# Toward improved LCC-informed decisions in building management

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## Abstract

**Purpose** – Stakeholders of the Architecture, Engineering and Construction (AEC) sector require information on the buildings economic performance throughout its life cycle. This information is neither readily available nor always accurate because building management (BM) professionals still face difficulties to fully incorporate the life cycle cost (LCC) concept into their daily practice. The purpose of this paper is to identify and contribute to solving these difficulties.

**Design/methodology/approach** – This paper provides a background knowledge review and set the ground for a structured research roadmap and a management framework that highlight the links and limitations to be addressed within and between LCC and BM. A six-stage method was used for developing conceptual frameworks targeting six goals: establishing a point of departure; mapping sources of information; literature research; notion deconstruction and conceptual categorization; overview of the applicable background knowledge; and structuring of a framework for LCC-informed decisions in BM.

**Findings** – Management solutions for the built context are necessarily connected with LCC and BM current concepts such as asset management, project, program and portfolio management, facility management and data management. These management approaches highlight the importance of incorporating life cycle concepts and promote LCC effective application within the AEC sector.

**Originality/value** – This paper identifies and discusses current limitations on the information availability for the economic performance of buildings throughout its life cycle. This work also identifies LCC-related topics that need to be further explored or addressed by both the scientific community and practitioners to overcome these limitations and facilitate the integration of the LCC concept into BM activities.

**Keywords** Building management, Asset management, Economic sustainability, Life cycle cost, Facility management, Project, programme and portfolio management

**Paper type** General review

## 1. Introduction

The Architecture, Engineering and Construction (AEC) sector is currently challenged by the complex task of addressing multiple regulations and standards designed to promote life cycle thinking and a sustainable approach to the built environment. Hence, and together with technical, functional, social and environmental concerns, there is a growing interest on the early stage assessment of the economic consequences and in the long term, on AEC-related investment decisions. However, there are currently missing steps required for the AEC sector to be able to fully implement this approach in practice.

Considerable research has focused on the life cycle cost (LCC) concept (Goh and Sun, 2016; Gluch and Baumann, 2014; Cole and Sterner, 2000; Meckler, 1977), and on the applications of life cycle costing to building projects (Bromilow and Pawsey, 2013; Marszal and Heiselberg, 2011). One of the main current challenges for the LCC implementation is accurate cost prediction throughout all phases of the buildings life cycle. This challenge has been highlighted by research on historical data (Arja *et al.*, 2009), costs probabilities

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distributions (Richard *et al.*, 2001), methods for costs prediction (Ma *et al.*, 2016; Bogenstatter, 2000) or costs indicators (Ive, 2006). Other authors have emphasized the importance of considering the uncertainty associated with the LCC application (Wang *et al.*, 2012; Arja *et al.*, 2009) and to carry out sensitivity analysis (Marenjak and Krstic, 2010).

The LCC concept does not directly address overarching issues such as policy and strategy for organizations, but it can be used to support decision-making processes in building projects or in managing building asset portfolios. It is also a driver for engaging stakeholders with noneconomic aspects of sustainability and encourages environmental sound building design (Grussing, 2014). For example, the LCC concept may highlight simultaneously the economic relevance of optimizing maintenance and operation costs, and the wider importance of energy efficiency or water savings throughout a building life cycle.

The management of the built environment has to be primed by the needs of their stakeholders. These building management (BM) activities are closely related and must integrate those that have been mapped by the disciplines of asset management (AM), project, program and portfolio management (PPPM) and facility management (FM), all of which depend on accurate economic information of the building life cycle. Hence, these activities require the support of data management (DM) solutions/approaches. The mentioned disciplines have been taking shape since the late 1970s, but the building environment management has only recently started to be considered as an independent discipline with its own applications to real case studies (Munteanu and Mehedintu, 2016; AMBOK, 2014; Henderson *et al.*, 2014; PMBOK, 2013; Mohammed and Hassanain, 2010; Edum-Fotwe *et al.*, 2003).

The AEC must contribute to the delivery of a sustainable built environment and BM plays an important role in this regard. However, the management approaches underlying BM, i.e. AM, PPPM, FM and DM have had parallel developments for several decades. These developments have consistently emphasized the need to incorporate life cycle thinking. Thus, BM should include and further integrate methodologies and tools that are known in AM, FM, PPPM and DM environments, namely, those related with the LCC concept.

This paper analyzes and conciliates the background knowledge of AM, FM, PPPM, DM and LCC. It provides guidance for the development of a problem-solving-orientated research roadmap and a management framework. These are expected to trigger a more frequent application of the LCC concept to the building sector. The comprehensive overview of the scattered existing background knowledge results in a much needed qualitative theorization process for building conceptual frameworks from multidisciplinary texts, thus contributing toward an enhanced integration of the LCC concept within BM activities.

The background knowledge of LCC and BM can be structured according to the management principles of the Plan-Do-Check-Act (PDCA) cycle followed in international management standards (e.g. ISO 9000). The outputs of this structuring pave a new comprehensive research roadmap whereby research topics are categorized and described following a PDCA cycle. It offers insights that can be used to improve the economic performance of buildings while addressing the recent challenges imposed by regulations such as the European Directive 2014/24/EU. The potential applications and benefits of the proposed joint approach for various stakeholders throughout all phases of the buildings life cycle are identified.

## 2. Method

A better understanding of complex phenomena requires a multidisciplinary approach and qualitative research methods for background knowledge collection (Myers, 2009). Background knowledge reviews and the development of integrated conceptual frameworks based on the existing multidisciplinary literature are qualitative processes of theorization. It enables the grouping and categorization of similar concepts and also the description and explanation of relations patterns. It applies a six-stage method for structuring the background knowledge (Figure 1), following an adapted version of the research process proposed by Jabareen (2009) for building conceptual frameworks from multidisciplinary texts:

(1) Establishing a point of departure toward a fuller integration of the LCC concept into BM, assuming that there are links to be explored and gaps that need to be addressed between these two interrelated key concepts or areas of knowledge.

(2) Selecting and mapping information sources that are representative of the background knowledge that is needed to explore the links and bridge existing gaps toward a fuller integration of the LCC concept into BM: scientific papers and technical guides, reports and technical publications (regulations in the field of BM activities were not considered in the general review).

(3) Reviewing literature on LCC and BM from the standpoint of the AEC sector within the last 50 years.

(4) Categorizing and analyzing information and identifying notions that interrelate the two key concepts or areas of knowledge (LCC and BM): it was found relevant to deconstruct interrelated notions within the fields of AM, PPPM, FM and DM.

(5) Conducting separate reviews on LCC and BM focusing on the origins and main developments historical, conceptual, technical and/or scientific, of both concepts and on how they are being addressed in regulatory (e.g. European directives) and non-regulatory environments (e.g. International Standards (ISO) and European Standards (EN)).

(6) Integrating, synthetizing and organizing the outputs of the previous stages in order to: confirm the initial hypothesis and structuring of a research roadmap based on the PDCA cycle for the scientific community and develop a management framework for practitioners toward improved life cycle cost-informed decisions in building management (LCC-IDBM).

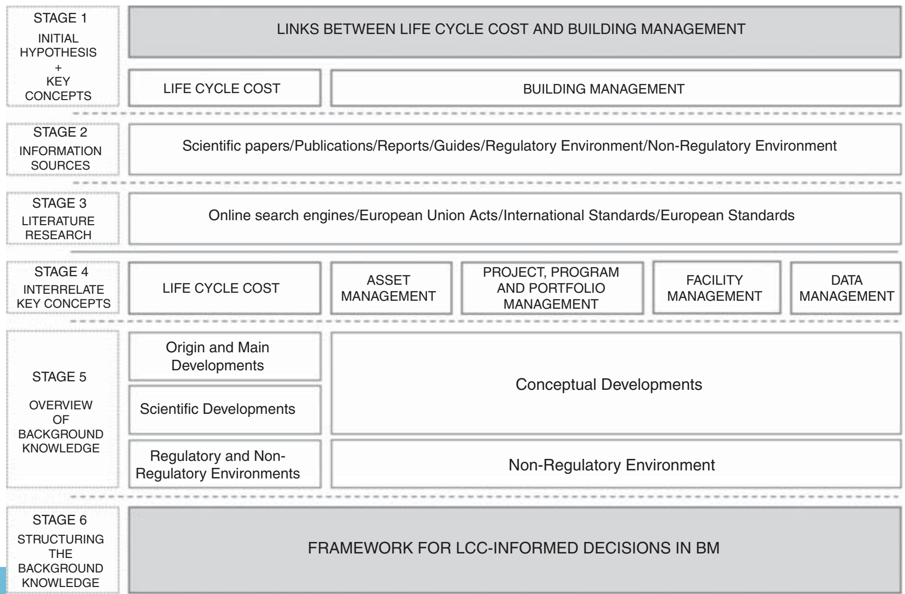



**Figure 1.**
Method for structuring the background knowledge on LCC and BM concepts

## 3. Background knowledge

### *3.1 LCC*

*3.1.1 Conceptual developments*. The concept of LCC in the AEC sector gained expression in the 1970s through institutional policies driven by the British and the North American Governments, more precisely associated to buildings energy consumption savings (Goh and Sun, 2016). In 1977, the British Government published a practical guide about LCC implementation in their assets management (GBCT, 1977). The National Institute of Standards and Technology published a guide on a LCC management program which was reviewed a few years later (Fuller and Petersen, 1995). An international reference publication presents real case applications (Flanagan and Norman, 1989). The first standard published at national level was the Norwegian NS 3454 in 1988.

Over the years, LCC has been applied in several procurement procedures, construction and operation of buildings in several USA states, as well as government institutions in other countries (ANAO, 2001; Mearig *et al.*, 1999).

In 2003, the European Commission published the Task Group Final Report 4 on LCC in buildings construction (TG4, 2003). Following these results, reports (Langdon, 2007) have been published presenting a methodology with a common procedure for the application of the LCC approach in the European Union. The Procurement Guide 7 (PG7, 2007) was published in the UK, establishing guidelines for costs management over the building life cycle.

In 2010 the Directive 2010/31/EU was published, establishing a comparative methodology framework for determining optimal levels of minimum energy performance of buildings. The concept of integrated sustainability analysis in the building life cycle (UNEP, 2011) was developed. In 2014, the new Directive on public procurement (Directive 2014/24/EU) introduced a recommendation based on the use of a LCC approach. A guide to help stakeholders to understand the process of LCCs calculation was published in 2016 (Churcher and Tse, 2016).

In the last 50 years, the growing scientific interest in methodologies based on LCC may be related to its capacity to translate the economic complexity of the building life cycle (Gluch and Baumann, 2014; Meckler, 1977). On the other hand, it can also be related to the increasing need to find more sustainable alternatives complying with the growing requirements for buildings rehabilitation (Korpi and Ala-Risku, 2008). These trends led to a significant increase of scientific publications related to LCC (Goh and Sun, 2016).

There are several specialized methodologies based on the LCC approach for buildings, as well as tools for LCC calculation (Kovacic and Zoller, 2015). Comparative studies on the advantages and disadvantages of these methodologies applied to buildings have been developed (Schade, 2007). However, there are few studies including real case studies and hence the usefulness of these tools remains uncertain (Gluch and Baumann, 2014).

In the initial phases of building life cycle, the potential for optimization is still high with low cost associated. Throughout the remaining phases, the possibility of change substantially decreases and the associated costs increase. About 80 percent of operating and maintenance costs, as well as environmental impacts, are determined during the design phase (Bogenstatter, 2000).

Comparative studies on software performance in applying LCC calculation during the initial phase of the project showed that a large quantity of data needs to be estimated. This aspect may thus represent a challenge with regard to reliability and optimization of the results (Kovacic and Zoller, 2015). It is anticipated that software availability encourages the application of LCC models as an iterative rather than retrospective process (Lattanzio *et al.*, 2016; Kirkham, 2005).

Regarding the construction costs and although there are historical data suitable for several types of building, there is a lack of reliable economic data for the operation and maintenance costs. To overcome this limitation, a few studies were conducted in the UK for office, school (Ive *et al.*, 2015) and for post office buildings in Japan (Minami, 2004). These studies define an economic framework for costs classification and suggest ways to analyze existing data and calculate economic indicators.

For decades, the AEC sector professionals focused only on estimating the initial costs (Lowe and Skitmore, 1994), leaving aside the costs associated with operation and maintenance (Ma *et al.*, 2016; Adeli and Wu, 1998). The scientific interest in modeling the running costs of buildings increased a few years later (Al-Hajj and Horner, 1998). Currently, the research interests are focused on the economic and BM costs during the life cycle (Ive *et al.*, 2015).

Regarding the uncertainty associated with operation and maintenance phases, formulas were developed to integrate impacts of several factors in the calculation of LCC alongside with economic indicators for different types of buildings (Arja *et al.*, 2009; Kishk, 2004). Additionally, Monte Carlo simulation is useful to reduce the uncertainty related to the costs prediction of future events and in the analysis of quantitative risk in LCC (Wang *et al.*, 2012). In studies on Australian university buildings with 30 years, existing data were used in order to estimate the LCC considering a life cycle of 100 years (Bromilow and Pawsey, 2013). Other studies conducted with real data of LCC aim to determine probability distributions costs of the several life cycle phases of hospital buildings through stochastic modeling. The historical data are analyzed in order to obtain parameters of theoretical distributions that describe the associated costs (Lucko and Mitchell, 2010; Richard *et al.*, 2001).

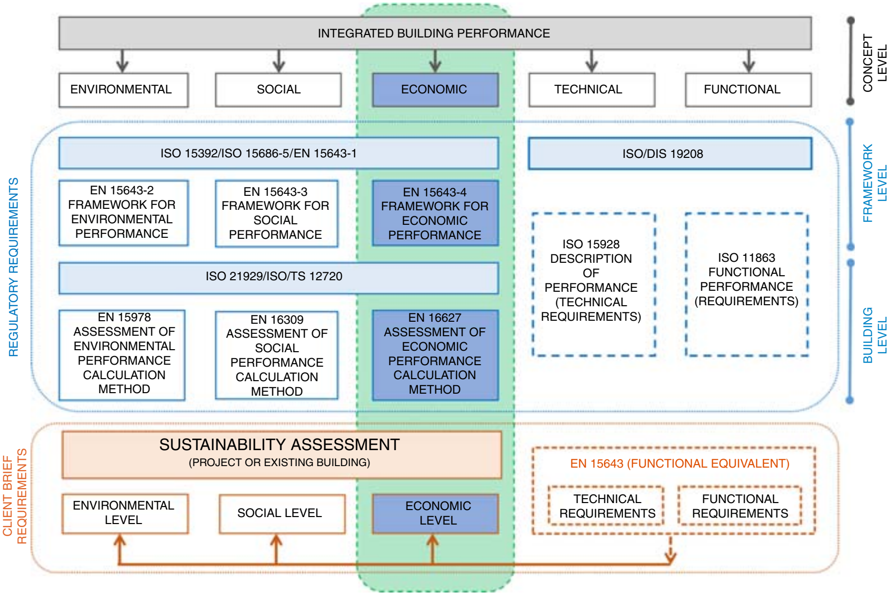
Several studies have been developed regarding buildings sustainability (Karunasena *et al.*, 2016), whereas economic indicators and reference values for buildings were established (Ive *et al.*, 2015; Konig and Cristofaro, 2012) as part of benchmarking strategies.

It is essential to make a sensitivity analysis after application of a methodology based on LCC. The results are dependent on the period of analysis as well as on the discount rate considered (Marenjak and Krstic, 2010). There is a large interest in using approaches based on LCC for the economic evaluation of investment decisions making, but there are several restrictions such as the uncertainties related to the use of long-term forecasts, difficulties in obtaining relevant input data or lack of experience in using LCC methodologies (Cole and Sterner, 2000).

*3.1.2 Regulatory and non-regulatory environments.* The Directive 2014/24/EU established new rules to be adopted by the contracting authorities. It makes reference to a cost-effective LCC approach. It also refers that the costs to be included in the LCC product, service or work, shall be presented as well as costs related to the acquisition, use, maintenance and end of life.

The ISO 9000 and ISO 9001 standards are applied to measurable characteristics and requirements of products and processes throughout their life cycle. ISO 15392 identifies and establishes general sustainability principles in buildings throughout its life cycle. ISO 21929-1 establishes a framework for the development of sustainability indicators along all phases of the building life cycle. ISO/TS 12720 aims to provide guidance and demonstrate for each stakeholder a way to implement the general principles of buildings sustainability. ISO 15686-5 considers the improvement of decision-making processes and the evaluation results in different phases of the building life cycle. It defines the LCC approach as a valid methodology to cost prediction in accordance with the project owner requirements.

EN 15643-1 provides the general principles and requirements for the assessment of buildings in terms of environmental, social and economic performance taking into account technical characteristics and functionality. EN 15643-4 provides specific principles and requirements for the assessment of economic performance and EN 16627 specifies the LCC calculation methods (Figure 2).




**Source:** Adapted from EN 15643

**Figure 2.**
Concept of economic sustainability of buildings

*3.2 BM*

*3.2.1 Conceptual developments.* AM. For several decades, the importance of AM has been under discussion taking into account the buildings life cycle concept (IBM, 2007). In an organization, AM integrates several areas such as engineering; financial management; risk management; logistics and support; relationship with customers; environmental management and legislation; and asset life cycle requirements. There are several research studies that demonstrate the importance of AM in various sectors, levels or applications (Abdelhamid *et al.*, 2015; Henderson *et al.*, 2014), as well as the different meanings, depending on the country where it is used (Davies and Register, 2008). In the area of engineering and maintenance, the AM has acquired growing importance in organizations over time.

In 2004, the Institute of Asset Management in partnership with the British Standard Institute (BSI) developed the PAS 55 specification, which defines AM as the systematic and coordinated activities and practices that an organization uses to manage its assets and systems in an optimal and sustainable way.

The publication of the Institute of Asset Management (2012) aimed at providing a broader view of the AM discipline. It presents a management model as a reference, with emphasis on the inclusion of the PDCA cycle and the risk analysis. It systematizes an AM conceptual model where risk management allows "all organizations to understand and develop an appropriate balance between the cost of doing something, the risk resulting from the expense of those resources, and the expected result of the performance of the asset and the organization" (AMBOK, 2014).

The application of AM techniques and tools to buildings is complex and presents several challenges, namely, the availability of numerous parameters of the AM activities to meet the life cycle needs (Grussing, 2014). In order to reduce the costs associated with assets and without compromising the performance of other requirements, a critical and holistic view of the entire life cycle is required. However, this task faces new challenges when applied not only to the built asset but to the entire project that encompasses it, and even more when it simultaneously associated with the management of program or portfolio by an organization (AMBOK, 2014).

PPPM. The technical complexity of projects, programs and portfolios has increased over time in the AEC sector. Thus, it was necessary to apply new techniques and to merge current practices with new knowledge, in order to develop planning, execution and monitoring activities associated with PPPM (PMBOK, 2013; Hedeman and Seegers, 2009).

An organization has the strategic objective of maximizing the return on its investments and can constitute a portfolio that includes a set of projects. It can also group these investments according to a common aspect and manage them in the form of programs. Portfolio management focuses on ensuring that projects and programs are reviewed in order to prioritize the allocation of organizational resources and to ensure that it remains aligned with organizational strategies (PMBOK, 2013).

Currently, there is no recorded theory to determine project success within the project management literature, which includes both the perspective of multiple stakeholder groups and shared use of success dimensions for a given project (Davis, 2017). The diverse set of activities and stakeholders not only plays a key role in the initial definition of the strategic objectives but also imposes a series of constraints (legal, environmental, temporal, economic, social, quality, etc.) on the projects. Thus, through its capacity to influence the decision-making process within PPPM, constraints promote iterative and progressive planning throughout the life of the project (PMBOK, 2013).

Cost levels are lower at the initial and final phases of the project but reach their maximum during the use phase, when the cumulative costs of the project are expected to increase considerably (Hedeman and Seegers, 2009). A coherent and holistic profile of project complexity has to be developed in order to provide reflections on its implications for project management theory and practice (Kiridena and Sense, 2016). It is also suggested that strategic control at the project portfolio level has an important role to play in the purposeful management of emergent strategies (Kopmanna *et al.*, 2017).

Recently, emphasis has been placed on the added complexity of construction PPPM by focusing on issues surrounding stakeholders as well as on sustainability-related issues (Walker, 2015). Other issues related to PPPM investment decisions are also necessary (Focacci, 2017).

FM. In the 1970s, the term FM began to have more recognition by professionals and the importance of having an organization specialized in FM began to be discussed (Scott, 1971). The concept of "Integrating People, Process and Place" emerged when the "IFMA Research Report No. 1" was published (Armstrong, 1984). In the early 1990s, FM grew through integration into many organizations, and several issues such as business continuity, security, risk management, social responsibility and financial instability have placed increased pressure on FM to provide greater efficiency in workplaces (Nor *et al.*, 2014).

Several organizations have emerged such as the British Institute of Facility Management, the BSI, the Japan Facility Management Promotion Association or the Facility Management Association of Australia, attesting the growing importance of FM activities.

The importance of LCC thinking within FM activities is currently being studied (Munteanu and Mehedintu, 2016). Also, the use of outsourcing strategies in FM contributes to the reduction of LCC hence maximizing profits (Kurdi *et al.*, 2011), improving competitiveness, adding value to the organization and providing access to professionals and experts (Ikediashi and Mbamali, 2014; Gajzlera, 2013). Similarly, benchmarking improves process performance thus providing cost savings in the operation phase of the building life cycle (Kuda and Berankova, 2014).

FM activities are commonly associated with the operational and maintenance phases (Chew *et al.*, 2004). Thus, several key issues related to the entire life cycle do not receive due emphasis during the early design phase (Edum-Fotwe *et al.*, 2003; Jaunzens *et al.*, 2001; Duffy, 2000). Early involvement of FM in the design and construction phases has received increasing attention by researchers in the last decade in AEC sector.

Assessing a facilities performance is important for measuring its contribution toward organizational and societal goals and is potentially effective in analyzing how maintenance expenditures can be optimized to maintain a desired level of condition (Lavy *et al.*, 2014). FM includes and requires several types of multidisciplinary actions with extensive data, which have been approached by a few FM information systems. Building information modeling (BIM) methodology is being increasingly adopted in AEC sector with a large potential to support FM activities (Bosch *et al.*, 2015).

DM. DM is also relevant to BM as it improves the organization and standardization of data, information and knowledge generated from AM, FM and PPPM activities. DM is vital to every organization and it is increasingly recognized that its data are a valuable resource. Like any valuable asset, data assets must be managed. Businesses, governments and other organizations are more effective when they use their data assets more effectively. The DM function seeks to effectively control and leverage data assets. DM is a shared responsibility between the business data stewards serving as trustees of enterprise data assets and technical data stewards serving as the expert custodians and curators for these assets. Within information technologies, DM is an emerging profession and related concepts and supporting technology have evolved quickly over in the last decades (DAMA-DMBOK, 2014).

The construction information classification systems (CICS) have been growing and nowadays have a major role on the organization of the information that is produced by the AEC sector such as: Uniclass (Kang and Paulson, 2000); OmniClass, including MasterFormat and UniFormat (OmniClass, 2006); COBie (East, 2012); or IFC (East, 2013; ISO 16739).

*3.2.2 Non-regulatory environments*. Related to the BM approaches, the following ISO and EN were selected. Such relevance is related with a linkage directly to LCC concept or to the LCC thinking (recent concerns of economic sustainability).

ISO 21500, ISO 21503 and ISO 21504 intend to provide high-level description of concepts and processes that are considered to form good practice in PPPM, and provide guidance on its principles in order to support strategies to deliver organizational value.

The ISO 41000 series will be the standard international management systems for FM. As a strategic tool and set of guidelines, these standards will set out a structure and framework as well as organizational processes along with requirements for key skills and competencies. FM represents an "organisational function which integrates people, place and process within the built environment with the purpose of improving the quality of people and the productivity of the core business" (ISO 41011).

ISO 55000 series establishes principles, requirements and guidelines for the implementation of AM. International cooperation confirmed that the common practices identified can be applied for an ample range of assets in diversified organizations and cultures.

Related to DM: ISO 8000 describes the resources and defines the requirements for data quality and its portability in organizations; ISO 12006-2 defines a framework for the development of built environment classification systems; and ISO 19650-2 establishes requirements for information during the delivery phase of assets and provides a collaborative environment within which (multiple) appointed parties can produce information in an effective and efficient manner.

Related to FM activities, the EN 15221 provides: the relevant terms and definitions; guidance on the preparation of agreements; guidelines on how to measure, achieve and improve the quality, guidance to FM organizations on the development and improvement of their processes; taxonomy, adding a PDCA cycle and link to existing cost and facilities structures; guidance to the development and improvement of an organization processes; and guidelines for performance methods for benchmarking.

## 4. Toward a joint approach

### *4.1 Structuring the background knowledge*

The inputs and the rationale used for structuring the background knowledge are presented in Table I. Columns present the background knowledge in the fields of LCC and BM. Rows frame the background knowledge according to the management principles of the PDCA cycle established in international management system standards such as ISO 9001. This structuring sets the framework for LCC-IDBM and enables the future development of a BM model that incorporates the LCC concept in a robust and comprehensive way (Almeida *et al.*, 2010), while adhering to the principles of consistency, generality, simplicity, correspondence with existing initiatives and adaptability (Almeida *et al.*, 2015; IFIP, 1998). The subcategories under PDCA are based on the requirements of ISO 15686-5, EN 15643-4 and EN 16627.

Each cell in Table I highlights the results for LCC-related topics that can be addressed by both the scientific community and practitioners of the AEC sector toward improved LCC-IDBM. Figure 3 illustrates the background knowledge findings in a PDCA format.

### *4.2 Planning LCC-IDBM*

*4.2.1 Objectives definition.* Table I shows guidelines, reports, technical publications and standards that direct the definition of objectives in the LCC field. The scientific community has yet to grow interest in this field, although there is a pressing need for doing so due to recent regulations (e.g. Directive 2014/24/EU) toward compliance with owner and end-user requirements (ISO 15686-5). BM activities standards are believed to be helpful in this regard (ISO 21500, ISO 21504, EN 15221, ISO 41000, ISO 55000, ISO 8000 and ISO 12006-2).

The building LCC-informed decision can be made at several levels of detail, depending on the information available and the type of analysis to be undertaken (ISO 15686-5). Objectives must align with the final intended decision to be informed and can include, according to ISO 15686-5: evaluation of different investment scenarios at the investment planning phase; choices between alternative designs for the whole or part of a constructed asset during the design and construction phases; choices among alternative components – all of which have acceptable performance during the construction or use phases; comparison or benchmarking assessment of previous decisions; and estimation of future costs for budgetary purposes or for the assessment of the acceptability of an option on the basis of cost of ownership.

The organizational strategy identifies opportunities in the context of PPPM (ISO 21500 and ISO 21504). Selected opportunities are further developed in a business case or other similar document and can result in one or more projects that provide deliverables and benefits.

*4.2.2 Structure for data collection and method for LCC calculation.* Standardized methods for LCC calculation have been established in standards such as ISO 15686-5, EN 15643-4 and EN 16627 and a defined structure for the collection of economic data exists. It includes three modules with several types of costs: Module A, costs related to before use stage – land and associated fees, raw material supply, transport and manufacturing; Module B, costs related to use stage – use, maintenance, repair, replacement, refurbishment, energy and water; and Module C, costs related to after use stage – deconstruction, transport, waste processing and disposal.

EN 15221-4 is related to FM and defines structures and generic methods for the classification of facility products. These are hierarchically organized and standardized to allow the allocation of consistent costs to improve the ability to combine, analyze and provide information. At an operational level, the item "1100-Space" and its subdivisions are especially suitable to provide information for LCC calculations: costs of capital (owner, external structure, internal structure and technical building equipment); and running costs (computer-aid for FM, real state optimization, help desk, structure operation, structure maintenance, equipment operation, equipment maintenance, energy, water and waste).

| PDCA components | Life cycle cost: Scientific papers | Life cycle cost: Guides, reports, technical publications | Regulatory and non-regulatory environments | Building management (AM, PPPM, FM, DM): Scientific papers | Building management (AM, PPPM, FM, DM): Guides, reports, technical publications | Non-regulatory environment |
|---|---|---|---|---|---|---|
| *PLAN (planning LCC-informed decision in BM)* | | | | | | |
| Objectives definition | Goh and Sun (2016), Karunasena *et al.* (2016) | Churcher and Tse (2016), UNEP (2011), Langdon (2007), PG7 (2007), TG4 (2003), ANAO (2001), Mearig *et al.* (1999), Fuller and Petersen (1995), Flanagan and Norman (1989), GBCT (1977) | Directive 2014/24/EU; Directive 2010/31/EU; Regulation (EU) No 305/2011 EN 15643-1; EN 15643-4; EN 16627; ISO 9000; ISO 15392; ISO 15686-5; ISO 19208; ISO 21929; ISO/TS 12720 | Davis (2017), Focacci (2017), Kopmanna *et al.* (2017), Kiridena and Sense (2016), Munteanu and Mehedintu (2016), Walker (2015), Grussing (2014), Henderson *et al.* (2014), Nor *et al.* (2014), Chew *et al.* (2004) | AMBOK (2014), PMBOK (2013), Institute of Asset Management (2012), Hedeman and Seegers (2009), Davies and Register (2008), PAS 55, 2008, IBM (2007) | EN 15221; ISO 21500; ISO 21503; ISO 21504; ISO 41000; ISO 55000 |
| Structure for data collection and method for LCC calculation | Kirkham (2005) | Langdon (2007), PG7 (2007), TG4 (2003), ANAO (2001), Mearig *et al.* (1999), Flanagan and Norman (1989), GBCT (1977) | EN 15643-4; EN 16627; ISO 15686-5 | Kang and Paulson (2000) | DAMA-DMBOK (2014), East (2012), OmniClass (2006) | EN 15221-4; ISO 12006-2; ISO 16739; ISO 8000; ISO19650-2 |
| KPI definition | – | – | EN 16627; ISO 21929 | Lavy *et al.* (2014) | AMBOK (2014), PMBOK (2013), PAS 55, 2008 | EN 15221-7; ISO 55001; ISO 55002 |
| *DO (implementing LCC-informed decision in BM)* | | | | | | |
| Collection of historical data | Ive *et al.* (2015), Bromilow and Pawsey (2013), Lucko and Mitchell (2010), Arja *et al.* (2009), Minami (2004), Richard *et al.* (2001) | Flanagan and Norman (1989) | – | Gajzlera (2013), Mohammed and Hassanain (2010), Chew *et al.* (2004) | – | – |
| Costs estimation | Ma *et al.* (2016), Ive *et al.* (2015), Wang *et al.* (2012), | – | – | Ashworth (1998) | – | – |

(*continued*)

**Table I.** Background knowledge for LCC-informed decisions in BM

Table I.

| PDCA components | Life cycle cost: Scientific papers | Life cycle cost: Guides, reports, technical publications | Regulatory and non-regulatory environments | Building management (AM, PPPM, FM, DM): Scientific papers | Building management (AM, PPPM, FM, DM): Guides, reports, technical publications | Non-regulatory environment |
|---|---|---|---|---|---|---|
| | Arja *et al.* (2009), Richard *et al.* (2001), Bogenstatter (2000), Adeli and Wu (1998), Al-Hajj and Horner (1998), Lowe and Skitmore (1994) | | | | | |
| LCC calculations | Lattanzio *et al.* (2016), Ive *et al.* (2015), Kovacic and Zoller (2015), Bromilow and Pawsey (2013), Marszal and Heiselberg (2011), Arja *et al.* (2009), Korpi and Ala-Risku (2008), Kirkham (2005), Minami (2004) | Langdon (2007), Flanagan and Norman (1989) | – | De Silva *et al.* (2016), Munteanu and Mehedintu (2016) | – | – |
| *CHECK (validating LCC-informed decision in BM)* | | | | | | |
| Uncertainties and sensitivity analysis | Wang *et al.* (2012), Marenjak and Krstic (2010), Arja *et al.* (2009), Kishk (2004) | Flanagan and Norman (1989) | ISO 15686-5 | Chew *et al.* (2004) | – | – |
| KPI calculation | Ive *et al.* (2015), Marenjak and Krstic (2010), Arja *et al.* (2009) | – | EN 16627; ISO 21929 | Lavy *et al.* (2014) | – | EN 15221-7 |
| Benchmarking strategies | Ive *et al.* (2015), Kovacic and Zoller (2015), Kuda and Berankova (2014), Konig and Cristofaro (2012) | – | – | Davis (2017), Kopmanna *et al.* (2017), Kiridena and Sense (2016), Henderson *et al.* (2014), Nor *et al.* (2014), Chew *et al.* (2004) | AMBOK (2014), PMBOK (2013), Institute of Asset Management (2012), Hedeman and Seegers (2009), Davies and Register (2008), IBM (2007) | EN 15221-7 |
| *ACT (enhancing LCC-informed decision in BM)* | | | | | | |

(*continued*)

| PDCA components | Life cycle cost | | | Building management (AM, PPPM, FM, DM) | | |
|---|---|---|---|---|---|---|
| | Scientific papers | Guides, reports, technical publications | Regulatory and non-regulatory environments | Scientific papers | Guides, reports, technical publications | Non-regulatory environment |
| Communication of results | Ive *et al.* (2015) | – | ISO 9000; ISO 15686-5 | Kang and Paulson (2000) | DAMA-DMBOK (2014), East (2012), OmniClass (2006) | ISO 55000; ISO 21500; ISO 21503; ISO 21504; ISO 8000; ISO 12006-2; ISO19650-2; ISO 41000 EN 15221-4 |
| Audits and reviews | Kuda and Berankova (2014) | – | ISO 9000 | Gajzlera (2013) | – | |
| Strategies to increase LCC application and improving guidelines | Goh and Sun (2016), Kovacic and Zoller (2015), Gluch and Baumann (2014), Kuda and Berankova (2014), Konig and Cristofaro (2012), Lucko and Mitchell (2010), Schade (2007), Kirkham (2005), Bogenstatter (2000), Cole and Sterner (2000), Meckler (1977) | Churcher and Tse (2016) | – | De Silva *et al.* (2017), Munteanu and Mehedintu (2016), Bosch *et al.* (2015), Grussing (2014), Ling and Ton (2014), Wong *et al.* (2014), Ikediashi and Mbamali (2014), Heng and Loosemore (2013), Kurdi *et al.* (2011), Mohammed & Hassanain, El-Harm and Agapiou (2002), Jaunzens *et al.* (2001), Duffy (2000) | AMBOK (2014), PMBOK (2013), Institute of Asset Management (2012), IBM (2007) | ISO 41000; ISO 55000; ISO 21500; ISO 21503; ISO 21504 |

Table I.

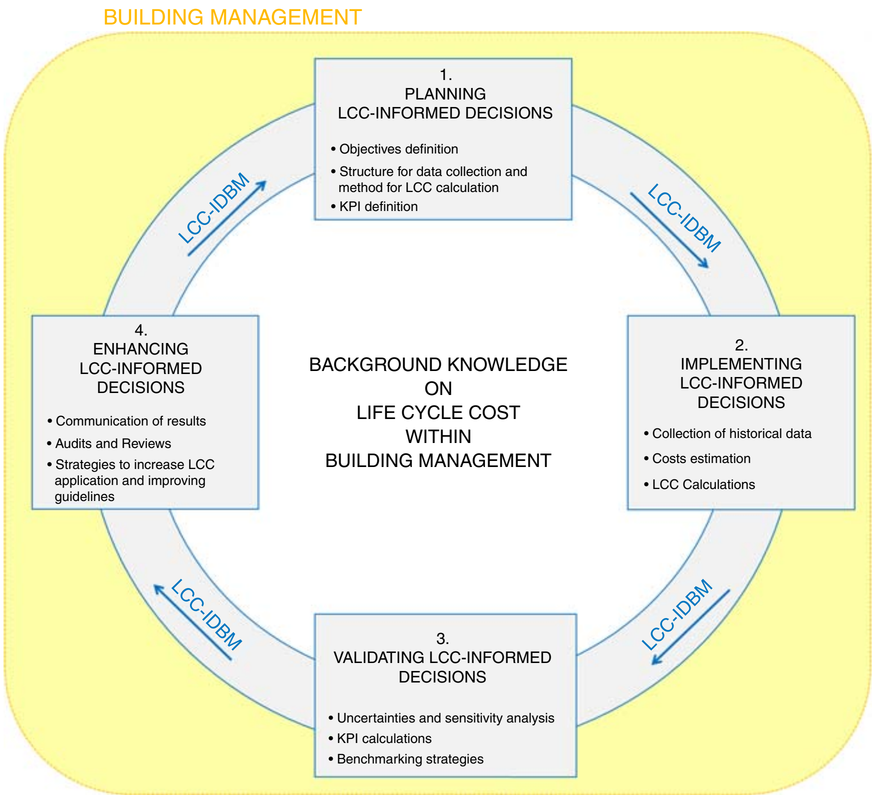



**Figure 3.**
Framework for LCC-informed decisions in BM

For the DM activities, ISO 12006-2 defines a set of tables as well as its nomenclatures for a comprehensive set of classes of construction objects. This classification structure is based on a basic modeling principle in which construction resources are used by construction processes to obtain construction results. The application of this principle defines an approach for the structuring of the main classes of the CICS. According to ISO 19650-2, the process related to the information management is framed on the organization management activities as well as within AM activities.

*4.2.3 KPI definition*. EN 16627 describes two approaches to the calculation of economic performance indicators: life cycle costing (economic performance expressed in cost terms over the life cycle, taking into account negative costs related to energy exports and from reuse and recycling of parts of the building during its life cycle and at the end of life); and life cycle economic balance (life cycle costing and in addition incomes over the life cycle and at the end of life).

ISO 21929-1 describes sustainability indicators along all phases of the building life cycle on the premise that sustainable development contributes to the technical and functional performance with minimal adverse environmental impact. EN 15221-7 provides guidelines for performance benchmarking in the field of FM.

Other indicators related to the results of the LCC assessment can be considered such as (ISO 15686-5): payback period; net savings or net benefit; savings to investment ratio; and adjusted internal rate of return.

EN 15643-4 defines other indicators such as flexibility and adaptability of the building, energy performance, environmental performance, adaptability of the building to climate change and durability.

### *4.3 Implementing LCC-IDBM*

*4.3.1 Collection of historical data*. The collection of historical data should be done in accordance with the defined structure for data collection. It is expected that this topic will offer various contributions for the scientific community both in terms of concepts and applications in the fields of LCC and in that of BM approaches as well.

*4.3.2 Cost estimation*. The estimation of costs can be carried out using several traditional techniques (Ashworth, 1998) or parametric analysis such as cost probability distributions or cost simulations (e.g. neural networks, case-based reasoning, linear regression and Monte Carlo). There are a number of scientific papers dealing with concepts and applications to case studies that can contribute for making these estimations. These estimated costs and the collected historical data will be used as inputs to LCC calculations.

*4.3.3 LCC calculations*. LCC calculations follow a well-established method. LCC calculation software may be used. ISO 15686-5 mentions the possible consideration of, for example, real costs, nominal costs, discounted costs and present value.

FM activities can provide valuable information about running costs but there is a harmonization gap in terms of the costs taxonomy preconized in ISO 15686-5, EN 15643-4, EN 16627 and EN 15221. The value of a linkage between FM and LCC lies in the sharing and use of economic information related to the use phase in the early stages of buildings life cycle. For example, this can be particularly useful for more robust value management studies to filter the options/alternatives at an early stage of the building life cycle (Trindade *et al.*, 2017; De Silva *et al.*, 2016; Munteanu and Mehedintu, 2016).

### *4.4 Validating LCC-IDBM*

*4.4.1 Uncertainties and sensitivity analysis*. In order to address cost uncertainty, the key issues to be considered in LCC assessments include (ISO 15686-5): confusion over costs to be included/excluded; variety of LCC measures and models; transparency and robustness of the underlying assumptions; lack of information about detailed design at the beginning of the project; prediction of a new technology/products life cycle; interface issues between capital costs and running costs; predicted inflation rates; overhead/profit and on cost allowances; labor and material costs; changes in legislation; or/and the impact of climatic changes.

Sensitivity analysis identifies the additional information required to collect and the most significant assumptions that are sources of uncertainties (e.g. discount rates, period of analysis, incomplete or unreliable service life or maintenance, repair and replacement cycles or cost data). It can also be used to consider how flexible or variable requirements can be managed during the period of analysis or the life cycle. If the recommended option varies depending on the assumed different discount rates, service lives or costs, etc., this indicates that further assessment is required or that the decision is based upon factors other than LCC (ISO 15686-5).

*4.4.2 KPI calculations*. The requirements of ISO 21929, ISO 15686-5 and ISO 15221-7 are relevant for this purpose, and there are a number of scientific papers covering this as well.

*4.4.3 Benchmarking strategies*. Benchmarking strategies help realizing the building economic performance level. These strategies have been discussed in some research papers.

The capital/acquisition costs are usually considered separately from costs that occur during the subsequent phases of the life cycle. These costs may be supported by different organizations or parties, or may be analyzed separately for benchmarking and comparison purposes (EN 15221-7).

Decisions, data feedback and continual monitoring and optimization of LCC assessment continue throughout the life cycle of the facility. These allow for original LCC assumptions to be reviewed and progressively refined or replaced by better analysis of quantities, costs and predicted performance of alternative products (EN 15643-4).

If the performance and costs of the constructed facility are monitored, deviations from the cost predictions can be highlighted. The same is true for consequences of changes to the operating and maintenance where increases in running costs can be as a result of client adaptations and overcautious or optimistic predictions or time estimates (ISO 15686-5).

*4.5 Enhancing LCC-IDBM*

*4.5.1 Communication of results*. At a strategic level, it is relevant to maintain information system and databases of results (ISO 9001). At a tactical level, LCC assessment results should be retained and reported (ISO 15686-5). At an operational level, the buildings economic performance can be presented by documents and visual aids (EN 16627).

When reporting results of the LCC assessment, the following information and description of assumptions can be included (EN 16627): intended use and scope; building identification and technical characterization; client; assessment method; point of assessment in the building life cycle; reference study period; statement regarding verification; functional equivalent assessed; data sources, type and quality; and statement of boundaries and scenarios used.

*4.5.2 Audits and reviews*. To improve the quality, reliability and consistency of data to be used on LCC assessments, audits and reviews are undertaken (ISO 9000, EN 15221-4). Strategies identified in this topic, which contribute to enhance the assessment of building economic performance, are incorporated into a new iteration of the LCC-IDBM.

*4.5.3 Strategies to increase LCC application and improving guidelines*. LCC assessments are developed concurrently with the design and are continuously related back to the initial plan, with any conflicts highlighted and resolved as applicable. Progressively, reliance on historic costs is replaced by confidence in predicted costs of a project under review (ISO 15686-5). Lessons learned and identified strategies to increase LCC application should be compiled and made available as guidelines for the practitioners of the AEC sector.

Literature researched showed recently that BIM is being increasingly adopted with a large potential to support BM activities as well as the LCC concept. It is also believed that appropriate outsourcing strategies in FM activities contribute to: reduce LCC value; maximize profits; improve competitiveness; add value to the organization; and provide access to professionals and experts.

## 5. Conclusions

This paper highlights that a joint approach to both LCC and BM is needed to facilitate the incorporation of the LCC concept into the AEC sector. Its originality lies in the structuring of the background knowledge on LCC and BM in a way that can be used by both the scientific community (research roadmap) and AEC practitioners (management framework) toward improved LCC-IDBM.

This structuring of the background knowledge is not a mere summary of literary findings. It enables practitioners with a PDCA framework to deal with real case situations and provides the scientific community with a systematic understanding of major research topics related with LCC and BM that need to be addressed or further matured. The proposed structuring follows a PDCA format which identifies the following main management or research topics: PLAN (objectives definition, structure for data collection, method for LCC calculation and

KPI definition); DO (collection of historical data, cost estimation and LCC calculations); CHECK (uncertainties and sensitivity analysis, KPI calculations and benchmarking strategies); and ACT (communication of results, audits, reviews, strategies to increase LCC application and improving guidelines).

The PLAN component of this background knowledge has been addressed both in regulatory and non-regulatory environments. However, the actual implementation of this knowledge (DO component) and its full applicability still requires testing (CHECK component). Also, it has to be improved before maturing into widespread implementation of the LCC concept in BM (ACT component). The outcomes of this research positively empower several stakeholder types throughout all phases of buildings life cycle: engineers and architects; facilities managers; facilities owners; regulators and authorities; banks and insurance companies; or end users.

LCC-IDBM depend on the widespread and consistent application of the LCC concept to the AEC sector, namely, by generating and making available the adequate quantity and quality of economic data. This strategy of using the PDCA cycle for structuring the background knowledge enables the future development of a robust BM model including the LCC concept, but further research in relation to each topic of this background knowledge is still needed. The validity and suitability of the proposed conceptual model on LCC for BM is presently being tested and will be detailed in future publications, together with the results of the application of the proposed PDCA cycle to real case situations and a commentary on: the impact in regulatory and non-regulatory environments; the opportunities and barriers to the generalized use of the LCC concept; the uncertainty of key variables in the final results of the LCC assessments; the criteria for robust sensitivity analysis; and the strategies for sustained success over time.

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