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Buildings and constructed assets — Service-life planning —

Part 5:
Life-cycle costing

Bâtiments et biens immobiliers construits — Prévision de la durée de vie —

Partie 5: Approche en coût global

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15686-5 was prepared by Technical Committee ISO/TC 59, *Building construction*, Subcommittee SC 14, *Design life*.

ISO 15686 consists of the following parts, under the general title *Buildings and constructed assets — Service-life planning*:

— *Part 1: General principles*

— *Part 2: Service life prediction procedures*

— *Part 3: Performance audits and reviews*

— *Part 5: Life-cycle costing*

— *Part 6: Procedures for considering environmental impacts*

— *Part 7: Performance evaluation for feedback of service life data from practice*

— *Part 8: Reference service life and service-life estimation*

The following parts are in preparation:

— *Part 9: Guidance on assessment of service-life data*

— *Part 10: Levels of functional requirements and levels of serviceability — Principles, measurement and use*

Introduction

0.1 Objectives

The key objectives of this part of ISO 15686 are to

- establish clear terminology and a common methodology for life-cycle costing (LCC),
- enable the practical use of LCC so that it becomes widely used in the construction industry,
- enable the application of LCC techniques and methodology for a wide range of procurement methods,
- help to improve decision making and evaluation processes at relevant stages of any project,
- address concerns over uncertainties and risks and improve the confidence in LCC forecasting,
- make the LCC and the underlying assumptions more transparent and robust,
- set out the guiding principles, instructions, definitions for different forms of LCC and reporting,
- provide the framework for consistent LCC predictions and performance assessment, which facilitates more robust levels of comparative analysis and cost benchmarking,
- provide a common basis for setting LCC targets during design and construction, against which actual cost performance can be tracked and assessed over the asset life span,
- provide guidance on when to undertake LCC, to what level and what cost headings are appropriate for consideration,
- help unlock the real value of effectively doing LCC in construction by using service-life planning,
- clarify the differences between life-cycle costing and whole-life costing (WLC),
- provide a generic menu of costs for LCC/WLC compatible with and customizable for specific national or international cost codes and data-structure conventions,
- provide cross-references to guidance on associated activities within the other parts of ISO 15686.

0.2 Life-cycle costing, service-life planning and other performance requirements

Life-cycle costing is a valuable technique that is used for predicting and assessing the cost performance of constructed assets. Life-cycle costing is one form of analysis for determining whether a project meets the client's performance requirements. Analyses can necessitate the use of other parts of ISO 15686 and current economic data from clients and the construction industry (see Figure 1). It should be possible to use this part of ISO 15686 without extensive reference to other parts, although a number of the terms and techniques described are covered in more detail in the other parts. Where applicable, this is referenced in the text. The other parts of ISO 15686 that are most relevant for life-cycle costing are ISO 15686-1, ISO 15686-3 and ISO 15686-6.

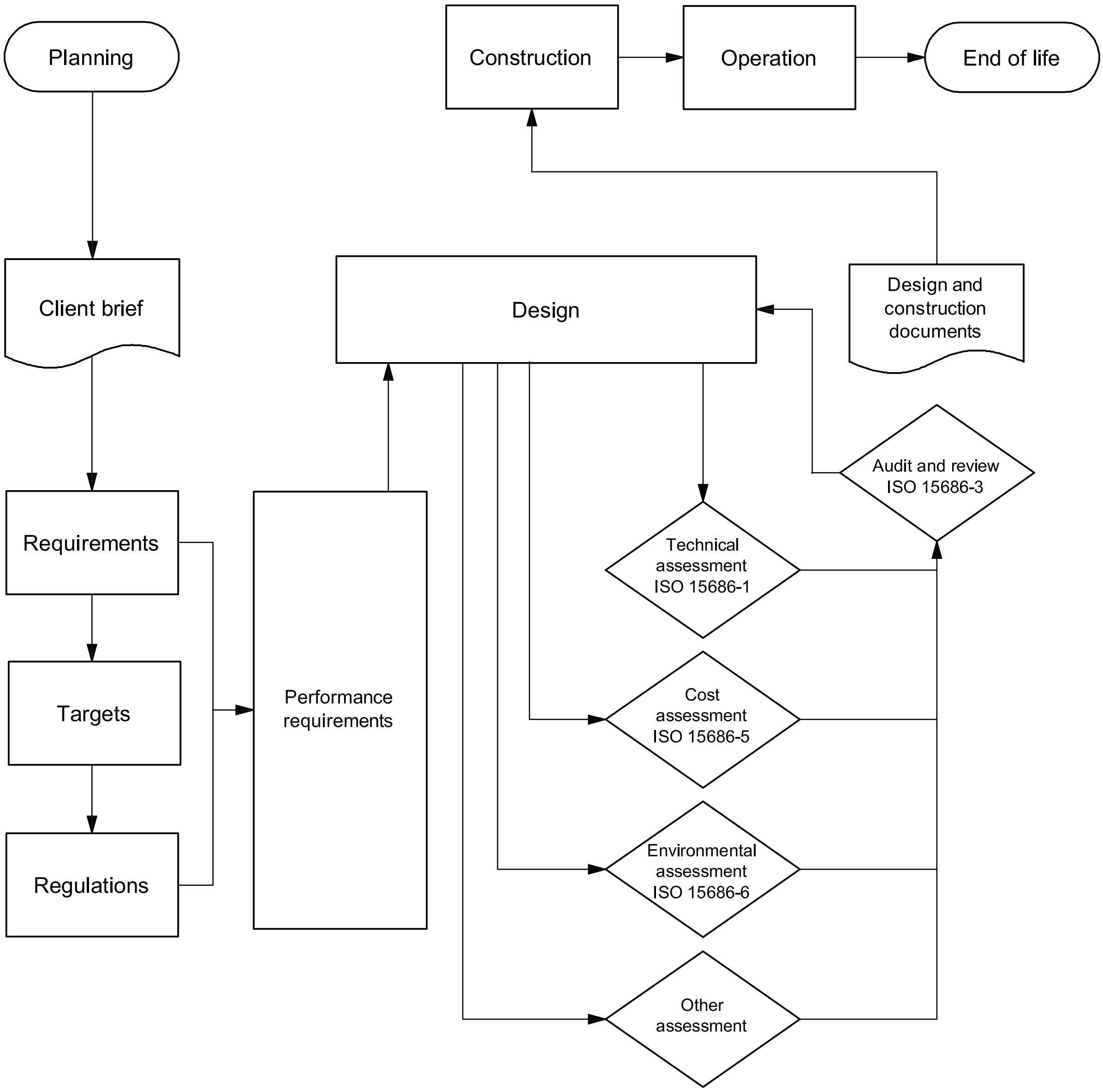


Figure 1 — Performance requirements in the context of the project life cycle

The Bibliography includes some informative national standards and guidance that provide more detail on aspects such as levels of cost analysis, examples of analysis and application of the principles for practical projects.

0.3 Who can use this part of ISO 15686?

The provisions of this part of ISO 15686 are intended primarily for

- procurers of constructed assets, with an interest in long-term ownership; these may be public or private, or lessees with a reasonably long period of interest in the property and/or responsibility for maintenance and/or operational costs,
- designers,
- constructors and their specialist suppliers of materials and components,

— facility operators (to help them input more effectively into the design process),

— cost consultants and other specialists.

The provisions in this part of ISO 15686 are particularly relevant to public clients, where the lack of any projected income from some constructed assets can make traditional investment appraisals more challenging. They are also relevant to the work of specialists providing information on service life and on environmental performance.

The period of interest of the client and the contractual responsibilities/liabilities for meeting costs tend to determine the requirements for life-cycle costing.

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.

Buildings and constructed assets — Service-life planning —

Part 5:
Life-cycle costing

1 Scope

This part of ISO 15686 gives guidelines for performing life-cycle cost (LCC) analyses of buildings and constructed assets and their parts.

NOTE 1 Life-cycle costing takes into account cost or cash flows, i.e. relevant costs (and income and externalities if included in the agreed scope) arising from acquisition through operation to disposal.

NOTE 2 Life-cycle costing typically includes a comparison between options or an estimate of future costs at portfolio, project or component level. Life-cycle costing is performed over an agreed period of analysis. It is advisable to make clear whether the analysis is for only part or for the entire life cycle of the constructed asset.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6707-1, *Building and civil engineering — Vocabulary — Part 1: General terms*

3 Terms, definitions and abbreviations

For the purposes of this document, the terms and definitions given in ISO 6707-1 and the following apply.

3.1 Costs

3.1.1
acquisition cost
all costs included in acquiring an asset by purchase/lease or construction procurement route, excluding costs during the occupation and use or end-of-life phases of the life cycle of the constructed asset

3.1.2
capital cost
initial construction costs and costs of initial adaptation where these are treated as capital expenditure

NOTE The capital cost may be identical to the acquisition cost if initial adaptation costs are not included.

3.1.3
discounted cost
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

3.1.4
disposal cost
costs associated with disposal of the asset at the end of its life cycle, including taking account of any asset transfer obligations

NOTE 1 Asset transfer obligations could include bringing the assets up to a predefined condition.

NOTE 2 Income from selling the asset is part of WLC, where the residual value of the building components, materials and appliances can be included.

3.1.5
end-of-life cost
net cost or fee for disposing of an asset at the end of its service life or interest period, including costs resulting from decommissioning, deconstruction and demolition of a building; recycling, making environmentally safe and recovery and disposal of components and materials and transport and regulatory costs

3.1.6
external costs
costs associated with an asset that are not necessarily reflected in the transaction costs between provider and consumer and that, collectively, are referred to as externalities

NOTE These costs may include business staffing, productivity and user costs; these can be taken into account in a LCC analysis but should be explicitly identified.

3.1.7
life-cycle cost
LCC
cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements

3.1.8
life-cycle costing
methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope

NOTE 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.

3.1.9
maintenance cost
total of necessarily incurred labour, material and other related costs incurred to retain a building or its parts in a state in which it can perform its required functions

NOTE Maintenance includes conducting corrective, responsive and preventative maintenance on constructed assets, or their parts, and includes all associated management, cleaning, servicing, repainting, repairing and replacing of parts where needed to allow the constructed asset to be used for its intended purposes.

3.1.10
nominal cost
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

3.1.11
operation cost
costs incurred in running and managing the facility or built environment, including administration support services

NOTE Operation costs could include rent, rates, insurances, energy and other environmental/regulatory inspection costs, local taxes and charges.

3.1.12
real cost
cost expressed as a value at the base date, including estimated changes in price due to forecast changes in efficiency and technology, but excluding general price inflation or deflation

3.1.13
sunk costs
costs of goods and services already incurred and/or irrevocably committed

NOTE These are ignored in an appraisal. The opportunity costs of obtaining or continuing to tie up capital are, however, included in WLC analysis and the opportunity costs of using assets can be dealt with as costs in LCC analysis.

3.1.14
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

3.1.15
whole-life costing
methodology for systematic economic consideration of all whole-life costs and benefits over a period of analysis, as defined in the agreed scope

NOTE 1 The projected costs or benefits may include external costs (including, for example, finance, business costs, income from land sale, user costs).

NOTE 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.

NOTE 3 This definition should be contrasted with that for life-cycle costing.

3.2 Analysis/measures

3.2.1
life-cycle assessment
LCA
method of measuring and evaluating the environmental impacts associated with a product, system or activity, by describing and assessing the energy and materials used and released to the environment over the life cycle

3.2.2
net present value
NPV
sum of the discounted future cash flows

NOTE 1 Where only costs are included, this can be termed **net present cost** (3.2.3).

NOTE 2 This is the standard criterion for deciding whether an option can be justified on economic principles, but other techniques are also used as described in Annex B.

3.2.3
net present cost
NPC
sum of the discounted future costs

3.2.4
present-day value
PDV
monies accruing in the future which have been discounted to account for the fact that they are worth less at the time of calculation

3.2.5
sensitivity analysis
test of the outcome of an analysis by altering one or more parameters from initial value(s)

3.3 Elements of calculation

3.3.1
discount rate
factor or rate reflecting the time value of money that is used to convert cash flows occurring at different times to a common time

NOTE This can be used to convert future values to present-day values and vice versa.

3.3.2
escalation rate
positive or negative factor or rate reflecting an estimate of differential increase/decrease in the general price level for a particular commodity, or group of commodities, or resource

NOTE An escalation rate is derived by tracking the change in price over time of a single commodity, group or commodities or resource, which might or might not be one of the items in the typical “basket” of goods that is used to derive a general inflation/deflation factor.

3.3.3
inflation/deflation
sustained increase/decrease in the general price level

NOTE Inflation/deflation can be measured monthly, quarterly or annually against a known index.

3.3.4
life cycle
consecutive and interlinked stages of the object under consideration

NOTE 1 The life cycle comprises all stages from construction, operation and maintenance to end-of-life, including decommissioning, deconstruction and disposal.

NOTE 2 Adapted from the definition of life cycle contained in ISO 14040.

3.3.5
nominal discount rate
factor or rate used to relate present and future money values in comparable terms taking into account the general inflation/deflation rate

3.3.6
period of analysis
period of time over which life-cycle costs or whole-life costs are analysed

NOTE The period of analysis is determined by the client.

3.3.7
real discount rate
factor or rate used to relate present and future money values in comparable terms, not taking into account the general or specific inflation in the cost of a particular asset under consideration

3.3.8
residual value
value assigned to an asset at the end of the period of analysis

3.4 Other terms

3.4.1
asset
whole building or structure, system or a component or part

3.4.2
externality
quantifiable cost or benefit that occurs when the actions of organizations and individuals have an effect on people other than themselves

EXAMPLES Non-construction costs, income and wider social and business costs.

NOTE Externalities are positive if their effects are benefits to other people and negative, or external costs, if the external effects are costs on other people. There may be external costs and benefits from both production and consumption. Adding the externality to the private cost/benefit gives the total social cost or benefit.

3.4.3
intangible
quantifiable cost and benefit that have been allocated monetary values for calculation purposes

3.4.4
risk
likelihood of the occurrence of an event or failure and the consequences or impact of that event or failure

3.4.5
time value of money
measurement of the difference between future monies and the present-day value of monies

3.4.6
uncertainty
lack of certain, deterministic values for the variable inputs used in an LCC analysis of an asset

4 Principles of life-cycle costing

4.1 Purpose and scope of life-cycle costing

The purpose of life-cycle costing should be to quantify the life-cycle cost (LCC) for input into a decision-making or evaluation process, and should usually also include inputs from other evaluations (e.g. environmental assessment, design assessment, safety assessment, functionality assessment, regulatory compliance assessment). The quantification should be to the level of detail that is required for key project stages. The scope of costs included/excluded from an LCC analysis should be defined and agreed with the client at the outset.

4.2 Costs to include in LCC analysis

4.2.1 Defining scope of costs included in the analysis

LCC analysis should cover a defined list of costs over the physical, technical, economic or functional life of a constructed asset, over a defined period of analysis. Life-cycle costing should also be influenced by non-construction costs and wider occupancy costs, as well as local, national or international policies, allowances, taxes, etc. LCC analysis may include allowances for foreseeable changes, such as future occupancy levels or changing legislative or regulatory parameters. LCC analysis may also form part of a strategic review of procurement routes or objectives (such as enhancing sustainability or improving functionality).

Practice can vary between users as to whether only costs borne by the customer for the analysis (typically the construction client) are taken into account, or whether customer/societal, etc. costs are also included.

NOTE 1 Where the user and the construction client are different parties (e.g. in social housing), it can be required to take these external costs into account.

NOTE 2 The definitions of the terms “intangible” (3.4.3) and “externality” (3.4.2) have been formulated to describe the wider costs. The former are monetarized aspects which have some (often indirect) economic impact on the client organization. The latter are external to the client organization. It is necessary that both be clearly identified as such in any analysis. This issue is dealt with in more detail in Clause 7.

Figure 2 indicates graphically the costs that should be included in life-cycle costing and those wider costs and incomes that should be referred to as whole-life costs.

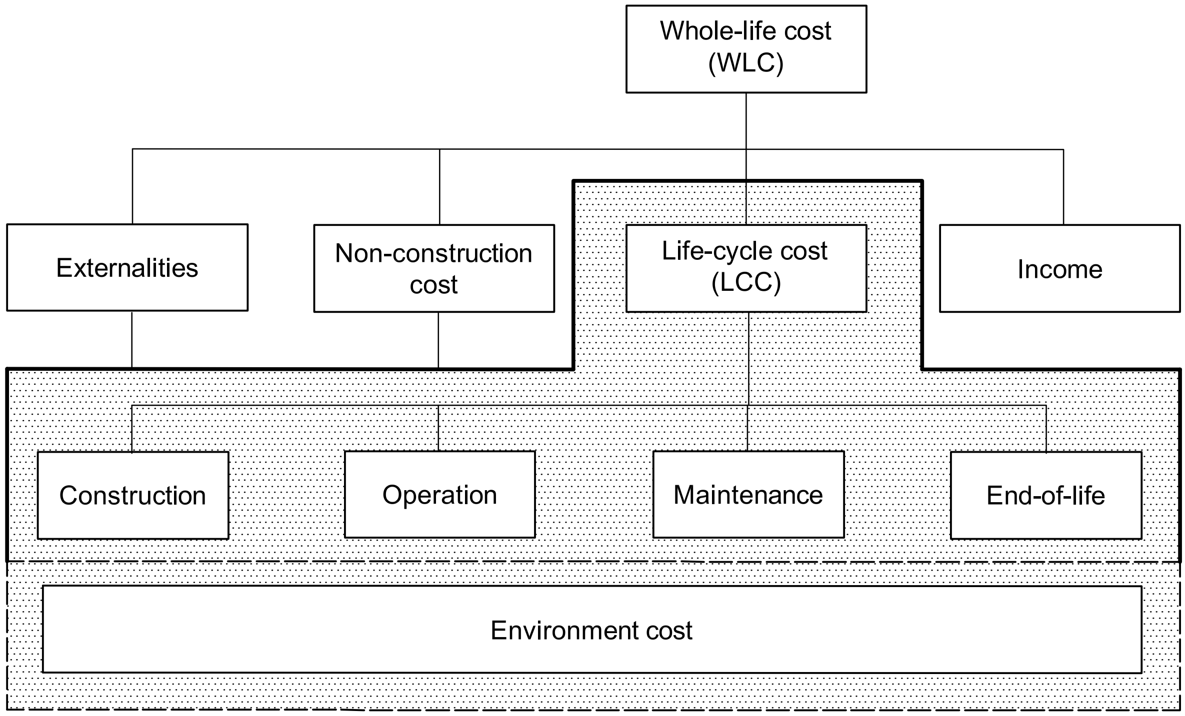


Figure 2 — WLC and LCC elements

The LCC analysis should consider all basic elements, such as the structure, envelope, services and finishes, fixtures and fittings, and the same cost issues for all options appraised.

4.2.2 Classification of costs

Figure 3 describes a generic cost classification that may be used to help define the specific scope of the analysis, providing a structured basis for comparative analysis that is intended to accommodate local practices.

NOTE 1 It is not necessary for every item included in the figure to be considered, and some additional costs can be required for certain projects. The intention is that more detailed guidance and cost structures applicable to national conditions are used to develop the cost plans, which can then be mapped to this structure.

Whole-life cost (WLC)

		Y/N	Examples of cost
Non-construction costs		Y/N	Examples of cost
	Land and enabling works	☐	Site costs (land and any existing building)
	Finance	☐	Interest or cost of money and wider economic impacts
	User support costs (1) strategic property management	☐	Includes in-house resources and real estate/property management/general inspections, acquisition, disposal and removal
	User support costs (2) use charges	☐	Unitary charges, parking charges, charges for associated facilities
	User support costs (3) administration	☐	Reception, helpdesk, switchboard, post, IT services, library services, catering, hospitality, vending, equipment, furniture, internal plants (plant care and flowers), stationery, refuse collection, caretaking and portering, security, ICT internal moves, snow clearance
	Taxes	☐	Taxes on non-construction items
	Other	☐	
Income			
	Income from sales	☐	Residual value on disposal of interest in land, constructed assets or salvaged materials, including grants, etc.
	Third-party income during operation	☐	Rent and service charges
	Taxes on income	☐	On land transactions
	Disruption	☐	Downtime, loss of income
	Other	☐	
Externalities			

Life-cycle cost (LCC)

		Y/N	
Construction		Y/N	
	Professional fees	☐	Project design and engineering, statutory consents
	Temporary works	☐	Site clearance, etc.
	Construction of asset	☐	Including infrastructure, fixtures, fitting-out, commissioning, valuation and handover
	Initial adaptation or refurbishment of asset	☐	Including infrastructure, fixtures, fitting-out, commissioning, valuation and handover
	Taxes	☐	Taxes on construction goods and services (e.g. VAT)
	Other	☐	Project contingencies
Operation			
	Rent	☐	
	Insurance	☐	Building owner and/or occupiers
	Cyclical regulatory costs	☐	Fire, access inspections
	Utilities	☐	Inluding fuel for heating, cooling, power, lighting, water and sewerage costs
	Taxes	☐	Rates, local charges, environmental taxes
	Other	☐	Allowance for future compliance with regulatory changes
Maintenance			
	Maintenance management	☐	Cyclical inspections, design of works, management of planned service contracts
	Adaptation or refurbishment of asset in use	☐	Including infrastructure, fitting-out, commissioning, validation and handover
	Repairs and replacement of minor components/small areas	☐	Defined by value, size of area, contract terms
	Replacement of major systems and components	☐	Including associated design and project management
	Cleaning	☐	Including regular cyclical cleaning and periodic specific cleaning
	Grounds maintenance	☐	Within defined site area
	Redecoration	☐	Including regular, periodic and specific decoration
	Taxes	☐	Taxes on maintenance goods and services
	Other	☐	
End-of-life			
	Disposal inspections	☐	Final condition inspections
	Disposal and demolition	☐	Including decommissioning, disposal of materials and site clean-up
	Reinstatement to meet contractual requirements	☐	On condition criteria for end of lease
	Taxes	☐	Taxes on goods and services
	Other	☐	

Figure 3 — Typical scope of costs (to select some, or all, for LCC analysis)

Costs should generally be placed by category; minor deviations due to restrictions of national coding should be stated. In some countries, it can be difficult to subdivide costs into cost groups. In these cases, groups may be combined for analysis purposes.

Cleaning may be categorized under “maintenance” (as defined in this part of ISO 15686) or under “operation”, in which case it should be noted as such.

Land costs within non-construction costs may include initial costs, such as soil improvement techniques or provision of infrastructure to allow development of the site.

NOTE 2 These costs are for enabling works, and while they can incur a cost to the client for the LCC analysis, they are rarely included in the analysis of construction costs, as they tend to occur in advance of the main construction works, and can incur costs to different landowners. Also, they can be sunk costs by the time the LCC analysis is commissioned. If the client for the analysis requires that enabling works costs be included, it is necessary that this be noted in reporting.

The LCC analysis should clearly include a scoping section that indicates which costs are within the boundary conditions (system and/or constructed asset) and any parts of the life-cycle costing that have been excluded.

The end of the service life of the constructed asset might or might not be included in the “end-of-life costs” of the building-life cycle.

4.3 Typical analysis at different stages of the life cycle

Typically, LCC analysis may be used during the following four key stages of the life cycle of any constructed asset:

a) project investment and planning; WLC/LCC strategic options analyses; preconstruction;

b) design and construction; LCC during construction, at scheme, functional, system and detailed component levels;

c) during occupation; LCC during occupation (cost-in-use); post-construction;

d) disposal; LCC at end-of-life/end-of-interest.

Figure 4 indicates the typical use of LCC analysis at distinct stages during the whole-life cycle, and the cost elements that should be included at each stage.

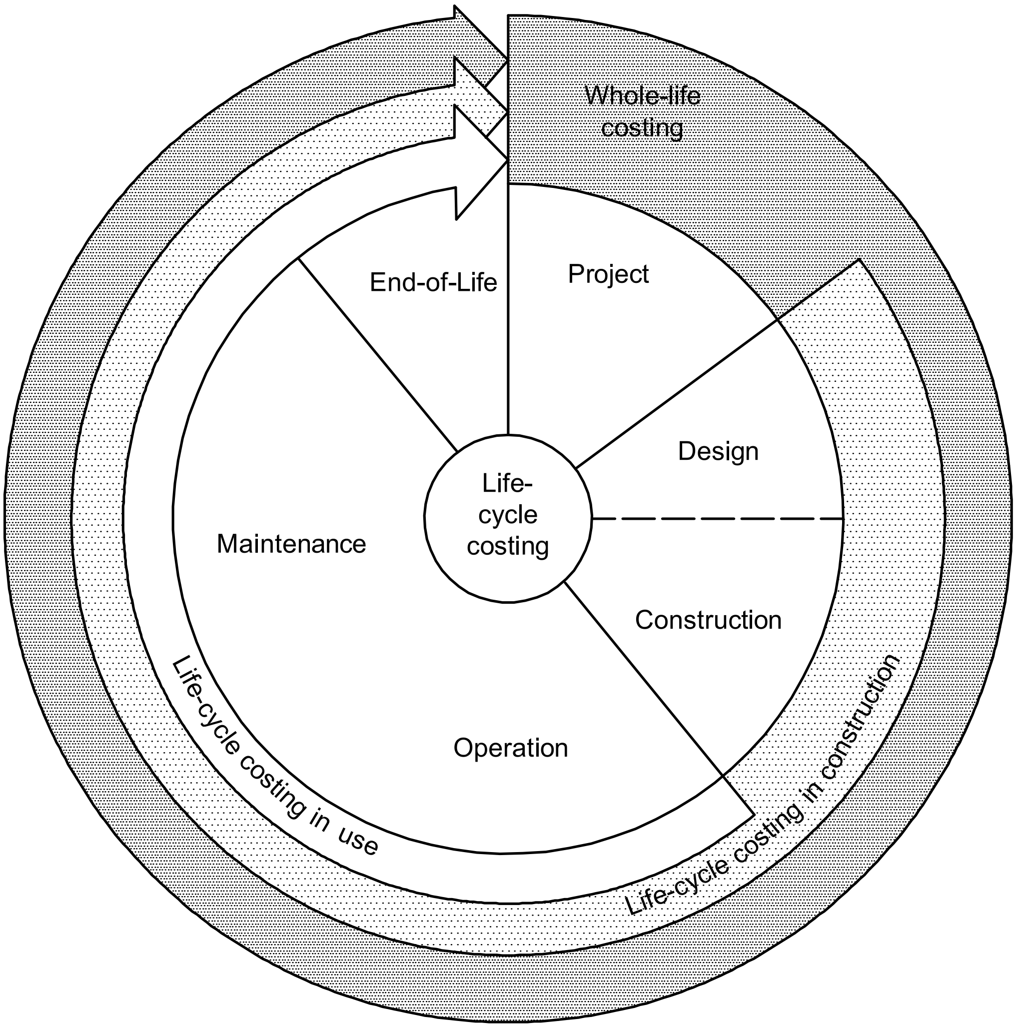


Figure 4 — Analysis at different stages of the life cycle

4.4 Analysis based on client requirements and the intended use of the results

4.4.1 Scope based on client requirements

The client's brief should define the objectives for the scope of the LCC analysis and the intended use of the results.

NOTE 1 The different decisions informed by LCC analysis are described in 4.4.2.

When the life-cycle costing involves an economic comparison of different options, they should meet all the functional, operational, maintenance and other performance (including aesthetic) requirements set by the client, and also take account of all known regulatory requirements over the period of analysis, as specifically defined and set out in the client’s requirements brief.

NOTE 2 Increasingly, client’s life-cycle costing briefs require more than a static analysis of two or more fixed options.

Earlier LCC analysis combined with other decision-support techniques can substantially influence design solutions, component specifications and/or contractual procurement routes adopted for new projects and strategic asset management.

NOTE 3 Decision-support techniques can include risk management; value management/engineering; operational cost and performance modelling.

NOTE 4 Strategic asset management can include capital-investment planning; maintenance strategies; outsourcing; demonstrating sustainability and reducing environmental impact; enhancing the functional performance of facilities; providing more flexible solutions in terms of space planning/functional capacity.

The client requirements may be revised and clarified through the project life cycle. Various briefing documents may be produced at different stages, and the requirements identified can be relevant to any stage of the life cycle, as indicated in Figure 5.

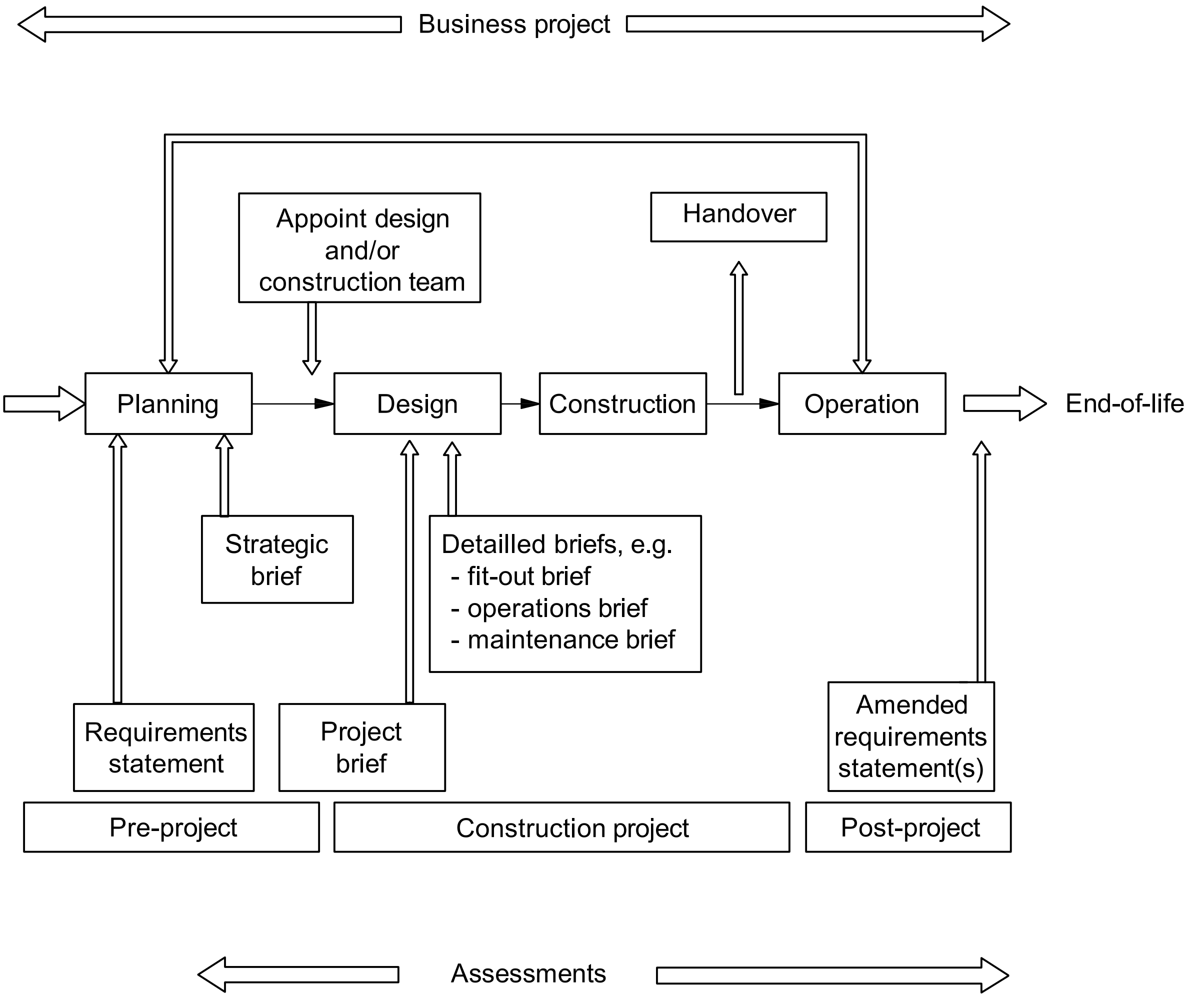


Figure 5 — Client requirements through the project life cycle

4.4.2 Decisions informed by LCC analysis

Figure 6 indicates the different levels of LCC analysis (strategic, system level and detailed level) that can occur at different stages of the life cycle. LCC analysis may be used for new assets or major refurbishments and planning the future use of existing assets. LCC analysis may be applied to a complete asset or to a specific assembly, component or system such as plant, road surface or a roofing assembly.

The LCC for a complete building or structure should be built up from the sum of the independent parts plus the interaction between them and the consequential costs, if any.

Typical decisions informed by LCC analysis can include

a) evaluation of different investment scenarios (e.g. to adapt and redevelop an existing facility, or to provide a totally new facility) at the investment planning stage,

b) choices between alternative designs for the whole or part of a constructed asset (asset, system or detailed element level LCC analysis) during the design and construction stage,

c) choices among alternative components, all of which have acceptable performance (component-level LCC analysis) during the construction or in-use stages,

d) comparison and/or benchmarking analysis of previous decisions, which may be at the level of individual cost headings (e.g. energy costs, cleaning costs) or at a strategic level (e.g. open plan versus cellular office accommodation),

e) estimation of future costs for budgetary purposes or for the evaluation of the acceptability of an option on the basis of cost of ownership.

NOTE Such decisions, especially those placed in a strategic (organizational) framework, can create added value for the asset and help to identify the most cost-effective operations and maintenance regime.

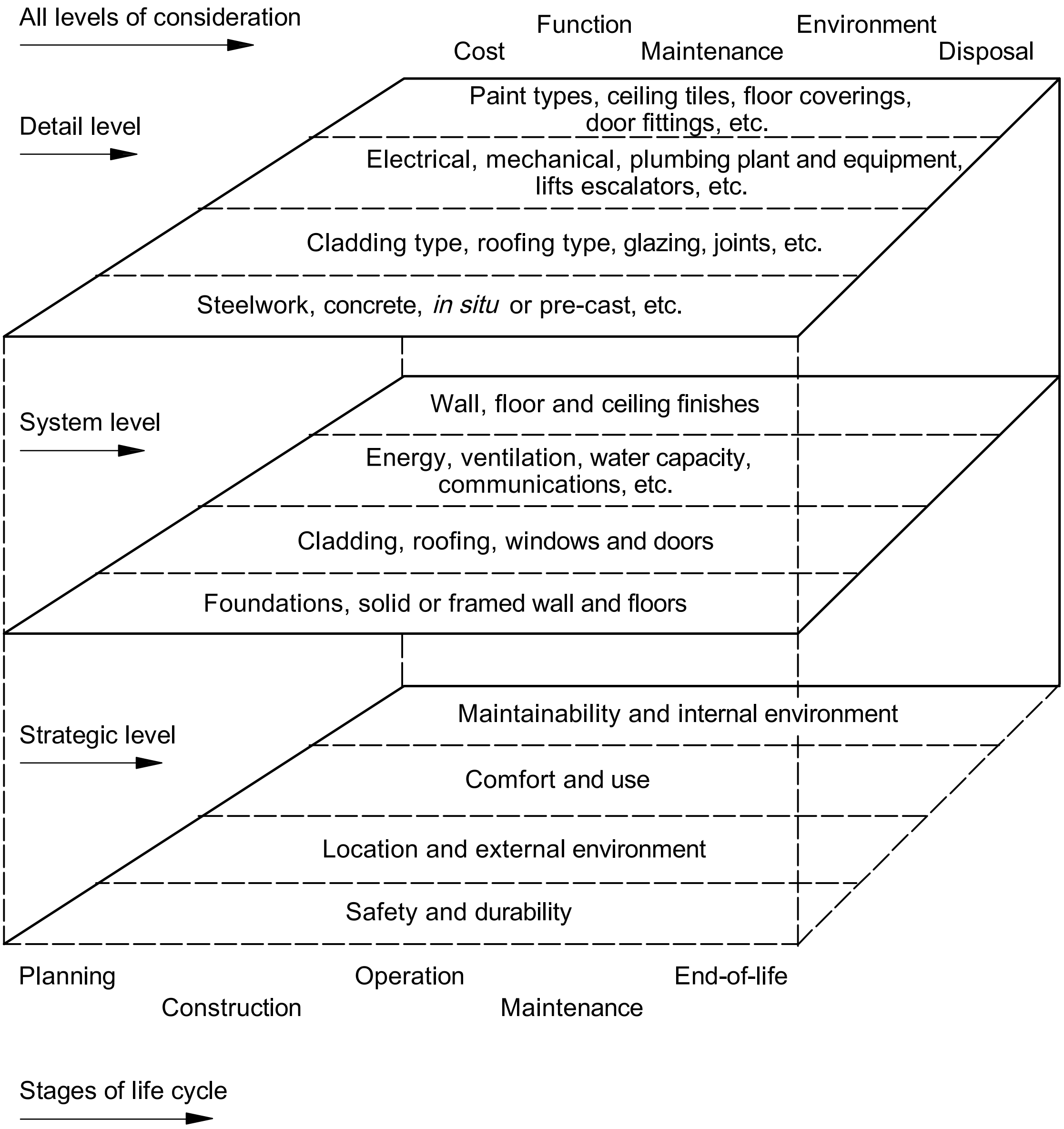


Figure 6 — Different levels of analysis at different stages of the life cycle

4.4.3 Strategic level project planning — Evaluation of alternative strategic options

This phase can include many individual activities relating to carrying out strategic-level option appraisals for the specific acquisition of a capital asset (acquire or construct), including the following:

a) definition of the requirements for a constructed asset, in terms of functional and performance requirements;

b) set design life and the level and period of analysis covered by the LCC analysis;

c) client priorities (e.g. required rate of return on capital investment and hand-back obligations);

d) preliminary design concepts and related life-cycle costing assumptions on specifications or service-life plans;

e) acquisition route (including construction/fit-out and commissioning and/or by purchase/lease);

f) purchase (including essential commissioning and taking into account income from the sale of the existing asset);

g) cost-of-ownership considerations (including or not the costs for the end-of-life/disposal of the asset);

h) other non-construction costs (as applicable for investment-decision-making purposes).

Each strategic option should have a separate life-cycle costing. Broad assumptions may be made at this stage for key variables and may include assumptions about future requirements (such as future accommodation needs), and about variables in the cost calculation (such as costs of energy and choice of applied discount rates). Technical assumptions may also be made about the data included in calculations (such as timing of cost flows and service life of components). All assumptions should be noted in the report of the analysis.

NOTE Guidance on these issues is included in ISO 15686-1, which describes a process of planning the service life of the asset going beyond simple comparisons between alternative solutions.

4.4.4 System and detailed decision level — Integrating life-cycle costing into design appraisals

Figure 7 provides an indication of the scope for LCC savings that can be made during the project life-cycle phases.

NOTE 1 The planning and design phase offers the greatest potential to influence the post-construction life-cycle cost, since the opportunity to influence the design and construction options becomes increasingly limited as the acquisition phase proceeds beyond the commitment to invest in purchase or construction of the asset. Up to 80 % of the operation, maintenance and replacement costs of a building can be influenced in the first 20 % of the design process.

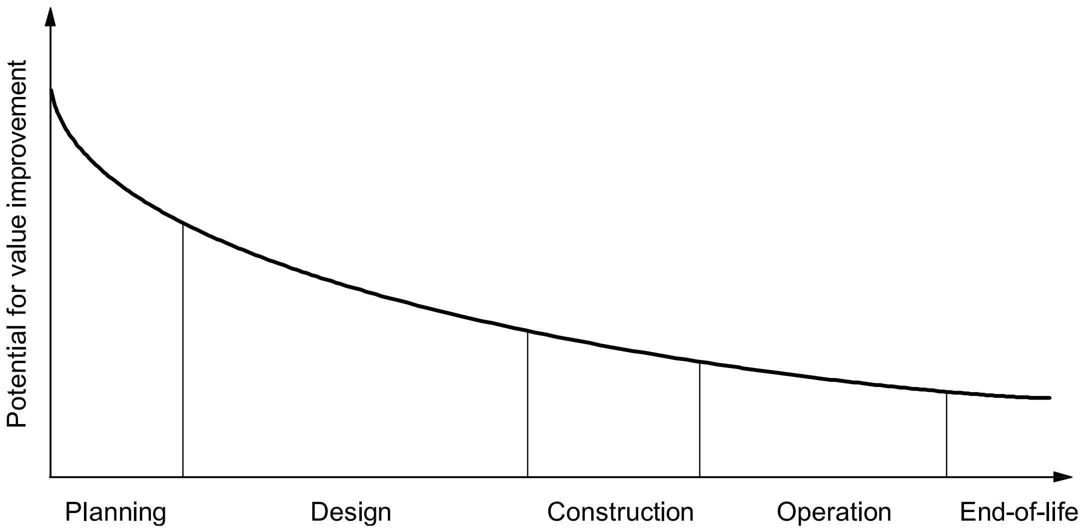


Figure 7 — Scope to influence LCC savings over time

Decisions, data feedback and continual monitoring and optimization of LCC should continue through the service life of the facility.

The original life-cycle costing assumptions should be reviewed and progressively refined or replaced by better analysis of quantities, costs and predicted performance of alternative components, materials and services as the design detail develops. Assumptions about the basis of calculation (such as the period of analysis and the discount rate to be applied) should also be confirmed during this phase of the analysis.

NOTE 2 As the design is developed, the LCC plan is estimated from the capital and operational cost plans, based on the level of information available.

The LCC analyses should be developed concurrently with the design and should be continuously related back to the initial plan, with any conflicts highlighted and resolved as applicable. Progressively, reliance on historic costs should be replaced by confidence in predicted costs for the project under review.

4.4.5 Service-life planning — LCC plans

The LCC plan should be developed from the construction information and updated during the construction phase to establish the LCC plan for the operation period.

The performance and costs of the completed construction should be monitored and can highlight deviations from the cost predictions; consequences of changes to the operating and maintenance regimes; increases in running costs that can be as a result of client adaptations; over-cautious or optimistic predictions or time estimates.

The LCC plan should include documentation of the reliability and durability information, maintenance plans, the estimated life cycle for major repairs, and the replacement of the components and building services. The plan should also include sufficient detail to allow monitoring of costs and timing of work. The completed construction project should be supported by manuals setting out the information on operational, maintenance and life-cycle repairs, and replacement/end-of-life disposal procedures. The timing of activities during the operation and maintenance phase activities should be forecast and agreed in the form of a schedule.

NOTE 1 See ISO 15686-1 and ISO 15686-2 for guidance on estimating and predicting the service life of components.

NOTE 2 See ISO 15686-3 for further details on documentation to accompany service-life planning.

The level of operation and maintenance activities should be included in the LCC analysis, as they can shorten or lengthen the service life.

NOTE 3 The operation and maintenance phases are usually the longest in the life cycle of constructed assets, but these phases are often neglected. The separately identifiable costs associated with operations and maintenance often occur repeatedly. They are likely to represent a large share of the total LCC of the constructed asset and often detailed analysis of major cost headings is necessary (e.g. to achieve an acceptable balance between capital and the operation and maintenance and replacement/end-of-life costs or to limit unacceptable risks of failure in use).

4.4.6 Major repairs, replacements and adaptations

The cost of planned major repairs, replacements and adaptations should be included in the LCC plan, even though the plan can require revision when the activities actually occur.

NOTE Major repairs, replacement (and adaptation if required) are essentially a partial repeat of the activities in the design and construction phases, but at a different point in the life cycle of the constructed asset. The operation and maintenance phase then begins again with different starting characteristics.

A new LCC analysis should be prepared if a major refurbishment or replacement is needed during the operation phase. The decision to undertake refurbishment should include assessment of the revised residual life of the constructed asset and whether the original design life estimates remain valid when set against achieved service lives and any changed requirements by the occupier/client.

4.4.7 End-of-life

The LCC analysis should indicate the costs that are included for the end-of-life phase of the life cycle. Demolition can occur before or after disposal and it should be clear whether the costs are included in the analysis.

NOTE 1 The end-of-life stage can include inspections prior to disposal and can require demolition, preparation for recycling and/or re-use and/or disposal as waste.

NOTE 2 Disposal can result in an income rather than a cost if the constructed asset or its parts have further potential use. Income can be considered, if required, in the WLC analysis.

4.5 Data for analysis at different stages of the project life cycle

4.5.1 General

Life-cycle costing can be carried out at a coarse level using industry-average or benchmark figures for that type of construction (these are sometimes termed “parametric estimates”) or at a detailed level on the basis of specific estimates or predictions of component performance and maintenance activities. Calculations of LCC can be made at various levels depending on which phase of the project process is involved. The degree of detail and information available should play a decisive role. The general principle that determines the level of detail at which calculations of LCC are made should be the corresponding level of detail employed to calculate the acquisition costs.

NOTE Generally, earlier analysis within the project life cycle is at benchmark level and later analysis is more detailed.

4.5.2 Benchmark LCC analysis

Typically, an initial (budget) cost analysis should be based on the functional unit (e.g. cost per bed) or total area of the asset (e.g. cost per square metres) or on the number of persons accommodated (e.g. in a school, prison or office).

NOTE 1 With more time, the LCC cost model can be calculated in the form of an elemental-level analysis using an integrated LCC structure, which improves the accuracy of the estimating. Caution is needed to ensure that previous projects used as the basis for rates (at asset or elemental level) are comparable with the proposed asset. It is necessary that the analysis also reflect changes in costs since the previous project was undertaken and any other local factors relevant to the new project.

The benchmark-level estimate should be progressively refined but can be retained only as a basis for checking against the detailed life-cycle costing analysis.

NOTE 2 A high-level classification of costs is included in this part of ISO 15686 (see Figure 3), but it is likely that more detailed cost structures are used to develop benchmark costs for specific design options.

4.5.3 Detailed LCC analysis

Detailed life-cycle costing analysis should be based on the proposed design detailing and a quantum of individual elements or components of the constructed asset. These should then be summed up to produce a LCC estimate based on first principles. As the design evolves, the impact of specific options should be tested to assess the impact on the overall cost (and other project performance requirements, such as time to complete the work). The level of analysis may include the specific consideration of service-life planning of the proposed design of composite items. More detailed service lives for particular assets should be considered to evaluate and inform specification choices.

There are various national standards available on how to break down costs into a structured analysis (see Bibliography), and it is important to note that the comparison of typical costs from different sources should ensure that each data structure is clearly understood.

4.6 Cost variables

For each cost, whether a cost benchmark or a detailed cost-analysis category, the associated time profile of when the cost occurs (or recurs) should be determined. Time profiles of the costs may consist of only one occurrence, but any cost that is spread over time, or one that is repeated, can also generate a series of cost and time pairs. Costs may be fixed or variable over time. The basis of the timing of life-cycle costs or other cash flows should be recorded in the form of a life-cycle-assumptions schedule.

NOTE 1 These time and cost pairs are most readily converted into LCC estimates over the period of analysis, using a computer spreadsheet or purpose-built software.

The costs should be expressed in real costs rather than the value in the future (e.g. the current cost of a boiler they are should be used, not nominal costs) due to the uncertainty of future values. However, nominal (future) values may be used, provided they are clearly differentiated in reporting.

Values for predicted, future life-cycle costs should be as accurate as possible. Particular emphasis should be given to the most significant cost variables and where robust benchmark data sets are limited. Values can be derived from

a) a direct estimation from known costs and components,

b) historical data analysis from typical applications (e.g. bills of quantities),

c) models based on expected performance, averages, etc.,

d) best guesses of future trends in technology, market and application.

Computer models set up for sensitivity and risk analysis should ideally be totally in parametric form, i.e. each value should be related to a parameter which, when changed, causes all other costs derived from it to change. Alternatively, logical analysis and checking of variables may be performed with each change.

The level of information about cost variables can be dependent on a number of factors, such as the difficulty of obtaining the range and detail of required input information upon which to base an LCC analysis or type of LCC evaluation methods and models used.

NOTE 2 This can result in inconsistency in the underlying scoping and assumptions.

It can be necessary to consider other cost variables, e.g. currency and cost conversion.

NOTE 3 Clauses 5 and 7 provide guidance on the variables that should be included in LCC analysis. Clause 6 covers optional variables that can be included in WLC analysis.

4.7 Calculating cost variables and the form of future costs analysis

Costs in an LCC analysis should be clearly indicated in real or nominal, and present or discounted, terms and should be used consistently. Ideally, real and discounted costs should be used.

NOTE More details are given in 5.4.5 and Clause 7.

4.8 Discounting costs to present values

Future values may be recalculated to present values when an investment requires

a) a payment at the beginning of the investment period, and/or

b) payments on future dates.

NOTE The concept of the "time value of money" suggests that, in investment terms, money has a value depending on the exact date on which it is received or paid; this is dealt with by discounting future values to arrive at the present value. The "time value of money" is allowed for by discounting future costs to reflect their diminished value in the year of transaction relative to the base year. The discount rate varies according to the organization involved.

4.9 Approval and validation

Funders and/or clients can require that the LCC assumptions and decisions be reviewed or audited to confirm that they provide an adequate and acceptable basis for the LCC estimate.

NOTE 1 Life-cycle costing requires assumptions about the future use and operation of the building or constructed asset and that decisions be made about the detailed life-cycle costing methodology and outputs. These assumptions and decisions have a significant influence on the outcomes of the life-cycle costing.

NOTE 2 ISO 15686-3 gives detailed guidance on reviewing assumptions and decisions. In particular, ISO 15686-3:2002, Table 1, gives guidance on the review and audit activities at various stages in the project. Approval and validation of the assumptions and methodology is covered at the project-definition stage.

4.10 Reporting LCC analysis

Reporting of the LCC analysis should make clear the scope of the analysis, the information on which it is based and the level of reliance that can be placed on the information.

NOTE 1 Confidence in the results of LCC analysis depends on the existence and use of the relevant information, the assumptions made, any omissions or exclusions and the input data used in the analysis. Erroneous conclusions can be drawn and wrong decisions made due to the use of incorrect data or the omission of cost-significant items (see AS/NZS 4536 [1]).

Two techniques that can be useful in indicating the range of uncertainty and risk associated with specific LCC analyses are the Monte Carlo method and sensitivity analysis.

NOTE 2 The Monte Carlo method and sensitivity analysis are briefly described in Clause 8.

NOTE 3 Clause 9 gives a brief indication of the requirements for reporting and the audit trail associated with reporting the LCC analysis. Further relevant guidance can be found in ISO 15686-3.

5 Setting the scope for LCC analysis

5.1 Relevance and importance of setting parameters for the use of life-cycle costing

LCC analysis should explicitly define the scope, form, level and period of analysis together with an anticipated level of uncertainty and risks relating to the LCC analysis and reporting. The parameters of the LCC analysis should depend on the purpose and use of the intended results. The validity and relevance of the analysis can depend on the parameters selected. In particular, people with broad expertise in facilities management, maintenance and repair should provide input to the appraisal.

An LCC analysis can be undertaken to understand the implications of an investment in a constructed asset. Often, it is used to compare and evaluate options that can have different implications.

NOTE 1 For comparison of alternative investment options, see Clause 6 and Annex B.

Doing nothing should be included as an option, especially in the case of refurbishment. All options should satisfy the client's requirements brief; comparing substandard options should be avoided. If the initial comparison results are unacceptable, this can indicate that the original brief should be revised.

The repercussions or consequences of selecting an option should also be considered; for example,

a) changing the thermal resistance properties of the envelope by selecting different materials can result in changes in heating and cooling costs;

b) changing from a paint to a lightweight stain can require a different application regime and re-coating at different frequencies;

c) providing a better initial specification can result in reduced disruption to the use of transport infrastructure assets during maintenance;

d) providing a specification that can adapt to changing demands (e.g. for road or school use) can provide a longer life cycle.

In particular, options can have different external or intangible costs, such as restricting access to the building or disrupting occupant activities. These might not be costs borne by the client (e.g. disruption and associated loss of retail income to tenants in a shopping centre during building maintenance) and so can be overlooked.

NOTE 2 Major cost implications tend to be associated with significant/strategic design options, such as orientation, building footprint, location or site, building height or layout. Similarly, the selection of options for indoor climate control, such as between passive ventilation/solar design and air conditioning/heating, can have significant capital and operating cost implications. For non-building assets, the long-term performance, safety and flexibility tend to be critical, as these assets often have a longer life cycle. Clauses 6 and 7 describe some of the critical variables that it is advisable to consider in an option appraisal.

5.2 Service life, life cycle and design life

The design life of the constructed asset is a key performance requirement and should be defined in the client's brief. The estimated service life of the asset should be at least as long as the design life.

Service-life replacement dates should be included in life-cycle costing. The life cycle should take account of the period during which the asset is intended to be used for its function or business purpose. This period can dictate the period of analysis of the LCC and can dictate the design life for major assets and components.

NOTE For further information on estimated service life and design life, see ISO 15686-1 and ISO 15686-2. Maintenance, repair and replacement are required for certain parts to achieve the predicted/estimated life cycle.

5.3 Period of analysis

The period of analysis should be based on the client's requirements, which may be over the life cycle of the asset.

NOTE 1 Where the life cycle is longer than 100 years, the period used in calculations can be 100 years (by agreement) as the calculation is unlikely to be significantly affected beyond this point.

Other factors can also be taken into account, such as the following:

a) the period of foreseeable need or occupation of the constructed asset (the entire life cycle); this is the preferred period of analysis; if the analysis is over a shorter period, this should be explicitly indicated in reporting;

b) a period determined by a contractual liability (e.g. for maintenance of the asset or for a mortgage financing the investment);

c) a standard investment-analysis period applied within an organization.

It can be necessary for the LCC analysis to consider costs occurring outside the period of analysis as they can significantly impact the client's costs of ownership.

NOTE 2 Such costs can include heavy maintenance costs due after the end of a period of analysis (and/or associated loss of performance) and the residual value of the asset.

The results of the LCC analysis may be reviewed over several periods of analysis if a shorter period than the life cycle is selected. There can also be a requirement to assess the risk inherent in delaying maintenance works beyond the end of the period of analysis.

Obsolescence should be taken into account when setting the period of analysis, as it can cause the unplanned end-of-service-life or a change of use. A sensitivity analysis can reveal how precise the calculation is, and how it affects the calculation if the input were different.

NOTE 3 More information on obsolescence is given in ISO 15686-1.

5.4 Cost variables

5.4.1 Acquisition costs

LCC analysis may be used to demonstrate whether or not higher acquisition costs are justified by lower in-use costs and/or enhanced performance.

NOTE Improvements (e.g. to the site landscaping, or certification to ISO 14001) can be justified on the basis of increase to the value of the building in a WLC analysis.

Acquisition costs may form a substantial part of the total LCC for new construction and/or assets with a short life cycle. Acquisition costs may include

a) site costs (potentially including site improvement, enabling works and infrastructure provision, although these may be the subject of separate projects or may be sunk costs);

b) temporary works/decanting costs;

c) design/engineering costs;

d) regulatory/planning costs;

e) construction and earthworks;

f) commissioning costs/fees;

g) business use of in-house resources and administration.

Sunk costs should not be included in an LCC analysis except where there is an opportunity cost in using an existing asset or land in the ownership of the client. In this situation, the opportunity cost may be included in the LCC analysis, but it should be noted.

5.4.2 Operation, maintenance and replacement costs

5.4.2.1 Operation, maintenance and replacement issues

The prime objectives of estimating the operation, maintenance and replacement costs should be

— to ensure that the service life is optimized to meet the specified design life,

— to understand the implications of options under consideration.

Operation and maintenance should be an integral part of any LCC analysis. A wide range of operation and maintenance types, activities and frequencies can have different costs and effects on the ongoing performance and future replacement cycles of a constructed asset. The results of the LCC analysis (with consideration of other performance requirements in the client brief) can determine an acceptable operation, maintenance and replacement plan for the constructed asset.

Issues that should be considered include

a) the performance over time of each element in the anticipated building location,

b) the identification of probable dates of failure and whether they conform to the client brief or regulations,

c) the work required and associated costs to retain and/or restore the element to acceptable performance at various stages through its life (by maintenance or replacement),

d) the costs associated with loss of the amenity due to unavailability or failure,

e) the costs associated with degraded performance,

f) the reduced service life (of the building or element as appropriate) resulting from any maintenance option,

g) the costs that a particular operation and maintenance option incur at the design stage (e.g. the costs of building in access for cleaning or replacement options),

h) the maintenance and associated management costs that tend to occur/recur on regular, short-term cycles,

i) replacement costs that can occur on (a) relatively longer cycle(s) and can be analysed separately or as part of the capital costs,

j) energy and other consumable/utilities costs associated with mechanical and electrical plant and machinery.

The issues described above can require iterative consideration following changes or developments to the design or to the client's requirements. LCC analysis can require reconsideration or full revision at different stages of the life cycle.

NOTE Failure and associated end-of-life can be functional, aesthetic or economic, or result from foreseeable changes in requirements or changes to technology. Replacements can be required in practice to associated elements in the course of major replacements (e.g. rainwater-disposal systems when roofs are recovered, or tiles when bathroom sanitary equipment is renewed).

5.4.2.2 Maintenance activities

Maintenance activities can be grouped into various categories for cost/budget analysis, but all should be taken into account. The categories may include maintenance that is

a) preventive in intention (including condition-based or predictive and scheduled),

b) corrective in intention (including allowances for emergency/unforeseen events or reactive corrections to failures),

c) deferred (a decision about timing and urgency, which can have cost consequences).

5.4.2.3 Maintenance management activities

If the LCC analysis includes maintenance management, the costs may encompass all activities necessary to arrange, prioritize, resource or check maintenance, such as

a) cyclical inspection (including condition surveys, specific inspections, condition monitoring),

b) maintenance planning (including scheduling, resourcing, tendering),

c) design and management of major replacements.

NOTE The design and management of major replacements is normally included in the costing of the major replacements, while inspection and maintenance planning can be dealt with as a separate cost heading.

5.4.2.4 Cleaning and minor repairs

Cleaning can be considered within the context of maintenance or can fall into the management category. Similarly, minor repairs (such as lamp replacement) can be considered as maintenance or dealt with as management activities. The LCC report should clearly indicate where cleaning and minor repairs have been considered, or that they are excluded, by agreement, from the analysis.

5.4.2.5 Indirect costs of maintenance

The LCC analysis should match the requirements of the client's brief. The client may require that some or all of the following indirect costs be taken into account:

a) down time (loss of function for a period);

b) disruption of business activity (e.g., disruption to retail or to transport);

c) non-availability of a building/structure (and any associated costs for alternative accommodation);

d) cost effects of aesthetic condition (e.g. loss of income resulting from difficulty in letting a building);

e) maintenance strategy (e.g. timing of cycles for cyclical maintenance of finishes or the presence/absence of *in-situ* professional maintenance personnel);

f) external costs/savings data (e.g. to tenants of the building).

If any other costs or savings are included for consideration as part of the option appraisal process, they should be identified in the LCC analysis.

NOTE 1 Examples include taxes on particular types of activity, such as design fees or environmental taxes for depositing waste.

NOTE 2 It can be necessary to include certain externalities and business disruption costs, i.e. costs associated with the process but not reflected in the interaction between the provider and the client.

5.4.3 End-of-life costs

LCC analysis should include assumptions about performance requirements that can affect end-of-life costs. It can be necessary to give specific consideration to environmental requirements, which can involve the use of nominal costs.

NOTE 1 For example, disposal costs can be affected by works required to decommission or make good a site following demolition or disuse under the "polluter pays" principle. Assumptions can be made about future costs, dependent on the use and the level of pollution/contamination likely to remain following demolition.

NOTE 2 Equally, where demolition of an existing constructed asset or other remediation of a brownfield site takes place early in a project, it can be necessary to consider appropriate and/or best-practice works at an early stage. There can be associated specific and identifiable costs (i.e. landfill tax) that indicate the advisability of investigating alternative options.

5.4.4 End-of-life residual valuations

Residual value should be evaluated by determining what similar, comparably-aged assets in similar locations are currently selling for in commercial markets. Alternatively, book estimates of the resale value of used assets can be available from industry or government sources. The values of similar, comparably-aged assets can also be assessed. If neither of these mechanisms can be utilized, a straight-line depreciation based on the capital value and depreciation over the service life or design life of the asset can provide a more accurate value. Positive residual values should be considered in whole-life costing; but it should be noted that they can be substantial and that the decision to consider end-of-life costs can generate a reasonable demand to also consider residual values. The condition of the asset at the end of the period of analysis can impact the residual or disposal value and can reflect the maintenance policies and expenditure during the life cycle.

5.4.5 Discount rate

The type of discount rate, either real or nominal, should be clearly distinguished.

NOTE 1 The real discount rate applied to costs (and benefits) that are also measured in real terms assumes that inflation/deflation applies equally to all.

Occasionally, escalation rates may be used as a form of sensitivity analysis where there are grounds to anticipate that the standard rate of inflation does not apply in the case of a specific option. Typically, real rates should be used; these exclude the impact of future inflation. Nominal rates may be used by agreement, if that is what is required by the client or justified by the situation.

The discount rate in the private sector should represent the opportunity cost of investing the capital, which can be

a) the interest cost of a loan for the investment,

b) the interest lost on reduction of cash on deposit,

c) the returns lost on investment elsewhere (e.g. in bonds or equities),

d) the actual return achieved on capital investment in the business,

e) the required rate of return of an investor in a new business.

Within the public sector, a discount rate can be determined by the central government (sometimes termed the social discount rate) as a test requirement for their investments, based on an assessment of the long-term opportunity cost to the public sector of selecting one investment rather than another.

NOTE 2 Historically, the real discount rate has reflected the general productivity rate of the producer, sector or field. Generally, productivity has been within 0 % and 2 % over the long term. However, rates as low as these are not universal. Discount rates of between 0 % and 4 % are typically used. A higher rate discourages long-term investments, while a lower rate encourages them.

NOTE 3 Where the discount rate is not a requirement fixed by the client (public or private), it is normal to undertake sensitivity analysis using a range of rates to test the validity of the conclusions if the input conditions change.

5.4.6 Inflation

If real costs are used in the LCC analysis, assumptions about the general rate of inflation should not be required. However, if nominal costs are used in the LCC analysis, assumptions can be made about discount rates (and underlying inflation rates), but they should be explicit and the sensitivity should be checked.

5.4.7 Taxes and subsidies

Taxes and subsidies can affect the relative price and the decision-making process. LCC analysis should be adjusted for any incidence of tax arising from the different options being considered. The existence of tax subsidies associated with the investment should be included.

5.4.8 Changes in costs over time

Possible disproportionate changes in costs relative to inflation should be considered when setting the scope of the analysis.

EXAMPLES Shortage of labour; cost of scarce materials for historic-asset renovations; costs associated with transport for works in remote locations.

5.4.9 Energy and utilities costs

Where an analysis is made of energy costs, present-day supply costs should be used unless it is foreseeable that the relative costs can change between alternative energy sources. Where an investment appraisal is assessing energy-efficient technology, energy savings should be treated as a future income stream (or negative cost) for comparison purposes.

NOTE 1 Energy-price escalation is a major LCC factor; refer to 8.3 for treatment of such uncertainty and pricing risk.

NOTE 2 While energy costs are the utility cost that has historically been most subject to price increases disproportionate to inflation, other utilities (especially water) can be subject to similar pressures over the period of analysis.

6 WLC variables used in some investment option appraisals

6.1 General

When undertaking investment option appraisals, many variables in addition to LCC variables can impact on the value-for-money assessment and should be taken into account.

For certain forms of construction procurement, these additional variables form an integral part of the investment option evaluation and appraisal process and can be referred to as whole-life cost (WLC) variables.

Typically, the difference between WLC and LCC analysis is that the variables for WLC can include a wider range of externalities or non-construction costs, such as finance costs, business costs and income streams.

A number of different analysis techniques to measure and compare the return on investment may also be used in WLC.

NOTE 1 Such issues are additional to the defined variables of life-cycle costs and are not mandatory. These can be relevant to some life-cycle costing appraisals as well, where the client demands them (e.g. variables of the acquisition costs and disposal income).

NOTE 2 Some of the measures typically used in WLC are included in Annex B.

6.2 Externalities

Life-cycle costing can help to ensure an optimized approach to asset selection, maintenance and use. However, judgements made on the basis of investment returns can be based purely on market efficiency, and can fail to recognize the wider implications economic decisions have on society. Market prices for construction might not value the social, environmental or business costs or benefits of production and consumption.

WLC analyses that consider the occurrence of externalities can highlight possible future risks and rewards that are not otherwise identified. Externalities that are considered should be clearly identified in the analysis.

NOTE A common approach by government in dealing with externalities is the imposition of regulatory taxes on negative externalities and subsidies for the external benefits. These are tangible costs that can be readily taken into account in an LCC analysis (they are tangible costs to the client). Analysis that considers the external costs and benefits is relevant because possible options can have real costs and revenues because of such government action.

6.3 Environmental cost impacts

Environmental legislation can introduce costs (or savings via rebates) to life-cycle costing depending on the impacts that the asset's location, design, construction, use and disposal place on the environment.

EXAMPLES Cost premiums for the use of non-renewable resources or for greenhouse gas emissions.

Where these costs are external to the constructed asset, they may form part of a WLC analysis.

NOTE An example is the pollution impact outside the construction site (e.g. to rivers), which are not priced within the construction cost. However, it is important not to monetarize aspects that have no economic consequence purely to take them into account (see also 6.5).

6.4 Social costs and benefits

Certain costs and benefits associated with an investment can have an impact on society in general, but should not be included in the LCC analysis (i.e. they are externalities) unless requested by the client. In this case, the limits on what is included in the LCC analysis should be defined.

NOTE 1 Within WLC option analysis, an example of a social benefit is the educational impact of providing an additional school in the community. An example of social cost is centralizing services to a new, more distant hospital.

The monetarization of non-economic costs/benefits should be avoided and externalities should be clearly identified in any analysis.

NOTE 2 A social cost that is rarely included in LCC calculations (unless imposed by a public client in the form of an allowance) is user costs (or benefits) associated with the provision of transport infrastructure. Allowances can be positive (e.g. costs associated with delay) or negative (e.g. where speedier journeys due to the provision of a new link improve efficiency).

6.5 Sustainable construction

The objective of service-life planning should generally be to allow decision makers to include technical, environmental, economic and social aspects, all within a long-term context, in their decision making. LCC analysis is a technique that should form part of an overall aim to balance the objectives of sustainable construction.

However, the balancing should be explicit and not included as a conceptual part of any of the elements. Consequently, LCC and WLC analysis should include only actual costs related to the constructed asset or those influencing its economy.

CO_2 “costs” should be included only if there is an actual payment (e.g. through taxes). Otherwise, such items can be doubly counted when integrating cost assessments with other quantifications of aspects of sustainability.

A life-cycle assessment (LCA) can be used to measure the impact of environmental externalities and, therefore, be used to aid WLC decisions that include a measure of the external cost of investment.

NOTE 1 Consideration of the environmental impact of potential investments can allow for the delivery of decisions based on sustainability issues. Further guidance on LCA is found in ISO 14040 and ISO 14044 and the link between service planning and LCA is dealt with in ISO 15686-6.

NOTE 2 ISO 21931-1 provides a framework for methods of assessment of environmental performance of buildings.

The integration of service-life planning into the procurement and management of constructed assets may involve assessment of the cost implications of adopting sustainable building policies and/or strategies. The assessment can measure the savings in environmental impacts per unit of cost.

LCC may also be used when assessing the cost of compliance with sustainable construction legislation.

NOTE 3 Sustainable construction legislation can encompass carbon trading or avoidance of landfill.

6.6 Intangibles — Impact on business reputation, functional efficiency, etc.

Where an economic assessment of an intangible has been made, it may be included in a WLC analysis.

Intangibles arise as a result of improvements in a constructed asset that can be difficult to quantify. These improvements can affect the user's comfort, amenity and efficiency, which can lead to increased satisfaction and efficiency, with associated financial implications (e.g. improvement in morale leading to reductions in absence through stress).

Intangibles can be difficult to measure in economic terms. Where a value has been attributed, such intangibles should be clearly identified as monetarized intangibles.

NOTE Examples of value being added to a built asset can include the following:

a) advertising for the business; landmark buildings or transport hubs can provide prestigious status symbols and even be used to trigger urban regeneration;

b) functionally efficient buildings can increase user satisfaction or reduce costs elsewhere in the business;

c) pleasant working conditions or better transport links can increase the productivity of the workforce, leading to direct improvements in the business case for investment.

6.7 Future income streams

Future income streams may be included in a WLC analysis but should not, generally, be present in an LCC analysis.

Future income streams can form a subsidiary part of an LCC analysis in the form of negative costs (e.g. to represent income from sales of refreshments or tolls from bridges or roads).

NOTE Future income streams are normally associated with the private sector (e.g. predicted income from a shopping centre through rental income). However, they can also be associated with public sector facilities in the form of annual payments for providing a public facility, such as a school.

6.8 Financing costs

The cost of financing the investment may be considered in WLC. These costs may be reflected in the discount rate, but frequently a non-discounted cash flow analysis is subject to a separate financial appraisal that includes both timing and cost of financing maximum borrowing at different dates. This can also require a “smoothing” of expenditure profiles, which can involve sub-optimal decisions in terms of LCC. This can make the investment case stronger, purely as a result of different financial implications for expenditures at different dates.

There should, generally, be a detailed risk analysis as part of the financial appraisal. The exact issues considered should reflect individual contractual agreements with financers.

7 Decision variables — Basis of calculating costs

7.1 Real costs

Real costs should, generally, be used in LCC analysis to ensure accuracy regardless of the point in time at which the costs are incurred.

NOTE 1 Using real costs allows the use of current known information.

A base date should be set in the recent past or near future.

NOTE 2 A recent or near base date is usually chosen because people are familiar with the current costs and the cost environment in which they live, work or think.

7.2 Nominal costs

Real costs might not be appropriate for preparing financial budgets where actual monetary sums are needed to ensure that funding is available when required. Nominal costs should be derived from projected economic, technological and efficiency factors. The nominal cost should be calculated by multiplying the real cost by the inflation/deflation factor, $q_{\text{i,d}}$, which should be determined using Equation (1):

$$q_{\text{i,d}} = (1+a)^n \tag{1}$$

where

a is the expected percentage increase in prices per annum;

n is the number of years between the base date and the occurrence of the cost.

7.3 Discounted costs

Discounted costs should be calculated by taking costs that occur in future years and reducing them by a factor derived from the discount rate. Different discount rates may apply depending on whether nominal costs or real costs are being discounted. If nominal costs are used, the discount rate should include an inflation/deflation factor. If real costs are used, the discount rate should not include an inflation/deflation factor.

A discount factor, q_{d}, should be calculated from the discount rate, d, using Equation (2):

$$q_{\text{d}} = \frac{1}{(1+d)^n} \tag{2}$$

where

d is the expected real discount rate per annum;

n is the number of years between the base date and the occurrence of the cost.

A real cost should be converted to a discounted cost using the factor $q_{\text{i,d}}$ as calculated in Equation (2).

A nominal cost should be converted to a discounted cost using the factor $q_{\text{d,nc}}$ calculated in Equation (3):

$$q_{\text{d,nc}} = \frac{1}{(1+d)^n (1+a)^n} \tag{3}$$

where

d is the expected real discount rate per annum;

a is the expected increase in general prices per annum;

n is the number of years between the base date and the occurrence of the cost.

7.4 Present value

7.4.1 General

The present value should be calculated by discounting future cash flows to the base date, and should be used for comparing alternatives over the same period of analysis. Present value calculations should be used to calculate the present monetary sum that should be allocated for future expenditure on an asset.

NOTE The value of money is not constant with the passage of time; see Annex A for a worked example of present value.

7.4.2 Net present value (NPV) or net present cost (NPC)

The net present value (NPV) may be described as the sum of the discounted benefit of an option less the sum of the discounted costs.

A stream of future costs and benefits should be converted to a net present value X_{NPV} using Equation (4):

$$X_{\text{NPV}} = \sum (Cn \times q) = \sum_{n=1}^{p} \frac{Cn}{(1+d)^n} \quad (4)$$

where

C is the cost in year n;

q is the discount factor;

d is the expected real discount rate per annum;

n is the number of years between the base date and the occurrence of the cost;

p is the period of analysis.

NOTE 1 The discount rate allows for any future inflation/deflation if the nominal costs instead of the real costs are used.

Where costs only are taken into account, the NPV may be called the net present cost (NPC).

The NPV should be a single figure that takes account of all relevant future incomes and expenditure over the period of analysis.

NOTE 2 NPV is the normal measure used in an LCC analysis, although others are available (see Annex B).

8 Uncertainty and risks

8.1 General

As LCC analysis requires assumptions about future behaviour, iterative risk analysis can be used to progressively reduce uncertainty, but a residual risk always remains. Therefore, LCC analysis should include consideration of uncertainty and risk.

NOTE The distinction between uncertainty and risk is that “risk” is used when probabilities can be estimated and “uncertainty” is used when they cannot.

8.2 Identification of the causes of uncertainty and risks

8.2.1 The level of uncertainty and risk associated with LCC analysis can depend on such issues as the quality of the data available and the robustness of the scoping, pricing assumptions and methods of calculation.

NOTE The lack of common methodologies for life-cycle costing in the construction industry has resulted in issues such as scope and definition rarely being clearly recorded.

8.2.2 In order to address cost uncertainty and reduce risks, the key issues and barriers to the widely used LCC should be understood. Issues that should be considered in LCC analysis include the following:

— confusion over costs to be included/excluded (e.g. scope of LCC and/or elements of WLC);

— variety of LCC measures and models (e.g. NPV, PDV, IRR, net savings);

- transparency and robustness of the underlying assumptions and methods of calculation;
- lack of information about detailed design at the beginning of the project;
- introduction of a new technology/products and prediction of the cycle of obsolescence;
- interface issues between capital costs and running costs through to end-of-life/disposal;
- lack of contractual incentives to do life-cycle costing on build-and-construct-only contracts;
- shortage of expert life-cycle-costing practitioners and professional education programmes.

8.2.3 Mistaken judgements that can increase the uncertainty of the LCC analysis include

- the use of optimistic estimates (in order to justify the project),
- the use of unattainable service lives,
- impractical maintenance programmes and replacement scheduling.

8.2.4 Judgements about future activities/occurrences that are outside the control of the person undertaking the LCC analysis but which can be considered within the scope of the analysis include

- a commitment to achieving maintenance levels (e.g. inability to manage maintenance),
- future users' requirements (e.g. flexible space utilization and functional suitability),
- changing user behaviour (e.g. intensity of use, vandalism).

8.2.5 Other issues that can also cause uncertainty in the results of LCC analysis over long periods include

- predicted inflation rates,
- overhead/profit and on-cost allowances,
- labour and material costs,
- changes in legislation (particularly with regard to health and safety and energy performance/carbon emission targets),
- the impact of climatic changes.

NOTE Factors for estimating the impact of these rely on expert judgement.

8.3 Monte Carlo analysis and confidence modelling

Where a range of possible costs is calculated, it can be beneficial to model the uncertainty attached to the cost or time variables using statistical techniques, such as the Monte Carlo analysis. This should allow the identification of a distribution of possible costs and a range of more and less probable figures for use in calculations.

NOTE To improve the confidence in the LCC analysis, for example, a client can require the estimation of costs with 10 %, 50 % and 90 % confidence levels. Software is available to model uncertain values using the Monte Carlo analysis and similar statistical techniques.

8.4 Sensitivity analysis and modelling the effects of changing key assumptions

Sensitivity analyses can be undertaken to examine how variations across a (plausible) range of uncertainties can affect the relative merits of the options being considered and compared. These ranges should be probable, within the limits of what is anticipated and fit within the client's brief. These analyses can help to identify which input data have the most impact on the LCC result and how robust the final decision is.

Examples of key assumptions that can have the biggest effects on the uncertainties include

a) discount rates,

b) the period of analysis,

c) incomplete or unreliable service life or maintenance, repair and replacement cycles or cost data based on assumptions.

Sensitivity analysis can be an important guide to assessing what additional information it is worthwhile collecting and what are the most significant assumptions that it is necessary to make. It can also be used to consider how flexible or variable requirements can be during the period of analysis or the life cycle.

EXAMPLE 1 A typical example of sensitivity analysis is to check the impact of future changes in operating costs, such as energy costs. Previously, certain building services installations have been rendered obsolete because the energy costs associated with them have risen disproportionately relative to the general price inflation. The effect of this has been to shorten the service lives for the plant installed and to increase the operational costs of the asset. More information on obsolescence is given in ISO 15686-1.

Escalation rates can also be used to assess the impact of differential changes.

EXAMPLE 2 A facility in a remote location that requires periodic maintenance can have different escalation rates applied to material costs, transportation costs and labour costs. These can be determined by local or regional economic factors.

Iterating the sensitivity-analysis calculation with a range of values for the variable data can indicate the vulnerability of the LCC to variable data.

If the sensitivity analysis indicates that alternative variables have little effect on recommendations, the decision should be unaffected. If, however, the recommended option is varied by different discount rates/ service lives or costs, etc. being applied, it may indicate that further analysis is required or that the decision is based upon factors other than LCC.

NOTE Examples of sensitivity analysis are included in Annex C.

9 Reporting

9.1 LCC analysis — Presenting the results and supporting information

The results of an LCC analysis should be documented in a report so that users can clearly understand both the outcomes and the implications, including clearly defining the purpose, scope, key assumptions, limitations, constraints, uncertainties, risks and effects of any sensitivity analysis.

The report should include

a) an executive summary,

b) the purpose and scope (including what costs have been considered/excluded and the period of analysis),

c) a statement of objectives,

d) the materials under consideration,

e) any assumptions made,

f) any constraints and risks identified,

g) alternatives considered in the analysis,

h) a thorough discussion of the interpretation of the results, including risk assumptions and exclusions,

i) a graphical representation of results,

NOTE While not essential, a graphical representation of results frequently aids understanding and provides a readily comprehensible summary of results. An example is included in Annex D.

j) a replacement and maintenance plan or profile, if included in the client's requirements and supported by the level of analysis,

k) a presentation of the conclusions related to the objectives of the study and recommendations for any further work.

The format and extent of analysis should be agreed in advance, including

— the decision and cost variables being analysed (including a statement of the agreed scope and any exclusions),

— whether sensitivity analysis should be undertaken and if so to what confidence levels,

— the data and analysis structure,

— the method of accounting for the time value of money,

— the period of analysis,

— any other specific client requirement, as applicable.

NOTE Some national standards and internationally agreed guidance describing data and analysis structures are listed in the Bibliography.

9.2 Reporting costs

Depending on the level of analysis undertaken, costs should be broken down into separate headings for consideration.

NOTE 1 See Figure 3 for an example of a high-level cost-data-reporting structure.

Capital/acquisition costs should be considered separately from costs that occur during the subsequent phases of the life cycle. It can be beneficial to consider separately, for example, maintenance and replacement costs or costs associated with different parts of the asset. These costs may be paid by different organizations or parties, or may be analysed separately for benchmarking and comparison purposes.

Typically, analysis at the early stages of the project may be at a coarse level (e.g. estimated costs per square metre or per head of occupation). A more detailed breakdown of different heads of cost should be provided at a later stage. Equally, as design evolves, it can be necessary to check alternative options at a strategic level or at a detailed level.

NOTE 2 An example of the levels of cost analysis and estimating techniques are included in Annex E.

9.3 Approvals and audit trail

For LCC analysis, records should be retained in accordance with the guidance in ISO 15686-3. These records should include

- cost calculations,
- evidence of service life,
- sources of cost data and any validation undertaken,
- discussions on the scope of analysis,
- retained copies of software packages/LCC models.

There can be potential liabilities associated with providing assessments of life-cycle costing and/or service-life planning. Record-keeping (whether paper or electronic) should include issues such as professional indemnity insurance retention, handover of relevant portions to other parties at later stages, and insurance cover.

Annex A
(informative)

Worked examples — Analysis techniques used in LCC

A.1 Present value calculation — Example showing rates between 1 year and 50 years

Table A.1 gives some of the discount rates that are used to provide a present value for a cost occurring in a particular number of years' time, at a variety of discount rates.

Table A.1 — Present value of a single monetary unit with discount rates of 1 % to 7 %

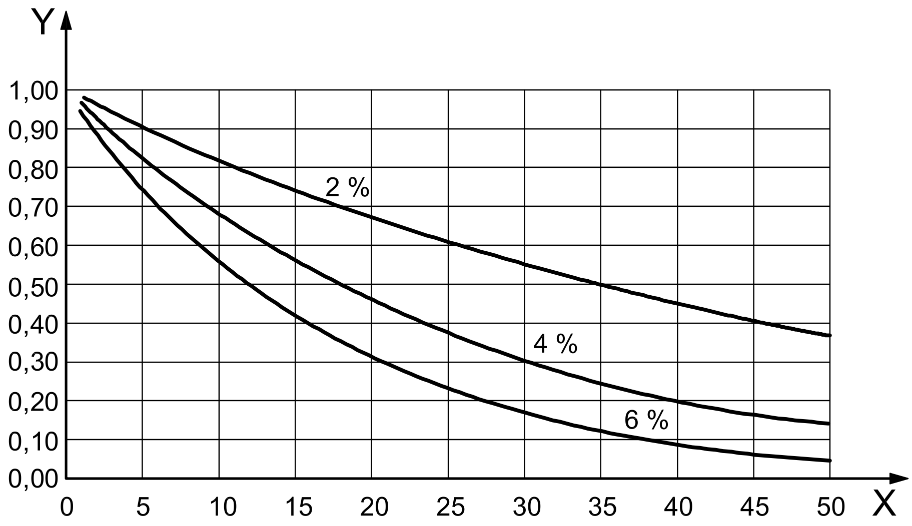
Years in the future	Discount rate						
	1 %	2 %	3 %	4 %	5 %	6 %	7 %
1	0,99	0,98	0,97	0,96	0,95	0,94	0,93
2	0,96	0,96	0,94	0,92	0,91	0,89	0,87
3	0,97	0,94	0,92	0,89	0,86	0,84	0,82
4	0,96	0,92	0,89	0,85	0,82	0,79	0,96
5	0,95	0,91	0,86	0,82	0,78	0,75	0,76
6	0,94	0,89	0,84	0,79	0,75	0,70	0,67
7	0,93	0,87	0,81	0,76	0,71	0,67	0,62
8	0,92	0,85	0,79	0,73	0,68	0,63	0,58
9	0,91	0,84	0,77	0,70	0,64	0,59	0,54
10	0,91	0,82	0,74	0,68	0,61	0,56	0,51
11	0,90	0,80	0,72	0,65	0,58	0,53	0,48
12	0,89	0,79	0,70	0,62	0,56	0,50	0,44
13	0,88	0,77	0,68	0,60	0,53	0,47	0,41
14	0,87	0,76	0,66	0,58	0,51	0,44	0,39
15	0,86	0,76	0,64	0,56	0,48	0,42	0,36
16	0,85	0,73	0,62	0,53	0,46	0,39	0,34
17	0,84	0,71	0,61	0,51	0,44	0,37	0,32
18	0,84	0,70	0,59	0,49	0,42	0,35	0,30
19	0,83	0,69	0,57	0,47	0,40	0,33	0,28
20	0,82	0,67	0,55	0,46	0,38	0,31	0,26
21	0,81	0,66	0,54	0,44	0,36	0,29	0,24
22	0,80	0,65	0,52	0,42	0,34	0,28	0,23
23	0,80	0,63	0,51	0,41	0,33	0,26	0,21
24	0,79	0,62	0,49	0,39	0,31	0,25	0,20
25	0,78	0,61	0,48	0,38	0,30	0,23	0,18
26	0,77	0,60	0,46	0,36	0,28	0,22	0,17
27	0,76	0,59	0,45	0,35	0,27	0,21	0,16
28	0,76	0,57	0,44	0,33	0,26	0,20	0,15
29	0,75	0,56	0,42	0,32	0,24	0,18	0,14
30	0,74	0,55	0,41	0,31	0,23	0,17	0,13

Table A.1 (*continued*)

Years in the future	Discount rate						
	1 %	**2 %**	**3 %**	**4 %**	**5 %**	**6 %**	**7 %**
31	0,73	0,54	0,40	0,30	0,22	0,16	0,12
32	0,73	0,53	0,39	0,29	0,21	0,15	0,11
33	0,72	0,52	0,38	0,27	0,20	0,15	0,11
34	0,71	0,51	0,37	0,26	0,19	0,14	0,10
35	0,71	0,50	0,36	0,25	0,18	0,13	0,09
36	0,70	0,49	0,35	0,24	0,17	0,12	0,09
37	0,69	0,48	0,33	0,23	0,16	0,12	0,08
38	0,69	0,47	0,33	0,23	0,16	0,12	0,08
39	0,68	0,46	0,32	0,22	0,16	0,10	0,07
40	0,67	0,45	0,31	0,21	0,14	0,10	0,07
41	0,67	0,44	0,30	0,20	0,14	0,09	0,06
42	0,66	0,44	0,29	0,19	0,13	0,09	0,06
43	0,65	0,43	0,28	0,19	0,12	0,08	0,05
44	0,65	0,42	0,27	0,18	0,12	0,08	0,05
45	0,64	0,41	0,26	0,17	0,11	0,07	0,05
46	0,63	0,40	0,26	0,16	0,11	0,07	0,04
47	0,63	0,39	0,25	0,16	0,10	0,06	0,04
48	0,62	0,39	0,24	0,15	0,10	0,06	0,04
49	0,61	0,38	0,23	0,15	0,09	0,06	0,04
50	0,61	0,37	0,23	0,14	0,09	0,05	0,03

A.2 Example of discounting deferred costs

Figure A.1 is an example showing the present value of one unit of monetary value occurring at the year shown, at a discount rate of 2 %, 4 % or 6 %.



Key

X years in the future

Y present value

Figure A.1 — Present value of one monetary unit at a discount rate of 2 %, 4 % or 6 %

Annex B
(informative)

Measures of comparison in WLC/LCC

B.1 Indicators and techniques in WLC/LCC analysis

A number of different analysis techniques exist for use in WLC or LCC analyses where investment or value is considered on a broad basis. Using these techniques can help the user to gain an overall picture of the value implications. Reports of the analysis should clearly express the results, indicate what they mean and provide clear recommendations on the basis of the results.

The equation can vary depending on whether measurement is from year 0 or year 1. Often these measures are built-in functions in software packages and the basis of the calculation should be checked.

NOTE There are other measurements, particularly as described in the ASTM standards, References [2] to [5].

B.2 Payback period

The payback period is the time it takes to cover investment costs. It can be calculated from the number of years elapsed between the initial investment, its subsequent operating costs and the time at which cumulative savings offset the investment.

Simple payback takes real (non-discounted) values for future monies. Discounted payback uses present values. Payback, in general, ignores all costs and savings that occur after payback has been reached.

When considering an investment with future expenditure, a discounted payback can be used to reflect the time value of money. It is possible that an investment with a short payback is a poorer option than one with a longer payback when looked at over the entire period of study. Generally, however, payback is a useful technique to compare large and small investments (although adjusted internal rate of return is also used) or to assess the time period during which the investment is at risk.

B.3 Net savings (NS)

Net savings is the present value of operating-related savings minus the present value of additional investment costs.

A calculation of the net savings is used to assess benefits, especially when they come in the form of cost reduction. A project is considered cost-effective if the net saving is positive. The net-savings technique can also be used to compare investment options. Choosing an option with the highest net savings is the same as choosing the option with the lowest WLC. Similarly, when the analysis is being used to assess the lowest WLC of a combination of options, the combination that offers the greatest overall net savings is the most economically viable.

B.4 Savings-to-investment ratio (SIR)

The savings-to-investment ratio (SIR) expresses the ratio of savings to costs. The SIR is calculated by dividing the present value of operating-related savings of an option by the present value of additional investment costs attributable to that option.

The SIR can be used to assess whether an investment is cost-effective (an SIR greater than 1) and for option selection (by choosing the option that has the highest SIR). The calculation can be used to prioritize projects (by ranking options in descending SIR order) subject to budget constraint. If the budget is insufficient to fund all cost-effective projects (those with a SIR greater than 1), a ranking of options in descending SIR order can determine the priority of alternative investments. If projects vary in expenditure, an allocated budget might not be enough to allow selection of a combination of options that have been ranked using the SIR.

B.5 (Adjusted) internal rate of return (IRR or AIRR)

The (adjusted) internal rate of return (IRR or AIRR) is the compound rate of interest that, when used to discount the costs and benefits over the period of analysis, makes costs equal to benefits when cash flows are reinvested at a specified interest rate.

By using the AIRR, it is possible to calculate the test discount rate that generates an NPV of zero. Thus, AIRR can be used to rank different sizes of investment and different patterns of cash flow over time. If all cash flows are negative costs, then the AIRR cannot be calculated.

B.6 Annual cost (AC) or annual equivalent value (AEV)

The annual cost (AC) or annual equivalent value (AEV) is a uniform annual amount equivalent to the project net costs, taking into account the time value of money throughout the period of analysis.

This technique is used to compare the merits of competing investments where the natural replacement cycle is not an exact multiple of the period of analysis. The annual equivalent value is the regular annual cost that, when discounted, equals the NPV of the investment. By choosing the option with the lowest annual equivalent cost, the option with the lowest total cost is chosen.

Calculate the annual equivalent value, X_{VAE}, as given in Equation (B.1):

$$X_{\text{VAE}} = \frac{Cd}{(1+d)^n - 1} \quad \text{(B.1)}$$

where

C is the cost in year n;

d is the expected real discount rate per annum;

n is the number of years between the base date and the occurrence of the cost.

EXAMPLE

$$X_{\text{VAE}} = \frac{100 \times 0{,}06}{(1+0{,}06)^{25} - 1} = 1{,}82$$

Therefore, a cost of 100 units in 25 years' time at an interest rate of 6 % is equivalent to an annual investment of 1,82 units.

Annex C
(informative)

Demonstrating sensitivity analysis

Sensitivity analysis calculates how changes in particular assumptions affect the NPVs and project outcomes. Table C.1 shows the sensitivity analysis for a series of costs, at various discount rates (1 %, 3 %, and 5 %). Tables C.2 and C.3 show the effect of increasing and decreasing those costs by 10 %, respectively.

Table C.1 — Sensitivity analysis at different discount rates

Year in which cost occurs	Expected yearly cost	1 % discount rate		3 % discount rate		5 % discount rate	
		Discount factors	NPV	Discount factors	NPV	Discount factors	NPV
1	1 000	0,99	990	0,97	970	0,95	950
10	500	0,91	455	0,74	370	0,61	305
20	1 000	0,82	820	0,55	550	0,38	380
Total NPV	2 500	—	2 265	—	1 890	—	1 635

Table C.2 — Sensitivity analysis with future costs increased by 10 %

Year in which cost occurs	Expected yearly cost	1 % discount rate		3 % discount rate		5 % discount rate	
		Discount factors	NPV	Discount factors	NPV	Discount factors	NPV
1	1 100	0,99	1 089	0,97	1 067	0,95	1 045
10	550	0,91	500,5	0,74	407	0,61	335,5
20	1 100	0,82	902	0,55	605	0,38	418
Total NPV	2 750	—	2 491,5	—	2 079	—	1 798,5

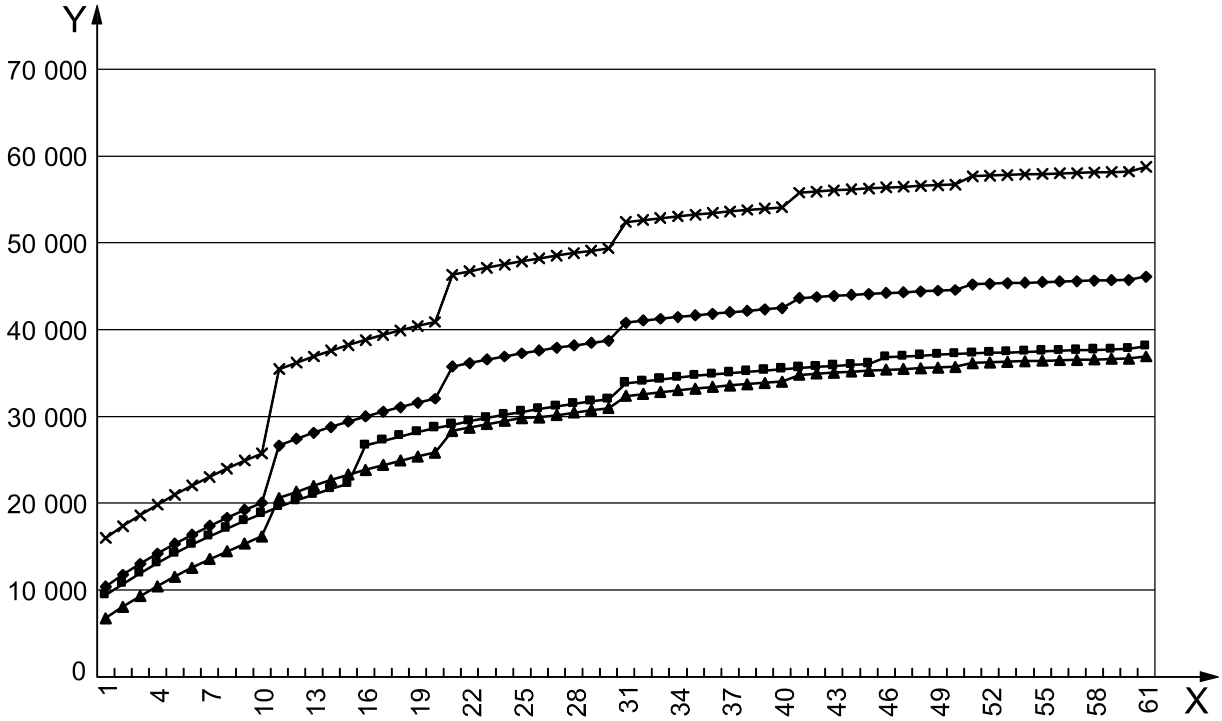
Table C.3 — Sensitivity analysis with future costs decreased by 10 %

Year in which cost occurs	Expected yearly cost	1 % discount rate		3 % discount rate		5 % discount rate	
		Discount factors	NPV	Discount factors	NPV	Discount factors	NPV
1	900	0,99	891	0,97	873	0,95	855
10	450	0,91	409,5	0,74	333	0,61	274,5
20	900	0,82	738	0,55	495	0,38	342
Total NPV	2 250	—	2 038,5	—	1 701	—	1 471,5

Annex D
(informative)

Graphical representation of LCC analysis

Figure D.1 shows a component-level comparison of LCC analysis for four alternate design options for floor coverings. Figure D.2 shows a whole-building-level comparison of LCC analysis.



Key

X time, expressed in years

Y cost

x indicates datapoints for floor covering A

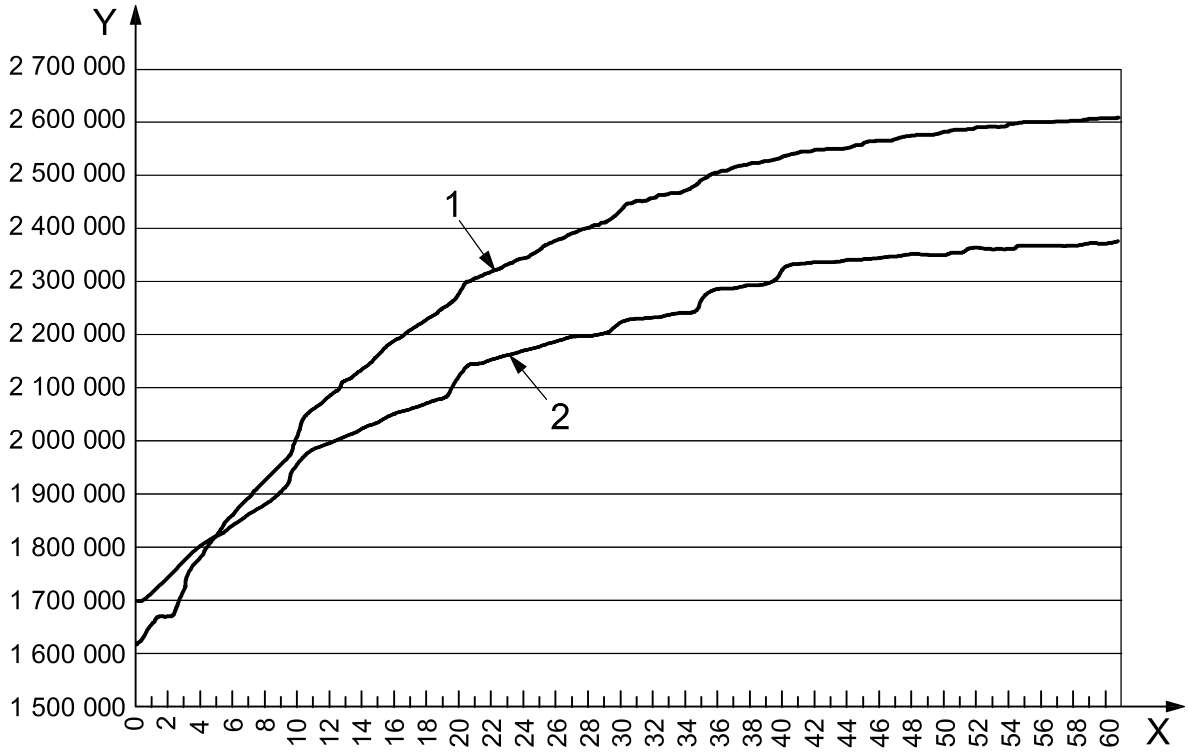
♦ indicates datapoints for floor covering B

■ indicates datapoints for floor covering C

▲ indicates datapoints for floor covering D

NOTE Does not include any allowance for end-of-life disposal costs.

Figure D.1 — Graphical reporting of component-level comparison



Key

X time, expressed in years

Y cost

1 option 1

2 option 2

NOTE Does not include any allowance for end-of-life disposal costs.

Figure D.2 — Graphical reporting of whole-building-level comparison

Annex E
(informative)

Example of levels of cost analysis

LCC analysis can be undertaken at various levels, depending on the information available and the type of analysis used (i.e. benchmark-level analysis, detailed life-cycle costing based on varying levels from cost-significant, key building items to construction elements down to sub-element/component analysis).

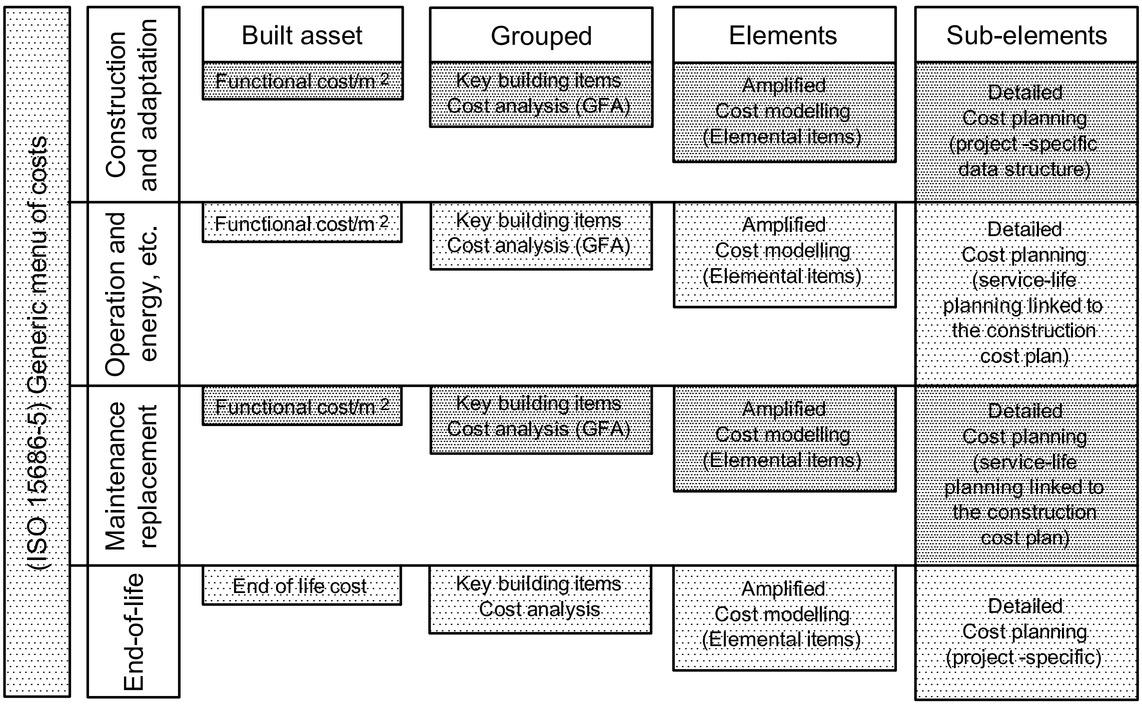


Figure E.1 — Example of typical levels of analysis within each key LCC category

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