judgement on the use of such data. For example, published life expectancies may be commercially based, to reflect contractual requirements or warranty expectations rather than the actual performance in-use data. Even where scientific testing analysis of component and material life expectancies are available this will likely reflect certain conditions, rather than the specific project or facility conditions. Specific variables can include location, start condition, specification, utilisation, operation, maintenance regime, and compliance requirements.

Physical life or condition-based life expectancy is empirical and the measure most commonly used in LCC models. Of course, all constructed assets and facilities deteriorate naturally over time, but accelerated deterioration may result due to external factors, such as corrosive environments, improper use, or lack of maintenance.

Further, the actual life expectancy of constructed assets, facilities, and their components are difficult to predict due to the variables involved in the 'Service Life' concept and the prospect of premature obsolescence, which could include the following:

a. **Physical obsolescence:** The point at which the physical condition of a facility, in terms of the deterioration of its fabric or services, can no longer function at acceptable levels.

b. **Economic obsolescence:** The point at which the economic viability of a facility is considered to be the least cost-effective way to meet an objective, it is just too expensive to maintain.

c. **Functional obsolescence:** The point at which a facility ceases to function for the purpose for which it was built. Functional and economic obsolescence are often closely related.

d. **Technological obsolescence:** This occurs when a facility or its components are no longer technologically superior to alternatives and there is a loss of competitiveness in terms of higher operating costs or lower efficiencies.

e. **Statutory or legal obsolescence:** This occurs when a facility or its components are no longer compliant with new regulatory or legislative requirements.

f. **Social obsolescence:** Social values and fashions change over time leading to the renovation, upgrade, or replacement of facilities due to market demand of what may otherwise be acceptable based on other foregoing criteria.

g. **Environmental obsolescence:** Related to the environmental impact of design, construction and operational processes and consideration of trans-generational equity, sustainability and resilience issues. This may give rise to the need to embrace change, such as alternate materials selection, pursuing circular economy principles, or achieving carbon neutrality, etc.

Individually or in combination any obsolescence can equate to loss of competitiveness in terms of higher costs or lower performance efficiencies. In life-cycle terms, obsolescence may necessitate a refurbishment, major adaptation, change-of-use, or an end-of-life event.

This results in consequential responsible materials recycling, recovery, and disposal activities. Such variables and contingencies should be considered as part of a comprehensive LCC plan and monitored for periodic updates throughout the operational phase of the facility life cycle.

Additionally other criteria and metrics can be considered, and LCC practitioners should be aware of carbon emissions, the circular economy, and the Sustainable Development Goals (SDGs). Refer to Figure 7 on the next page. The 17 SDGs support the United Nations' 2030 Agenda as a pathway to end extreme poverty, fight inequality and injustice, and protect our planet through sustainable development - https://sdgs.un.org/goals.

LCC planning should take a holistic systems-based approach, noting that many failures result from the interaction of components or some specific materials or workmanship defect that results in a premature failure of components with long life expectancies. The failure of composite components will often be determined by the 'weakest link' in the system.

Hence, LCC analysis results can be difficult to benchmark due to the need to take into account specific client, design, construction, location, local conditions, utilisation, maintenance regimes, or operational end-user requirements.

This can lead to the need to consider two (2) approaches to LCC performance benchmarking; comparing a project/facility against its own targets or 'dynamic' benchmarking; and separately comparing a project/facility against other similar projects/facilities, and market expectations or 'static' benchmarking.

Figure 7: The UN's 17 Sustainable Development Goals (SDGs) are a call for action by all countries to promote prosperity while protecting the planet.

The absence of historical data in a consistent format of cost classification is often cited as a major drawback to the effective use of LCC analysis. This hurdle can be overcome as LCC analysis is integrated with the project planning and design process and both capital cost and LCC planning share a common database or bill of quantities for a newly constructed asset, or maintenance schedules and asset registers for existing facilities. Invariably when undertaking LCC analysis there will be gaps in the available data and/or project specifics which will require the build-up of items and rates from *'first principles'* estimating.

This is also known as the zero-based budget methodology. It uses a combination of detailed asset lists, measured quantities, engineering specifications, and performance standards to assess resource needs, life expectancies, and market unit costs to create a total LCC plan and budget. No reference is made to previous expenditure levels when using the zero-based budget methodology.

The incorporation of sensitivity analysis into LCC models will assist in avoiding unrealistic expectations of the accuracy of LCC analysis. This sensitivity analysis function should be applied to key variables like the period of analysis, life expectancies, service level agreements, obsolescence factors, discount rates, etc.

Regardless LCC analysis formulation, presentation, and interpretation should be appropriate to evaluate all costs incurred over the entire facility life cycle or project phases for a range of applications. LCC analysis should support more effective decision-making on acquisitions, construction, maintenance, refurbishment, major adaptation, or disposal.

Simplistically, LCC analysis may result in the use of specifications or quality products, which may have a higher initial cost but lower maintenance and operating costs. This would be expected on long-term infrastructure holdings where lower WLC are desirable.

However, this may not always hold when considering a shorter period of analysis to achieve specific cycle times commercially designed to avoid functional or technological obsolescence. This could be the case in short-term event precincts where temporary facilities are in use.

The LCC analysis should document the approach, outcomes, and implications of any evaluation along with any limitations and assumptions associated. This may extend to qualitative risk analysis by assigning the likelihood, impact, and consequences of LCC variables or uncertainties when scheduling project/facility risks. This will involve using professional judgement and experience to explain the scope, quality, and accuracy of the available data upon which the LCC analysis depends.

Typically, the resulting LCC analysis report should contain:

- **Executive Summary:** a brief synopsis of the objectives, results, conclusions, and recommendations of the analysis.
- **Purpose and Scope:** a statement of the objectives, project/facility description, intended/current use, operating scenarios, assumptions, constraints, and alternatives considered.
- **LCC Application:** a presentation of the LCC model results including the identification of cost drivers, the results of sensitivity analyses, and the output from any other related analyses.
- **LCC Analysis:** details of the LCC model, including relevant assumptions, the LCC breakdown structure, and cost elements along with the basis of estimates and exclusions.
- **Conclusions and Recommendations:** a presentation of conclusions related to the objectives of the analysis and a list of recommendations along with identification of any need for further work or revision of the analysis.

Given the potential significance of such reports on decision-making, a formal peer review of the LCC analysis process may be required to confirm the correctness and integrity of the results, conclusions, and recommendations presented in the report.

For more details, a references and resources list including LCC standards and guides has been provided as part of this AIQS paper.

3.2 CALCULATION METHODOLOGIES

The basic formula for LCC analysis is as follows:

Life Cycle Cost (LCC)	
=	Initial acquisition / capital costs (AC)
less	tax depreciation entitlements (TD)
plus	operating and maintenance costs (OC)
plus	replacement / disposal / upgrade costs (RC)
less	residual / salvage value (RV)

Typical LCC* = (AC - TD) + (OC + RC) - RV

***Note:** *LCC adjustments should be made for the 'time value of money' or 'discounting' in terms of Net Present Value (NPV) or Annual Equivalent Value (AVE) per the following within this AIQS paper.*

Figure 8: Typical LCC formula. *This graphic has been created by Stephen Ballesty (2022).*

Note: Appropriate allowances should be made within each LCC component noting amortisations (if applicable) for trade costs (labour, material, plant, etc.); project preliminaries, supervision, margins and overheads; and professional fees etc. The basis of estimates, inclusions and exclusions should be stated within the LCC methodology with particular attention to allowances for escalation, contingency and applicable taxes, such as GST in Australia.

Such LCC analysis can be readily processed and presented via a spreadsheet, such as MS Excel, and be customised to suit jurisdictional issues and specific client, project, or component assessment purposes.

Costs over time and discount rate selection need to broadly consider the:

- prevailing market conditions and local escalation
- minimum acceptable rate of return and investment alternatives
- likely 'opportunity cost' of the timing of decisions, or the loss of other alternatives when one alternative is chosen
- available funding options and the cost of capital.

The basic principle of LCC analysis is the 'time value of money' – a dollar today is worth more than a dollar in the future, due to its earning potential if invested in the interim. Notwithstanding the prevailing low-interest-rate environment globally, this continues to be true, though perhaps to a lesser extent than some periods in the past.

There are two (2) methods of evaluating the time cost factors:

1. **Net Present Value (NPV)**

   The aggregation of initial costs and annual expenditure estimates modified by deduction of the interest (at an assumed rate) theoretically earned had a sum of money been invested with a financial institution such as a bank during the period from inception of the project to the actual date of payments.

   The NPV method is currently favoured by the ICMS 2021.

2. **Annual Equivalent Value (AEV)**

   Expresses the aggregated amounts in terms of the 'mortgage payable' or the interest (at an assumed rate) theoretically lost by investing a sum of money in a project rather than an investment with a financial institution such as a bank, based on the initial costs and annual expenditure estimates. This same method which provides a 'snap-shot' at a point in time can also be used for comparison of rental options.

Whichever method is used, all costs are equalised to a common base date for comparison under a given set of assumptions. Initial capital costs are amortised over the period of analysis or facility life cycle. Future refurbishment, major adaptation, maintenance, and operational costs are re-calculated to an annual impact brought back to the common base date.

Each of these methods can be calculated with or without selected financial variables such as inflation and/or taxes.

The effects of inflation on discounted cash flow (DCF) are at any time a problem of forecasting and an argument against the whole process of adjustment for time value.

Given that tax depreciation relief may be available in the form of capital allowances and against most revenue expenditure the effects of such savings need to be calculated before discounting.

The effect of interest earned on the calculated worth of deferred expenditure as described above is, in practice, calculated from tables of factors produced for the purpose or from first principles under a given set of assumptions.

Adjustment for time value using NPV:

To convert a future cost to the present value (cost) at the Common Date, the following formulae, using $ as an example currency, can be used:

Present value (PV) = future cost × discounting factor

Rate of interest (R%) = discount rate per annum

Discounting factor for the same cost spent at the end of year N after the common base date:

= PV of $1 after N years

$= 1 / (1 + R\%)^{N}$

Discounting factor for a cost spent annually for N years after the common base date:

= PV of $1 per annum after N years

$= [1 - 1 / (1 + R\%)^{N}] / R\%$

These NPV outputs should be combined with other assessment tools, such as payback period, or return on investment, and subjected to rigorous sensitivity analysis. This allows for multiple outcomes based on altering the values of key variables within the model such as the discount rate or the period of analysis. Such sensitivity analysis tests the range of uncertainty and may give rise to the prioritising of alternatives and support scenario planning in the presentation of results and the subsequent decision-making process.

More information on the calculation of NPV and the relationship between real and nominal costs and discount rates can be found in ICMS 2021 and ISO 15686-5:2017.

3.3 RISKS AND ASSUMPTIONS

Not undertaking full LCC analysis presents stakeholders with a range of opportunity cost and performance risks including but not limited to:

- decision-making is based on initial capital costs alone
- minimising capital costs without the knowledge of the consequential life-cycle impact
- acceptance of life expectancy claims without full investigation or modelling of alternatives
- failure to make adequate provision for maintenance and operating costs
- difficulty in planning for future refurbishment, major adaptation, change of use, or end of life events
- accurately reporting on 'value for money' achievements
- failure to achieve sustainability, resilience and affordability performance targets.

The risks and assumptions involved with undertaking LCC analysis and which can contribute to unrealistic expectations and/or failure to achieve desired outcomes include:

- **Databases** – the use of insufficient or inappropriate data can lead to incorrect outcomes. The increased use of building information modelling (BIM) / asset information modelling (AIM) software and data analytics should over time improve the quantity and quality of databases and the availability of consistent benchmarking.
- **Period of Analysis** – the use of shorter or longer life-cycles can distort the outcomes to the benefit of one alternative over another. This can be partly addressed by the use of sensitivity analysis.

- **Discount Rates** – the use of higher discount rates can lead to the selection of low capital cost and high operating cost alternatives, due to the future expenditure being significantly diminished in value. This can be partly addressed by the use of sensitivity analysis.
- **Life Cycle** – the use of life expectancies based on published data or physical or condition-based criteria alone provides a basis only. Always consider the specific project or facility circumstances and the potential impact for functional, technological, compliance, and market demand factors on life expectancies.
- **Sensitivity Analysis** – this can be applied to a range of key LCC variables. Always run a range of assumptions for key LCC variables in isolation and combination allowing best-case and worst-case scenarios.

The use of an LCC classification, database and benchmarking system should be consistent, in terms of the scope inclusions and exclusions by sector, facility type, and project.

The overarching risk with LCC analysis is the complexity and number of variables involved. LCC analysis is significantly more complex than (Quantity x Rate) + Fees + Contingency = Estimated Cost.

This complexity risk applies to Quantity Surveying Professionals delivering the LCC service and the interested parties and stakeholders relying on the LCC advice.

Managing a client's expectations is crucial to the success of any project and facility performance, and involves considering the risks from the perspective of a range of stakeholders across the:

- setting of realistic/agreed goals
- definition of the project/facility scope
- detailed planning with specified benchmarks and milestones
- budget agreement, adoption and adherence
- identification of common risks, uncertainty, and bias.

All LCC analyses should include contingency allowances for risk in addition to capital cost allowances for design, construction, and operational risks. The additional allowances for LCC risks could cover variances in the:

- confirmation of assumptions
- changes in project/facility objectives, complexity, scope, quality, timing, life expectancies, etc.
- design development and value engineering initiatives (alternate methods or materials etc.)
- accuracy of capital cost estimates (actual versus forecast)
- operational efficiencies or variance in maintenance regimes
- legislative, statutory, or economic changes, etc.

It should be noted that erroneous project/facility conclusions may be drawn and poor decisions made due to the incorrect use of data, inappropriate modelling, changed conditions, or the omission of cost significant items.

3.4 TECHNOLOGY AND TOOLS

Digital design, construction, and management technologies, commonly referred to during design and construction documentation as Building Information Modelling (BIM) and operationally as Asset Information Modelling (AIM), are fundamentally transforming our industry practices in the delivery and management of the Built Environment. New technologies will improve the opportunities for enhanced productivity, transparency, and sustainability, as well as the level of integration and collaboration across the various disciplines throughout the industry supply chain.

In its advanced form, this can result in a Digital Twin being created as a data repository and virtual representation of one or more constructed assets or physical facilities.

BIM brings together technology, processes, and digital information to radically improve client objectives, project procurement, and facility operations. BIM is a strategic enabler for improving decision-making across the project or facility life cycle. This applies not only to the delivery of constructed assets; but crucially supports the renewal, operation, maintenance, and end-of-life costs associated with the Built Environment – the largest share of the WLC.

In the case of the delivery of constructed assets a typical BIM package can contain graphical (2D/3D objects) and non-graphical (object data) information that can be extracted for quantification. The designer needs to create, place and export their models in a manner that enables this information to be used for quantification purposes. The data maturity levels are expressed from Level 0, through Levels 1, 2, 3, and beyond. Adding programme data or the time dimension makes it 4D BIM, with the inclusion of capital cost information makes it 5D BIM. Beyond the traditional design and construction phases, and shifting the focus to WLC and sustainability is where 6D BIM comes in. Sometimes referred to as integrated BIM or iBIM.

There are many BIM authoring software packages in use that produce their own proprietary native file type. Various interoperable file types exist which can be read by differing estimating and cost planning packages thereby enabling data from BIM files to be leveraged whatever the originating design software.

Quantity Surveying Professionals should review their software to determine which file formats they will require to best leverage the BIM model. The extent of information that can be leveraged for LCC purposes varies depending on the software used.

It is recommended that software vendor guidance be sought on the capacity to produce a life cost plan in parallel.

Assuming the use of the capital cost plan model for the scoping of LCC, it is desirable that be measured in accordance with a relevant standard method of measurement and be ICMS compliant, for consistency and benchmarking.

For existing facilities, the creation of a Digital Twin will often require the documentation of the scope of works and asset quantification to support ongoing LCC analysis. Common approaches to this data collection challenge for the capture of key elements include compiling asset registers and conducting condition surveys. Additionally, this process can involve using physical or virtual inventories and/or 3D laser-scanning surveys and photogrammetry techniques for the digitisation of the constructed asset. These techniques enable the asset data capture in terms of physical characteristics, quantities, dimensions, and operational information as the basis for a digital model to support LCC analysis, and the simulation and benchmarking of other aspects of the Asset/ Facilities Management project life cycle phases.

Increasingly building automation will drive even deeper insights into facility performance, operational efficiency, resiliency, and maximising the Service Life of constructed assets, facilities, and their component parts. For existing facilities, a useful tool is the use of a Facility Condition Index (FCI) approach for understanding the status of a facility, or systems within a facility and objectively assessing the current and projected condition of a constructed asset. By definition, the FCI is defined as the ratio of the current year's required renewal cost to the current building replacement value. The FCI is often a key input for Asset Registers and Computerised Maintenance Management Systems (CMMS).

LCC analysis should embrace emerging technologies and tools including leveraging BIM and AIM concepts and principles for managing information applicable to the life span of the Built Environment.

4.0 GLOSSARY OF TERMS

It should be noted that there is a diversity of LCC terminology that has developed and is currently in use. The following provides guidance on the key terms adopted and the definitions used in this document. Notwithstanding referenced materials, the general convention adopted has been nouns are open form (life cycle), the adjective and verb usage are hyphenated (life-cycle), and the closed-form (lifecycle) has been avoided. The source of each definition where known is provided in brackets.

Asset	Item, thing, or entity that has potential or actual value to an organisation. (AS ISO 41011:2019 and AS ISO 55000: 2014)
Asset Information Modeling (AIM)	A sub-type of Information Models supporting the maintenance, management, and operation of an asset throughout its life-cycle. An Asset Information Model (AIM) is used (a) as a repository for all information about the asset; (b) as a means to access/link to enterprise systems (e.g. CMMS and BMS); and (c) as a means to receive and centralise information from other parties throughout project stages. (AIQS & NZIQS, 2018)
Asset Management	Coordinated activity of an organisation to realise value from assets. (AS ISO 41011: 2019 and AS ISO 55000: 2014)
Building Information Modeling (BIM)	A process that leverages technology to facilitate collaboration amongst all parties during the project life-cycle. BIM is not software, nor is it solely a 3D model. BIM can be used, in various forms, on all sizes and types of projects. (AIQS & NZIQS, 2018)
Built Environment	Collection of buildings, external works (landscaped areas), infrastructure, and other construction works within an area. (AS ISO 41011: 2019)
Capital Cost	Initial construction costs and costs of initial adaptation where are treated as capital expenditure. (ISO15686-5: 2017)
Client	The person(s) or entity that pays for the works and services provided. This may include external clients as well as internal. (ICMS 2nd edition, 2019)
Circular Economy	An economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles. (ISO 20887: 2020)
Constructed Asset	The output from any building or civil engineering project. (ICMS 2nd edition, 2019) *Author's note:* 'Constructed Asset' or 'Facility' have been adopted throughout this document rather than 'Asset', 'Building', 'Infrastructure', 'Property' or 'Real Estate'.
Digital Twin	A digital model of a real-life object, process, or system.
Discount Rate	Factor or rate reflecting the 'time value of money' that is used to convert cash flows occurring at different times. (ISO 15686-5: 2017 and ICMS 2nd edition 2019).

Due Diligence	Compilation, comprehensive appraisal, and validation of information of an organisation required for assessing accuracy, commercial integrity, financial stability, and functional competence integrity at the appropriate stage of the agreement sourcing process. (AS ISO 41011: 2019)
Economic Evaluation	A method of project appraisal to take account of all significant cost and benefit effects, quantifiable in money terms, of a particular course of action or investment, upon the community. (AIQS' ACMM, 2021) This can also be referred to as economic cost-benefit analysis, or cost:benefit analysis.
End-users	Person or organisation which uses products or services from a supplier. (AS ISO 41011:2019) *Author's note on the definition:* End-users may include owners, tenants, occupiers and visitors.
Externalities	Quantifiable cost or benefit that occurs when the actions of organisations and individuals have an effect on people other than themselves, e.g. non-construction costs, income and wider social and business costs. (ISO 15686-5: 2017 and ICMS 2nd edition, 2019)
Facility Management, Facilities Management or FM	Organizational function which integrates people, place, and process within the Built Environment with the purpose of improving the quality of life of people and the productivity of the core business. (AS ISO 41011: 2019)
Facility or Facilities	Collection of assets that is (are) built, installed or established to serve an entity's (client's) needs. (AS ISO 41011: 2019) *Author's note on the definition:* 'Constructed Asset' or 'Facility' have been adopted throughout this document rather than 'Asset', 'Building', 'Infrastructure', 'Property' or 'Real Estate'.
First Principles Estimate	An estimate derived from a calculation of labour, plant, and material costs, including direct (e.g. trade costs) and indirect costs (e.g. preliminaries). (AIQS' ACMM)
ICMS	International Construction Measurement Standards being a collaborative, high level, international standards for cost reporting and data collection developed by the ICMS Coalition https://icms-coalition.org/.
Income	Money received from sales and other activities during the life of an asset. (ICMS 2nd edition, 2019)
Infrastructure	System of facilities, equipment, and services needed for the operation of an organisation. (AS ISO 41011: 2019)

Interested Party or Stakeholder	Person or organization that can affect, be affected by, or perceive itself to be affected by a decision or activity. (AS ISO 41011: 2019)
Life Cycle	The time interval between a product's recognition of need or opportunity and its disposal. (AS/NZS 4536: 1999 (R2014) *Author's note on the definition:* Consecutive and interlinked stages related to a product, from the raw material acquisition or generation from natural resources to end-of-life treatment. (ISO 14067: 2018) Note to entry: Stages of a life-cycle related to a product include the raw material acquisition, production, distribution, use and end-of-life treatment.
Life Cycle Cost (LCC)	Cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements. (ISO 15685-5: 2017) *Author's note on alternate definitions:* The following are also current and relevant. Cost of a constructed asset or its parts throughout its life-cycle from construction through use, operation, maintenance, and renewal till the end-of-life or a shorter period of analysis, while fulfilling the performance requirements. (ICMS 2nd edition, 2019) Total costs (in present-value terms) expected to be spent on an asset during its operational existence. (AS ISO 41011: 2019)
Life-Cycle Costing	Methodology for the systematic economic evaluation of life-cycle costs (LCC) over a period of analysis, as defined in the agreed scope. (ISO 15686-5: 2017) ISO notes to entry: 1) Life-cycle costing can address a period of analysis that covers the entire life cycle or (a) selected stage(s) or periods of interest thereof.
Net Present Value	The sum of the present values of all benefits (including residual value, if any) minus the sum of the present values of all costs. (AIQS' ACMM, 2021)
Non-Construction Costs	Includes finance costs, service charges, parking charges and charges for associated facilities. (ICMS 2nd edition, 2019)
Period of Analysis	Period of time over which LCC are analysed as determined by the Client. It may cover the entire life (physical, technical, economic, functional, social, or legal life) or a selected stage or stages or periods of interest as required by the Client. (ICMS 2nd edition, 2019) *Author's note on definition:* This may also be referred to as a 'project life cycle' or the 'facility life cycle'.
Quality	Degree to which a set of inherent characteristics of an object fulfils requirements. (AS ISO 41011: 2019)

Quantity Surveying Professional	A qualified construction industry professional with expert knowledge and experience in construction costs, contracts, methodology, procurement, management, and risk. (AIQS' ACMM) *Author's note on definition:* Notwithstanding the ICMS' use of the term Cost Management Professional, within this paper the AIQS preferred term of Quantity Surveying Professional has been used as having the same meaning.
Sensitivity Analysis	Testing the outcome of an evaluation by altering the values of key factors about which there might be uncertainty. (AIQS' ACMM, 2021)
Service Life	Period of time after practical completion that a constructed asset or facility, or its elements and component parts, meet(s) or exceed(s) the performance requirements. (ISO 15686 11: 2014 and ISO 21930: 2017, AIQS modified) *Author's note on definition:* 'Service Life' has been adopted throughout this document due to its use within ISO15686-5: 2017 and ICMS 2nd edition 2019, though neither includes a definition. Service Life within this document has been used as synonymous with other terms in common industry use, namely 'Design life', 'Economic life', 'Effective life', and 'Useful life'.
Strata Title	(a) The formal ownership of property held within strata plan where the property is defined within horizontal and vertical boundaries; (b) A scheme of property ownership where each proprietor owns parts of a building and has joint rights with other proprietors over the land and other common areas. (Property Council of Australia, Sept. 2019)
Sustainable Development	Development that meets the environmental, social and economic needs of the present without compromising the ability of future generations to meet their own needs. (ISO Guide 82: 2019)
Sustainable Development Goals (SDGs)	The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs)- https://sdgs.un.org/goals.
Terotechnology	The pursuit of the optimum technical and economic cost of ownership or lease of a facility over its whole life span from conception through acquisition to operation and finally disposal. (AS HB-261: 2001)
Value Analysis	A disciplined procedure directed towards the achievement of necessary functions for minimum cost, without detriment to quality, reliability, performance, and delivery. (AIQS' ACMM)

Value Engineering/ Value Management	A structured and analytical process that follows a prescribed work plan to achieve best value or, where appropriate, best value for money. (AS 4183: 2007)
Whole Life Cost (WLC)	All significant and relevant initial and future costs and benefits of an asset, throughout its life cycle, while fulfilling the performance requirements. (ISO 15685-5: 2017)
Whole-life costing	Methodology for systematic economic consideration of all whole life costs (WLC) and benefits over a period of analysis, as defined in the agreed scope. (ISO 15685-5: 2017) *ISO notes to entry:* 1) The projected costs or benefits may include external costs (including, for example, finance, business costs, income from the land sale, user costs). 2) Whole-life costing can address a period of analysis that covers the entire life cycle or (a) selected stage(s) or periods of interest thereof. 3) This definition is to be contrasted with that for life-cycle costing.

Note: This concise glossary has not included all possible relevant terms. Hence, some terms may have been omitted where they have common language meaning, or would be readily understood by AIQS members, or are not required to understand this document and/or could be sourced from other documents such as the ICMS.

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