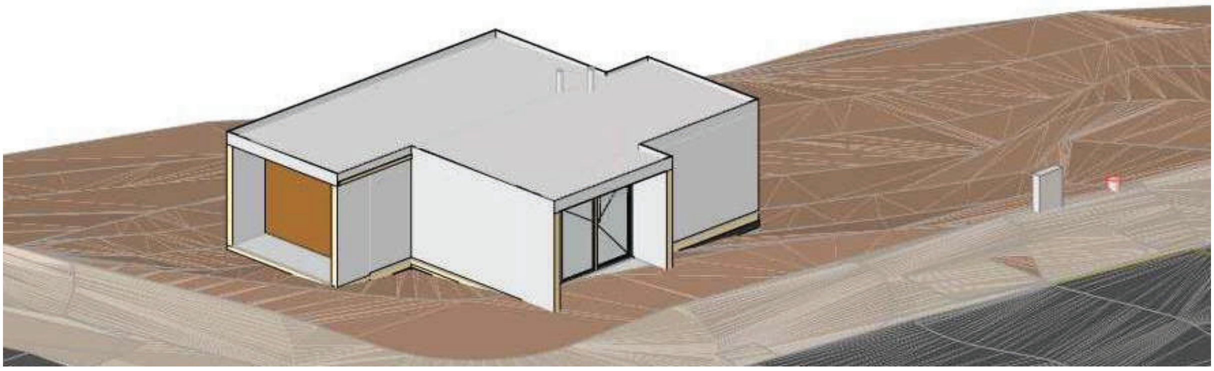
TÉCNICO LISBOA



Minimal house

Building systems service life costs ‘ comparative study
for a detached single family house

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Extended Abstract

Decem ber 2015

1. Introduction

In five chapters, this thesis sets the importance of estimating economic performance, earlier as possible, not only in the construction and installation phase, but along all buildings service life assets, timely adjusted in revisions, in today´s resource shortage context. Indeed, for years buildings investigation had been advising decision makers to minimize, to select materials regarding its service life and to adopt reversible systems, as a contribution for sustainability in the construction sector [1].

The present study´s framing is conscience, since the end of the XXth century, that an emerging variety of lifestyles [2] made popular building module's flexibility and adaptability [3] for low-cost housing. Industrial product constituted by separated layers, dry wit and, in recent years, integrating environment friendly materials and technologies for higher energy efficiency [4] and lower waste [5], prefabrication is a sustainable proposal and a serious alternative to conventional reinforced concrete and brick construction, which density guarantees building´s durability.

This study´s purpose is to select, through life cycle cost analysis, the most convenient option for a user-payer to own a home with minimum comfort along proper time. Two building systems to construct the same detached single-family house shall be compared: a wooden structure with fibre panels and dry wit, and a conventional reinforced concrete and brick structure with external thermal insulation system. Project type is a single floor, one bedroom, detached house. The comparison is centred on both options economic performance, regarding a system boundary including accumulated costs since the before use phase, along the use phase, until the buildings end of life phase. Life cycle cost analysis is the method, standardized in ISO 15686:2008's part 5 [6], accounting time value of money, complementary to an economic aspects structure to quantify buildings performance, divulged in standard EN 15643:2012's part 4 [7], both published. Accumulated expenses along the two buildings equal service life will be calculated subjecting present costs to an annual discount rate. EN 16627:2015 standard, when published, shall be the european method for the detailed calculation in buildings economic performance analysis.

2. Economic assessment of buildings and constructed assets

Already since the 1990's, some sectors in society claimed economic, social and cultural principles to be added to construction sector´s conventional concerns on costs, deadlines and quality. "Sustainable Construction" was then redefined as the responsible creation, rehabilitation and management of a healthy building environment, based on resource efficiency and ecological principles, adding to social and economic balance [8]. Economic principles are focused on equity and on long term decisions. In such context, sustainable construction doesn´t aim an excellent environmental performance sacrificing an entity´s economic viability, neither an excellent financial performance at adverse environmental and social costs [9].

Facing today's paragon change, from industrialization to sustainability, last decade saw standards development on buildings service life planning.

Next, focus is set on recent standards addressed to buildings economic performance along all its life cycle phases.
EN 15643-4 standard dates 2012 and is a series part which proposes criteria to assess buildings sustainability. The document's writing is the European Committee for Standardization (C.E.N.) Technical Commission 350's responsibility. Depending on the object of analysis, statements on buildings sustainable performance shall address all three dimensions (environmental, social and economic), or each isolated dimension [7].

According to the european standard, buildings economic performance analysis objectives are:

- to identify the economic aspects and impacts of the building and its site;
- to enable the client, user or designer to make decisions and choices [7].

EN 15643-4:2012 standard proposes to allow an economic evaluation concurrently and on equal footing, of objects with similar technical characteristics and functionality. For this, the document quantifies economic aspects and impacts over buildings life cycle, for their whole, their parts or their elements, whether new or existing buildings, distinguishing two assessment indicators:

- Economic performance expressed in cost terms over the life cycle quantifies the "lowest life cycle cost" building, without including developments on the real estate market, gathering only cost data;
- Economic performance expressed in terms of financial value over the life cycle quantifies the best financial value building, i.e. the building with the highest (discounted) revenue minus the cost over the life cycle, approach including market-related revenue streams.

The aspects and impacts of a building that relate to its economic performance are influenced by actions taken throughout its entire life cycle, starting with the decision whether to build, refurbish, renew, extend, retain or demolish, proceeding through the contractual arrangements for design and specification, procurement of products, construction work, handover for fit-out and use; until the building’s end of life, with its decommissioning, deconstruction or demolition.

The first of the european document's requirements for the assessment procedure is the definition of the object of assessment, which shall be the building, its foundations and external works within the area of the building's site (curtilage) and temporary works associated with its construction.

Functional equivalence is a mandatory condition in case of the purpose of the economic performance analysis being options comparison.

Next requirement is the specification of the system boundary that applies at the building level, from the beginning of the planning of the development, acquisition or refurbishment of a building, or from the start of the assessment of any existing building, including its integrated technical system and its related fixed furniture, fixtures and fittings, through the life cycle of the building. The European pattern relates the system boundary’s definition to the assumption of economic aspects specific to the building, selecting all relevant information from modules A to D, which key-term is the Use Stage:

- economic aspects and impacts at the Before Use Stage (Modules A_0 and A_1-A_5);
- economic aspects and impacts excluding the building in operation at the Use Stage (Modules B_1-B_5);
- economic aspects and impacts of the building operational use (Modules B_6-B_7);
- economic aspects and impacts at the End of Life (Modules C_1-C_4 and D) [7].

The object's quantification follows economic data selection. The correspondent cost or value's indicators calculations shall comply with standards EN 16627:2015 [10], to be published, or with early ISO 15686-5, or with historical data. Now the buildings service lives shall be estimated in accordance with European product standards, or with applicable ISO 15686 series parts [7].

EN 15643-4:2012 standard conditions data quality in the assessment of economic performance from appropriate, accurate, precise, complete and representative sources of cost information on products, processes and services for buildings. The document also appeals for the assessment methods transparency, requiring applied scenarios modeled explicitly and made available for communication.

The following cost information and results verification shall be in accordance with the requirements of the assessment standard for economic performance to be published as EN 16627:2015 [10], which suggests a sensitivity analysis to describe the potential influence of non-assessed aspects, regarding pattern ISO 15686-5 [6] [7].

The results of the assessment shall be organized according to information groups exemplified in Figure 2.1 below, a graphic translation of the European standard working structure resumed further in Figure 3.2. Results shall be interpreted and reported in an accurate, verifiable, relevant and not misleading or deceptive summary of information to any third part. Any economic requirements given in the client's brief, or resulting from regulations, shall be included in the assessment report and declared on communication.

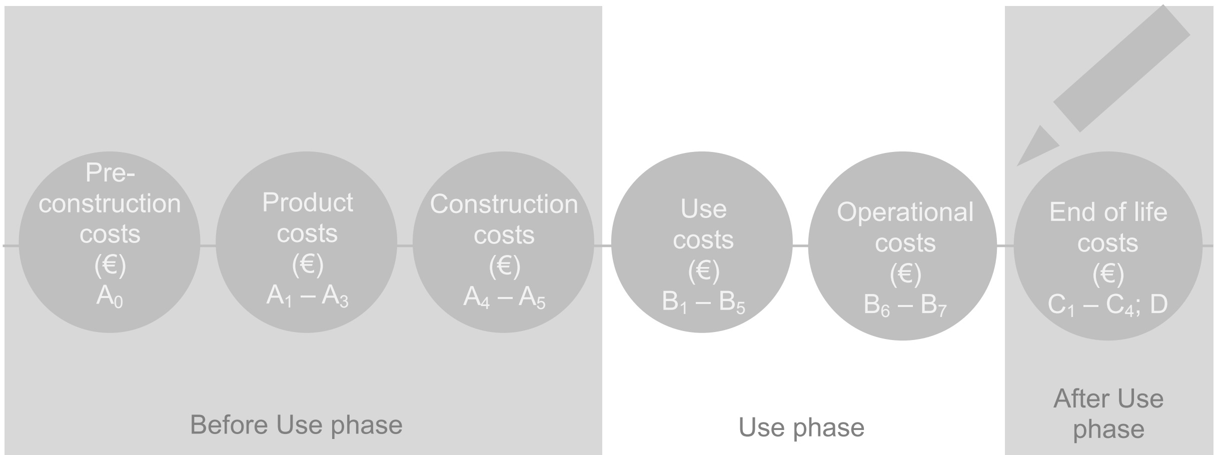


Figure 2.1. Abacus representing buildings life cycle cost categories (adaptation of [7])

Interpretation and valuation of the results of the assessment are not within the scope of this series of European Standards, as its purpose is to enable comparability of the results of assessments, measured without value judgements, excluding the economic risk assessment of a building and return on investment calculations [7].

To measure economic sustainability, this study's building systems comparison method regards their service lives planning. Service life is the reference for related previsions on constructions durability and buildings ability to keep the required technical performance along time, subject to planned maintenance, under predictable degradation agents effects [7]. An investment´s "economically reasonable planning" [7] carries out a cost assessment not just on the sketch plan stage but during the whole life cycle of a construction or refurbishment project, in order to provide a broad estimate of the investment’s expenses.

One of the methods which enable cost analysis along buildings durability is Life Cycle Costing (L.C.C.). It may be used for new assets or major refurbishments and can be undertaken for the whole building, for parts of the building which can be used separately, or for elements of the building, regardless of manufacturing process: any objects which accumulate costs and/or revenues throughout their service life.

This buildings splitting of costs ‘ early references date back to the 1960's decade, and relate to the american army's procurement, on a rationing criteria: to justify considerable material and equipment purchase expenses with long term benefits. In the early 1970's, the term 'use cost' starts figuring in industry and in literature, referring to an asset operation expenses, susceptible to influence civil consumers decisions [11]. Originally outside of construction industry, user costs main principles were, although, admitted applicable to buildings and important structures [12]. In 1971, the british Royal Institute of Chartered Surveyors (R.I.C.S.) established the Building Maintenance Cost Information Service (B.M.C.I.S.), a database to provide liable information on performance and use costs, for those interested in applying L.C.C. techniques. Since then, diverse models were discussed, from engineering to accounting, mathematics and statistics, for L.C.C.'s application to construction undertakings. Three decades of practice generalized standards, in diverse countries, about this input-output accounting method, for the economic assessment of construction investments. Reviewing today's construction research, cost-benefit analysis is applied essentially in case studies. There's a wide variety of constructed assets, existing or in project, to compare, impelled by an early tendency of accounting buildings energetic performance.

To select the most economically efficient project option throughout a certain period of time, L.C.C. analysis considers total costs sequency unfolded, year after year, during design life, regarding time value of money. In the owner's interest, it is advisable to aim for the lowest cost, in long term [13]. The client's requirements can, and should be, revised and cleared along the investment's life cycle. Forecasts for decades may be at stake, during which cost calculation basis may vary, such as inflation and energy costs. So, several reports in diverse stages may be produced.

ISO 15686-5:2008 [5] standard contains the operating procedure for the present investigation's L.C.C. analysis. The standard requirements resume were adjusted from [13] and [14]:

I. Identify the purpose of the assessment, the period of analysis and the analysis level;

II. Costs categorization;

III. Assemble and calculate cost variables;

IV. Assemble time variables;

V. Discount costs for present values

To variable comparison by L.C.C. analysis, it is necessary to determine cost categories Net Present Value through discount technique [6], which converts future monies to present monies, to reflect their diminished value in the year of transaction relative to base year [6]. The sum of the discounted future costs is L.C.C.'s Net Present Value (N.P.V.), as equation (2.1.) presents:

$$LCCNPV = \sum_{n=1}^{p} x \frac{C_n}{(1+d)^n} \tag{2.1}$$

where:
LCCNPV = L.C.C.'s Net Present Value;
n = The number of years between the base date and the occurrence of the cost;
p = The period of analysis, defined according to the client´s requirements and equal design life period minimum;
C_n= The cost in year n;
d =The expected real annual discount rate, which calculation is presented in equation (3.1); that factor's type should be clearly indicated as real, nominal, or other. Ideally, real discounted costs should be used, as they enable applying current data.

When only costs will rise, NPV can be designated as Net Present Cost (NPC) [6], to select building options based in economic aspects, as the present case study which accounts only expenses. A flux of future costs is converted in L.C.C.'s Net Present Cost (L.C.C.N.P.C.) in Table 4.1.

Another parameter will also be used: L.C.C.'s Annual Equivalent Value (A.E.V.), a uniform annual amount equivalent to the project net costs, taking into account the time value of money throughout the period of analysis. Selecting the lowest annual equivalent cost, the lower cost option is definitely selected [6]. L.C.C.'s A.E.V. calculation is formulated in equation (2.2):

$$LCCAEV = \sum_{n=0}^{p} x \frac{C_n}{(1+d)^n} x \frac{d(1+d)^n}{(1+d)^n-1} \tag{2.2}$$

where:
LCCAEV = L.C.C.'s Annual Equivalent Value
n = The number of years between the base date and the occurrence of the cost;
p = The period of analysis;
C_n= The cost in year n;

d = The expected real annual discount rate, which calculation is presented in equation (3.1); S.C. 2 and S.C. 3's annuities are presented in Table 4.1.

VI. Identify uncertainty and risk causes, as well as identify the need for additional analysis (risk/uncertainty or sensitivity analysis) and perform assessment´s verification

An L.C.C. analysis requires previsions on future behaviour, so the assessment should include the consideration of risk and uncertainty. Risk is analysed when estimation of probabilities is possible; uncertainty is analysed when probabilities cannot be estimated. The range of uncertainty and risk associated with L.C.C. analysis depends on the type of data available, on the period's extension, on pricing and on calculation methods. To indicate L.C.C. analysis uncertainty and risk percentage, two techniques are advanced: Monte Carlo and sensitivity analysis [6]. The present L.C.C. related uncertainty was dealt with a sensitivity analysis. For such, a range of rates was used to test conclusions validity if initial conditions change. The case study's sensitivity analysis results are in subchapter 3.7.

VII. Interpret and report results in the required format

A graphical representation of results frequently aids understanding and provides a readily comprehensible summary of the outcomes [6]. A graphic representation of this thesis results is set in chapter 4. A thorough discussion of this study's results, to be consulted also in chapter 4, precedes the presentation of the conclusions related to the objectives of the study, followed by recommendations for any further work, in chapter 5.

This thesis following chapter contains construction, maintenance, operational energy and water use, deconstruction, transport and disposal costs of the 2 compared buildings, which incorporate diverse materials, with different expenses flows.

3. Case study

For testing economic sustainability framed by recent standards reviewed in previous chapter, is intended a comparison of two house building solutions, proposed by two local contractors.

3.1. Construction works and building systems descriptions

Figure 3.1. shows works as the construction of a one bedroom single family detached house with a single floor, composed by living room and kitchen, hallway, bedroom, W.C. and two covered porches. Gross area is 60,40 m².
The house shall be built in a 340,50 m² plot located in a portuguese continental community urban centre, 20 Km far from sea.

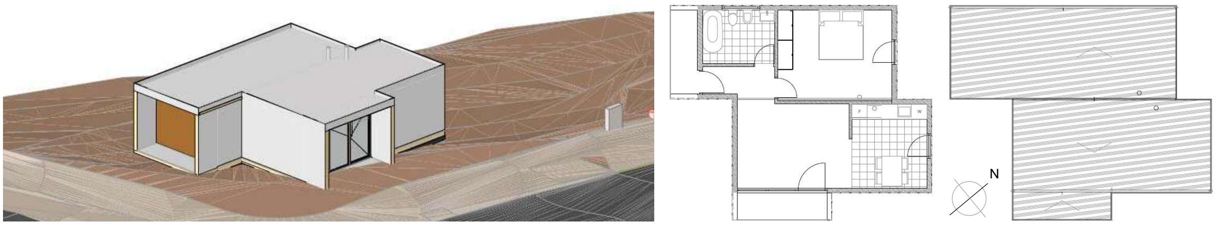


Figure 3.1. Architecture's external view (left), floor plan (centre) and roof plan (right)

The land is sloped and its soil is considered consistent. There's access to the plot by the urbanisation's main street and the property is served by public potable water supply and drainage, as well as served by private electric and telecom networks.

In the research seminar, two building systems, S.C. 2 and S.C. 3, were tested on their compliance of all regulation applicable performance requirements, verified in 12 projects integrating the building license request process.

S.C. 2 and S.C. 3 are low-cost solutions proposed by two contractor companies located at 45 Km and 10 Km distance, respectively, from construction site. The two buildings main difference is their structure material, S.C. 2’s 540 Kg/m³ solid *Pinus sylvestris, ait.* wood at 12% humidity, and S.C. 3’s resistance class C16/20 reinforced concrete, respectively. There are various finishing materials for two different structures. S.C. 2's claddings are fibre wood and gypsum-cardboard panels with rockwool insulation layers, dry wit to pinewood’s frame. S.C. 3 is a current brick with external thermal insulation building. Both options have flat roof, steel-expanded polystyrene sandwich profiled sheeting, and continual coatings on their external walls. S.C. 2 and S.C. 3's envelopes are typified in Table 3.1.

3.2. Calculation criteria

To respond to the purpose of quantifying both buildings economic performance, within the area of the site, calculation based on cash flow along life cycle shall be applied. Cash flows are capital input and output streams presented as lump sum, in an equal time period. Standard cash flow modelling procedure for the present study requires money equivalence calculation in time by L.C.C.'s Net Present Value (N.P.V.), and by Annual Equivalent Value (A.E.V.), respectively explained in equations (2.1) and (2.2).

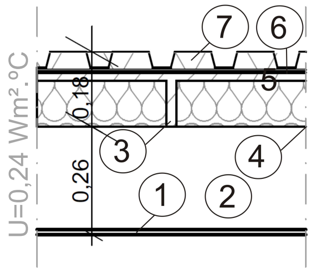
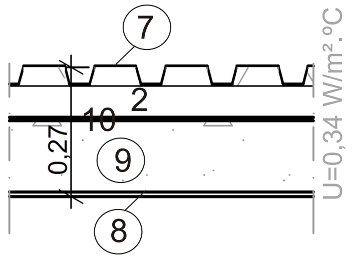
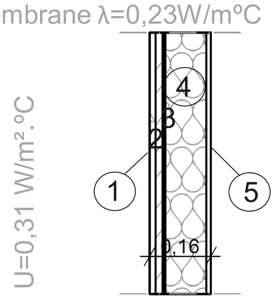
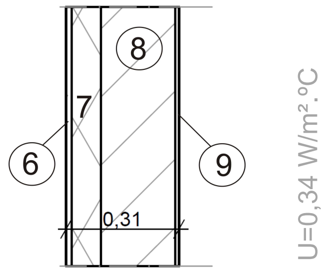
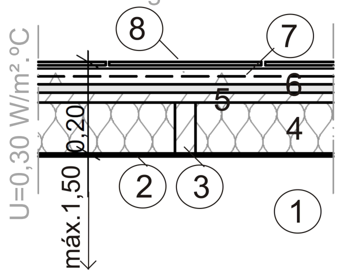
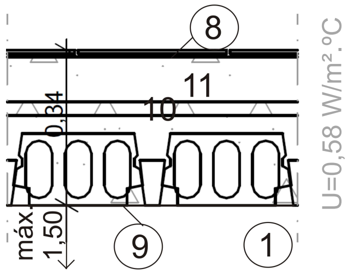
The analysis period was assumed from listed reference structural service lives, it is equal for both buildings, and is explained on subchapter 3.4.2.

There is functional equivalence between compared buildings, as housing is their identical future use.

The present study's system boundary is those buildings life cycle stages construction costs, use costs and end-of-life costs, resumed on subchapter 3.5.

The case study's cost variables adoption criteria are real costs at a real discount rate for only expenses will accumulate through compared buildings life cycle: legal property's cost-effectiveness is not possible at this moment.

Table 3.1. 2 building systems envelopes

Envelope's parts	S.C. 2	S.C. 3
Flat roof		
	1. Internal gypsum-cardboard skimmed painted suspended ceiling t=0,012m λ=0,25W/mºC; 2. Air space; 3. Pinewood beam 70x140mm λ=0,29W/mºC; 4. Rockwool insulation layer t=0,11m λ=0,042W/mºC; 5. Oriented Stranded Board (O.S.B.) t=0,02m λ=0,13W/mºC; 6. Micro-perforated high-density polyethlyene sheeting e=1,5µmm λ=0,50W/mºC; 7. External lacquered steel-expanded polystyrene sandwich profiled sheeting t=0,04m λ=0,037W/mºC; 8. Internal painted plastered coating t=0,01m λ=0,18W/mºC; 9. Solid reinforced concrete slab t=0,15m λ=2,50W/mºC; 10. Bitumen membrane λ=0,23W/mºC	
Typical external wall		
	1. External single layer render coating on glass fibre net t=0,015m λ=1,0W/mºC; 2. O.S.B.; 3. Micro-pierced high-density polyethlyene sheeting; 4. Rockwool insulation layer; 5. Internal gypsum-cardboard panel; 6. External painted render coating t=0,015m λ=1,3W/mºC; 7. External Thermal Insulation Composite System (E.T.I.C.S.) e=0,20m λ=0,0W/mºC; 8. Half-brick thick hollow wall e=0,20m λ=0,38W/mºC; 9. Internal painted plastered coating	
Floor		
	1. Sanitary closed air space on natural cleared packed ground; 2. Polyethylene sheeting; 3. Pinewood beam 80x160mm λ=0,29W/mºC; 4. Rockwool insulation layer; 5. O.S.B. t=0,022m λ=0,13W/mºC; 6. Fibre-cement panel t=0,019m λ=0,22W/mºC; 7. Waterproof synthetic coating with fibre glass net t=0,03m λ=1,0W/mºC; 8. Ceramic tile cladding t=7,8mm λ=1,3W/mºC; 9. Precast concrete slab t=0,20m λ=1,176W/mºC; 10. Expanded polystyrene insulation panel t=0,03m λ=0,81W/mºC; 11. Cement mortar bed t=0,10m λ=0,30W/mºC	

U. Thermal transmission ratio; λ. Thermal conductibility ratio; e.Thickness

Equation (3.1) explains the discount rate calculation to be used in the present case study's selected costs.

The present L.C.C. analysis necessary data are: buildings usage, discount rate, building options estimated service lives, construction costs, operation and maintenance costs, end-of-life costs, uncertainty and risk.

Next steps are quantifying objects and selecting economic data for calculation, followed by verifying and reporting results on a summary [10], still in this document's present chapter.

3.3. Cost and time variables

Discount rate is the cost factor used to convert future monies into present monies and vice versa, reflecting money valuation in time. Typically, discounts between 0% and 4% are applied [6].

Investments evaluation at real costs should use a real discount rate and its calculation followed equation (3.1):

$$(1+T_{sr}) = (1+T_n) \times (1+T_{inf}) \times (1+P_r) \quad (3.1)$$

where:

T_n = Real discount rate;

T_{sr} = Nominal non-risk discount rate [15];

T_{inf}= Annual inflation in 2014 [16];

P_r = Risk premium [17], measure of additional profitability on portuguese stock market.

The following data were accounted:

T_{sr} = 2,75%, T_{inf} = -0,27% e P_r= 7,2%. Therefore, T_n = 3,89% is the discount rate.

Another cost variable was necessary, currency exchange [18].

For both buildings, it was assumed a service life time period p = 50 years, from a european document construction products working lives [19], the same scope as the previously explained european standard. 50 years is the working life assumed for normal category construction works. Despite S.C. 2's solid *Pinus sylvestris, ait.* wood framework claddings fragility, painted rendered wood and gypsum-cardboard fibre panels short thickness, the building was designed with continual reinforced concrete and cement block foundations. The wooden building system reference life could therefore be equated to S.C. 3's porticos of reinforced concrete and brick, solid and thick materials which guarantee adequate protection from internal and external environmental degradation agents.

Both buildings components reference service lives, the basis for periodical maintenance works planning, and basis for correspondent costing, were obtained from typical life expectancy of buildings components tables [20].

3.4. System boundary

EN 15643-4:2012 standard [7] information modules table, relates economic aspects with buildings life cycle phases as Figure 3.2 signs, and establishes what is included for each building systems economic performance assessment.

BUILDING ASSESSMENT'S INFORMATION

Building's life cycle information																		Additional information beyond the building's life cycle
Before use stage						Use stage								After use stage				
A_0	A_1-A_3			A_4-A_5		B_1-B_7								C_1-C_4				D
PRE-CONSTRUCTION	PRODUCT STAGE			CONSTRUCTION PROCESS		USE STAGE								END OF LIFE STAGE				Benefits and loads beyond system boundary;
Land and related fees	Raw material(s) supply	Transport	Manufacture	Transport	Construction	Installation process	Utilization	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	Deconstruction	Transport	Waste processing for reuse, recovery, recycle	Disposal	Reuse Recovery Recycle potential
A_0	A_1	A_2	A_3	A_4	A_5		B_1*	B_2	B_3*	B_4*	B_5*	B_6	B_7	C_1	C_2	C_3*	C_4	

Figure 3.2. Selected economic aspects (adaptation of [7])

* Not applicable; A_0 Preconstruction costs are an annual constant land fee since 2011; $A_1A_2A_3$ Product costs are projects expenses already paid

- Buildings construction costs (A_4-A_5); works were assumed to start and complete within year 0 of the buildings predicted service lives. Those are explained in subchapter 3.5.1.
- Maintenance costs (B_2) during each building use stage, assumed since year 1 to 49 of the buildings predicted service lives. Those are resumed in subchapter 3.5.2.
- Operational energy use costs (B_6) over each building life cycle, assumed from year 1 to 49 of the buildings predicted service lives and described in subchapter 3.5.2.
- Operational water use costs (B_7), over each building life cycle, assumed from year 1 to 49 of the buildings predicted service lives and described in subchapter 3.5.2.
- Buildings demolition costs (C_1) and correspondent Transport (C_2) and Disposal costs (C_4) in waste dump, at the end of the 50 year predicted service lives and explained in subchapter 3.6.3.

3.5. Case-study's results

After justifying cost and performance data for S.C. 2 and S.C. 3's life cycle economic impacts, the results of the selected modules economic comparative analysis are presented next.

3.5.1. Before use stage costs

I. Construction costs (A_4-A_5)

For the present L.C.C. analysis, construction costs were estimated by both owner contacted contractors, who produced works detailed budgets, accounted on Architecture and Engineering license projects data. Those calculations include all economic aspects of material, labour, equipment and building works, as well as subcontract works and the house’s delivery [7]. Operational energy and water costs during construction phase were not included.

Transport costs were also considered included in the construction budgets as the further contractor is located just at 45 Km distance from site.

To variable construction budgets will be added fees and other charges related to building and use licenses, respectively. Such costs depend on actual council regulation and fees table [21]. The house’s installations certification costs were only estimated.

3.5.2. Use stage costs

I. Maintenance (B_2) costs

Maintenance estimation main purpose is to guarantee the buildings service lives optimization for reaching design life [6]. For the present case study, a Maintenance Plan was elaborated based on the house's most relevant maintenance reference components, variable with each building system and presented in Table 3.2.

A wide variety of maintenance actions and frequencies in current performance cycles, as well as of future replacement, were prescribed for the constructed assets. The Maintenance Plan actions frequencies were obtained from maintenance data tables [22a] [22b], as well as from local suppliers pricing for some equipment and fittings. Costs of scaffolding and excavation to access certain buildings parts were included.

On maintenance planning, one of the main objectives was to minimize costs, therefore preventive maintenance strategies along the buildings life cycle were preferred, and cleaning actions were mostly prescribed, some of which might be performed by the user itself. Replacement actions were considered for the two buildings continual wall and ceiling coatings. The installations periodic inspections were considered external skilled services.

Market study found material and labour unit prices tables for 2014, from specialist entities in costmodeling [23].

Table 3.2. Most relevant maintenance reference components

Building elements	S.C. 2's R.M.C.	S.C. 3's R.M.C.	Maintenance action	Frequency
External drainage	Half-round stainless steel gutter, bituminous membrane finished	Half-round molded cement mortar gutter, bituminous membrane finished	Local cleaning	Annual
Concrete elements	Foundation columns, beams and blocks	Foundation footings, columns and beams	Local cleaning, followed by liquid bitumen coating	25-25 years
Timber structures	Pinewood posts, beams and diagonals	-	Local cleaning, followed by impregnation coating	25-25 years
Stone	Smoothed limestone thresholds and windowsill	Smoothed limestone flat roof protection wall cape, thresholds and windowsill	Local cleaning	Annual
Wall finishes	(internal) Skimmed gypsum-cardboard panels	(internal) Cement/sand rendering in 2 coats to brick wall	Local finishing coat removal, cleaning and replacement	10-10 years
	(internal) Ceramic wall tiles on fibre-cement panels	(internal) Ceramic wall tiles on cement/sand rendering in 2 coats	Local cleaning, or joints removal and replacement	5-5 years cleaning; 10-10 years replacement
	(external) Single layer render coating on glass fibre net and O.S.B. panels	(external) Skim and primer coatings on glass fibre net, render and E.P.S.	Local removal, cleaning and replacement(S.C.2); Local cleaning and repainting (S.C.3)	6-6 years S.C.2's M.R.C 5-5 years S.C.3's M.R.C
Floor finishes	Ceramic floor tiles on fibre-cement panels	Ceramic floor tiles on cement/sand mortar bed	Local cleaning, or joints removal and replacement	5-5 years cleaning; 10-10 years replacement
Ceiling finishes	-	(internal) Plaster on cement/sand rendering in 2 coats	Local finishing coat removal, cleaning and replacement	10-10 years
	-	(external) Cement/sand rendering coat to *insitu* reinforced concrete slab	Local removal, cleaning and replacement	2-2 years
Roof finishes	Lacquered steel-expanded polystyrene sandwich profiled sheeting	Lacquered steel-expanded polystyrene sandwich profiled sheeting	Local cleaning	Annual
Suspended ceilings	(internal) Gypsum-cardboard panels	-	Local removal and replacement	30-30 years
Woodwork	Internal wood particle board doors	Internal wood particle board doors	Local removal, ease, adjust and rehang	Annual
Metal work	Aluminum frames	Aluminum frames	Local ironmongery lubrication, without removal	10-10 years
Painting	(internal walls) Emulsion anti-fungus paint on skimmed gypsum-cardboard panels	(internal walls) Emulsion anti-fungus paint on plaster	Local removal, cleaning and replacement	2-2 years
	(internal ceilings) Emulsion anti-fungus paint on skimmed gypsum-cardboard panels	(internal ceilings) Emulsion anti-fungus paint on plaster	Local removal, cleaning and replacement	2-2 years
	(external ceilings) Varnished suspended cedar boards	(external ceilings) Emulsion anti-fungus paint on render	Local removal, cleaning and replacement	2-2 years S.C.2'sM.R.C 5-5 years S.C.3'sM.R.C
Plumbing	Syphonage units	Syphonage units	Local obstruction clearing and cleaning	3-3 years
	Sanitaryware and fittings	Sanitaryware and fittings	Local refixing, or removing existing and applying new mastic around, or cleaning and disinfection	3-3 years
	Domestic cold and hot water installation	Domestic cold and hot water installation	Local draining and pipe cleaning	Annual
	Heating firewood oven installation	Heating firewood oven installation	Local obstruction clearing, joints replacement and cleaning	Annual
Electrical work	Lighting circuit	Lighting circuit	Inspection and fittings replacement	Annual
	Telecom circuit	Telecom circuit	Inspection	Annual
	Cooking appliances	Cooking appliances	Inspection	Annual
	Domestic electric circuit	Domestic electric circuit	Inspection	Annual

Those prices were accounted with quantities from project measurements, and thus a detailed budget for maintenance costs was obtained.

Costs for Refurbishment actions were not considered, as those were regarded unpredictable at the present project stage. However, a percentage for inevitable unexpected pathologies corrective actions was added to those maintenance costs.

Planned maintenance was assumed to be implemented from year 1 to 49 of the buildings predicted service lives. Both building systems life cycle partial maintenance costs can be graphically compared in Figure 3.3.

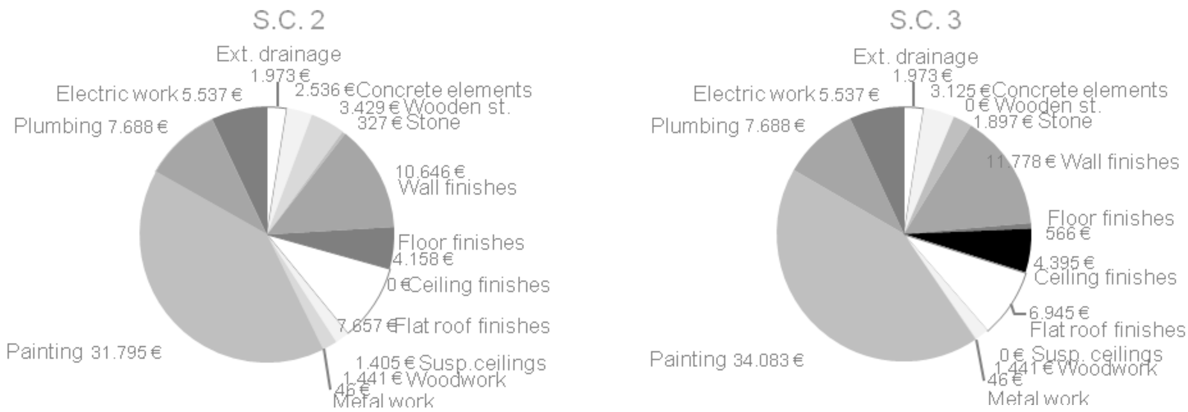


Figure 3.3. S.C. 2 and S.C. 3's maintenance actions discounted costs comparative graphics

According to previously mentioned standards, the present case study's use costs include two more parameters, energy and water consumption costs, related to internal thermal comfort, electric and hydraulic installations [7]. The house was assumed occupied from year 1 to 49 of the buildings predicted service lives.

II. Operational energy use costs (B_6) include the house's internal thermal comfort, as well as electricity supply and a telecom service for the plot. The last two are provided by private operators and monthly charged.

For the projected house, part of energy installations expenses during operation [7] come from internal heating by firewood, supplying a wood-burning steel and cast iron heater, properly installed. According to retail market [24], such equipment returns an average 60% to 80% heat, it has a 9 KW nominal power and it was adapted to both buildings heating needs, regarding the actual portuguese thermal calculation regulation [25]. A previous thermal performance verification, calculated for both building options, revealed that S.C. 2's envelope has a better thermal performance than S.C. 3's: the first's annual heating, cooling and primary energy needs are lower than the second's; S.C. 2's energy class B is also higher than S.C. 3's B-.

Fuel costs were calculated according to the envelopes complementary heating needs, converted in load units and multiplied by the correspondent actual fuel unit cost [26] [7].

Due to cost, as well as due to the place's micro-climate amenity, no installation for internal cooling was prescribed by the house's project.

Specific economic impacts of operational energy use included, still, domestic electric and telecom installations.

For the present single-family house, electrical energy consumption is destined only to artificial lighting and socket use. Calculations included the actual temporary fee [27] for clients with 6,9 KVA contract power, which stands until December 31st, 2015.

For the telecom installation, it was considered the fee for a service pack of voice and internet [28], which monthly cost depends on telephone calls cycle, time and territory, as well as on cable data transmission speed.

The house's electric supply life cycle costs are invariable for the two building systems.

III. Operational water use costs (B_7) for the building, or for the user, will come from water consumption registered by the managing local services installed counter in the plot. The house's internal installation will supply potable water to kitchen and sanitary fittings. Outside the house will be installed a hose tap. A single solar panel, equipped with hot water storage, will be installed South-oriented on the flat roof, to supply a kitchen sink and three sanitary fittings with hot water.

The house's potable water consumption and domestic drainage treatment are invariable for the two building systems. Fees are tabled and actualized by the managing municipal services [29], which charge a fixed fee and a variable fee as use cost components, every month. Potable water consumption depends on the counter installed calibre, on the fee level and on the water volume monthly supplied to the plot. Drainage service includes a variable fee, to be added to a fixed fee, proportional to monthly potable water supply estimation.

Same as for the operational energy use calculation, the present module criteria were unit costs modelling, and its results presentation are aggregated to life cycle energy costs, but isolated from specific buildings costs [7].

3.5.3. After use stage costs (C_1-C_4)

These occur at the buildings end of life cycle [7], which requires conventional demolition, deconstruction or selective demolition services (C_1 costs), adequate transport fees (C_2 costs) for recycling or disposal works (C_4 costs), in correspondent private facilities, of each building systems waste. Those works should be executed by specialist contractors.

First, a detailed plan for the deconstruction, previewed for 50 years from now, was elaborated. The two deconstruction works were quantified as loads from materials volumes and densities, and multiplied by actual unit prices [23]. Thus were obtained two detailed budgets for each building’s desintegration.

To select waste transport and disposal, each building deconstruction works were divided into conventional demolition debris and into selected recoverable components. After measurement, a market research pricing was performed. Two companies with logistics for selective pick-up and transport of deconstruction debris, into proper facilities were selected. Once arrived at those facilities, waste is subject to selection and processing for conduction to reuse, recycle, incineration or landfill.

Transport costs origin were specific budgets based on waste loads and waste selection, as well as on 86 Km and 60 Km distances to private managed disposal facilities. Debris certified pick-up unit costs origins were a 20 ton vehicle transport fee, as well as 6 m^3 containers monthly rent fee, available at works site. The several waste types were accounted at variable disposal unit costs, due to recyclable materials diverse valuation criteria by the contacted companies.

S.C. 2 and S.C. 3's lowest end of life costs within 50 years are presented in Table 4.1.

3.6. Sensitivity analysis

The present L.C.C.'s results test was a brief sensitivity analysis, in which discount rates varied (1%, 3% and 5%) and Maintenance costs (B_2) were, respectively, raised and lowered 10%. Calculations variation iterated both building systems close results on life-cycles cost parameters. The performed sensitivity analysis confirmed, however, despite the short difference, S.C. 3's service life costs N.P.C. and A.E.C., constantly and unmistakably, as the lowest.

4. Results discussion

The present chapter presents the 2 building systems L.C.C., this comparative study's basis, resumed in a total costs table and in a graphic, as well as interprets its results.

2 building systems economic performances in project, respectively a pinewood reticule and a set of reinforced concrete porticos, were assessed by the systematic multi-task approach Life Cycle Costing (L.C.C.), according to EN 15643-4:2012 [7] standard's information modules, complementary by ISO 15686:2008 [6] standard's calculation guidelines.

This assessment's purpose was to account each building system economic performance, for a single-family detached house construction works, along assumed service lives of 50 years. The system boundary included all life cycle phases, since pre-construction to deconstruction and buildings waste disposal. Real costs excluding V.A.T. and a real 3,89% discount rate with risk were assumed. The impact assessment indicator was the lowest life cycle cost.

All necessary inventory data were provided whether by actual construction services market pricing research, as well as by costing tables research.

No variation was considered on preconstruction or on product costs to differ both buildings life cycle accounting.

S.C. 3 established its advantage at before use phase. S.C. 2's construction expenses, to be paid along 12 months maximum, are about 10.000,00 € more than S.C. 3's, according to subjective detailed budgets by two contractor companies, located at 45 Km and 10 Km distance from site. S.C. 3's structure raw material (reinforced concrete) source and the construction site are located in the same county.

The comparison of the construction pricings per area, with legal fixed fees by zone (700,24 €/m²) for 2014 [30], reveals S.C. 2 's 1296 €/m² costs and S.C. 3's 1112,69 €/m² costs.

In the Use phase, the longest, decade counted, of buildings life cycle stage, S.C. 2's future Maintenance costs are little 1.000,00 € lower than S.C. 3's, as well as shows a short advantage of 39,60 €/year, accounting all Operation and Maintenance (O&M) costs. S.C. 3 loses because it incorporates the only component which maintenance unit price has 3 digits (230,10 €/m² for replacing 35% of its façades area E.T.I.C.S.), in detailed budgets obtained from maintenance planning, implemented since year 1 to 49 of the buildings predicted service lives. For maintenance budgeting, quantities measured in both projects were multiplied by actual current maintenance unit prices for the two buildings, future costs were then discounted and summed.

Although incurring in the Use phase, the buildings life cycle operational energy and water costs influence on results were regarded limited, due to $B_{6.1}$'s low proportion, as well as due to $B_{6.2}$ and B_7's identical monies.

In the end of life year, the 50^{th}, for only a few days long, S.C. 2's deconstruction (5.027,10 €) is slightly higher for the option which allows to recover more building components to reuse or recycling, according to a detailed budget with higher labour costs than S.C. 3's brief demolition (3.933,02 €).

Still in the 50^{th} life year, and also reduced to some days long, Transport and Disposal works, load paid, are costly to S.C. 3, the solution with more solid and less valuable materials.

In the present service life costs comparative study, S.C. 3 is lower, L.C.C.'s S.C. 3 is lower, with clear differences of 10.389,07 € on N.P.C. and 404,13 €/year on A.E.V., in 50 years. The results verification through deterministic Sensitivity Analysis, varying discount rates and Maintenance costs, confirmed always S.C. 3's service life costs sum and annuity as the lowest.

Complying with standardized [7] presentation, S.C. 2 and S.C. 3's life cycle costs were organized in Table 4.1. Complementary, one of L.C.C.'s results graphic translation is Figure 4.1.

Table 4.1. S.C. 2 and S.C. 3's L.C.C.

			S.C. 2	S.C. 3		
		Use:	Housing	Housing		
		Gross area:	60,40 m²	60,40 m²		
		Structural working life:	50 years	50 years		
		Discount rate:	3.89%	3.89%		
		Residual value:	0 €	0 €		
		Income value (not applicable)	0 €	0 €		
Before Use stage	Present costs	Construction Costs (A_5)	79.044,00 €	67.926,00 €		Year 0
Use stage	N.P.C.	Maintenance costs (B_2)	82.569,13 €	83.447,05 €		Years 1 to 49
		Operational heating costs ($B_{6.1}$)	338,17 €	478,44 €	Buildings functioning	
		Operational electric & telecom circuits costs ($B_{6.2}$)	4.756,89 €	4.756,89 €		
		Operational water use costs (B_7)	2.435,75 €	2.435,75 €		
After Use stage	N.P.C.	Deconstruction costs (C_1)	5.027,10 €	3.933,02 €		Year 50
		Transport costs (C_2)	388,70 €	976,20 €		
		Disposal costs (C_4)	-61,53 €	155,79 €		
		N.P.C.L.C.C.	174.498,20 €	164.109,13 €		
		A.E.C.L.C.C. (Life cycle cost annuity)	6.786,98 €/y	6.382,85 €/y		
		A.E.C.O.&M. (Operational & Maintenance annuity)	3.503,89 €/y	3.543,49 €/y		

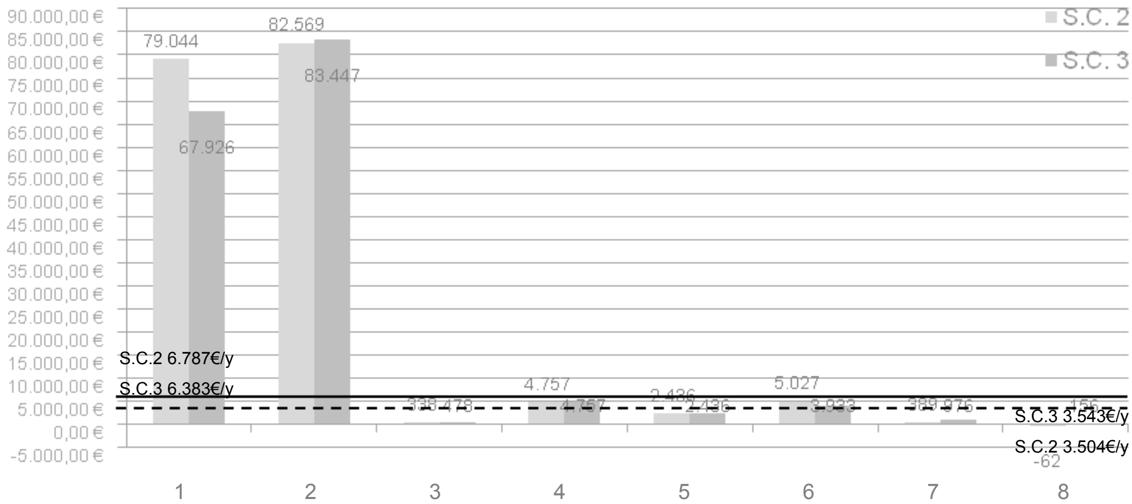


Figure 4.1. S.C. 2 and S.C. 3 L.C.C. stages ' comparative graphic (costs in Euro)
1 Construction; 2 Maintenance; 3 Energy - Heating; 4 Energy – Electric telecom circuits; 5 Water; 6 Deconstruction; 7 Transport; 8 Disposal; — A.E.C.L.C.C..; --- A.E.C.O.&M.

Figure 4.1's graphic represents monetary costs through the buildings eight selected life cycle phases, from Construction to Disposal. That graphic's reference is the previous Table 4.1. For an adequate buildings comparison, the graphic includes the scaled annuities line(s) referred to the whole life-cycle, as well as for Operation and Maintenance during Use stage.

All future costs were discounted to year 0, the construction year, to make possible to sum the firsts to the latter present costs, according to Table 4.1.

5. Conclusions and further developments

Answering the purpose set in this thesis Introduction, the obtained life cycle costs comparison results allowed to order, from cheaper to costly:

- S.C. 2 (174.498,20 €) and S.C. 3 (164.109,13 €), based on 50 years life cycle's Net Present Costs (N.P.C.);
- S.C. 2 (6.786,98 €/year) and S.C. 3 (6.382,85 €/year), confirmed by 50 years life cycle's Annual Equivalent Costs (A.E.C.).

The variation is admitted related to cost difference that some of the eight selected life cycle information modules influence, raising C.A.L.C.C.'s S.C. 2. Real costs were assumed, V.A.T. was excluded and life cycles accounted with a 3,89% real discount rate with risk.

In the owner and future user's interest, the option to choose is S.C. 3's porticos of reinforced concrete and brick, for presenting lower service life costs costs on both parameters required for the present buildings comparative study by L.C.C. - Net Present Cost and Annual Equivalent Cost.

Life Cycle Costing (L.C.C.) analysis was used on a case study's construction procurement, revealing the client that the solution which requires lower initial investment presents also lower use costs. Buildings economic assessment, at life cycle scale, examples construction’s planning wide vision towards the actual post-industrial society's Sustainability paragon.

The immediate goal is the owner's adjudication of S.C. 3's contractor proposal for the house's construction works. The future goal, according to this Life Cycle Costing analysis's scope, and complying with the standardized procedure, is this L.C.C. ‘s periodical revision and up-date. Thus, an assessment of the construction costs should be undertaken, as soon as S.C. 2 is built, to compare its estimated and its effectively paid monies. Estimated costs deviations may, or not, stick out; need to change functioning or maintenance planning, might stand out; higher current costs from user adaptation may occur; cost and time variables assumed can be revealed pessimistic or optimistic. Such will help establish life cycle planning for the Use stage.

This translation, explanation and application of EN 15643-4:2012 (CEN) and ISO 15686-5:2008, two recent standards which allow economic investment planning on Construction regarding buildings life cycle cost, and complementary in the present specific research’s context, is expected to conscience all of us users, as well as serve as a study basis for present and future designers and clients. Namely, building and divulging national maintenance tasks unit prices data bases.

References

[1] Comission International du Bâtiment (CIB), *Agenda 21 on sustainable construction.* Report publication nº.237, 1999.

[2] Miró, A., *From modular architecture to adaptable collective housing: A design charrette bringing the open building knowledge to the Solar Decathlon 2012 Europe*. Joined conference edition “C.I.B. W104 e W110 - Architecture in the fourth dimension”, E.U.A., pages 139 to 145, 2011.

[3] Gervásio, H., Murtinho, V., Santos, P., Mateus, D., *Affordable houses: A sustainable concept for a light weight steel dwelling*. Conference edition “Portugal SB10: Sustainable building affordable to all”, Vilamoura, pages 247 to 254, 2010.

[4] De Capua, A., Giglio, F., *Materic character of constructive dry systems for prefab-house. Research and didactics experience*. Conference edition “Portugal SB10: Sustainable building affordable to all”, Vilamoura, pages 193 to 200, 2010.

[5] Aye, L., Ngo, T., Crawford, R. H., Gammampila, R., Mendis, P., *Life cycle greenhouse gas emissions and energy analysis of prefabricated reusable building modules*. Energy and Buildings, volume 47, pages 159 to 168, 2012.

[6] International Organization for Standardization (ISO), *ISO 15686-5:2008 - Buildings and constructed assets. Service life planning - Part 5: Life cycle costing*, Switzerland.

[7] European Committee for Standardization (CEN), *EN 15643-4:2012 - Sustainability of construction works - Assessment of buildings - Part 4: Framework for the assessment of economic performance*, Belgium.

[8] Pinheiro, M., *Environmental management systems for sustainable construction*. Environment Engineering Doctoral Thesis, Instituto Superior Técnico, Lisbon:, 2008.

[9] Sesana, M., Salvalai, G., *Overview on life cycle methodologies and economic feasibility for nZEBs*. Building and Environment, volume 67, pages 211 to 216, 2013.

[10]European Committee for Standardization (CEN), *FprEN 16627:2014 - Sustainability of construction works - Assessment of economic performance of buildings – Calculation methods*, Belgium.

[11]Deutsch, M., *Life cycle cost disclosure, consumer behavior and business implications: Evidence from an online field experiment*. Journal of Industrial Ecology, nº.1, volume 14, pages 103 to 120, 2010.

[12]Boussabaine, A., Kirkham, R., *Whole Life Cycle Costing: Risk and risk responses*, 1st. Edition, Blackwell Publishing, United Kingdom, 2004.

[13]Dziadosz, A., *The influence of solutions adopted at the stage of planning the building investment on the accuracy of cost estimation.* Procedia Engineering, volume 54, pages 625 to 635, 2013.

[14]Langdon, D., *5.2.5 Life Cycle Costing (LCC) as a contribution to sustainable construction: A common methodology, 2007.* Part of “Deliverable 5.4: Proposed methodology for a Life Cycle Assessment Tool (LCAT)”. Mainline Consortium, page 22, 2013.

[15]Agência de Gestão da Tesouraria e da Dívida Pública, *Treasury Certificates Savings Plus: gross interest rate*, http://www.igcp.pt/gca, 2014, consulted October 2014.

[16]Instituto Nacional de Estatística (INE), *Harmonized consumer price index: Annual average growth rate – Base 2005*, http://www.ine.pt, 2014, consulted October 2014.

[17]Fernandez, P., Aguirreamalloa, J., Corres, L., *Market Risk Premium used in 82 countries in 2012: a survey with 7,192 answers*. IESE Business School, Madrid, 2012.

[18]Banco de Portugal, *Daily reference exchange rates*, 2014, https://www.bportugal.pt/pt-PT/Estatisticas/DominiosEstatisticos/EstatisticasCambiais/Paginas/Taxasdereferenciadiarias.aspx consulted from October to December 2014.

[19]European Organization for Technical Approvals (EOTA), *Assessment of working life of products Guidance Document GD002*, 1999, Belgium.

[20]Costmodelling, *Typical life expectancy of building components*, http://www.costmodelling.com/building-component-lifespans.htm, consulted October 2014.

[21]Câmara Municipal de Caldas da Rainha, *Caldas da Rainha municipal regulation and charges table*, December 2009.

[22a]Flores-Colen, I., *Buildings predictive maintenance*. Subject support slides of “Construction and Rehabilitation” Advanced Master, Instituto Superior Técnico, Lisbon, 2013.

[22b]Flores-Colen, I., *Sundry subject support documents*. Subject support slides of “Construction and Rehabilitation” Advanced Master, Instituto Superior Técnico, Lisbon, 2013.

[23]Building Cost Information Service (BCIS), *Building Maintenance Price Book 2014*, 34th edition, Royal Institution of Chartered Surveyors (RICS), United Kingdom, 2014.

[24]Leroy Merlin, *Steel layer brazier - black 9KW*, http://www.leroymerlin.pt/Site/Produtos/Construcao/Aquecimento-e-acessorios/Salamandras/1595

4855.aspx, consulted June 2015.

[25]Ministério da Economia e do Emprego, *DECREE-LAW n.118/2013, August 20th - Buildings Energy Certification System and Energy Efficiency Regulation for Housing.* Diário da República, Série I, August 20th 2013, pages 4988 to 5005.

[26]LeroyMerlin,*Corkoakfirewoodbag10Kg*,http://www.leroymerlin.pt/Site/Produtos/Construcao/Aquecimento-e-acessorios/Combustiveis/14170884.aspx, consulted June 2015.

[27]Entidade Reguladora dos Serviços Energéticos (ERSE), *Provisional sale fees to end customers in Portugal mainland in 2014,* http://www.erse.pt/pt/electricidade/tarifaseprecos/2014/Documents/Diretiva%20ERSE%20252013.pdf,2013, consulted October 2014.

[28]Lojas Meo, *September 2014 campaign: Wired Net + telephone*, http://www.meo.pt/pacotes/mais-pacotes/todos-os-pacotes-meo/fibra/net-voz, consulted October 2014.

[29]Serviços Municipalizados de Caldas da Rainha (SMAS), *Water supply service fees,* http://www.smas-caldas- rainha.pt/portal/page/portal/SMAS/REGULAMENTOS, consulted October 2014.

[30]Ministério do Ambiente, Ordenamento do Território e Energia, *INFORMATION n.353/2013, December 4th - Housing prices per service area square meter in 2014*. Diário da República, Série I, December 4th 2013, page 6644.