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Sustainability within the Construction Sector

CILECCTA – Life Cycle Costing and Assessment

SEVENTH FRAMEWORK PROGRAMME

CILECCTA

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CILECCTA – Life Cycle Costing and Assessment
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CILECCTA
«A user-oriented, knowledge-based suite of **C**onstruction **I**ndustry **L**if**E** **C**ycle **C**os**T** **A**nalysis software for pan-European determination and costing of sustainable project option»

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2013

Editor's Note

Sustainability is a word that is being increasingly used. We use it in the context of nature, where we want biological systems to remain diverse and healthy. Sustainability is used to talk of how we can live within the means provided by our planets resources. Humanly speaking sustainability is measured in culture, politics, the ecology and economic terms. An underlying driver to improved sustainability is change which implies new and innovative thinking, which will in turn drive our behaviour.

CILECCTA is about change. Two very different disciplines are brought together into a single process. Life Cycle Costs and Life Cycle Indicator Results work together to advance into Life Cycle Costing and Assessment (LCC+A). World wide financial and environmental data can be integrated and shared via a single platform. And another important thing: we move from deterministic to probalistic thinking.

CILECCTA has been co funded by the European Commission's FP7 programme. The 15 partners have worked together to develop something unique. A decision making tool that incorporates probabilistic thinking. Thank you to everyone for your contribution.

I hope you, the reader, enjoy this book as much as we have enjoyed writing it.

Change is inevitable in the context of sustainability. **CILECCTA** will help you make more informed decisions whether you look five or even 50 years ahead.

Rick Hartwig
Exploitation and Dissemination Manager

CILECCTA is a large-scale collaborative project co-financed by the European Commission under the 7th Framework Programme Cooperation. The **CILECCTA** consortium comprises 15 partners from 7 European countries. All partners bring their individual expertise to the project and each is necessary for its execution. In short, the consortium forms complementary enterprises that have a broad reach across all aspects of the construction industry; from architects (Cambridge Architectural Research Limited, APIA XXI) to large enterprises in the infrastructure (ACCIONA), from hotels and resorts (TUI), Research Institutes (Fraunhofer-IBP, SINTEF) and an association representing their members in the industry (Norsk Teknologi) to service providers (Holte as, BSRIA, PE International, TechnoBee, ASM, DesignTech). In addition, the University of Stuttgart and the Luleå University of Technology provide a direct route to higher education in the building sector.

Contents

1 About CILECCTA

The CILECCTA project has developed a bridge between life cycle thinking connected to both economics and the environment, and has created demonstration software based on this.

When a decision is made in the construction sector, it is often made on the basis of an economic evaluation of various alternatives. Often these calculations are based on investment costs, not considering outlays on future maintenance or waste treatment, and neglecting the lifetime of the system components. Life Cycle Costs (LCC) is a calculation method taking these issues into account. The same can be done for environmentally damaging emissions using the method of Life Cycle Assessment (LCA). The **CILECCTA** software combines the two methods, thus creating a new term: Life Cycle Costing and Assessment (LCC+A).

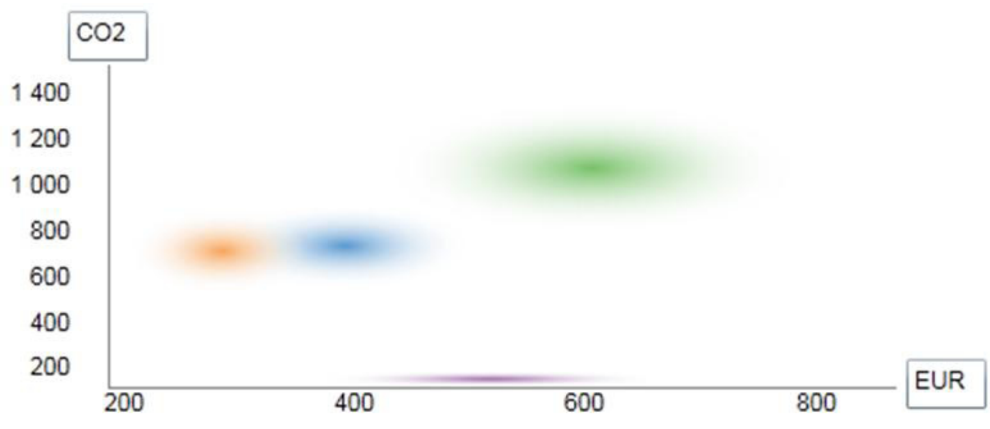


Figure 1.1
Combining LCC and LCA

The **CILECCTA** software is an innovative tool developed to be a decision making tool which can be used for sustainable planning within all kinds of construction projects. How to handle uncertainty, together with the possibility of implementing flexible systems, are issues which are dealt with in a unique way.

Future uncertainty

Traditional LCC and LCA software does not take uncertainty into consideration in the analysis. Current LCC or LCA tools require precise data input for all variables throughout the chosen study period. With this precise input data the tools generate precise values for life-cycle cost and environmental impact, known as the *deterministic approach* to LCC/LCA.

With a typical study period of 20 years plus, many factors are certain to change, e.g. the price of fuels or energy carriers, building products, the service life of building products, refurbishment measures, the usage of buildings and infrastructure etc. Each has an impact on the cost and environmental effect of an item's lifecycle.

It is therefore preferable for the variables in LCC/LCA tools to be given ranges of values rather than precise values. This is the *probabilistic approach* to LCC /LCA. In this way it is possibe to make analysis based on different scenarios. As a result, the data values are defined as ranges, typically «three-point estimates» (lowest conceivable value, most likely value and highest conceivable value).

Flexibility

A further important feature of **CILECCTA** is the ability to model flexibility. Flexibility answers fundamental questions like «how much does it cost me to invest a little extra when setting up the construction, compared to the cost of wanting to change the construction at a later point in time». Since they provide the analysis with cost and environmental data, these two scenarios can be compared. This kind of combined analysis has not been possible with any other tools.

Integration of LCC and LCA

The integration of economic-oriented LCC and environmentally-oriented LCA presents significant challenges as they are quantified in different units. In addition they originated in very different contexts – investment efficiency for LCC and environmental conservation for LCA – and adopt different assumptions. Time preference (the increased weight given to costs or benefits that occur in the near

Life Cycle Thinking

When making a holistic evaluation of a systems impact or costs it is often defined as life cycle thinking. By consuming a product or service, a series of associated activities are required to make it happen. Raw material extraction, material processing, transportation, distribution, consumption, maintenance, reuse/recycling, and disposal are all examples of the phases a product can go through. Looking at it as one system it is seen as the life cycle of the product.

future compared to those that are further in the future) is formalised through a discount rate in LCC, but in LCA a discount rate is not used. In connection with this issue, together with making it possible to import data from Price Banks (PBs) and Life Cycle Indicator Results (LCIRs) across Europe, a mapping tool has been developed using the International Framework for Dictionaries (IFD). This is a standard for ontology based on internationally accepted open standards. For **CILECCTA** this means that each potential data provider will implement a common interface that accepts a standardized input and generates a standardized set of return values. The mapping approach guarantees that the different material categories are globally unique and therefore the interface to each data provider will be kept very simple. In this way the user can be sure that apples and pears are not being compared when data from different databases are used.

The CILECCTA e-handbook

The booklet in which you are reading these lines is the «**CILECCTA** e-handbook». The book aims to give you an introduction to the methodology behind **CILECCTA**, together with information about the project and how you can use **CILECCTA** to your benefit. Chapters **2, 3, 4** and **5** explain the LCC, LCA and LCC+A methods. Chapters **6** and **7** provide knowledge of how the software is built up including information regarding Price Banks and Life Cycle Indicator Results.

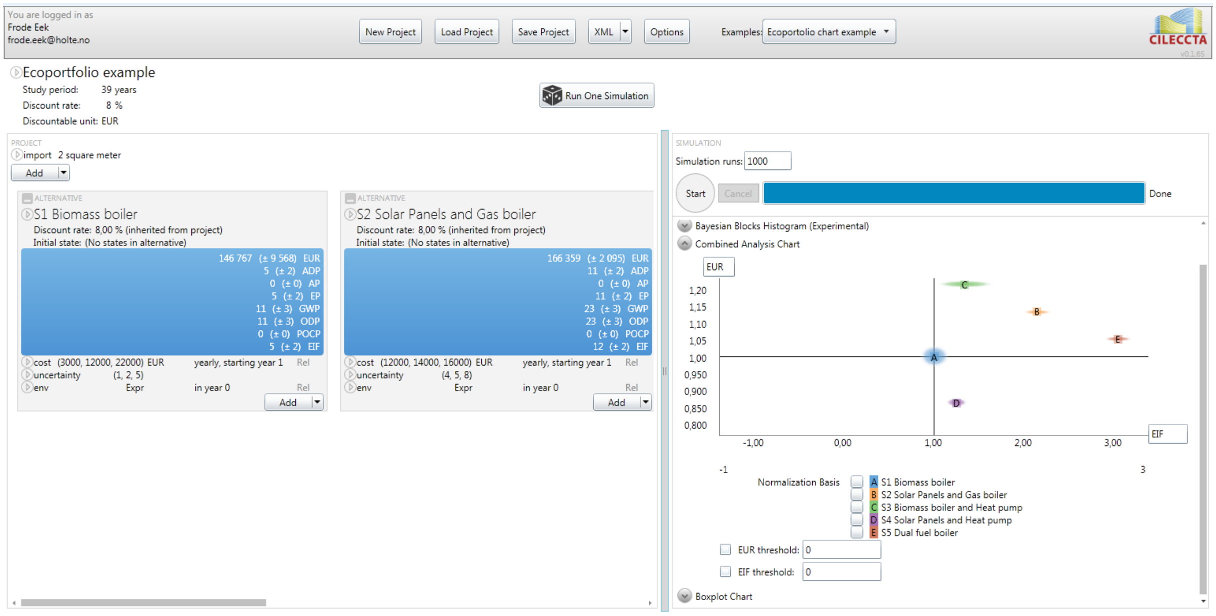


Figure 1.2
Screenshot of the finished **CILECCTA** software showing a comparison of two different heating systems

For an industry dominated by small enterprises (SMEs) it is important that **CILECCTA** features are applicable for all enterprises regardless of their size. All kinds of construction projects, as well as project stages can be analysed. In order to make the software more tangible and gather experience, the software has been tested using three demonstration examples:

- decision making on road construction with regard to layout and changing mobility.
- decision making on using phase change materials for application in residential housing.
- decision making on what energy system to implement at a resort in Mallorca.

Chapter **8** presents the case studies and experiences gathered from these.

An e-learning program together with educational courses has been constructed to give potential users the possibility to learn about life cycle methodology and how the **CILECCTA** software works. In chapters **9** and **10**, *Training and E-learning and Seminars, Papers and Scientific Articles* you can learn more about **CILECCTA** and the topic of LCC+A.

The demo version of **CILECCTA** software is a solid platform for further add-ons or applications to address specific cases according to specific enterprise's needs. Chapters **11** and **12** are about the time after the **CILECCTA** project – How to use **CILECCTA** in standardisation work and how you can use **CILECCTA** for your benefit.

Figure 1.3
CILECCTA provides an innovative tool to improve decision-making for construction projects. Photo: Mette Langeid, SINTEF Academic Press

2 Life Cycle Costing

Life cycle costing (LCC) is the economic appraisal of a potential investment or existing asset taking into account immediate and longer term costs and benefits. Its purpose is to assist decision-making and it can be applied to individual products or components, to complete building services systems, or to entire construction or refurbishment projects.

The principles of life cycle costing

Life cycle analysis is an iterative process, as can be seen from figure 2.1. The steps start with need to thoroughly understand the problem that has initiated the analysis, and also to formulate a range of possible technical solutions to that problem. Since LCC is essentially a method for evaluation of costs aspects along the life

Applications of LCC

Life cycle costing has two principal applications. Firstly it is used to compare different design solutions to a technical problem – in this case it is the relative differences between the calculated life cycle costs that are assessed. Secondly it is used to estimate budget expenditure in future years for the selected design.

Comparative LCCs can also be used to prioritise projects competing for limited funds, by calculating how much benefit each gives per unit of investment.

These two applications are quite different. For a comparative study any common factors that apply across all the designs can be ignored, since it is only the relative costs that are appropriate. This means that underlying inflation and any items of cost that are duplicated across all designs need not be considered.

cycle, it is important that those solutions/designs provide the same levels of performance or output. For example, comparing different lighting schemes will require that each scheme provides the same level and quality of workplace or task illumination, or different heating systems must deliver the same heat output.

Once a range of alternative designs have been set up, each one is modelled according to its costs and benefits over the same time period. For some LCC applications, the time period is pre-defined, whereas other applications will require a sensible time period to be chosen. Each model captures the complete profile of costs over time – initial installation, maintenance, equipment replacement, energy use and other operational costs, and also any end-of-life costs such as decommissioning or waste treatment.

The LCC data from the models is calculated turning each costs and benefits profile into a single number, which is the net present value of the design. This requires the use of a single discount rate across all models. The choice of this discount rate is a fundamental part of the LCC process. Within **CILECCTA**, the discount rate can be adapted by the user to represent individual preferences.

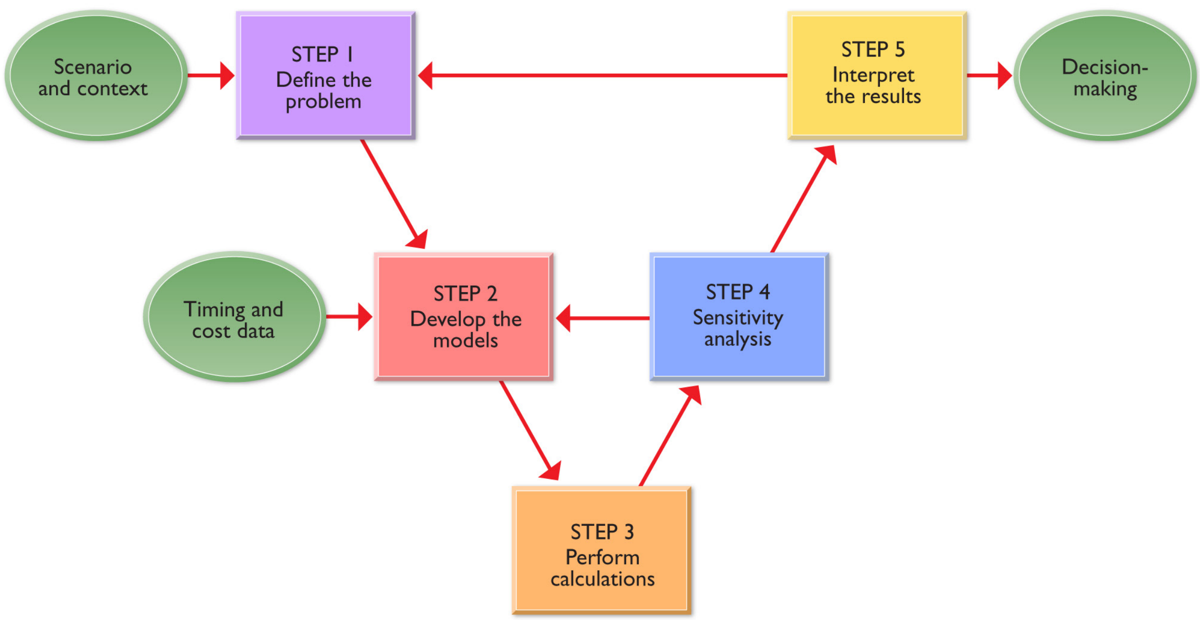


Figure 2.1
The iterative process of decision making

The system boundary

Just like LCA every LCC analysis has a system boundary within which are contained all the relevant activities that contribute to the cost and benefit differences. This may be more widespread than at first thought. For example, the life cycle analysis comparing an innovative plasterboard with phase change material against a standard product will also need to include the effects on the heating and cooling system in the building. This is because the principal benefit of the innovative plasterboard is to reduce the peaks and troughs in room temperature and therefore reduce the energy consumption of the building because of less need for heating or cooling.

The system boundary needs to be set in discussion with the client, to make sure that the assumptions contained in the analysis are appropriate and reasonable in terms of the level of design detail when the LCC is carried out, and in terms of the available sources of input data.

Iteration is a key part of the process

Iteration in LCC occurs at two distinct levels. Once the initial LCC models have been created and calculated, the inputs can be tweaked to assess the impact of uncertainties in any of the data. This might be something very specific such as the life expectancy or energy consumption of a particular component, or something much broader such as the likely future movement in energy costs, or even the timescale for which the LCC is calculated.

The second level of iteration can occur when the overall results are interpreted, as this may indicate some assumptions in the original scenario need to be investigated or challenged, or some changes made to the set of designs being modelled (new ideas to be included or existing designs to be modified or removed).

Modelling uncertainty in LCC

Uncertainty in data can be modelled using a range of techniques. Simple variation in one or two variables can be assessed by altering the model(s), rerunning the calculations and then comparing the results. At its simplest this might be done by selecting high and low estimates for the variable and seeing if there is any change to which alternative produces the most favourable life cycle cost.

However, multiple variables or more complicated probability distributions need to be analysed using Monte Carlo simulation. The models are recalculated many hundreds or thousands of times using sets of input data chosen at random according to the predefined probability distributions. This functionality in the **CILECCTA** software is further described in chapter **4**.

Sources of LCC data

LCC data is required in two main forms. Firstly there are the estimates of cost for different project activities, and secondly there are the estimates of life expectancy and maintenance intervals that dictate when equipment replacement and maintenance needs to happen.

Cost data can be obtained from existing in-house records, supply chain contacts, from industry price books or online services. Life expectancy data for building services equipment can be obtained from estate records, from equipment manufacturers or from published sources.

You can read more about price banks in chapter 6.

The results from all the calculations can then be analysed statistically. This gives mean and median values which indicate «average» values and also standard deviations to show how the results vary. The results can also be shown graphically – see fFigure 2.2. In this case, it can be seen that there is a large area of overlap between the LCC results from two competing designs.

Precision of results

One of the natural implications of uncertain input data, even if it is not explicitly modelled, is that there is a limit to how precise the results of LCC analysis can be. For example, life cycle costs carried out at the early stages of design should really be interpreted with a margin of error of ± 15 %, and even those carried out at detailed design stage should have a margin of error of at least ± 5 %.

For the analyst this means that it is meaningless to quote life cycle costs to their calculated precision. Only three significant figures need be given (£ 103,000 rather than £ 102,731.28), and sometimes only two significant figures (£ 100,000 in the above case).

The **CILECCTA** software addresses this by generating scatter plots of cost and environmental impact for the alternatives being modelled, so that the variety of results for the various alternatives can be easily seen and interpreted. You can read more about this in chapter **4** and **7**.

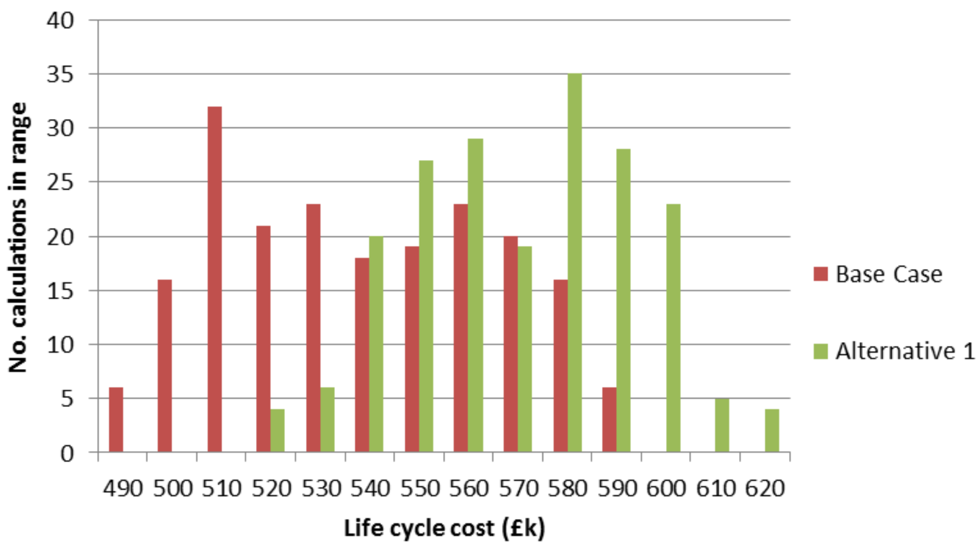


Figure 2.2
Frequency distribution of results from LCC Monte Carlo simulation

3 Life Cycle Assessment

Life cycle assessment (LCA) is a structured method for calculating the environmental impact of goods and services. It can be applied to any product or process and may include manufactured products, processes, assemblies, entire HVAC systems, or even whole buildings within construction and building services application. This might sound complicated but in fact the principles are simple.

Different meanings of «life cycle»

The assessment can represent many different life cycle stages of the goods or services – see figure 3.1. The two main ones are «cradle to grave», where goods are modelled from raw material extraction through manufacture, delivery, use and disposal, and «cradle to gate», where goods are modelled from raw material extraction

Applications of LCA

Life Cycle Assessment can be used in many different ways, by a wide range of stakeholders.

Policy makers at regional, national and international level can use LCA to inform policy decisions in environmental protection.

Manufacturers of goods and suppliers or services can use LCA to show how new products or technologies can be less environmentally damaging than existing products, and thereby support sustainable growth and development.

Purchasers of goods and services can use LCA to compare alternative products and solutions, to inform their decision-making and to support any goals they have to favour lower-impact designs.

through to manufacture and packaging ready to be shipped to a wholesaler, retailer or end-customer. A third life cycle is «gate to design» which is used for modelling processes just within a single manufacturing organisation, say taking a set of off-the-shelf products and assembling them into a new product.

Environmental Impact Categories and EcoPoints

Environmental impacts are organised into categories that represent different types of impact. At face value these different categories cannot be directly compared or combined. For example, a material with a high impact in non-renewable resource depletion but a low global warming potential cannot be directly compared with an alternative material that has a low resource depletion but a high global warming potential.

LCA software packages usually present their results according to each impact category. For example, global impact categories include ozone depletion as well as the resource depletion and global warming potential mentioned above. Regional impact categories include water use, land use, eutrophication and photochemical oxidation.

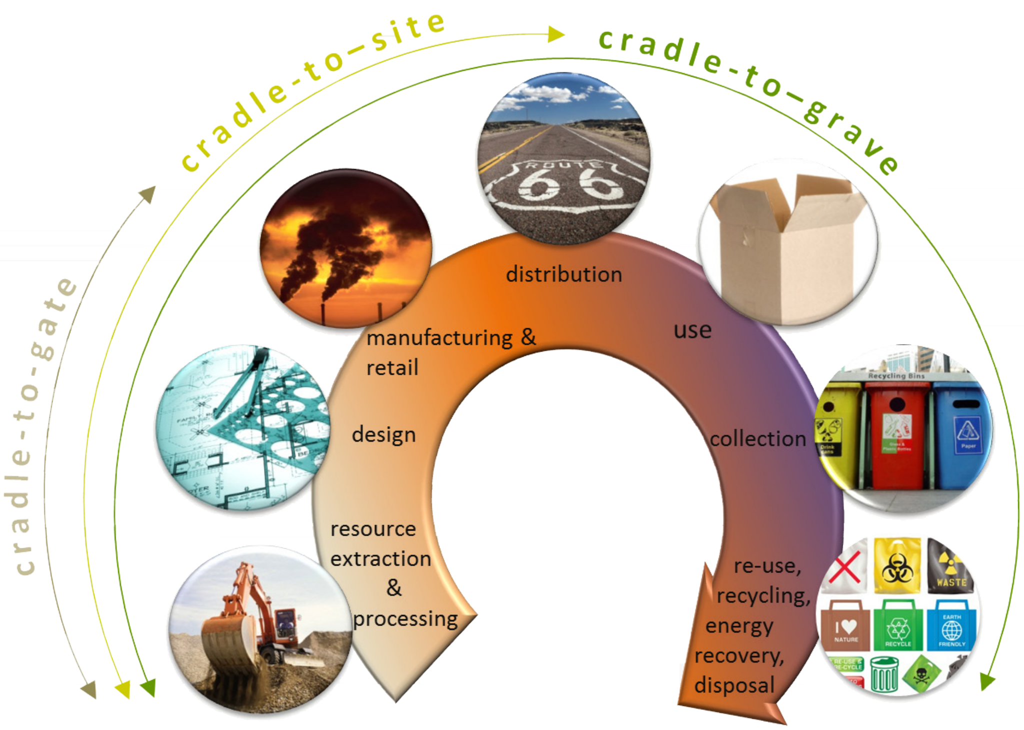


Figure 3.1
Typical lifecycles within LCA

In addition to this detailed and comprehensive list of impacts, **CILECCTA** will also offer the possibility of a «Combined Analysis Chart». This aggregates the environmental impacts to a single value and then sets it in relation with the economic aspects of a solution. While losing the objectivity of the assessment, this offers an intuitive way to support decision making.

More than just carbon

The impacts covered in LCA are very broad. They go far beyond carbon dioxide emissions or other greenhouse gases. For example, the standard impact categories include non-renewable resource use, acidification of soils leading to forest decline, eutrophication of water bodies leading to fish decline and others. Greenhouse gases are more correctly covered under global warming potential, where the global warming effects of different gases are appropriately factored and combined into a single figure expressed as Carbon Dioxide equivalent (CO_2 e). The same is done for other impact categories that are expressed in other reference units.

Complex relationship between diverse in- and outputs

The range of goods and services that contribute to the manufacture or use of a single product can be unexpectedly complicated, or even circular. The complexity of life cycle inventories, where the list of constituents for a given product are stored, can be demonstrated by the case of the mineral wool that might be used as an insulation material for ductwork and pipework. The inventory for this product contains many different inputs of products, recycled materials and natural resources including basalt, limestone, coke, electricity, water, rail transport, and many different outputs of wastes including waste heat, particulates, and municipal solid waste, and different emissions to air, water and soil including carbon dioxide. All of these inputs themselves have inventories and their inputs will also have inventories, and so on. The ultimate aim is to compile the full list of outputs and emissions in sufficient detail for the analysis.

In fact, loops can often be found within the life cycle inventory analysis, where the impacts of all resource, material and process flows that cross the system boundary are analysed. For example, a product that has steel as a raw material means that coal is included as this is one of the inputs for manufacturing steel. But coal is mined and processed using equipment that includes steel.

The reliance on inventory data and the complexity of its analysis means that software is usually needed to carry out LCA.

Sources of LCA inventory data

LCA inventory data is critical to calculate environmental impacts. Each inventory is a detailed list of the inputs (e.g. resources, raw materials) and outputs (e.g. emissions, waste) arising from the lifecycle of a given material, product, system or service. There are some wellknown LCA inventory datasets including the construction sector (Covering different regions in the EU and worldwide). These are available for a license fee or may be included in the price of LCA software packages.

- GaBi (English/ German)
- Ecoinvent (English/Japanese/ German)
- DuboCalc (Dutch/English)
- IVAM LCA Data (Chinese/ English).

In addition, inventory data has been compiled by a range of international trade and material federations. Most of these datasets are free.

- American Plastics Council
- European Aluminium Association
- International Iron and Steel Association
- Plastics Europe.

Based on those databases, product systems are modeled and their overall environmental impact can be expressed in an objective way.

Read more about Life Cycle Inventories in chapter 6.

The functional unit

The description of the mineral wool inventory, above, raises another important issue – that of the functional unit. As well as its ability to identify environmental hot-spots, LCA is also a comparison tool where one technical design can be compared with one or more alternatives to find out which is the best. To make the comparison valid, each solution has to be analysed on the basis of its performance. For example, two different insulation materials for pipework would be analysed on the basis of the U-value they provide, as this expresses their insulation performance. This would then need to be analysed to understand how much of the insulation would be needed in each case – for example, insulation for a 10 m length of 50 mm pipe might require x kg of mineral wool and y kg of expanded foam. The inventories stored in the database would both be compiled on the basis of 1 kg of the insulation material and the various inputs and outputs would be scaled accordingly.

This gives rise to the possibility that 1 kg of a new material produces much higher environmental impacts than 1 kg of a traditional material, but because the new material is so much more effective in its performance, the impacts to deliver a required level of performance actually turn out to be much less.

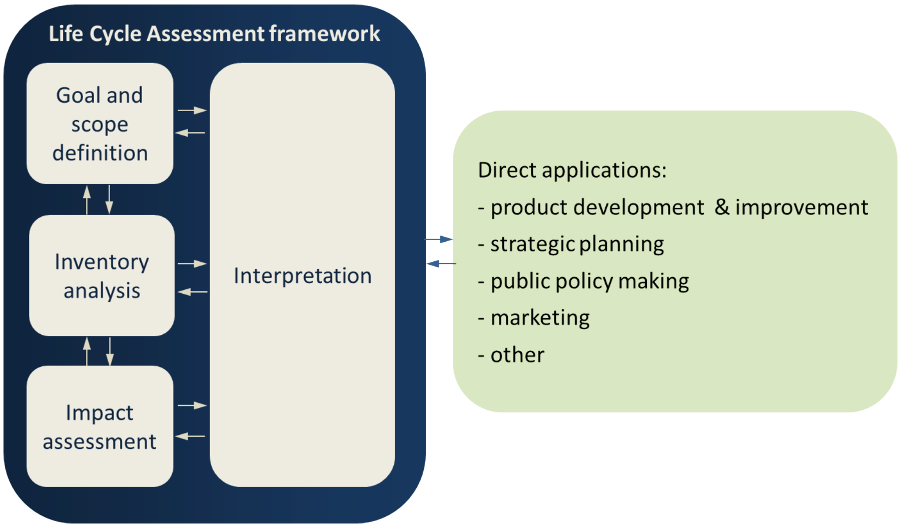


Figure 3.2
Framework for life cycle assessment (based on ISO14040:2006)

The system boundary and the LCA process

The product being analysed, the hierarchy of inputs and the level of detail in the life cycle all go to define the system boundary. The definitions of the system boundary and of the functional unit are fundamental tasks in setting the goal and scope of a Life Cycle Assessment. From this the inventory is constructed and then analysed for the environmental impacts – see figure 3.2. At each stage, the analysis is interpreted and checked to make sure that the required levels of model accuracy and levels of completion and precision of the inventory are all achieved.

4 Combining LCC and LCA: LCC+A

The life cycle of buildings or products is becoming more important as more people learn that investment in the construction stage can have a significant effect over the lifetime. To take account of these concerns in construction decision-making, we need tools that look at all the phases a material or product goes through. With the two different focuses as LCC and LCA have, it can be difficult to see what the best overall solution is. According to CILECCTA the answer is to combine these two approaches into one single method: LCC+A.

While there may be one parameter that is more influential in making a decision, it could help to make a better overall decision to present the whole picture to the decision-maker. For example the financial director would only be concerned with the cost of the project whereas the environmental manager or person in charge of the corporate environmental policy would be interested in the environmental impacts. In the world we live in today, both factors have their place and should be considered.

Current approaches are based on two separate assessments. An LCC study will be conducted to assess the discounted cost of different scenarios or options, while an LCA will be carried out to quantify environmental impacts. This is typically done in different software tools. While there are special LCA and LCC tools, there are no sophisticated tools for an integrated assessment of both environmental and economic aspects. When creating two separate models in different tools, there is always a danger of neglecting aspects in one study that is not included in the other, which can result in comparing scenarios that are supposed to be identical, but actually have a different scope and/or system boundaries. **CILECCTA** and its underlying LCC+A approach allow the modelling of both economic and environmental aspects in a single model, thereby ensuring identical scope and system boundaries for all scenarios or alternatives to be assessed. Furthermore, the impacts of uncertainty on both result dimensions can be included in the assessment.

To show this graphically, a simple XY plot allows the reader to see how the cost and environmental impact interact. The figures obtained from LCC and LCA calculations may represent probabilities rather than absolute figures due to sensitivity or unknowns. In some cases the potential scatter in the results will overlap.

In the Combined Analysis Chart, cost and environmental results of analysis are shown. The centre of the ellipses represents the mean values while the width and height represent standard deviations. It is the bottom left-hand corner that we are interested in, as this is the part of the chart indicating least cost and least environmental impact.

A simplified example is plotted in figure 4.1 showing the possible cost and equivalent CO_2 impacts to build $1m^2$ of wall out of standard construction materials such as brick, concrete block, steel, and reinforced concrete.

As can be seen, in this case the reinforced concrete has both the highest cost and environmental impact. The size of the markers gives an indication of the potential scatter in the values, so brick could have a higher or lower environmental impact than block. This is an oversimplified example; if full analysis was undertaken then the insulation material, mortar, financial aspect of time to build, etc. would have to be considered to give the full picture of which is the best solution for both cost and environmental impact, but it does demonstrate how the cost and impacts can be easily compared for different alternatives.

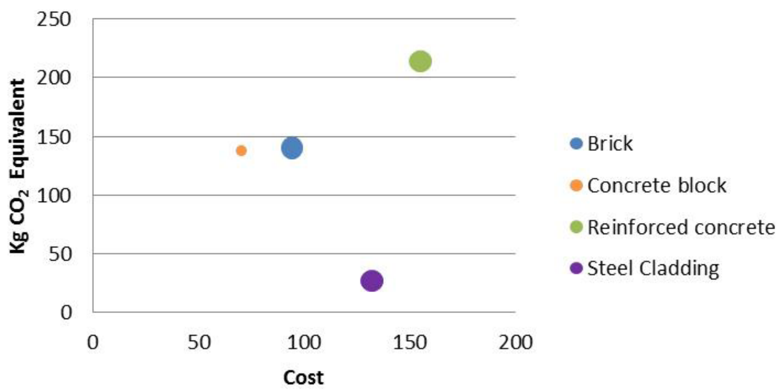


Figure 4.1
LCC+A results of a wall of 1 m^3

If the timing of the wall activity is not known, such as in the case where an extension to an existing building will be constructed at some future date, then probabilities can be applied. This effectively increases the scatter of the various numerical results for each different wall material. So, using the example of a company needing expansion sometime over a 10-year period and needing to build an extension, with the probability of it happening of 10% at yearly intervals, then we can use Monte Carlo simulation (see fact box) to see the effect. The midpoint is the average and the range (diffuseness) of the spot shows the results of the simulation, in this case run 1000 times. There's a vertical diffuseness (= sensitivity to environmental impacts) and a horizontal diffuseness (= sensitivity to costs aspects). Now we can see that steel is more sensitive to costs, than to environmental aspects and that it touches the cost range of both brick and reinforced concrete. This sort of plotting can be produced via the software development within the **CILECCTA** project.

While this way of interpreting the data should not detract from the individual LCC and LCA reports, it does however show to the less technically knowledgeable decision-makers in these areas that sometimes a small increase in building costs can have a significant effect on their environmental impact, or conversely where there is very little difference in techniques for environmental impact the cost variation may be dramatic.

As we continue into a future where the environmental impact will play a more significant role in policy, the understanding of both the cost and environment will become a more important part of decision-making.

Monte Carlo simulation

Monte Carlo simulations rely on repeated random sampling to obtain numerical results. By running simulations many times over the probability of an occurrence can be calculated. This can be compared to actually playing and recording your results in a real casino situation: hence the name.

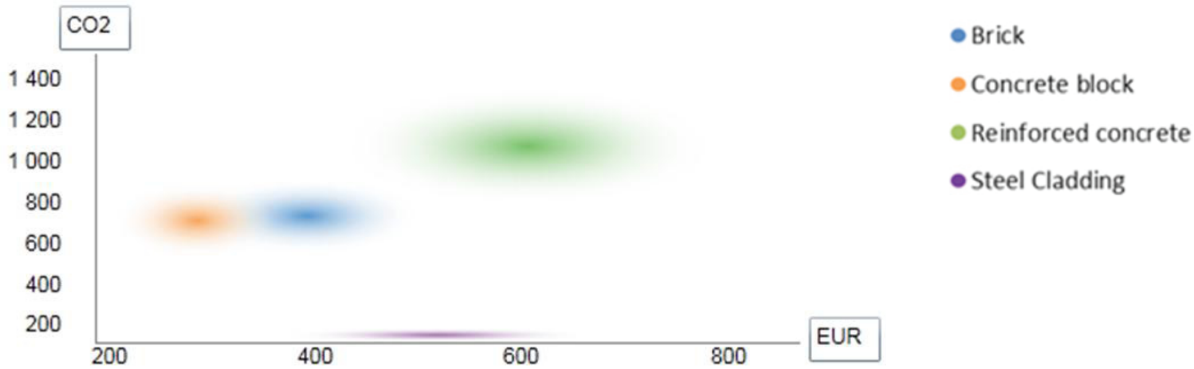


Figure 4.2
LCC+A results of a wall of 1 m³ with Monte Carlo simulations

5 Advances in LCC+A

Any approach to the life cycle evaluation of buildings and building components involves looking into the future. But the future is uncertain. The CILECCTA software for LCC+A provides new ways of taking account of future uncertainty.

Impossibility of prediction

Even though it is impossible to predict the future, many existing software systems for LCC and LCA require precise data inputs for every year of the project study period, typically 20–60 years. The data inputs are in fact estimates based on today's assumptions about the future. Because the assumptions are subject to uncertainty, the input values also have a margin of uncertainty. For example, the future CO_2 emissions from the electricity used in a building will depend on both the amount of electricity used and the carbon content of the electricity, but neither of these factors can be accurately predicted.

When the input data for an LCC or LCA study consists of precise values, or «single-point» estimates, the output is also a precise number that looks like a prediction – but it is actually an uncertain estimate.

Instead of ignoring uncertainty, CILECCTA treats it as an integral part of LCC+A. Uncertainty can be pictured by a «fan» diagram as done in figure 5.1. Time runs from left to right – the left-hand side represents «now». If we know today's value for a system of interest, such as the price of natural gas or the embodied CO_2 of concrete, there is a single point on the «now» line. In situations where the future is totally predictable, such as the movement of the sun, there is a single line from today's certain value to certain values in the future. In situations with uncertainty there is a range of possible values in the future, shown on the right hand side of the diagram. The greater the uncertainty, the wider the range of values.

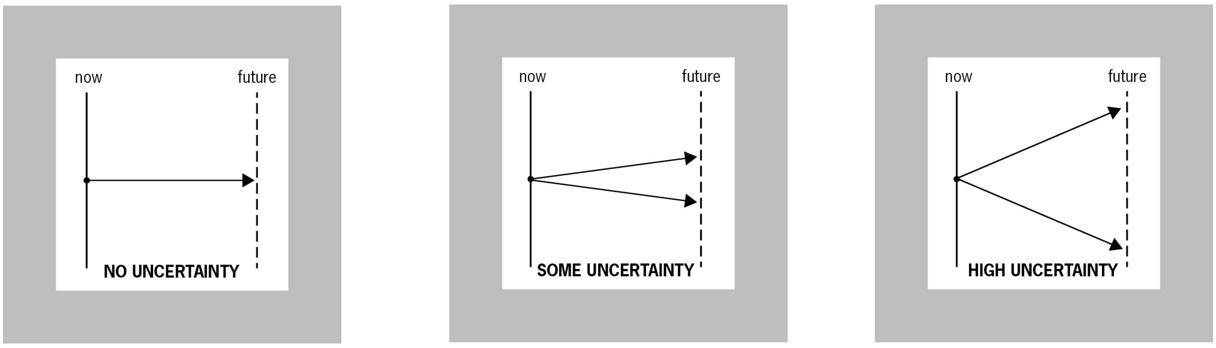


Figure 5.1
Illustrating uncertainty

Describing uncertain data

It is more realistic (and also easier) to specify what will happen in the future using a range of possible values, rather than a «single-point» estimate. A «three-point» estimate is a good way of doing this. The three points are: a) the lowest conceivable value, b) the most likely value, and c) the highest conceivable value. Three-point estimates are widely applicable; for example, to estimate the service life of the carpet in a hotel bedroom, the three points might be: a) 1 year (lowest conceivable value), b) 5 years (most likely value) and c) 10 years (highest conceivable value). Users of the **CILECCTA** software for LCC+A can enter input data as three-point estimates.

With the input data specified by data ranges, the **CILECCTA** software gives a range of possible LCC+A output values. Using the method of Monte Carlo simulation, **CILECCTA** generates a large number of trial runs – maybe 1,000, 10,000 or even 100,000 runs. In each trail run the values for the uncertain inputs are randomly selected from the data ranges. When the output values from all the runs are combined they form a probability distribution – the probabilistic estimate of LCC+A (figure 5.2).

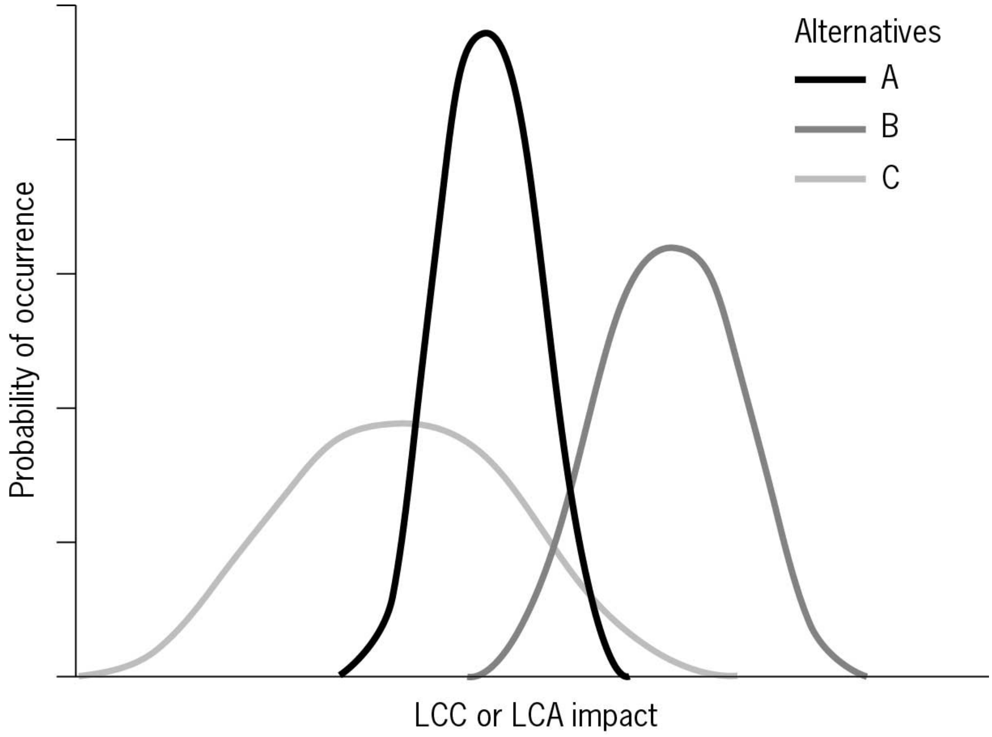


Figure 5.2
Illustrating the probabilistic estimate of LCC+A

Using probabilistic results

When **CILECCTA** presents the results of LCC+A as a range of values, the user gains additional information compared to the single value given by conventional methods of LCC and LCA. The average LCC+A value, at the peak of the probability distribution, is important, but the shape of the probability distribution is also significant. It indicates how likely it is that that the true value will be higher or lower than the average. A steeply peaked probability distribution suggests that the true value will be close to the average; but with a flatter probability distribution the true value can vary considerably from the average. This tells the user how much confidence to place on the average value, and how much allowance should be made for different outcomes.

Future decisions and flexibility

The most common use of LCC and LCA is to help in today's decisions between alternatives for a construction project. However, during the service life of the project many other decisions are made, including decisions about the replacement of components that have a shorter life than the study period.

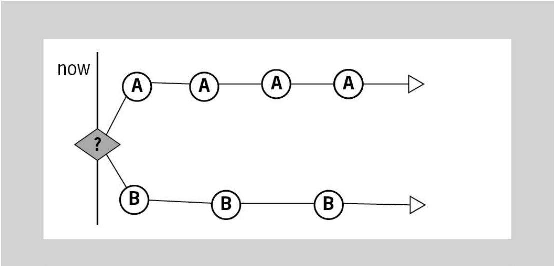


Figure 5.3 a
Illustration of a decision which is repeated like-for-like throughout the study period

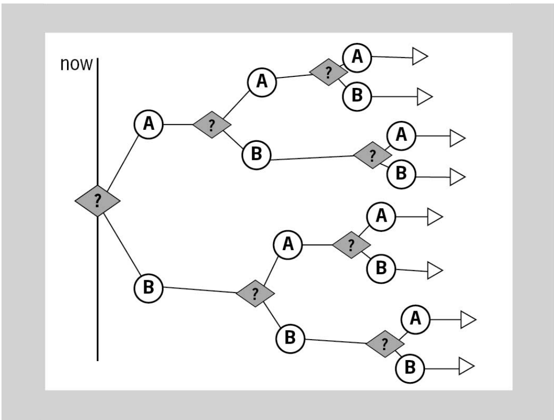


Figure 5.3 b
At the time of replacement there is a new decision and a previously rejected alternative might be chosen

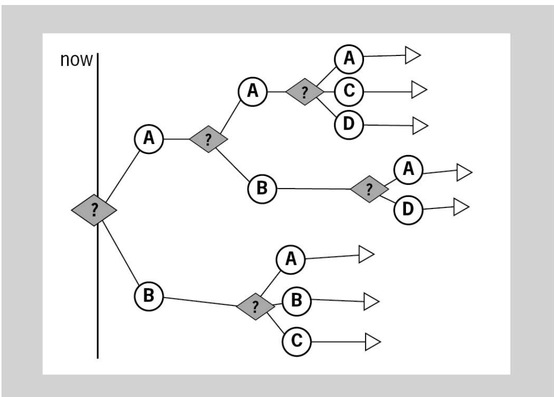


Figure 5.3 c
Some alternatives can be expected to disappear during the service life, and new ones become available

In conventional LCC and LCA it is assumed that the first decision is repeated like-for-like throughout the study period (figure 5.3 a). This is unrealistic. At the time of replacement there is a new decision and a previously rejected alternative might be chosen (figure 5.3 b). Also, some alternatives can be expected to disappear during the service life, and new ones become available (figure 5.3 c).

These future decisions allow a construction project to adapt to unfolding events that are uncertain at the time of design. For example, in a particular project we may know that a wood-pellet boiler is a good decision today, but we cannot know whether like-for-like replacement will also be a good decision in 2030. But the decision-makers in 2030 will know, and decide accordingly. Therefore, future decisions improve life-cycle performance.

To maximise the benefit from future decisions, construction projects should be designed with many opportunities for future decision-making – that is, they should be flexible. This is not a new idea, but the **CILECCTA** method of LCC+A is the first that can model flexible designs.

Evaluating flexible strategies

CILECCTA describes flexibility by specifying the alternatives that can be selected by future decision-makers. In the Monte Carlo simulation runs for a flexible strategy the most favourable alternative is chosen at each replacement cycle, and over many simulation runs the LCC+A performance of the flexible strategy is established. It can be compared to the LCC+A performance of other, non-flexible strategies. Because there is often an additional cost for flexibility, the benefit given by flexibility over the life-cycle must be compared to its initial cost to determine whether the flexible strategy is a good idea. This evaluation of flexibility is a unique feature of the **CILECCTA** software for LCC+A.

6 Price Banks and Life Cycle Indicator Results

It is a clear objective of the CILECCTA development that the software will be able to access a number of Pan-European data sources. A task was therefore established to develop a deep understanding of the two types of data sources, namely Price Banks (PBs) and Life Cycle Indicator Results (LCIRs) that would support CILECCTA's development of an integrated tool.

The **CILECCTA** team's objective were to identify PBs and LCIRs, and to:

- Analyse the data presented, the architecture and mechanism of access for each dataset.
- Benchmark the existing PBs and LCIRs against best practice at a global level.
- Build on identified best practice to design a generic architecture and access mechanism for both Price Banks and Life Cycle Indicator Results.
- Ensure compliance with existing ISO standards and begin the process of encapsulating them in new standards if appropriate.

Characteristics of identified Price Banks

Both data base types are generally region or country specific and therefore the **CILECCTA** team were tasked to identify Price Banks in each of the four European regions (the North, East, South and West) and if possible, at least one in each EU state. A United States based PB was included to compare with our findings. A total of 32 price banks from 13 countries were identified.

A **Price Bank** is a database that includes product and cost data which is used to calculate life cycle (financial) cost of a structure.

Life Cycle Indicator Results is a database which is used to evaluate and quantify the energy and material inflows and outflows during the life of a structure. Data from LCIRs are used to assess the environmental impact that a particular product or process has throughout its entire life cycle.

Feature	Finding
Accessibility	The programmatic accessibility is as a major performance characteristic, which could be achieved with direct access via an API or export capability. The majority of the databases have no API available. API's existed where a close relationship the dataset and software. However there are many PBs in simple electronic formats which can be imported by any customer – CD's spreadsheet and pdf files.
Codification	The classification coding is of key importance for CILECCTA as there is a need to map a units between databases and with their respective i» of codification. Many «internally codified» databases are based on national standard. We need to note that the codification of elements has a growing importance in the software industry due to the tendency to integrate design, measurement and tender or budget procedures. However many of the databases are based on several national standards often enriched with internal codification. Our study showed no relationship with any international European wide standard.
Integration	In response to the question 'What relation does the database hold with software programs? Generally datasets exist as separate entities or stand-alone files. These have their origin in old provided by engineering associations or institutions that are not linked to any specific software application. Databases that reported a close relation with specific software generally used online tools.
Classification	A hierarchical structure characteristic, related to the granularity held or used in the databases with more than three levels found.

Characteristics of identified LCIR databases

Life Cycle Indicator Results (LCIR) databases is a new term defined in **CILECCTA**. *Life Cycle Inventories* (LCIs) are the basis for the calculation of LCIRs.

The Life Cycle Inventory investigations revealed two categories of LCI database, namely «pure LCI databases» and «indicator based LCI databases» – 23 and 13 databases respectively. The differences can be summarized as follows:

- A **«pure LCI database»** offers datasets which contain pure LCI information on different processes, regardless if unit or aggregated processes are displayed. By the help «characterization factors» and using «Life Cycle Impact Assessment» methodology, input and output flows are transferred into potential environmental impacts. If this type of database is used, a tool for conducting the LCIA is essential and the outputs are not easily incorporated into calculations.
- An **«indicator-based LCI database»** contains already «characterized information», also known as environmental Life Cycle Indicator Results (LCIR), on potential environmental impacts for different processes. Information on mass and energy flows may be only partly reflected.

Few provided datasets exists specifically for the use in the construction sector or the building industry, as most LCIs provide raw output data (e.g., CO_2, SO_2) of different production processes. Nine of the LCIs contain or are indicator based LCIR data. With regard to a European construction database on a European level, the application of an already standardized XML data format and an electronic data transfer has been established. The ILCD format technology only requires a web-editor to access data.

We found «pure LCI databases» not appropriate for use, whereas LCIR databases or results (e.g. of environmental product declarations) provide a better solution.

Investigation of price banks and LCIs constitutes the one of the first steps for achieving the broader aim of integrating LCC and LCA for the assessment of sustainable and economic options in the construction industry.

Feature	Finding
Availability	– 40% of the LCIR databases have full online access – 29% is available in CD/DVD.
Languages	Majority available in language of host country
Nature	There are many university and consultancy-based LCI databases which characterize particular industrial sectors and product groups. They are generally very diverse and fragmented, with a low level of cross-national harmonisation. Germany, Sweden, and Switzerland lead the way in LCI data development.
Data	LCI databases provide raw data which may be compared for different options in LCC+A. Assume that there are two materials, A and B, which can be used interchangeably during construction. When comparing the environmental impact of producing those materials, the material that with the least amount of is selected. – For material A, a raw LCI database provides an output that 0.3 kg SO_3 will be produced – For material B, the output is 0.4 CO_2. In this case, it is not clear which one should be selected since the output is expressed in different units. However, indicator based databases express the output as a number for each material production, global warming potential would be expressed as GWP g CO_2 = 100 000 We concluded that we should use LCIR databases
Classification	Classification system indicates how the data is indexed in a database and which standard is used. Data for building elements, materials, equipment and labour prices is classified on national standards and about 20% of them are based on organization-specific internal standards.

CILECCTA data classification

All Price Bank and Life Cycle Indicator Results databases that have been identified use some form of classification and codification system to identify where an item's financial and environmental data belongs. The **CILECCTA** vision is to have a single tool dealing with data from PBs and LCIRs from all over Europe there will be many different classifications to take into consideration.

There is, however, the need to store all in standardized defined concepts and their meaning in a central repository that all data users can access. There are many ways of developing such a tool. However, there has already been done a lot of work by the buildingSmart community to accommodate solutions that use these ideas in the IFD Library. IFD stands for «International Framework for Dictionaries» which is simply a standard for terminology libraries or ontologies.

Read more about IFD and data mapping in chapter **7**.

7 CILECCTA Software

The main objective of CILECCTA has been to develop software that a) goes beyond state of the art, as far as existing available tools and methodologies are concerned, and b) includes and combines cost data and environmental data in construction industry decision making. This chapter explains how CILECCTA deals with issues like building product classification, uncertainty, probabilistic cost modeling and environmental impact categories.

IFD Library – from products to concepts

In the process of mapping cost data and environmental data, in general or for a specific case, it is of vital importance that data providers find products and concepts that are similar. In order to allow data providers from all over Europe to map their domain data against comparable building concepts, **CILECCTA** have to follow a common building product classification (see fact box). To achieve this, the partners decided to lean on the work currently under development by the buildingSmart community – The IFD Library.

The IFD Library is a building SMART development project and are basing its solutions on the framework provided by ISO *12006-3:2007 Framework for object oriented information.*

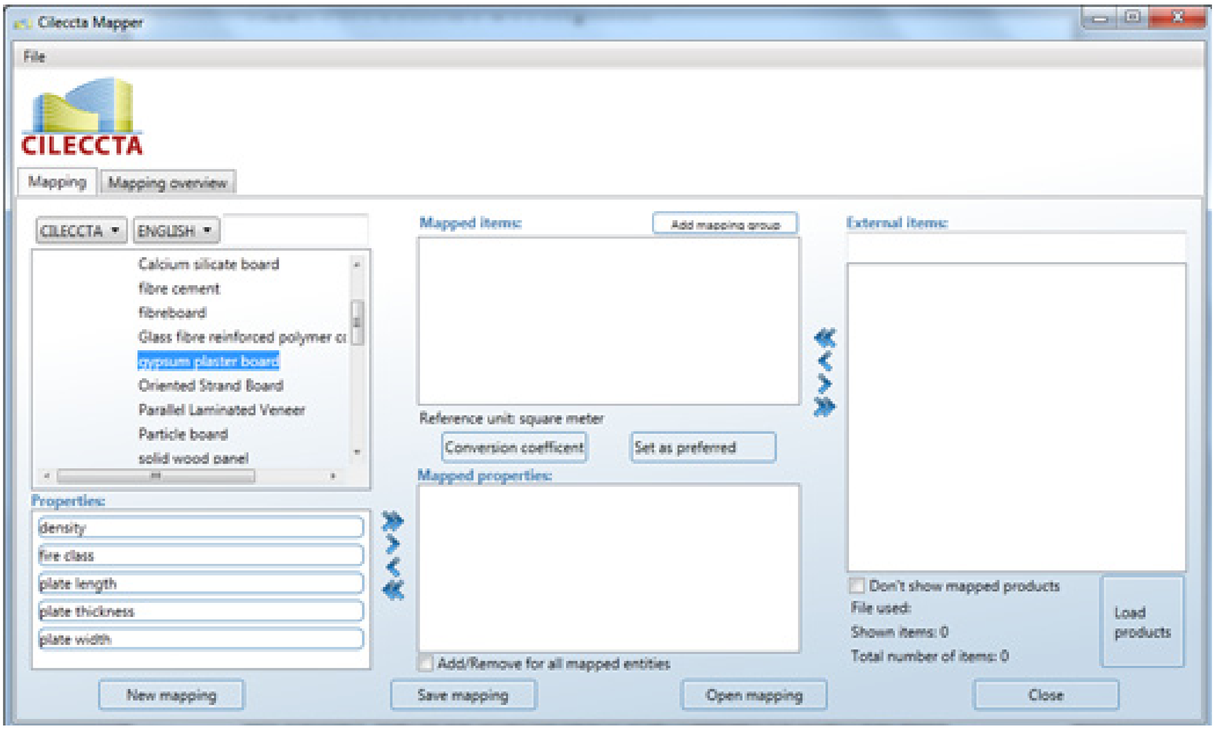
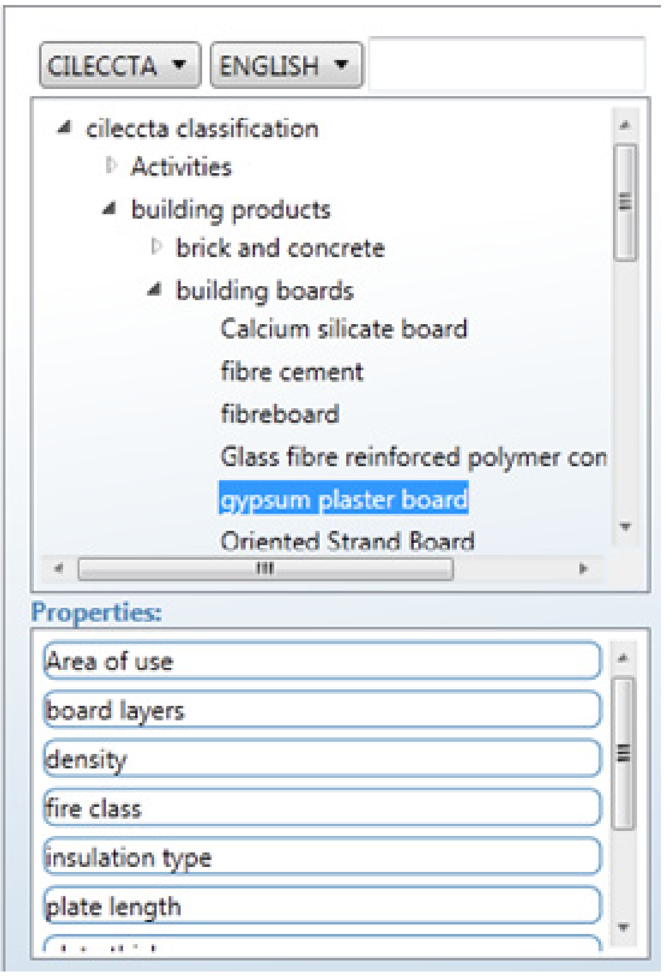


Figure 7.1
Screenshot of the mapping tool used to create mapping files



Building product classification

The benefits of using an internationally developed building-product classification are many:

- One gains access to already defined concepts from other members
- It is possible to compare products with the same properties across borders
- The IFD community has rules that will make sure concepts are defined at the same levels
- One could contribute to the community by defining/ adding concepts to the constantly growing concepts database.

Figure 7.2
The structure of the IFD Library implemented in the software

Uncertainty on input values

Current practice in performing LCC analysis is to discount the fact that the future is uncertain. The CILECCTA tool offers several tools to model various types of uncertainty; Three Point Estimate, Binomial Tree and Expression.

Three Point Estimates

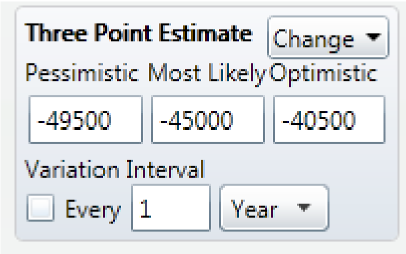


Figure 7.3
Screenshot of the possibility of using *Three Point Estimate*
Using three point estimates on data input will provide the decision-makers with output results that are more realistic than just discounting uncertainty. This is a commonly used technique when making a probabilistic LCC analysis.

Binominal tree

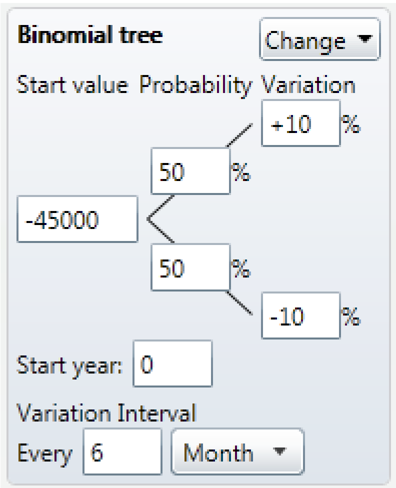


Figure 7.4
Screenshot of the possibility of using *Binominal tree*
In the binomial tree approach the uncertainty of the value of the underlying asset is assumed to follow binomial variation. Therefore the binomial tree is an explicit statement of the underlying uncertainty of the value of the asset.

Mathematical Expressions

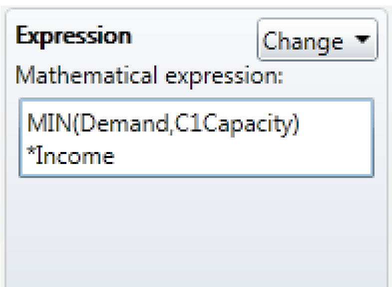


Figure 7.5
Screenshot of the possibility of using *Mathematical Expressions*
Users are also allowed to add their own mathematical expressions to express how the input values should be represented.

Probabilistic cost modelling

Included in the software is the possibility to use Monte Carlo simulation. Monte Carlo is a widely used approach for probabilistic cost modeling. The approach is relatively simple in terms of use, understanding and reporting, and can handle many different formulations of uncertainty, overcoming some of the limitations of other approaches.

When uncertainty is described in terms of a probability distribution, the Monte Carlo approach randomly samples from this probability distribution and simulates the response of the system to this changing, uncertain parameter (e.g. switch to a cheaper energy source, develop a building, or «wait and see»). This process is repeated multiple times, and the results of each sample run are aggregated to give probability distributions of the option value – which can be used to inform decision-making. Figure 7.6 shows a screenshot of the presentation of the results when probability is included into the analysis.

When modelling probability and uncertainty, the output data will be shown with standard deviation. The output is Net Present Values (discount rates on input values over a given study period) and not actual costs. The cost output, shown as NPV-values, includes one-off costs together with ongoing costs during the life time (figure 7.7).

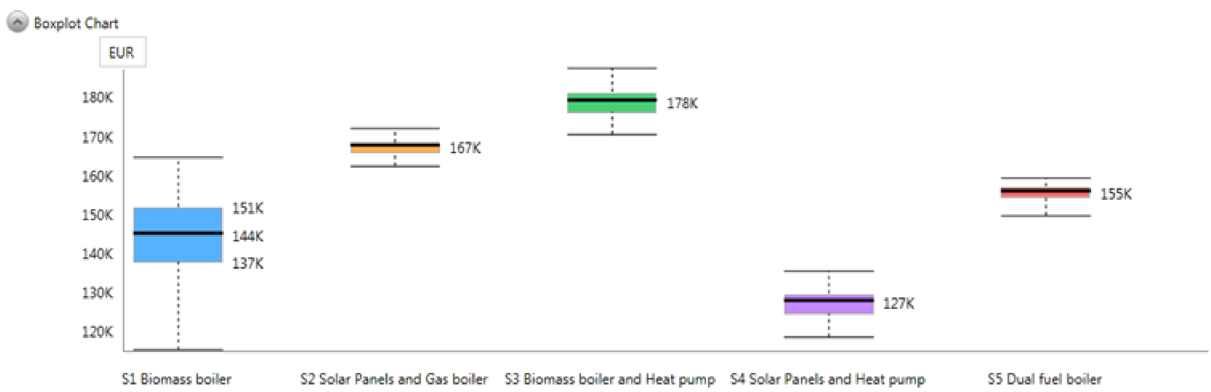


Figure 7.6
Screenshot of the presentation of the results with probability included

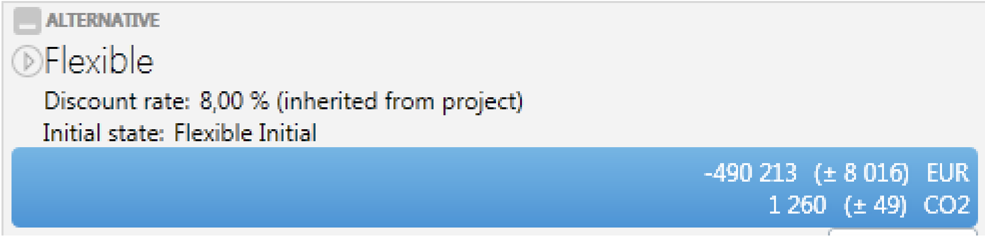


Figure 7.7
Screenshot of the presentation of the results with probability included

Environmental Impact Factor (EIF)

To be able to compare costs against more than one environmental impact category (e.g Global Warming Potential, unit: kg CO_2 eq.) the term Environmental Impact Factor (EIF) has been defined. In this way the results presented by the software can be two-dimensional, but still considering more than one environmental impact category at once. The Environmental Impact Factor is weighing the different environmental categories against each other resulting in one final factor. The user of the software can decide what emphasis she will make on each impact category depending on what the assessment shall enlighten. See figure 7.8.

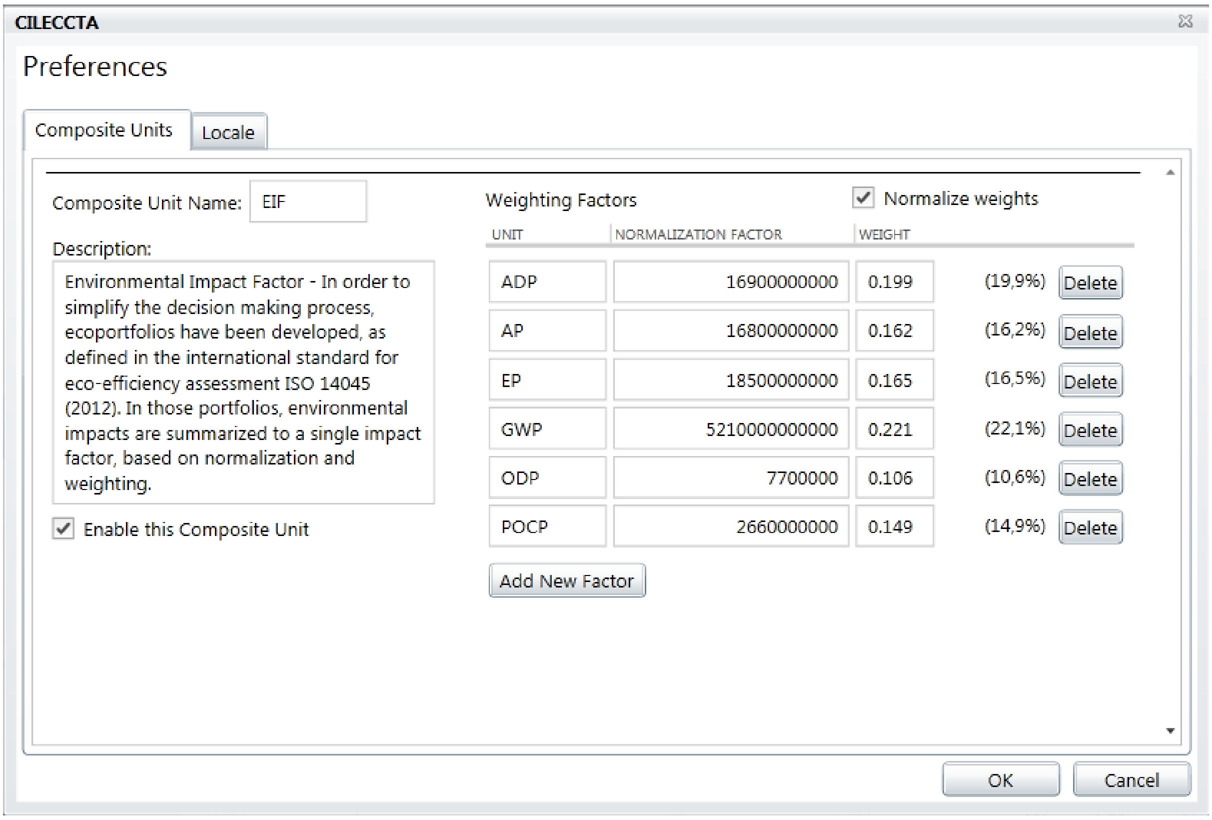


Figure 7.8
Weighting factors in the **CILECCTA** software (screenshot)

Version 0.1 of the CILECCTA software

The **CILECCTA** software v 0.1 has been systematically tested and evaluated by the demo projects and the project participants during the project period. The feedback formed the basis of making new specification for improved versions of the software. Figure 7.9 shows a screenshot of the final version as we see it today. The alternatives which are to be compared are presented to the left and the graphs illustrating the results to the right. Chapter 8 demonstrates the software through real cases.

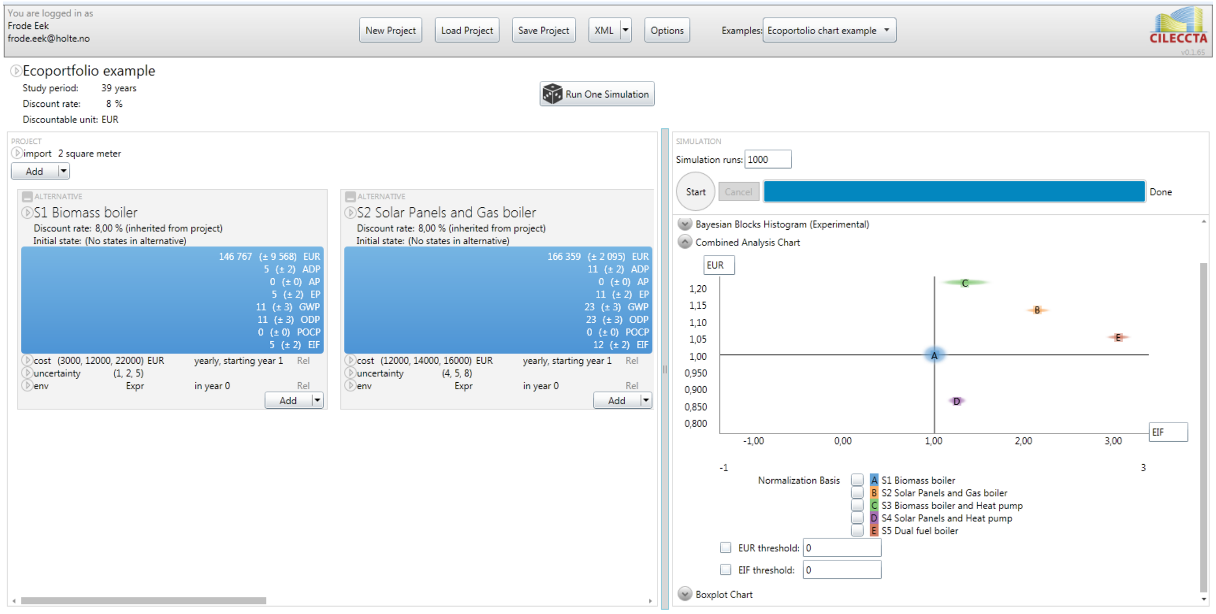


Figure 7.9
Screenshot of the final version of **CILECCTA** software

8 Case Studies

In order to test the features of the CILECCTA software tool, three demonstration projects were selected. The demonstration projects represent a wide range of scenarios in the construction sector and have allowed in-depth testing of the CILECCTA software.

The three demonstration projects are

- The MESSIB Demonstration House
  Economic and environmental impacts of thermal storage systems in buildings are assessed for the MESSIB demo-house in Greece. Responsible partner: Acciona.
- The Heating System Case
  Different scenarios for heating systems are assessed for an employee house related to a resort in Mallorca, Spain. Responsible partner: TUI.
- The Road Case
  Optimal specifications for road constructions are identified based on uncertain development of traffic in Spain. Responsible partner: APIA XXI.

Apart from providing actual case studies for the general application of the software tool, each case study also has a slightly different scope. The MESSIB demo case focuses on the assessment of newly developed construction materials, such as phase-change insulation material. The Heating System Case has a special focus on the result presentation and interpretation. Finally, the road case has been used to improve the uncertainty analysis part of the CILECCTA tool.

In the following, the demo projects are described in detail, with their testing scope, experiences and lessons learned during the testing and feedback of the tool use.

The MESSIB demonstration house

MESSIB (Multi-source Energy Storage System Integrated in Buildings) was a four-year project financed by the European Commission under the 7th Framework Programme from 2009 to 2013. It has been dedicated to developing, evaluating and demonstrating the multi-source energy storage systems in buildings, based on new materials, technologies and advanced intelligent control systems to manage energy demand in buildings. Energy storage is the way to conserve energy (thermal or electric) in one form and release it when needed in the same or another form.

One of the forms of thermal energy storage is realised via special latent heat storage in Phase Change Materials (PCM) (figure 8.1). These materials can be integrated in the building structures, such as: walls, windows, ceilings or floors.

CILECCTA is used to assess the paraffin-based PCM system installed in the plasterboards of external and internal walls of the MESSIB demo house which is a residential building in Amphilochia, Greece (figure 8.2).

Plasterboard is a common lining material used in steel-framed constructions, such as the MESSIB demo-house. Replacing it with PCM plasterboard provides greater heat capacity, and more en-

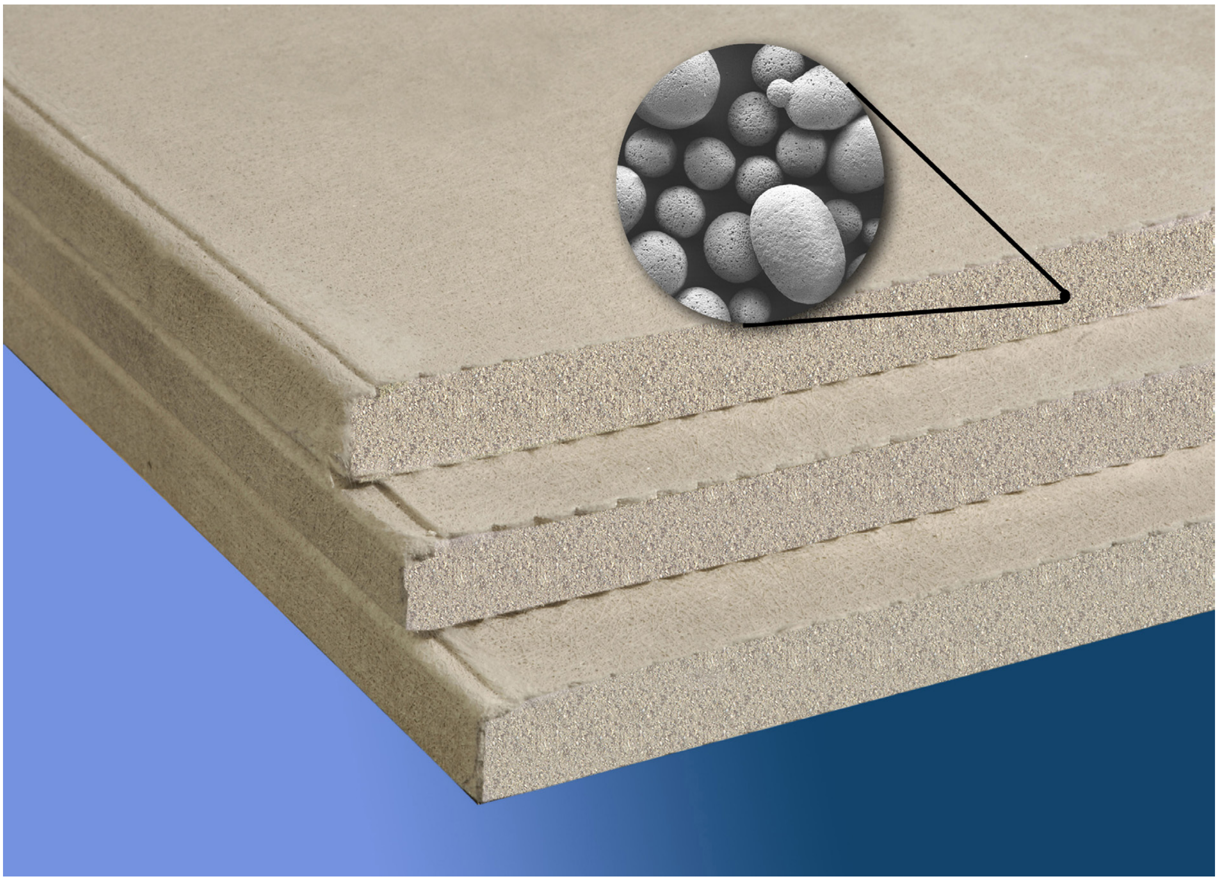


Figure 8.1
Gypsum Plaster Board with PCM.
© BASF SE, 2013

ergy can be stored in the building´s envelope, which helps to reduce energy consumption for cooling or heating in a passive and sustainable way.

Two alternatives have been assessed with the **CILECCTA** tool:

- Lower energy consumption related to the «MESSIB building» with PCM plasterboards
- Higher energy consumption related to a traditional building with traditional plasterboards.

Within this demo project, **CILECCTA** has been used to quantify the saving potential of new materials and the capability of **CILECCTA** to assess newly developed materials. Furthermore, the identification of the influence of single components such as the PCM on the entire house has been assessed with **CILECCTA.**

Figure 8.3 and 8.4 shows results from the testing. PCM plasterboard seem to be more environmentally friendly than the conventional material. In the result of sensitivity analysis (figure 8.4), the target price of the PCM plasterboard 30 mm should be lower than 27€/m² to get lower cost of the MESSIB building in the initial stage of its life cycle.

Figure 8.2
MESSIB demo-house in Amphilochia (Greece)

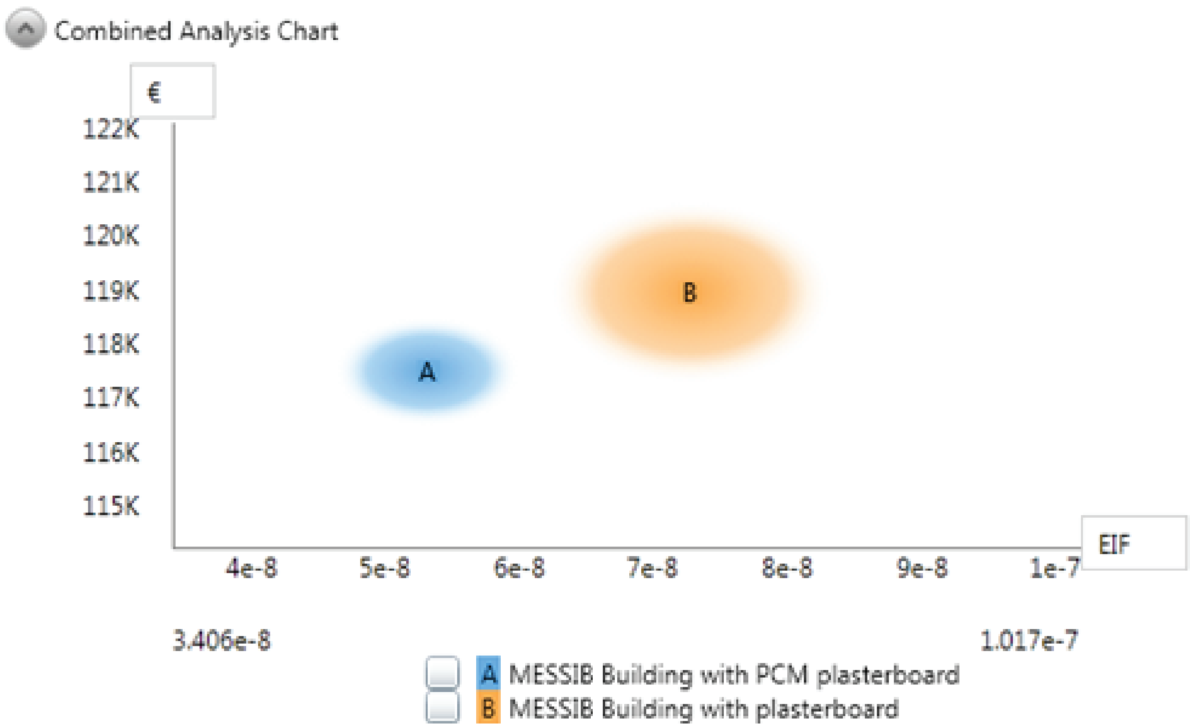


Figure 8.3
Analysis Chart illustrating the results from the testing of MESSIB demonstration case (screenshot)

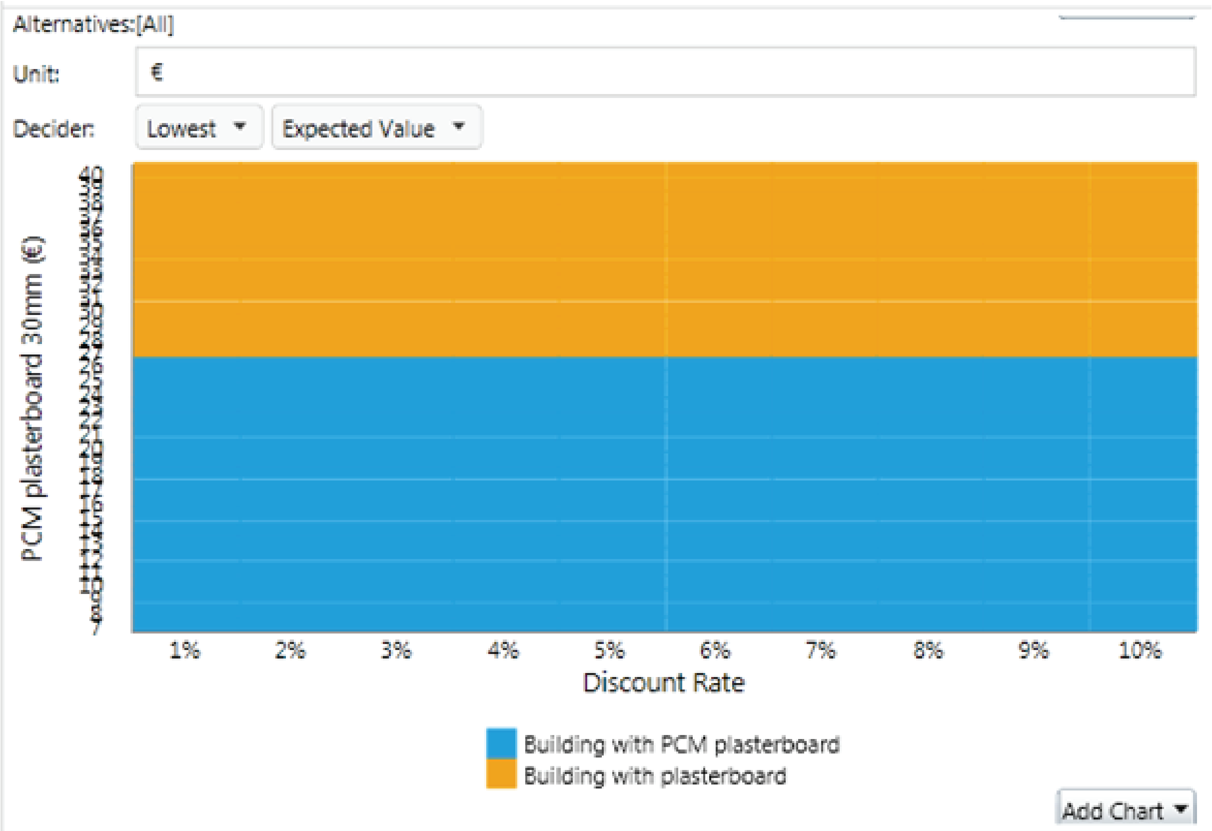


Figure 8.4
Sensitivity analysis on life cycle costs for the MESSIB demonstration case (screenshot)

Testing experience and lessons learned

«The CILECCTA software is easy to use and gives flexibility in evaluation of the economic aspect in the construction sector. For example probabilistic analysis that helps to calculate the degree of uncertainty of a construction investment. At present time it doesn´t have direct competitors in the market, which makes CILECCTA software unique.

From the early testing we learned that the process of integration of PBs and LCIRs with the CILECCTA software was tedious and time-consuming. It required the use of another mapper program to have access to the LCIRs. Moreover, in the case of the MESSIB demo-house some new construction materials had been installed, which do not exist in any available data-base, which made it challenging to do the analysis properly.

This was all important experiences for further developments of the software.»

Ewa Alicja Zukowska, Acciona

The Heating System Case

Different heating systems were considered for the Robinson Club Cala Serena, a TUI resort in Mallorca. In 2010, a biomass heater using wood pellets as fuel was integrated in a staff house. This was taken as a real-life case basis for the different scenarios conducted, as renewable energy sources are being considered for the entire club.

It was decided to assess the measure utilizing the **CILECCTA** software and to compare it with alternative renewable heating systems. This was done to identify both economic and environmentally reasonable systems and combinations of heating systems in a life-cycle perspective. In particular, there were four systems being assessed:

- S1: a biomass heating system, current status of the building, which supplies all the heat demand.
- S2: a solar thermal heating system, which supplies 60% of the domestic heated water demand, combined with a natural gas condensing boiler, which provides the balance of the heated water.
- S3: a biomass heating system, responsible for the domestic heated water demand, combined with a water-water heat pump and a subfloor heating installation to heat the building.

Figure 8.5
Robinson Club Cala Serena, Mallorca

- S4: a solar thermal heating system, which supplies 60% of the domestic heated water demand, combined with a water-water heat pump which provides the rest of the domestic heated water and a subfloor heating installation to heat the building.

A scenario S5 was also included to compare the scenarios to a system with a duel fuel boiler using fossil fuels.

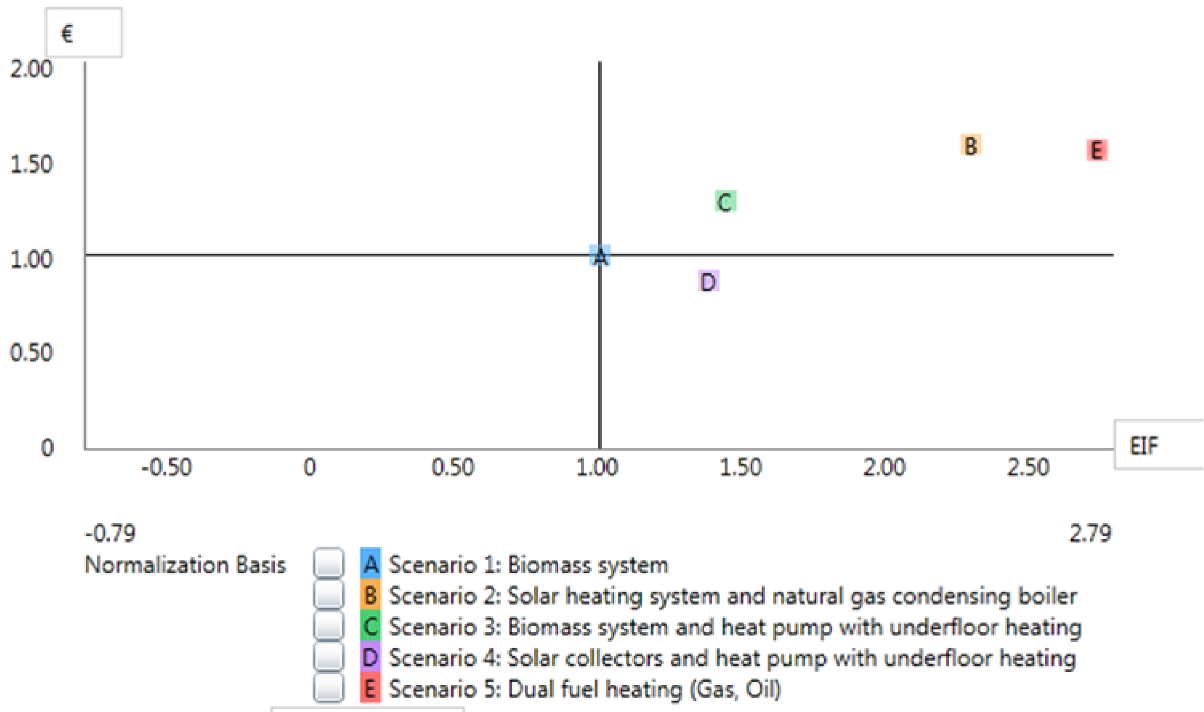
Figure 8.6 shows some of the simulation results were the heating systems are compared. As can be seen, the biomass system (S1) is the alternative with the least normalized Environmental Impact Factor and are here used as reference with Environmental Impact Factor (EIF) = 1. The solar collector and heat pump system (S4) is a bit cheaper, but has over 40% larger EIF.

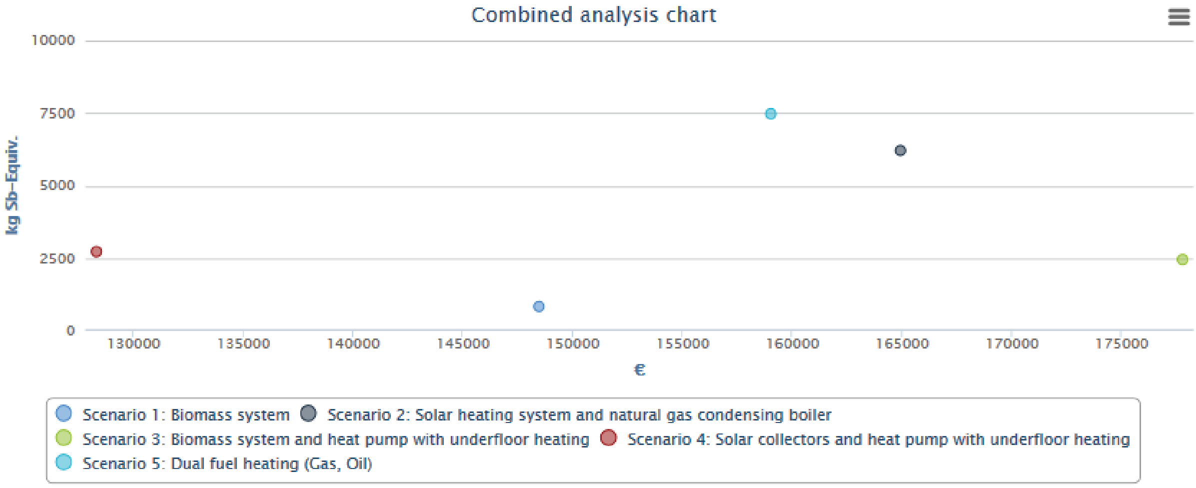
Deterministic versus probabilistic approach

Figure 8.7 shows a simulation where a deterministic approach is used to compare the alternatives against kg Sb equivalents. When comparing this figure with figure 8.8, where uncertain energy prices are taken into consideration leading to a probabilistic approach, it becomes clear why a probabilistic approach can give better and more realistic results.

On the other hand, the costs of the future are also uncertain. The **CILECCTA** software gives therefore the percentage probability of costs for the different scenarios. The result can be studied in figure 8.9.

Figure 8.6
Comparison of heating system scenarios S1-S5 (screenshot)





Figur 8.7
Deterministic approach (screenshot)

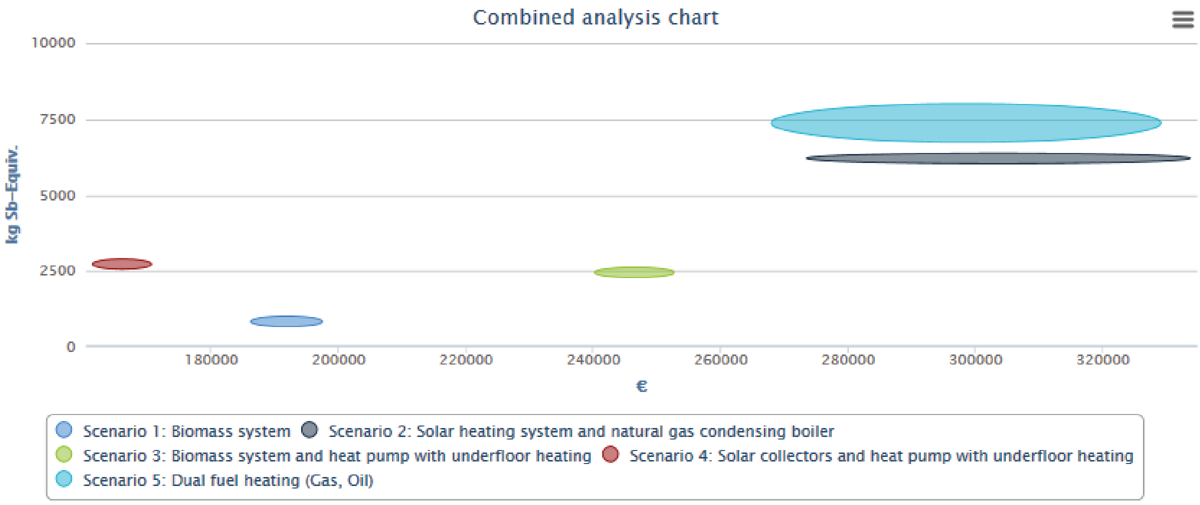
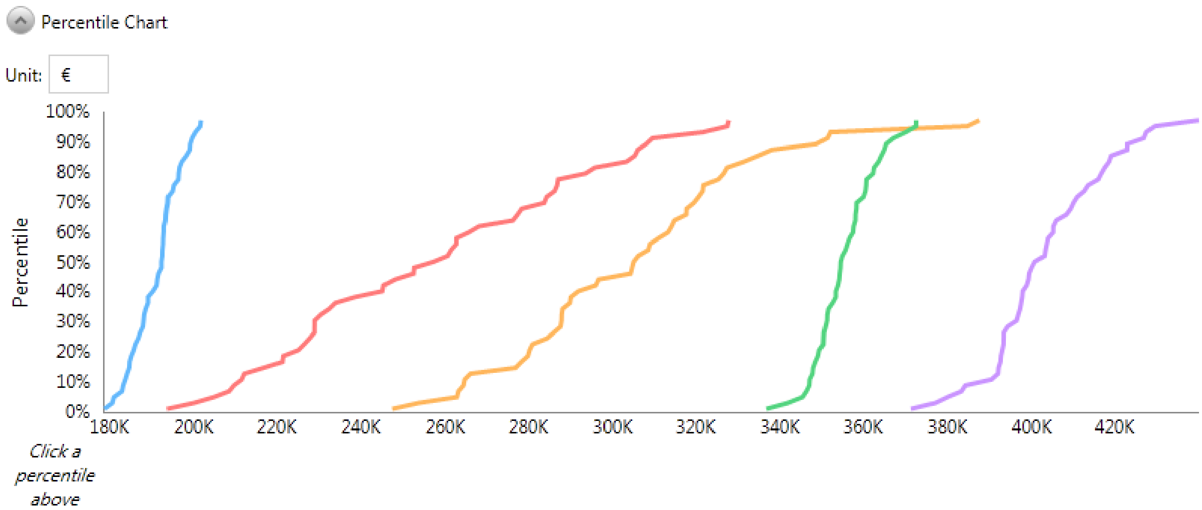


Figure 8.8
Probabilistic approach, taking into account uncertain energy prices (screenshot)



	50%	70%	90%
Scenario 1: Biomass system	192K	193K	199K
Scenario 2: Solar heating sys	305K	319K	348K
Scenario 3: Biomass system a	354K	358K	365K
Scenario 4: Solar collectors a	400K	410K	422K
Scenario 5: Dual fuel heating	257K	283K	308K

Figure 8.9
Graph illustrating the probability of costs for the different scenarios (screenshot)

Testing experiences and lessons learned

«While in general economic and environmental impacts of heating systems can be calculated separately with other software tools, an integrated assessment of both dimensions with existing tools is currently not possible. Furthermore, CILECCTA allows assessment of the implications of the uncertain development of energy prices, among other factors.

The CILECCTA tool is based on an easy-to-understand modular modelling approach that enables the user very quickly to get first results, but on the other hand to model very complex situations. Especially the possibility of including probabilistic scenarios enhances the global picture of a project by far, and helps the attempt to achieve a notion of future trends. It allows you to systematically support decision-making processes for all types of construction-related decisions from both an environmental and an economic point of view.

Apart from regular feedback concerning the use of software and minor comments related to improvement, the TUI demo case found the presentation of the results to be a key factor in the wider use of the CILECCTA tool. CILECCTA processes a large amount of data, both from an environmental and economic point of view. This data has to be presented in a user-friendly way and should be easily understandable.»

Dieter Semmelroth, TUI

The Road Case

A complete road design project includes detailed topographic studies, geotechnical surveys, analysis and characterization throughout the entire length of the road, and the design of different structures (pavement, drainage, bridges, retaining walls, etc.). The engineering process includes many variables and a long term project analysis, making it possible to take into account upgrade situations depending on traffic evolution or even financing capabilities. The current road demonstration case focuses on the design and selection of the pavement structure for a generic square meter of the road, based on the same parameters used on a real case by the civil engineers.

The design of pavement structures is a science that involves studying the constraints of the road paths, the supporting capacity and material characteristics of the available substrates, as well as the climate, period and above all the traffic usage planned for the infrastructure. The case study follows the standards used in Spain to select and size the structural section of the pavements depending on two main parameters: the available foundations for the «subgrade», and the «traffic category» the road must serve during its life cycle. As the future development of traffic is subject to uncertainty, **CILECCTA** can contribute to the decision making process by analyzing the associated real options and offering the economical and environmental evaluation of different alternatives, including

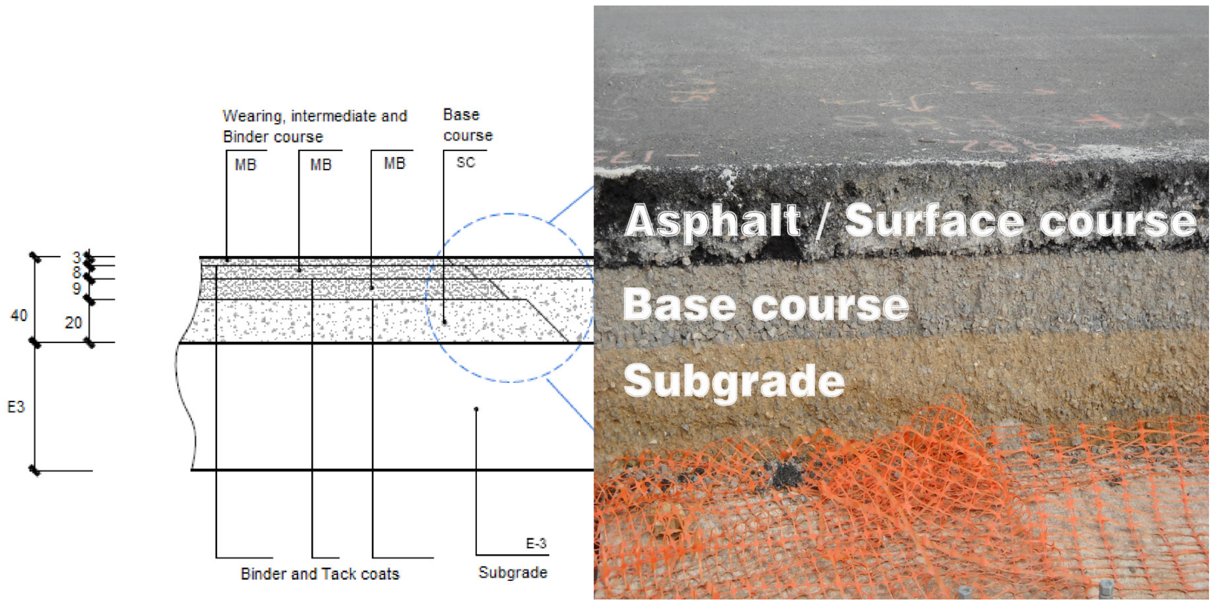


Figure 8.10
Road base pavement structure detail

aspects of the construction phase, the O&M phase and the potential upgrades. Therefore, the focus related to the road case has been the application of the Life Cycle Option assessment module of the **CILECCTA** tool. One example is the evaluation of the impact the discount rate uncertainty has when deciding if a flexible alternative is more advantageous than a fixed non-upgradable one. Figure 8.10 shows the combined environmental and economical evaluation comparing several road pavement structures, with different surface course, base course and subgrade combinations (E1 212, E2 122 etc.), as well as the possible upgrade paths (from a 232 to a 132, etc.), while figure 8.11 shows the resulting economical evaluation and turning points when the discount rate is changed. In this use case there was also uncertainty related to traffic growth (evaluated as a three point estimate). Figure 8.12 shows that with low traffic growths the flexible alternatives offer a much better economical result in the long term, while when higher traffic growths appear high specification roads are preferred.

The sensitivity analysis proved to be a very powerful tool in order to understand the context dependency of the choices to take. Since the road case showed a big dependency of two main parameters, both related to the economy, the discount rate and the traffic growth, it was logical to progress the analysis into a two dimensional sensitivity analysis. In order to allow a two dimensional sensitivity analysis there must be a selection done among the alternatives based on a certain criteria; therefore we must define a

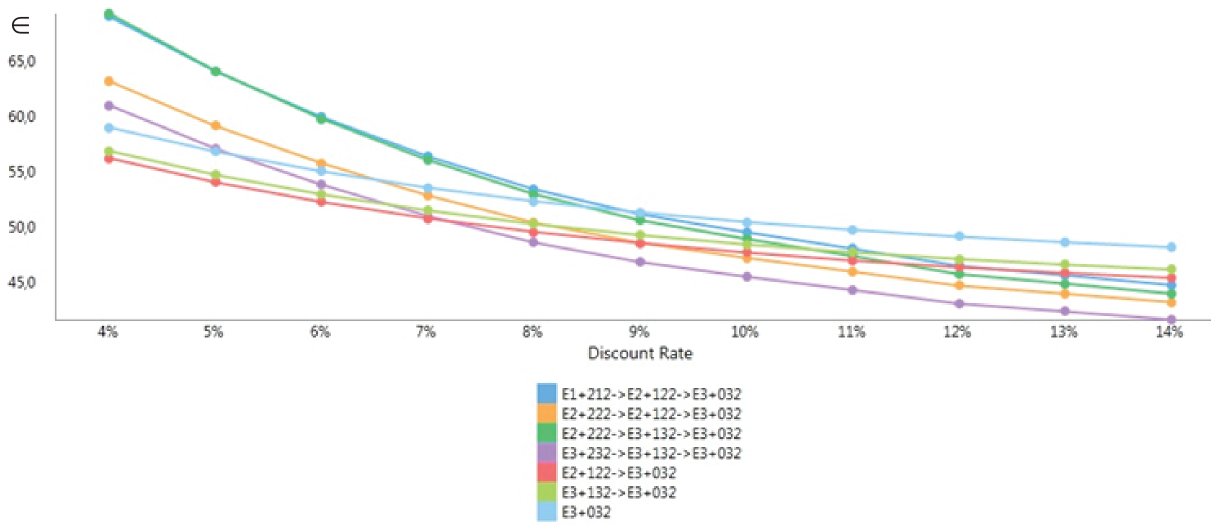


Figure 8.11
Economical sensitivity analysis of the road case alternatives when the discount rate varies from 4% to 14%

decider associated to a certain unit within the calculations. For the road case the lowest LCC expected value was kept as selection criteria, while varying the discount rate from 4% to 14% and adding the uncertainty to the traffic intensity growth (from a typical 0% to a 4.75%), getting the next combined graph (figure 8.13).

The general trend is that for low discount rates and high traffic growth rates, high specification solutions perform best, whereas for high discount rates and low traffic growth rates, low specifications with flexibility for upgrading perform best.

CILECCTA should not be treated or measured as a future prediction crystal ball, but instead a present wide range evaluation tool that unhides the uncertainties, and is capable of successfully providing context aware updatable decision roadmaps. The process involves modelling the basic premises, with the capability to introduce the associated uncertainties for each variable, and provide environmental and economical life cycle evaluations of the alternatives that can help you argument the value of not only the straight forward solutions, but also the flexible real options alternatives. **CILECCTA** allows the construction sector to efficiently analyse and reason any decision making process by offering a clear picture of where the alternatives might change, allowing for wiser and more sustainable decisions.

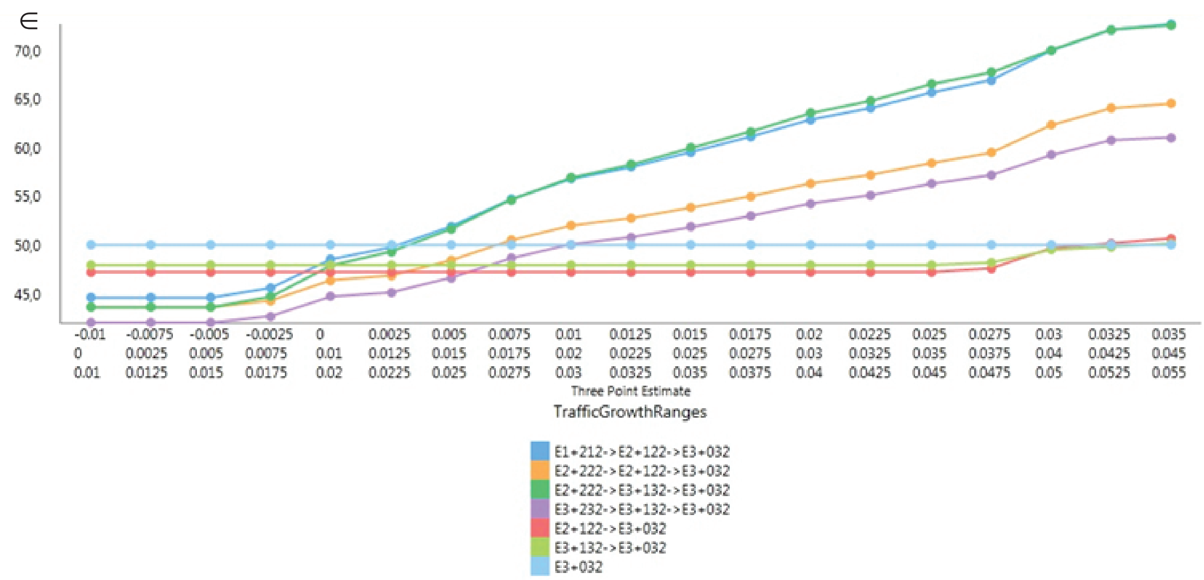


Figure 8.12
Economical sensitivity analysis of the road case alternatives when keeping the initial conditions, but varying the typical traffic growth from 0% to 4.5%

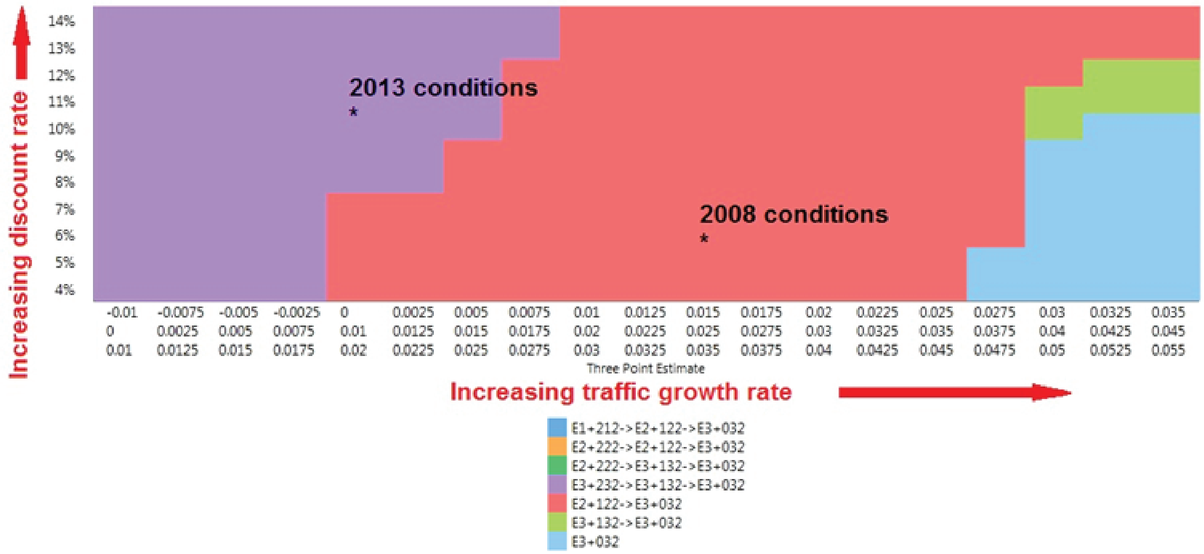


Figure 8.13
Combined economical sensitivity analysis of the road case alternatives when the discount rate is varies from 4% to 14% and the traffic growth changes from 0% to a 4.75%

Testing experiences and lessons learned

«For the testing process the different road design alternatives need to be clearly defined and modelled, based on the different units and parameters of the materials to use of each layer and work to perform in order to construct it. As a general experience this task takes a significant portion of the design phase, but has the advantage that once the model is in place results will be possible for a wide range of scenarios. Furthermore one of the greatest added values of the tool is to be able to take uncertainty parameters, like the future road traffic category, and use it to simulate possible alternative changes – road pavement upgrades- that can provide some very interesting decision taking assessments on the most optimal solution for the current project.»

Ignacio Robles Urquijo, APIA XXI

9 Training and e-learning

Parallel with the CILECCTA software development, the partners in the consortium have been developing training courses and e-learning modules. This has been done to explain the topics of sustainability, LCC, LCA, LCC+A, together with the CILECCTA software. The courses combine knowledge from research as well as experience from the demo-projects.

Norwegian Technology has developed in-house training modules and vocational courses, BSRIA has constructed industrial courses, and USTUTT, together with LTU, has had the responsibility for development of university courses.

In-house training

To allow training of the in-house participants in the project, a series of e-learning courses has been developed and divided into three modules:

Module 1 Basic training contains general theory about LCC and LCA, and users are presented with the concepts of flexible design. The purpose of this training course is to give the project participants basic knowledge and understanding of the principles the **CILECCTA** software is based on. These modules will form the basis for vocational training. You can take Module 1 e-learning course by clicking on figure 9.1.

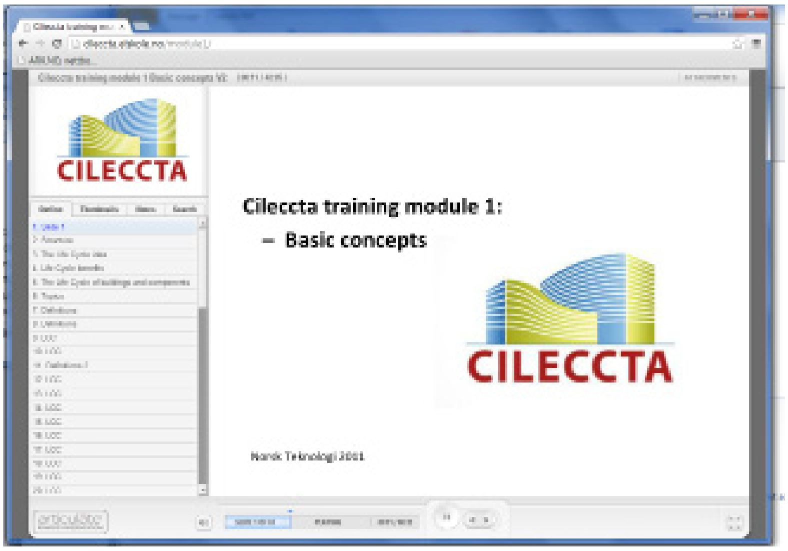


Figure 9.1
Module 1 Basic training. Click on the figure to take the course

Module 2 is the in-house training course for the **CILECCTA** software v0.1. The purpose of this training course is go give project participants' basic training in trying out the software to provide feedback to the developers of the software. This module is available to project participants on the **CILECCTA** website and requires login.

Module 3 is more advanced training in the use of the **CILECCTA** software. The purpose of this training course is to show what the software is capable of, and will focus on how changes in input data will affect the results of the calculation. Parts of this module will also be included in vocational training.

Figure 9.2
e-learning Module 3. Three animation videos are made illustrating each demonstration case: The MESSIB Demonstration House, The Heating System Case and The Road Case (picture)

CILECCTA education possibilities

You are able to do courses within the environmental and economic topics that **CILECCTA** is built on. Education within **CILECCTA** is divided into three levels; vocational, industrial and higher education.

Vocational training

Vocational training will be an e-learning course using Module 1 Basic training as basis. In addition it will show an example from the **CILECCTA** software and focus on the results from the calculation and how to understand them. This training course will be available on the **CILECCTA**website. It is planned to offer this course for example in summer school.

Industrial training

Industrial training aims at potential applicants of the **CILECCTA** software from industry. Therefore, the course will focus more strongly on everyday aspects of LCC, LCA and LCC+A. Special focus will be on model generation, modelling guidelines and interpretation of results, while scientific background is not at the core of training. The course will be offered to industrial applicants through members of the **CILECCTA** consortium.

Figure 9.3
CILECCTA training
Photo: Taran Gjoeystdal

Industrial training has been divided into three courses. Two of these courses are in a classroom style that is aimed at industrial personnel who wish to learn how to understand or carry out life cycle costing or life cycle analysis. The third course will be delivered via webinar and covers LCC+ A. This course is aimed at decision-makers within industry so that they can understand how to use both LCC and LCA in the decision-making process.

Course 1

Advanced Life Cycle Costing – a one-day course

(This is an add-on to a 2-day course on Life Cycle Costing).

Life Cycle Costing enables project sponsors and delivery teams to evaluate the combined capital and operating costs of construction work. This is important to make sure that the client is getting long term value for money from the project. This training course presents some advanced topics such as probabilistic analysis, «the options-based approach», the principles of deferring decisions, the Binomial Tree method of calculating costs or benefits of deferring decisions, and the impacts of these approaches. Pricing a deferred decision enables a client to take a realistic view of the financial benefits of incorporating flexibility into a design. Examples might include deliberately designing a new building so that it can be converted from commercial to domestic use and vice versa as cheaply and easily as possible, or deliberately designing a heating system that can use multiple fuels so that the primary fuel can be switched as prices change.

Course 2

Life Cycle Assessment – a two day training course

Life Cycle Assessment is becoming a key tool in understanding the environmental impact of a product or process. LCA enables project teams to make informed design decisions as to which options have the lowest impact on the environment across their whole lifetime. A full LCA covers the cradle-to-grave scenario, analysing the impacts of the raw materials used, manufacturing processes, use of the product and finally disposal processes. Outputs can be various, not just the carbon emissions, thus providing a full picture of the predicted impact on the environment. The course will cover the key processes in LCA as outlined in ISO 14040:2006 – Environmental Management – Life Cycle Assessment – Principles and Framework, and ISO 14044:2006 – Environmental Management – Life Cycle Assessment – Requirements and Guidelines.

Course 3

Combining life cycle costing and life cycle assessment – Webinar

Life cycle costing is becoming more widely used to help project teams understand the long-term cost implications of the design implications they make, for example whether a higher equipment specification is worthwhile in terms of savings from increased energy efficiency or equipment life expectancy. Life cycle assessment is also being used to highlight the environmental impacts of design decisions such as choice of construction materials, or passive vs. active heating and cooling.

These two analyses are usually reported separately to cost consultants and to sustainability consultants respectively. But to make the best overall decision it is necessary to combine the economic and environmental performance into a single set of results. This webinar will explain how the results of lifecycle costing and life cycle assessment can be brought together in a practical way, to help clients, designers, contractors and specialist suppliers make better decisions. The webinar will also explain some of the pitfalls that clients and project teams should avoid.

If you are interested, please contact Ian Wallis at BSRIA (**ian.wallis@bsria.co.uk**). More information about the courses can also be found at **www.bsria.co.uk**.

Figure 9.4
CILECCTA education
Photo: Taran Gjoeystdal

Higher education

The probabilistic approach of the software allows benefits compared with deterministic approaches, as it is possible to evaluate the future outcome connected to uncertainty. With these possibilities there is a need of knowledge among students. The university courses have been constructed as general decision making courses and are suitable for both economics and engineering students. The entry requirements are general; no other university course is necessary before taking the first course. In total, there are four courses: a Sustainability course, an LCC course, an LCA course and an LCC+A course.

The sustainability course focuses on what sustainability actually is and why it is relevant to industry and society today. It also introduces the students to the concept of life cycle thinking (LCT).

Among the topics in the LCC course are the advantages and disadvantages of different economic methods for cost analysis and different life-cycle cost models.

Life Cycle Assessment or LCA describes a method of quantifying the environmental impacts of products, processes or services along their entire life cycle. Within this segment of the course, the background methodology of LCA, as well as its applications, is described.

The LCC+A course focuses on the analysis and evaluation of input and output for the software. The students will learn and use different concepts such as real option alternatives and multidimensional decision criteria.

LCC+A Course

The LCC+A course at university level is available free of charge for students and university employees, as well as for members of non-profit research bodies. This course is based on the outcomes of the CILECCTA project with major contributions by BSRIA, the University of Luleå and the University of Stuttgart.

If you are interested in this course, please contact Hannes Krieg at the University of Stuttgart (**hannes.krieg@lbp.uni-stuttgart.de**)

10 Seminars, Papers and Scientific Articles

Results and findings from the CILECCTA project have been made available to the public through seminars, papers and articles in scientific journals.

From January to May 2013, **CILECCTA** seminars were held in eastern, western, northern and southern Europe. The seminars were aiming to give an introduction to the methodology behind **CILECCTA**, together with information about the software and how it can give benefits to the construction sector.

In January a seminar was held in Poznań, Poland. The seminar took place at the BUDMA Construction Fair, which is considered the most important trade meeting in Poland. In April two training events connected to the **CILECCTA** demonstration cases were organised, focusing on assessment capabilities for the software. One was held in Madrid, Spain, and another one in Hannover, Germany.

In May **CILECCTA** was represented by a stand at the Elfack trade fair in Gothenburg, Sweden. Here the tool was presented by an animation video and a quiz was held to challenge the audience to see how much they know about life cycle assessments and **CILECCTA**.

A full-day seminar took place in London in February. In total 47 feedback forms were received at the end of the event. 65% of all delegates completed a form. This is a very high return, given that the feedback forms where not submitted by some of the **CILECCTA** partners present and actual speakers who felt that their views might be biased.

Figure 10.1 shows that building owners, consulting engineers and FM and maintenance providers comprised three quarters of all those attending.

Delegates were asked for their objectives for attending the seminar. From the 45 responses answering this question, life cycle in general was a key objective, accounting for 56% of responses. As for the overall difference between LCA (environmental) and LCC (financial) implications, there was no overall difference with 20% each (figure 10.2).

As can be seen in figure 10.3, an very high percentage (93%) of respondents stated their objectives had been met.

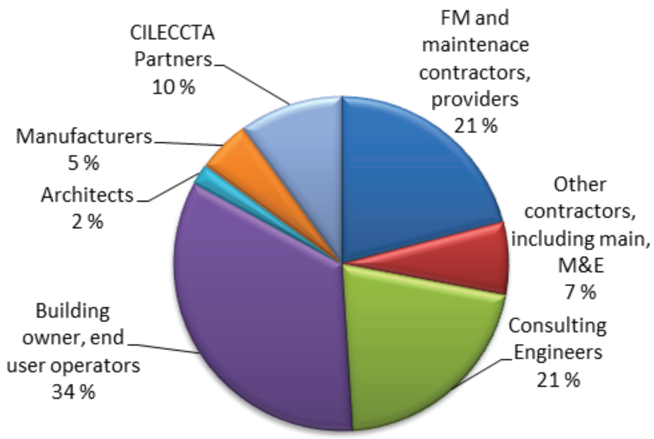


Figure 10.1
Attending delegates

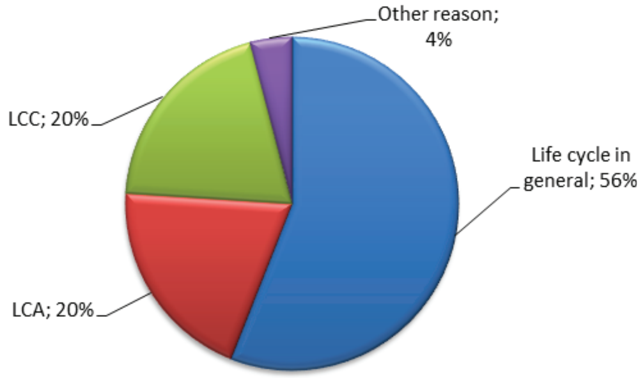


Figure 10.2
Question: What were your objectives for attending this event?

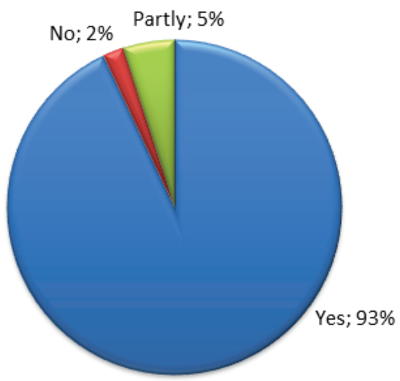


Figure 10.3
Question: Where your objectives met?

The presentations from the seminar in London were captured on film. Just click on figure 10.4 and you will be guided to these five presentations:

- Life Cycle Costing: David Churcher, BSRIA
- Life Cycle Assessment: Hannes Krieg, University of Stuttgart
- Evaluating Life Cycle Options: William Fawcett, Cambridge Architectural Research
- Road Construction – Utilizing Traffic: Ignacio Robles, APIAXXI
- Low Carbon Heating Systems: Hannes Krieg, University of Stuttgart

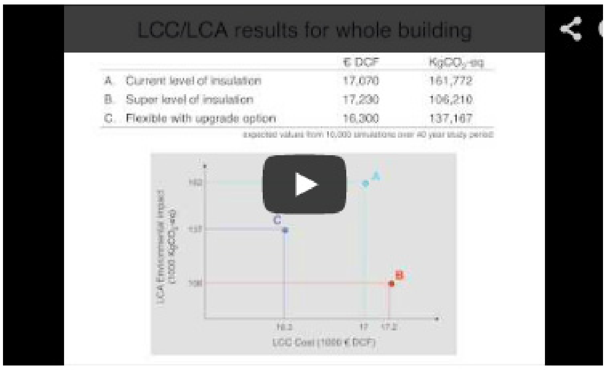


Figure 10.4
The presentations from the seminar were captured on film

Figure 10.5
Seminar in London, England

Figure 10.6
Seminar in Poznan, Poland

Figure 10.7
CILECCTA event in Hannover, Germany

Figure 10.8
Elfack trade fair in Gothenburg, Sweden

Figure 10.9
CILECCTA event in Madrid, Spain

Papers and scientific articles

Many papers and scientific articles have been produced during the four years of **CILECCTA**. Selected examples are listed below.

2013

Title	Integrated environmental and economic assessment in the construction sector
Authors	Hannes Krieg, Stefan Albrecht, J. Gantner, William Fawcett
Where	SIM conference, June 26-29, Lisbon

Title	Time Preference and Risk Aversion Among Development and Construction Professionals and Managers
Authors	Ian Ellingham, William Fawcett, and Peter Wallström
Where	The International Association of People-Environment Studies (IAPS), 25-28 June, A Coruna, Spain

Title	Whole-life carbon analysis: integrating the analysis with design
Author	William Fawcett
Where	Ecobuild 2013, London, 7 March

2012

Title	Flexible strategies for long-term sustainability under uncertainty
Authors	William Fawcett, Martin Hughes, Hannes Krieg, Stefan Albrecht & Anders Vennström
Where	Building Research & Information, Volume 40, Issue 5, Routledge

Title	Quantifying the benefits of open building
Authors	William Fawcett and Martin Hughes
Where	International Conference on Open Building 18th, 19–21 Nov, Beijing

Title	Embodied carbon: an overview of measurement techniques and current material labelling
Author	William Fawcett
Where	Ecobuild 2012, London, 21 March 2012

2011

Title	Investing in flexibility: The Lifecycle options synthesis
Authors	William Fawcett
Where	Projection, Volume 10, MIT
Link	http://web.mit.edu/dusp/projections/projections10web/Projections10_fawcett.pdf

Title Sustainiable construction projects: case study of flexible strategies for long-term sustainability under uncertainty
Authors William Fawcett, Hannes Krieg, Martin Hughes, Stefan Albrecht & Anders Vennström
Where SB11 conference, November, Helsinki

Title Using Life Cycle thinking approaches for energy price sensitivity analysis along the value chain
Authors Stefan Albrecht, Hannes Krieg, Thilo Kupfer, Jan Paul Lindner
Where SIM2011 – Sustainable Intelligent Manufacturing
ISBN : 978-989-8481-03-0

2010

Title Determination and costing of sustainiable construction projects: option based decision support
Authors Anders Vennström, Thomas Olofsson, William Fawcett, Attila Dikbas
Where CIB W78 – Applications of IT in the AEC Industry&
Accelerating BIM Research, 27th International Conference 16-19 November, Cario

Title CILECCTA Herramientas de análisis de ciclo de vida, costes y opciones
Authors Juan José González Méndez, Ingacio Robles Urquijo
Where SB10mad Sustainable construction. Revitalization and rehabilitation of neighborhoods, 28th of April, Madrid
Link http://www.sb10mad.com/ponencias/archivos/c/C059.pdf

11 Input to Standards

The CILECCTA project was initiated to try to combine methodologies related to Life Cycle Costing and Life Cycle Assessment. The aim was to develop software which will make it possible to take both costs and environmental impact into consideration before making important decisions. In practice, this means going beyond «state of the art» and established practices.

The results developed by **CILECCTA** are innovative. Most standards in the building industry are not based on innovative thinking. They are the result of existing practices over time. Output from **CILECCTA** would naturally constitute input to guidance documents, training-courses or specifications that could make the industry adopt the new approaches and perhaps work differently than they do today.

Over the last 10–15 years a lot of specifications and standards have been drafted and developed in order to increase and improve the flow of building information in building projects. Organizations like buildingSMART International have made it possible to organize projects providing standardization bodies with new innovative specifications and standards. Results from **CILECCTA** may also constitute input to buildingSMART or relevant standardization committees.

Recommendations for existing and new standards

The **CILECCTA** project has provided relevant standardization committees with technical report containing recommendations to existing and new standards. Experiences concerning data-mapping and development of mapping tools are topics discussed, together with recommendations related to the following topics:

- **New terms and methods**
  - LCC+A: describing both cost and environmental aspects of a project
  - Flexible alternatives: alternatives modelled with real option techniques
  - Probabilistic instead of deterministic thinking

- **Case-use examples**

  The 3 demo projects in **CILECCTA** could all constitute informative annexes to standards showing how it is possible to use probabilistic techniques when analyzing costs and environmental impacts on projects. This is not something existing standards promote today.

- **Uncertainty**

  Existing standards are what one could call a result of how the building industry thinks Life Cycle Costing should be dealt with. Most analyses are done based on historical data and probabilistic analyses are seldom used. Existing standards barely mention this as a possibility.

  A real improvement to existing standards would be to implement, as an alternative to traditional deterministic analyses, simple workflows and techniques describing how to perform various probabilistic analyses. Examples in the informative section of the standard could show the benefits of carrying out analyses in this way.

Figure 11.1
Construction work at Bjørvika in Oslo, Norway. Photo: Mette Langeid, SINTEF Academic Press

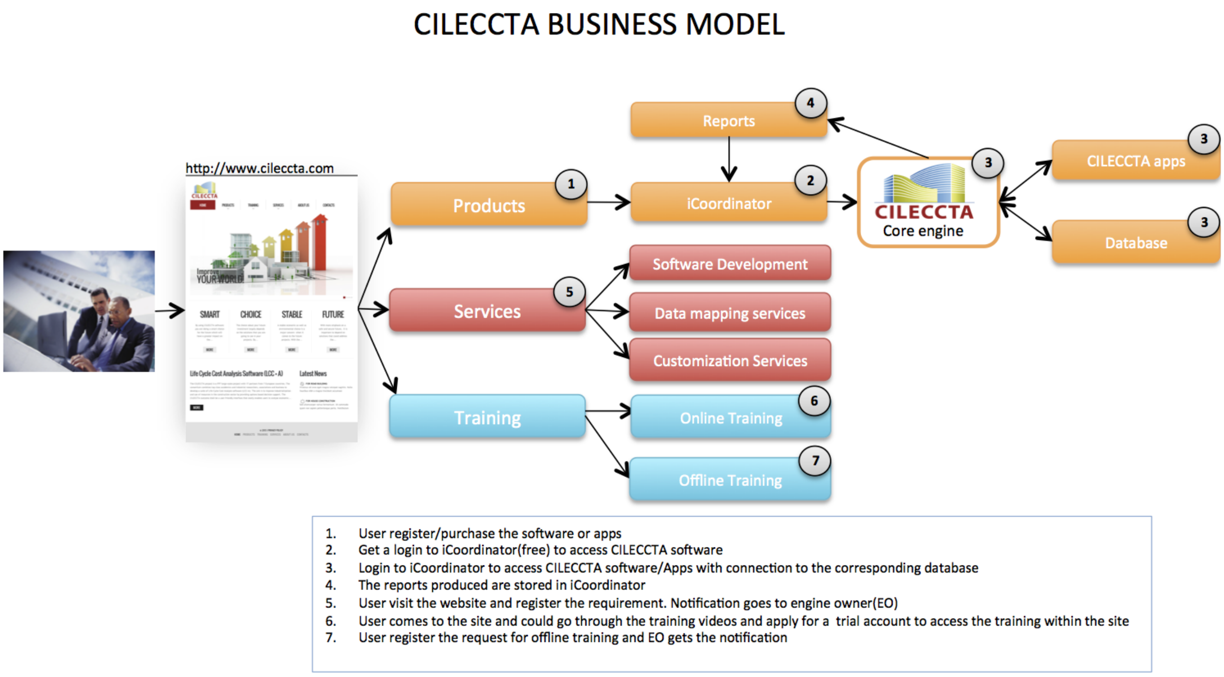
12 CILECCTA Business Plan

The purpose of CILECCTA is to offer decision support when modeling various construction related scenarios – start up through operation, maintenance, change of use and demolition phases of a construction project.

The core of the **CILECCTA** software is the calculation engine that can be accessed through a web enabled interface. The software will connect to external data bases of financial and environmental data. Alternatively a user has the option of uploading proprietary data.

The **CILECCTA** team is offering customers the option of developing unique template for the running of the software. Theses application templates will be developed at a price to be agreed with a user. They will have the option of making these applications available through a library, for at a fee which will generate an income stream for the application owner.

It is also possible to consider customization if a customer would like to directly connect the **CILECCTA** core engine or applications with their existing system.



Figur 12.1
Illustration of the **CILECCTA** business model

Regional exploitation strategies

In addition to this main overall strategy the **CILECCTA** partners have explored other possibilities on a more regional or local level. Several of the partners have monitored other ongoing projects, possible future projects or business opportunities throughout the **CILECCTA** project.

The new CILECCTA webpage

The consortium will be launching a new commercial page. Please go to **www.cileccta.com** for more information on the **CILECCTA** software.

This is the most important contact point for attracting new partners who might be interested in **CILECCTA** as «Software as a Service», or additional services like applications development services, customization services, training and support.

You can also find us on
Facebook: **https://www.facebook.com/cileccta**
Twitter: **https://twitter.com/cileccta**
Google + :
https://plus.google.com/110518289328581828009
Pinterest: **http://pinterest.com/cileccta/**
Slideshare: **http://www.slideshare.net/cileccta**

The possibilities are numerous to use **CILECCTA** knowledge as a basis for further developments in the years to come.

Partners

Holte as (Norway)
www.holte.no

Cambridge Architectural Research Ltd (UK)
www.carltd.com

BSRIA (UK)
www.bsria.co.uk

Luleå University of Technology (Sweden)
www.ltu.se

Fraunhofer Institute for Building Physics (IBP) (Germany)
www.ibp.fraunhofer.de

University of Stuttgart (Germany)
www.lbp.uni-stuttgart.de

TechnoBee (Turkey)
www.technobee.com.tr

Designtech (Sweden)
www.designtech.se

PE INTERNATIONAL AG (Germany)
www.pe-international.com

Norsk Teknologi (Norway)
www.norskteknologi.no

SINTEF Building and Infrastructure (Norway)
www.sintef.no

TUI AG (Germany)
www.tui-group.com

ACCIONA Infraestructuras S.A. (Spain)
www.acciona.com

APIA XXI S.A. (Spain)
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