Integrating Life Cycle Uncertainties for Evaluating a Building Overall Cost

M. Arja, G. Sauce, and B. Souyri

Abstract—Overall cost is a significant consideration in any decision-making process. Although many studies were carried out on overall cost in construction, little has treated the uncertainties of real life cycle development. On the basis of several case studies, a feedback process was performed on the historical data of studied buildings. This process enabled to identify some factors causing uncertainty during the operational period. As a result, the research proposes a new method for assessing the overall cost during a part of the building's life cycle taking account of the building actual value, its end-of-life value and the influence of the identified life cycle uncertainty factors. The findings are a step towards a higher level of reliability in overall cost evaluation taking account of some usually unexpected uncertainty factors.

Keywords—Asset management, building life cycle uncertainty, building value, overall cost.

I. INTRODUCTION

THE construction and property industry has a long investment period, with ordinary buildings having a life cycle of approximately 50 years and some assets having over 100 years [1]. During the long period of a building's operational phase, many changes may appear in the building life cycle. Most buildings do not conform precisely to the life cycle assumed in their conception phase. Some change their functions or maintenance regimes. Others are expanded or altered. Several are rehabilitated many times through their complete lifetime before being demolished. These alterations may considerably affect the building life cycle as well as its overall cost.

Many researches have been conducted in order to develop overall cost (usually known also as life cycle cost) evaluation in the building sector [2]-[9]. Although, many uncertainties were deeply analyzed in these studies, the treatment of life cycle evolution was not sufficiently developed. The operational period that represents approximately 88% of the building life cycle [3], is presented simplistically in all overall cost methods.

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Most researchers consider historical data for operational costs when calculating a building overall cost without taking account of the possible life cycle evolutions. They estimate the overall cost in steady conditions supposing that no change will appear in the initial life cycle scenario. This direct use of historical data may invisibly integrate some life cycle uncertainty, but do not explain the details of costs arising from planned operational costs and those from life cycle evolution.

The current research focuses on integrating the impact of life cycle uncertainty in overall cost evaluation. Besides, it proposes an approach for estimating the real current and end-of-life building values depending on the state of buildings' components. The study arises from the analysis of case studies through a feedback process on the historical cost data. The main purpose is to reduce the level of uncertainty in overall cost calculations.

After a short state of the art review, the main characteristics of the method will be presented, uncertainty factors will be identified, general formulae will be developed, and method's elements will be defined.

II. STATE OF THE ART REVIEW ROCEDURE

Overall cost (or life cycle cost LCC) concept was firstly developed in the early 1960s in the US department of defense [10]. Since the beginning of its studies, roughly 50 years ago, the concept has spread from defense-related matters to a variety of industries and problems.

Historically, building designs were aimed at minimizing initial construction costs only [7]. Conversely, in the 1930s many building users observed that the running buildings' costs could affect significantly the occupiers' financial plan [11]. Thus, it became inadequate to choose between different alternatives depending on the initial construction cost only. By example, a heating system with a cheaper initial cost may expand the exploitation invoice what could simply change the client's choice.

Therefore, the construction industry has adopted a new way of thinking to answer this new need. Another costing technique known as building overall cost or life cycle costing (LCC) has been developed over the years. In France, this concept was introduced in the 1970s with the first studies of building maintenance costs [12]. Recently, several research projects have been conducted to develop an overall cost methodology for the construction industry [4]. For example, Aye et al. [13] used overall cost data to analyze a range of properties and options for building construction. Leigh and Won [5] employed this cost as a decision-making tool for

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choosing heating, ventilation and air-conditioning (HVAC) building systems. Foucault and Leclerc [14] studied the exploitation/maintenance cost in four types of buildings (common schools, colleges, universities and hospitals) and calculated their annual values.

Most overall cost studies consider that this cost should be evaluated during the first design phase [8], [12]. It is essential to evaluate overall cost at this phase; however it could be evaluated at any instant of the building life cycle when a decision should be made by a building stakeholder. Different stakeholders have different visions of the building life cycle, Fig. 1.
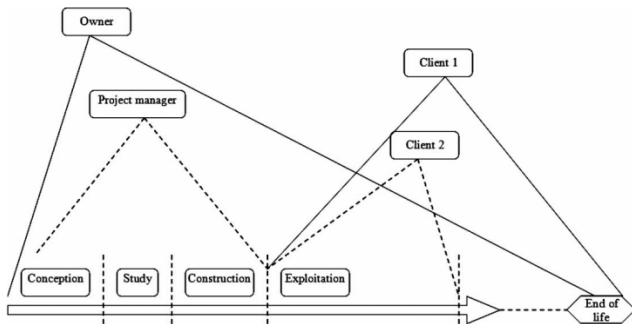

Fig. 1 Building life cycle limits, different viewpoints [15].

In addition, existing methods do not take account of the evolutions of building life cycle. According to these methods, operational costs are constant or progress linearly with time. However, the real development of these costs cannot be presented in this simple way. Actually, many factors affect these expenses and cause many peaks in their evolution curve, Fig. 2. These peaks represent the influence of many unexpected uncertainty factors like regulatory change, technological change, and functional evolution.

In order to integrate these evolutions of operational costs and to identify and quantify their causes the research project analyzes several case studies and proposes a new overall cost approach.
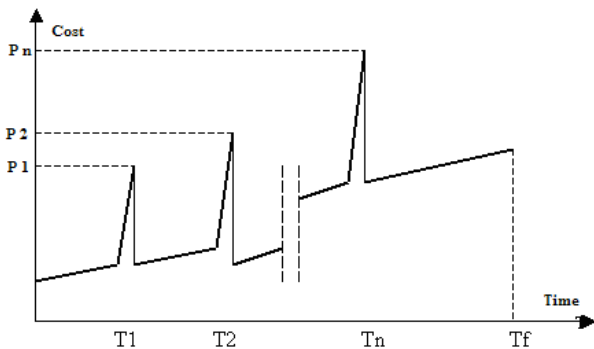

Fig. 2 Operational costs evolution.

III. METHODE DESCRIPTION

A. The objective

Existing methods estimate the overall cost in stable conditions using the ordinary formula (1):

$$C_g = C_{int.} + C_{op.} \pm V_R \qquad (1)$$

C_g Overall (global) cost,
$C_{intl.}$ Initial cost,
$C_{op.}$ Operational costs,
V_R Building end-of-life value.

Traditional methods use average annual expenditure, estimated from historical data analysis, for operational costs. This manner of calculation may indirectly and invisibly integrate a part of possible cost evolutions, Fig. 2.

With time, the building life cycle advances and the amount of its overall cost changes. It is no more equal to that calculated in the design phase, with time one gets closer of the exact value. Evaluating a building overall cost at different moments of the life cycle does not give the same result due to the evolution of our knowledge of the life cycle, Fig. 3. At the design stage, where the level of knowledge is minimal, the overall cost is estimated at Cg1. After a first operational period, the application of a new building law is known; one can refine the assessment to Cg2. After a second operational period a functional change is imposed; the evaluation will be at Cg3. The real overall cost Cg4 will be known only at the end of building life.
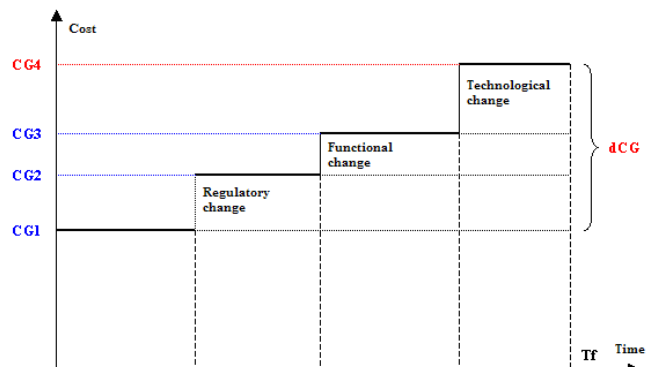

Fig. 3 Overall cost knowledge evolution.

Existing methods are not adapted to integrate these types of life cycle changes. The aim of this research work is to reduce the uncertainty amount dCg in overall cost evaluation by integrating life cycle uncertainty in the calculation formula. It aims also to propose a new method for evaluating the overall cost at any instant of the life cycle.

B. Study period

As previously indicated, the proposed overall cost method will be applicable at every moment of the building life. Thus, the study period in this approach should be a partial movable period, Fig. 4.
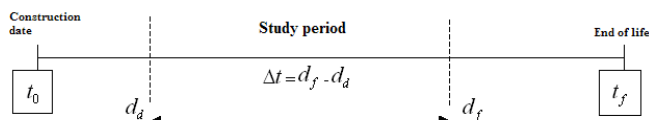
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Fig. 4 The partial, movable, study period.

Evaluation instant d_d could be t_o (the design phase) or any other instant t of the building life. Similarly, the end of study instant d_f could be t_f (the end of the building life) or any other instant t.

Therefore, it is essential to provide an assessment of the building current value at the evaluation moment d_d, of its end-of-life value at the end of study moment d_f and of the uncertainty factors during the study period Δt.

C. Life cycle uncertainty integration

This approach focuses on the uncertainty in life cycle development and building current and end-of-life values. Other uncertainties, such as calculation methods' errors, future costs uncertainty, inflation and interest rates evolution, are not explicitly treated by the method. Many studies are available on using risk assessment techniques like sensitivity analysis, probability-based techniques, and fuzzy approach for predicting and reducing the influence of these uncertainties [7].

On the basis of historical data analysis [15], financial data (operational accounts, maintenance accounts, principal works histories, etc.) of several case studies were analyzed in order to separate operational costs in two categories:
- regular, expected, operational costs; and
- added, unexpected, operational costs.

This second category represents spontaneous costs not identified in the initial life cycle scenario. These costs are caused by some uncertainty factors usually not controlled by the building manager. According to the studied examples, the most important uncertainty factors are:
- fonctional change,
- technological evolution,
- regulatory change, et
- unexpected maintenance.

Table 1 represents the justifications of unexpected works in a residential building example.

TABLE II
FACTUAL TABLE (RESIDENTIAL BUILDING)

Works	Cost €	Year	Causes
Lifts	133 174,83	1997	Functional change
Heating repairs.	64 239,87	1997	Maintenance
Maconry	46 787,93	1997	Technological change
Exposure replacement	30 529,28	1994	Maintenance
Watertightness	26 154,20	2004	Maintenance
Television	19 817,39	1997	Functional change
Works control	15 167,92	1996	Others
Lighting of stairs	13 768,94	2003	Legislative change
Cutting gaps in concrete walls	11 582,78	2003	Functional change

After the analysis of this information, one can calculate the amount of works caused by each factor. Then, these amounts can be presented as percentages of the initial cost or the annual operational cost. Table 2 presents the impact of uncertainty factors on the overall cost in an industrial building example. The results are given in percentage of construction cost and depend on the study period. Uncertainty will increase for longer study periods.

TABLE I
UNCERTAINTY FACTORS IMPACT

	Industrial building			
	5 years	10 years	20 years	40 years
Technological evolution (F1 %)	0	1.08	2.4	5.43
Functional change (F2 %)	1.01	2.23	10.67	11.29
Legislative change (F3 %)	0	0.03	0.61	2.97
Unexpected maintenance (F4 %)	0	0.06	2.52	4.09
Somme (F %)	1.01	3.39	16.19	23.77

IV. OVERALL COST METHOD

A. General formulation

For integrating the impact of life cycle uncertainty factors, a new component (ΣC_{fac}) will be added to the initial formula (1). Equation (2) represents the new overall cost formula:

$$C_g = V_{cur.} + C_{op.} \pm V_R + \sum C_{fac.} \qquad (2)$$

$V_{cur.}$ Current building value at the evaluation instant,

ΣC_{fac} Sum of costs added by the factors of uncertainty.

Where:

$$\sum C_{fac.} = C_{tech.} + C_{fonc.} + C_{rég.} + C_{ma\,int.} + C_{aut.} \qquad (3)$$

ΣC_{tech} Cost added by technological evolution,

ΣC_{fonc} Cost added by functional change,

ΣC_{reg} Cost added by legislative/regulatory change,

ΣC_{maint} Cost added by unexpected maintenance operations,

ΣC_{aut} Cost added by other factors,

It could be better to replace the new cost component $\Sigma Cfac$ by augmentation rates ΣFi in order to facilitate the calculation process. These rates may be applied on one or more of overall cost components (initial cost, operational costs, and end-of-life value).

The separation of the factors' influence on these three components is very difficult. Consequently, the method simplifies the formula by applying augmentation rates only on one component. This will be on the initial cost or on the operational costs, equation (4). The rates are not the same in the two cases.

$$C_g = C_{int.} + (1 + \sum F_i) \times C_{exp.} \pm V_R \qquad (4)$$

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Or $$C_g = (1 + \sum F_i) \times C_{int.} + C_{exp.} \pm V_R$$

ΣF_i Total augmentation rates, equals the sum of all the impacts of life cycle uncertainty factors, see table2.

B. Method's components

B.1. Building current value

When using the method for calculating the overall cost at an instant d_d, there should be an evaluation of the current building value at this instant. Tow similar methods, not detailed here, are proposed for estimating the building value depending on an expert initial evaluation or using market prices for similar buildings.

The method consists of decreasing this value (expert or market price) according to the building degradation. A health state (new, good, median, bad, and out of service) will be associated to each building component. The price will be decreased depending on the overall building health state.

Afterward, the obtained building value will be decreased by a conformity rate that represents the conformity of the building with current standard. This global scale evaluation is based on a reduced number of building technical components (less than 10) for not complicating the process.

B.2. Building end-of-life value

The same approach will be used to evaluate the building value at the end of study period. The maintenance policy of building components plays a vital role in this evaluation while it determines the health state of components at the end of study period.

B.2. Profiles constitution

For facilitating the use of analysis results in future overall cost evaluations, they should be classified in profiles by types « type profiles, by example residential buildings or industrial buildings» or by organization « organization profiles, by example University of Savoie ».

Each profile should contain the following elements:

 - Characteristics parameters for estimating building values: the importance percentages of building components, the weight of each health state, reference prices, etc.

 - Operational costs parameters: costs types, their annual amounts, their annual evolution, etc.

 - Life cycle uncertainty factors as well as their impact on overall cost, Table2.

V. CONCLUSION

Evaluating the real overall cost of a building is difficult because of the long investment period and various uncertainties. The paper proposed a new method for evaluating a building global cost taking account of the life cycle uncertainty and the building's current and end-of-life values. The approach is adequate for investor's uses. It offers a simple decision making tool needs a minimum level of knowledge at any phase of the building life.

The method bases on the definition of buildings profiles. The difficulty is to draw up suitable profiles to be used for other similar buildings. A current study is carried out in collaboration with an important building manager in Paris. The aim is to clarify the feasibility and the added value of the method by comparing several life cycle evolution scenarios with different life periods and determining the best one.

More case studies are needed to evaluate the impact of uncertainty factors on building overall cost. The same analysis should be developed for other buildings and building types in order to obtain more reliable results. More extensive analysis of such data from other projects would facilitate the development of more reliable overall cost formulae, which in turn should contribute to more appropriate building design, costing, and more effective strategic planning in building maintenance management, and facilities management.

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