Integration of LCA and LCC for decision making in sustainable building industry

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Abstract

A great deal have been written about the climate change and global warming in recent years, but most of literatures focus on the nature of problem rather than feasible strategies and appropriate education to minimize climate problem. We all know in general that we should use renewable energy and environmental friendly products in our daily lives, for instance, purchase more fuel-efficiency vehicles, improve energy efficiency in industry, and choose green power from our local utility. However, it is not enough for us to accomplish the very steep green house gas reduction just from the technological aspect. Worldwide, fossil fuel use in the last 50 years has gone up nearly five times, form 1.715 billion tons to 8 billion tons today. The bulk of the world's energy consumption is within cities, and much of the rest is used for producing and transporting goods and people. Hence, if we want to improve the climate situation, we should not only rely on the technological or scientific way to solve the problem, like stabilize the carbon dioxide emissions, decarbonization of fuels, and natural sinks, but we should also concern more on developing strategies for sustainable use of energy, particularly in the context of global warming.

The understanding developed of the way ecosystems function has a major contribution to make to dealing with problems of urban sustainability. So, the analysis to metabolism of cities is necessary. The flow of natural resources into cities and waste out of them represents big challenge to urban sustainability. Recently, scientists and engineers raise idea about 3R strategy, which means the resource loop should be closed by recycling, reusing and re-producing and otherwise diverting materials from usual destination in landfills and incinerators. Implement this strategy successfully needs residents have awareness of categorizing waste and buying products made from recycled materials. In additional, the structure of cities should be compacted. It is regarded as an efficient way to decline vehicles, which definitely leads to obvious reduction of GHG emissions.

If we take urban as a system, each building can be seen as a small component of it. However, we can't ignore their environmental impacts. According to statistic data, buildings are accountable for approximately 40% of society's total environmental impact and 60% of total energy used. Hence, there has been a gradually increasing interest for the impact that human activities have on the environment in construction industry. Although the green ideas of construction have been introduced for several years, different participants have chosen to focus on different aspects and thus depending on the context and the actors, green construction cannot be realized easily. It is necessary to joint endeavor bringing all stakeholders involved in developing solutions to climate change and research disciplines together in order to building a bridge between different views and positions and find a feasible solution.

Methodology

During my master study, through learning relevant knowledge of construction engineering and environmental science, I get an idea that is to find a solution which can provide optimal decision in building sector based on a combination of results of integration of LCA and LCC research. LCA is used for selecting construction material based on its life cycle—from cradle to grave. Environmental impact and energy consumption from whole process are taken into consideration, even as a criterion to make sure that construction can achieve the requirement of sustainability. LCC is a sort of economic method which can help controlling cost of whole process. Compared to traditional way of building estimate, LCC can take environment and energy aspect into account, which will result in big effect to future capital variable. My entire research is divided into three main steps: firstly, analyze characteristic of LCA and LCC respectively then compare and conclude similarities and differences between them; secondly, judge whether it is possible to integrate them; if it is feasible, finally, develop this integrated tool that offers client and other participators in building sector a better decision. The result of my research has shown two ways of integration. On one hand, it is possible to establish an impact and cost database for the dominant range of building and services components and materials, which facilitate building designers to choose right materials in the beginning; On the other hand, we will use VE/LCC and LCA for the decision making process to select the most proper alternative and integrated decision making tool is V (Value) = F (Function)/(C (Cost)*E (Environmental assessment)). While, through survey of building sector, life cycle technology and management can just be used in pre-design and design phase, which means it only offers suggestion to designer, technical engineers and clients. To achieve a completely sustainability, we still need adopt environmental management in construction phase and spread sustainable idea among tenants. Hence, how to set up an acceptable system combining life cycle technology and environmental management is an important issue in developing sustainable building industry, which needs further research and more communication with stakeholders.

The aim for my thesis is to help all the participants understand the importance of environmental impact and energy consumption during construction process. Moreover, construction and design manager can educate their staffs to concern to their daily behaviors in order to create a green working environment. In additional, sustainable construction is not just a idea related to civil engineering field, but also will drive policy makers to set an appropriate regulations to standardize the whole building sector. For example, design and construction of infrastructure should depend on the local environmental condition and make use of that, rather than change it by advanced technology; construction materials should get Green certification; energy using in construction should be improved its efficiency; waste and emissions from site should be controlled in minimum content; construction materials should be reused or recycled after building disposal. In a word, enhance integration of technology and management in building sector will profoundly reduce the environmental impact of urban energy system and change climate in a better way.

Chapter 1 Introduction

1.1 Background

Sustainable development is required for the continuous survival of our global society. It was defined as 'development that meets the need of the present without compromising the ability of future generations to meet their own needs'. During the last two or three decades there has been a gradually increasing interest for the environment and the impact that human activity and actions have on the environment.

The building sector has shown considerable interest in environmental issues during the 1990s. The building sector is one of the key sectors in the pursuit of a sustainable society, according to statistic data, buildings are accountable for approximately 40% of society's total environmental impact, for instance, half of all resource use, up to 40% of energy consumption, 30% of raw materials consumption, 25% of timber harvest, 35% of the world's CO_2 emissions, 16% of fresh water withdrawal and 50% of ozone-depletion. (Jacob 2001) Another way of saying is that building sector is involved in the transformation of large quantities of natural resources into designed physical services.

Interference with the natural environment occurs during all phase of the building process—planning and construction, building use and maintenance and demolition. Although the green ideas of construction have been introduced, different groups have chosen to focus on different aspects and thus depending on the context and the actors, green construction cannot be realized easily. Design and construction, facility management and the use of LCA in the building material sector have been reviewed. It appears as if different aspects of the environmental performance of the building over the life cycle are regarded depending on where the focus is set. The building material industry seems concerned with the production and application of the materials produced. The construction industry aims at collecting information to support decisions and educating the staff (Mathias 2001).

Many organizations are now expected to have an environmental management system and to consider environmental aspects---green idea in the whole construction process. In order to understand how environmental consideration and other related concepts become defined and translated into physical artifacts in contemporary green building projects, it is necessary to have a grasp of earlier and current stream of ideas (Baumann 1998). The decision making performed in the building sector is suggested to be influenced by the utilized production technology and developed structure of the company organization. The environmental decision making occurring is suggested to be similar to the general way of deciding proceeding in the company.

1.2 Practical Problems

In this paper, author mainly makes analysis for two kinds of life cycle technologies which are commonly used in environmental management and attempt to integrate them together to offer some useful suggestions to decision makers. In fact, assessment of environmental impacts in the building sector is a quite complex and difficult task. When it comes to assessments of how building products influences the environment, an improvement in one area of the product life cycle can lead to an unwanted impact in another area of product life cycle. In additional, building products have a relative long service life and many actors involved during the product life cycle which makes it difficult to predicting what actually happens during the life cycle, especially in the usage phase (Thomas 1999). It is therefore desirable with a further development of the LCA methodology to more systematically take into account the influence of the usage phase in the building product choice. For decision makers, it is of outmost importance to have a comprehensive view over the whole sphere, which is influenced by an assessment, has shown to be a powerful tool to compare several products concerning their environmental performance.

1.3 Concerns and purpose

Making optimal decision in building sector has been based on advancing improvements through a combination of results of integration of LCA and LCC research. On one hand, it can be seen as development of process-oriented research which makes use of tools and techniques through building life cycle; On the other hand, it also focus on product-oriented research which can help decision maker choose better choice and provide customers and society with sustainable building they want. Combining with the practical problems of utilizing life cycle technologies in building sector, the research concerns of this thesis are as followings:

1. Understand the definition, process and function of LCA and LCC, as well as how these two life cycle tools implemented in building sector;

2. Compare with LCA and LCC, and conclude both similarities and differences between those. Then, according to differences between LCA and LCC, illustrate whether it is possible to integrate them together;

3. If it is possible, develop a integrated tool based on life cycle assessment and life cycle cost that strives for better cooperation between many phases in building sector like, design, construction and material supply, and with recognizes the customer's entitlement to have comfortable living environment, supported by transparent cost structure;

According to concerns of research in this thesis, the following goals will be achieved:

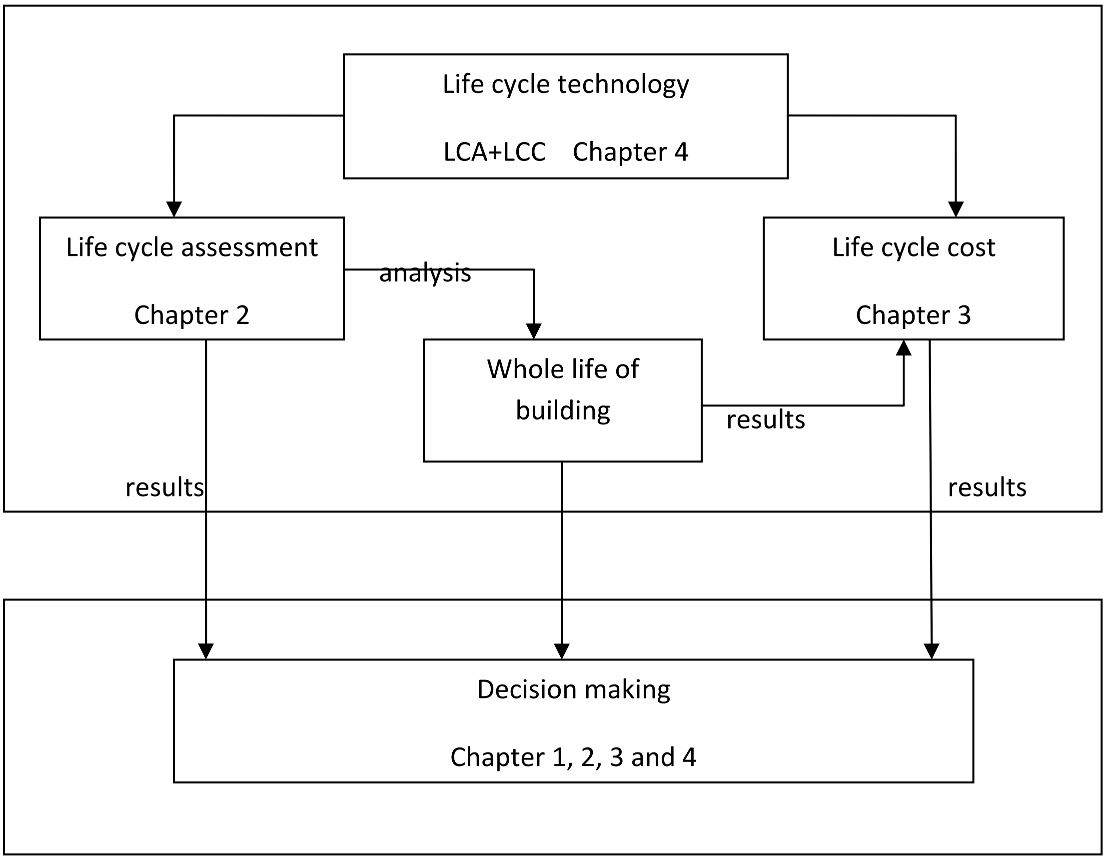
1. Sustainable suggestions are offered to decision makers and cause both benefits to building sector and society.

2. Increasing the benefits and value to decision maker at all points in building sector through the provision of new version based on processes that are environmental

friendly and cost-effective and which can deliver consistently high quality in long term.

3. Affordable and environmental friendly housing that meet the needs of customers and sustainable development;

1.4 Structure of thesis



Chapter 2 Life cycle assessment

2.1 Definition and methodology of LCA

LCA means product is followed from its “cradle” where raw materials are extracted from natural resources through production and use to its “grave”, the disposal (Baumann 2004). Figure 1 shows the life cycle model, in which boxes indicate physical processes and arrows flows of energy and matter. The aim of LCA is to highlight those particular areas in the environmental profile of a product where producers or vendors should focus their response in order to minimize their environmental impact.

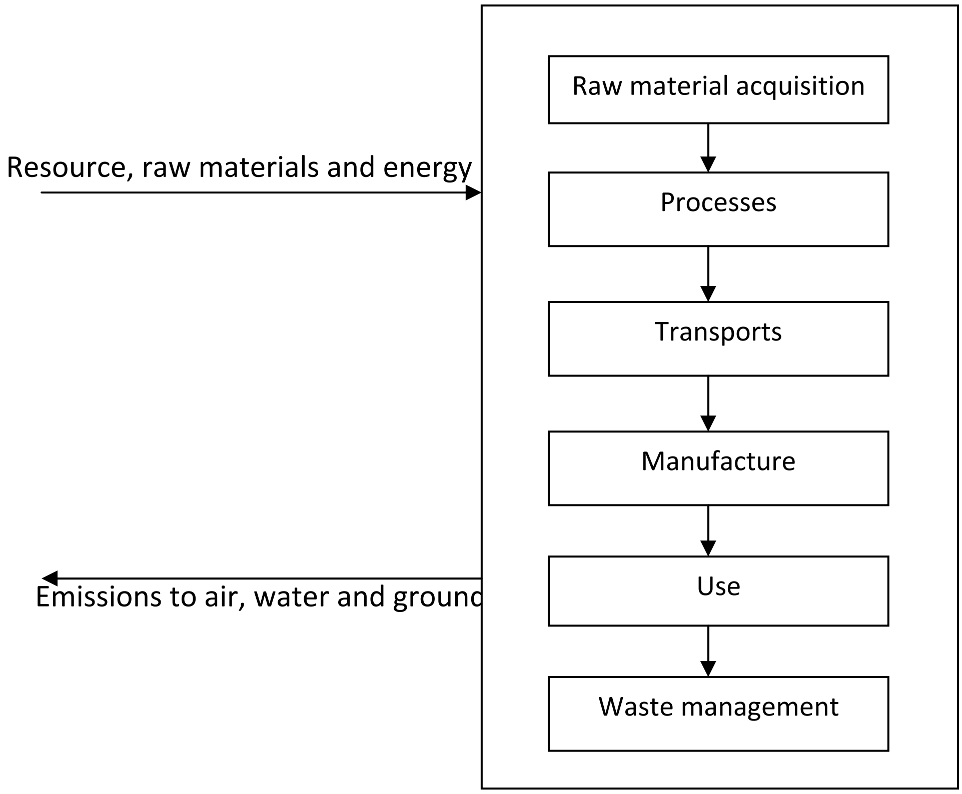


Figure 1 Life cycle model (Richard 1996)

The LCA methodology can be divided into five successive phases; goal and scope definition, inventory analysis, impact assessment, result interpretation and application, which are presented in Figure 2.

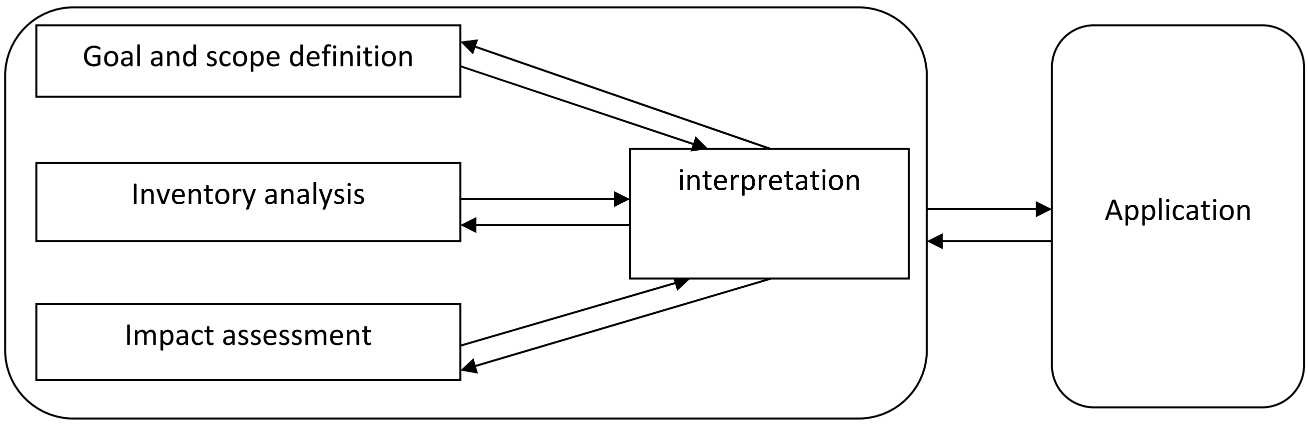


Figure 2 Methodology of LCA (Baumann 2004)

1. Goal and scope definition---it states the intended application of the study, the reason for carrying out and to whom the results are intended to be communicated.

2. Inventory analysis--- Inventory analysis means to build a systems model cording to the requirements of the goal and scope definition. This phase involves gathering quantifiable data relating to the material and energy inputs into a product across its whole life cycle and any associate emissions, discharges and wastes. This also should relate to all stages of the product life from “cradle to grave”. The process of inventory analysis shown in Figure 3.

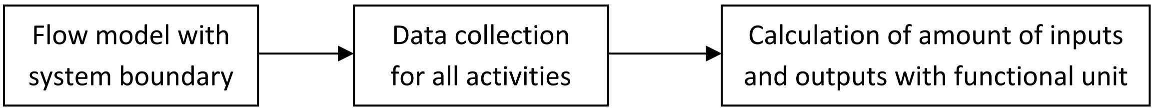


Figure 3 Process of inventory analysis

3. Impact assessment--- it aims to describe the impacts of the environmental loads quantified in the inventory analysis. It turns the inventory result into more environmentally relevant information. It focuses on the environmental problem rather than emission or resources use. Human health, resource and ecology should be taken into consideration (Richard 1996). In the impact assessment phase, it is often broken down into four distinct phases, which is presented in Figure 4:

- Selection of impact categories--- the choice of impact categories to use for the visualization of the impact on the environment, like global warming potential, acidification/ eutrophication potential and ozone depletion potential.

- Classification--- grouping the data in an inventory table into a number of impact categories;

- Characterization--- this involves the quantification, aggregation and analysis of impact data within the agreed impact categories;

- Valuation--- in this phase, the indicator result can be further elaborated by:

  Normalization, calculating the magnitude for each indicator result relative to reference level;

  Grouping, sorting or ranking of impact categories;

  Weighting, usually aggregating the indicator results based on some value choice based numerical hierarchy.

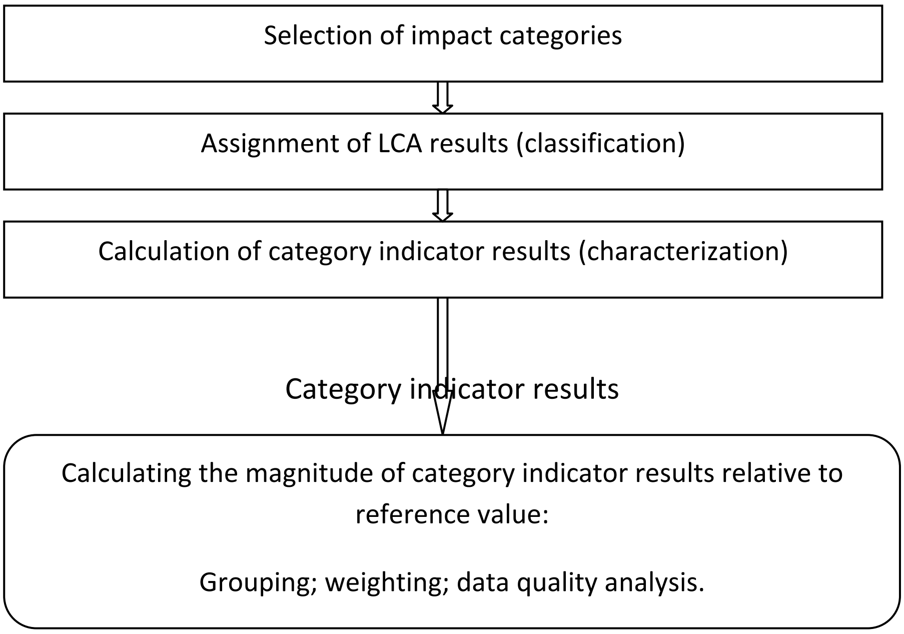


Figure 4 Model of life cycle assessment (Jacob 2001)

4. Interpretation--- the content of the result interpretation phase of an LCA is dependent on the goal of study; the life cycle interpretation phase of LCA consists of three elements: Identification of significant issues, evaluation and conclusion.

5. Application--- different application put different requirements on the methodology. Figure 5 gives some examples:

Application	Requirement on methodology
Decision making, choice between alternative actions	Reflection of consequences of contemplated action
Market communication	'Fairness', possibility to compare
Product development and purchasing	Results presented with a high level of aggregation
Decisions on national level	Data representing national averages
Identification of improvement possibilities	Site specific data

Figure 5 Examples of how different applications have different needs for methodology

2.2 LCA in the building sector

With the increasing concern for the built environment amongst the public, governmental regulation and the aspiration towards a sustainable society has resulted in that the building sector has shown rising interest in methods or technologies for the environmental assessment of the activities of the sector as well as the valuation in the whole process. The

LCA methodology has developed rapidly during these years, which aims at assessing local and regional direct and indirect environmental effects of societal activities. The use of LCA in the building sector has initiated an adoption of LCA to special condition of the building sector and the efforts to utilize it have lead to several international methodologies. Examples are the development of a methodology for environmental profiles of construction materials, components and buildings. Another incentive for development of LCA for the building sector is the fact the building sector is a main contributor to the use of energy and various materials in society.

When an LCA is carried out for a building product, the whole life cycle has to be considered. In Figure 6, an illustration is given over the life cycle for an unspecified building product. The life cycle is divided into 6 stages, which are placed in 4 different system levels (Jacbo 2001). The system level, regards the complexity of the structure in which the product participates. The actors influencing the impacts from the product vary during the life cycle stages.

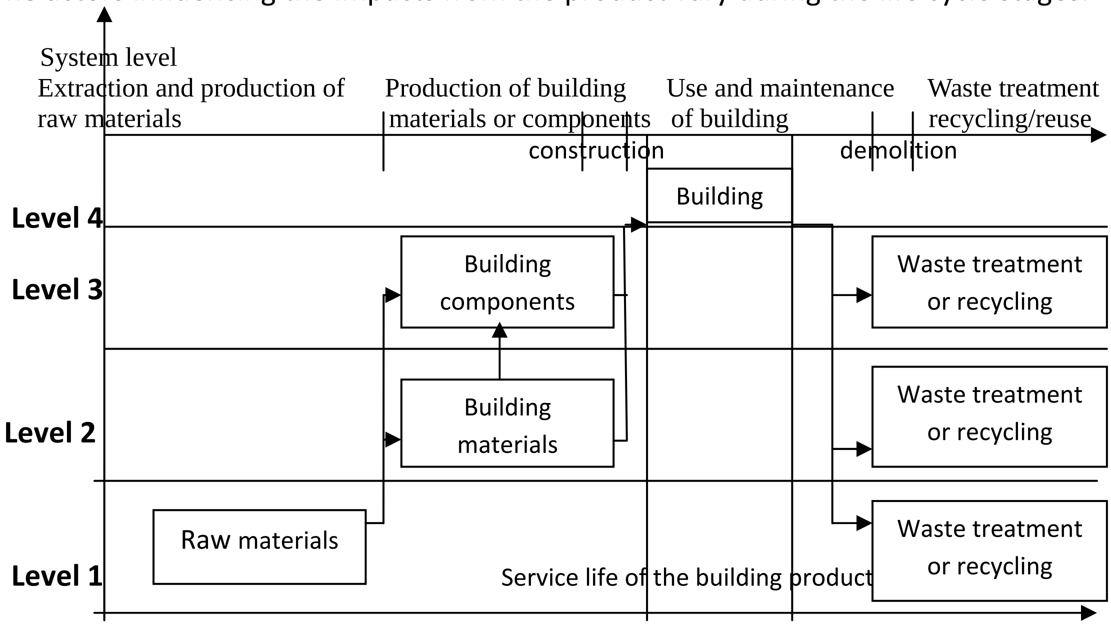


Figure 6 System levels in a building products life cycle (Jacbo 2001)

- Extraction of raw materials (system level 1): The life cycle of building product normally starts with extraction of raw materials followed by a preparation into building material. In most case the product is send forward to a producer of building materials or components, but in some case, the raw materials are used directly on the construction side.

- Production of building materials or components (system level 2 and 3): the raw materials from the first LCA stage are converted into building materials or more complex products like building components or parts.

- Construction: In the construction phase, the building products are applied to a whole building. This means that all the products are raised from system level 1, 2 or 3 up to 4. The product starts to serve as a function and can be related to a ‘function unit’.

- Use and maintenance of buildings (system level 4): in this phase, the building products are incorporated in a more complex system, a building. The environmental impacts from a functional unit in this stage depend on several factors other than the building product chosen for the actual function.
- Demolition: the demolition of a building indicates the end of a functional unit preserved by a building product.
- Waste treatment, disposal or recycling (system level 1-3): after the demolition, the outcome can be treated in different ways either as waste or reused/recycled in new application.

Seen from the illustration stated above, a product life cycle can be divided into three steps:

1) Before installation of the product in building;
2) During the usage phase in building;
3) After the product is removed from the building.

Hence, the system levels can be divided into two system levels:

1) Building level, a product provides a function (maintenance);
2) Product level (materials or wastes), before or after the usage phase for the product. The products don't have any function in these stages.

LCA can be adopted in the building sector on these two system levels, assessment of building materials and components and assessment of buildings and constructions. Assessment on the material and component level can be performed with two different aims, to generate input to whole building assessment or for materials comparison, improvement and development. Assessment on building and construction level can be conducted to be a sort of decision support, either in the design phase or construction phase, even in the process of establishing the environmental status of existing building in the context of procurement or alteration situations.

2.2.1 Assessment on product level

As the words stated above, the product level means the stage before or after the usage phase for the building. In building sector, design phase plays an important part in materials selection. Hence, how to do assessment on product level is illustrated through tools implemented in design stage.

The example building demonstrated that an integrated tool which utilizes a life cycle assessment of building materials enables design practitioners to make timely informed decision on reducing environmental burdens of building materials as well as facilitating selfassessment from an environmental point of view at the design stage rather than at the post-construction stage. A range of performance indicators are available in such tools, use of these performance indicators can lead the designer in choosing right materials which produce the lowest environmental impact of building as a whole (Newton 2004).

How to choose the right materials or do environmental design in this phase depends on appropriate environmental analysis. In LCA, according to different purposes, it has been divided into several kinds of analyze tools. Among those, contribution analysis is right for using in design phase, since it can help choosing materials. Contribution analysis is to identify which environmental loads contribute most to the total environmental impact (Baumann 2004). It is necessary to compare emissions and resource use on the characterization level or the weighting level for this type of analysis. The results from analysis can show which material or component of building causes the biggest pollution and make material alternative easily.

While, selection of sustainable building materials frequently requires difficult decisions since it is carried out considering a range of different environmental indicators. To deal with this difficulty effectively, some integrated evaluation tools in the market, which can support decision makers for building environmental performance have been developed. For instance, LCADesign is a significant contributor to stakeholder needs in that it provides (Seo 2003):

- Objective detailed and comparative assessment rather than subjective assessments;
- Real time detailed design appraisals and evaluation with tool automatic take-off CAD;
- Generation of meaningful comprehensive environmental analyze graphics, tables and reports;
- Comparing alternatives at all level of design analysis;
- Environmental assessment of building’s development from cradle (extraction of raw material) to start of construction.

The principal aim of LACDesign is to integrate building environmental assessment in a 3D CAD model to avoid any manual transcription of data from one step to another in evaluation processes. A schematic diagram of LCADesign is shown in Figure 7. This tool is divided into three main parts which comprise the following key steps:

Input: create a 3D CAD model of building and use the dimensional information in the model to estimate quantities of all materials in the building;

Analysis: estimate all material and gross building environmental burdens by factoring each material quantity with results of their emissions generation and resource depletion from a comprehensive database of a wide range of building materials, then calculate a series of environmental indicators based on life cycle assessment;

Output: provide facilities to undertake detailed analysis of alternative designs and benchmarking over time to facilitate designers' creation of buildings with least environmental impact considering their service delivery requirements.

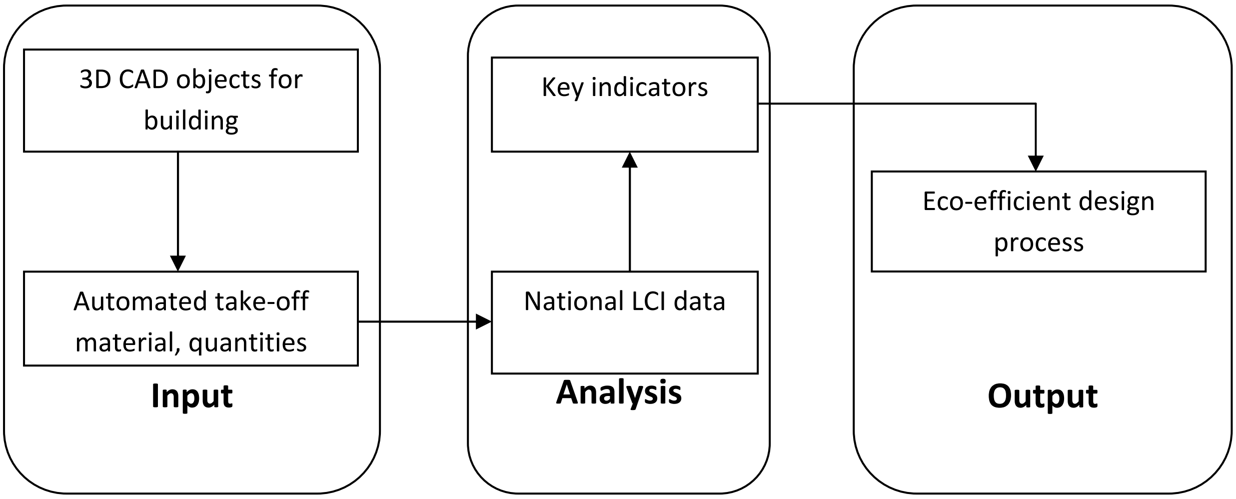


Figure 7 Essential steps for 3D CAD modeling and environmental evaluation tool (Seo 2003)

2.2.2 Assessment on building level

The building sector of today strives towards converting the design process of buildings and constructions from having a focus on the physical building towards using performance requirements as the basis for design, like the concern is to satisfy the need for certain services rather than providing a simple physical structure. This approach to the definition of building or construction has as a consequence that the assessed object is a dynamic system that provides different services over time (Mathias 2001). Hence, in the assessment of building sector, we should take the sequential life cycle thinking into consideration. This means we cannot just focus on the planning and construction phase but also the activities in maintenance, rebuilding, extension, operation and 'end of life scenarios', which contains demolition and material recycling. However, different life cycle phase should be treated separately in the life cycle inventory analysis. Depending on actual boundary conditions it is possible to choose different goals and scopes to analyze.

Based on the aspect of assessing buildings and constructions with a basis in both the physical building and service of building or construction provides, the following topics (see Figure 8) are needed to be considered during the whole process.

Decision supported by	Sub groups	Topics
Scope	Building life cycle phases and status	Definition of the building life cycle phase;
		Assessment of new building;

		Assessment of existing building
		Assessment of activity.
		Water consumption and use;
	Service coverage	Waste water system;
		Heating and cooling system;
		Ventilation system;
		Building maintenance;
Methodology	Inventory	Allocation for process;
		Materials recycling;
		Sunk cost;
		Scenario modelling;
		Time dependence;
		Procedure obtaining data
	Impact assessment	Indoor air quality;
		Time dependence;
		Spatial difference;
		Geographical difference;
		Impact categories;
		Conservation of resources;
		Valuation methods

Figure 8 Different topics used to characterize different LCA systems applicable for buildings (Mathias 2001)

During studying of assessment on product level and building level, we can draw a conclusion that is energy consumption and environmental impact in usage phase can be influenced by the choice between different building products. Through research of common building materials (Paulsen 2001), it is obvious that several product alternatives for the same application but with slightly different properties can cause a difference in the energy consumption.

2.3 LCA in decision making in building sector

Based on the analysis above, there are two system levels through life cycle of building. One is product level and the other is building level (see 2.2). Although environmental assessment can be adopted in both levels, the analyze objective is quite different. In building level, LCA is only used for evaluating the environmental impact from building but nothing to do with decision making in this phase. While in product level, the analyze objectives are materials or components. From the perspective of life cycle of building, design and construction stage and demolition stage belong to product level. However, decision making is only made in design and construction stage. Because this phase is related to the creation of something new, like selecting and comparing alternative solution, materials, work partners and contractors. The creating of entire building is long term decision but there are still some short decisions along this way, like materials or structure using.

According to the process of design and construction phase, which is shown in the Figure 9 below, the first step is to clarify the clients' needs. Hence, many building design professionals are now involved 'sustainable design' in response to expressed interest or requirements from their clients, regulations or their own intention to reduce human impacts on the environmental-local and global. Design performance appraisal requires consideration of environmental performance criteria and best practice performance benchmarks, communication of environmental principals for strategic decision making as well as interactivity with supporting framework.

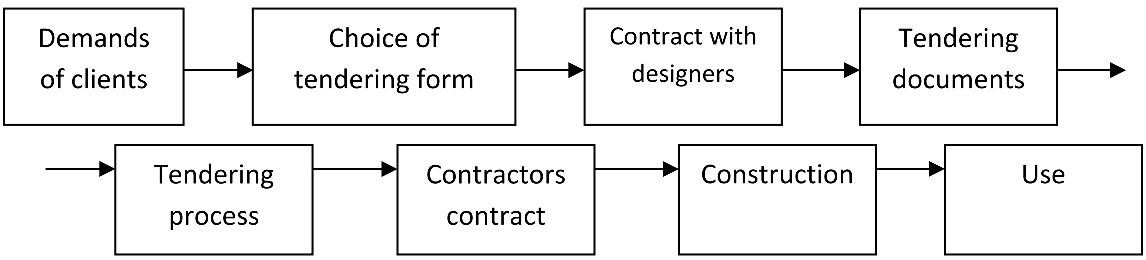


Figure 9 Design and Construction process

Besides decision making in design phase, it is also very vital to make appropriate decision by utilizing LCA approach in procurement from purchase and sale aspect respectively (see Figure 10).

Decision making actors	Strategic decisions	Construction & design	Purchase	Sales

Authority	Support for legislation; studies on infrastructures; Identification of research.	Public service company	Choice of product; Recommen-dation	Eco-labelling; Recommen-dation
Company	Selection of key production technology; Business concepts.	Choice of materials; Improvement of production	Choice of products/ suppliers	Marketing
Individual	Choosing a lifestyle	------	As consumers, using the eco-label	------
NGO	Lobbying	-------		-------

Figure 10 Suggested application of LCAs and results to decision making (Thomas 1999)

In additional, LCA can also offer suggestion to clients other than designers and engineers. There are two analysis can be used for initial planning of project.

First is dominance analysis, which is used to investigate what parts of the life cycle give rise to the greatest environmental impact (Baumann 2004). It is carried out by looking at the emissions of each activity in the life cycle. The analysis allows for identifying where improvements are most wanted or needed. Hence, it is important for example for a company wanting to know whether they are at risk of exposure in the environmental debate or if it is their own production processes or those of their suppliers that cause the greatest problems.

The other is decision maker analysis. The basis for this type of analysis is identification of the different participators and organizations that carry out the different activities in the technical system. From the result of this analysis, it is clear to judge the level of environmental influence from different parties. Therefore, decision makers can focus on choosing right partners in the greatest pollution part.

Chapter 3 Life cycle cost

3.1 Introduction of LCC

Life cycle cost (LCC) is a technique to estimate the total cost of ownership. In the building and construction industry, LCC is applied to quantifying costs of whole buildings, systems and building components and materials. The technique can assist decision-making for building investment projects (Nelson 2002).

Due to the environmental load imposed by the construction industry, there has been an urge to make the construction supply chain more sustainable. As what has been mentioned in the last chapter about LCA, which adopted as the technique to assess the environmental performance of a building throughout its life cycle, LCC can be also used as an economic tool to make construction sustainability.

The LCC analysis takes the investment costs and costs in operation of all phases into account. In General, LCC yields present value of current and future expenditures for procurement of building and operating and maintaining the building through its life. As the operational costs make up the main part of the total costs over the whole lifetime of a building, the comparison the LCC of different scenarios creates the necessary transparency for the decision-making process. Operating, maintenance and rehabilitation costs of new and existing facilities amount to more than 80% of total life cycle costs. The majority of decisions about these costs are predetermined at the design stage.

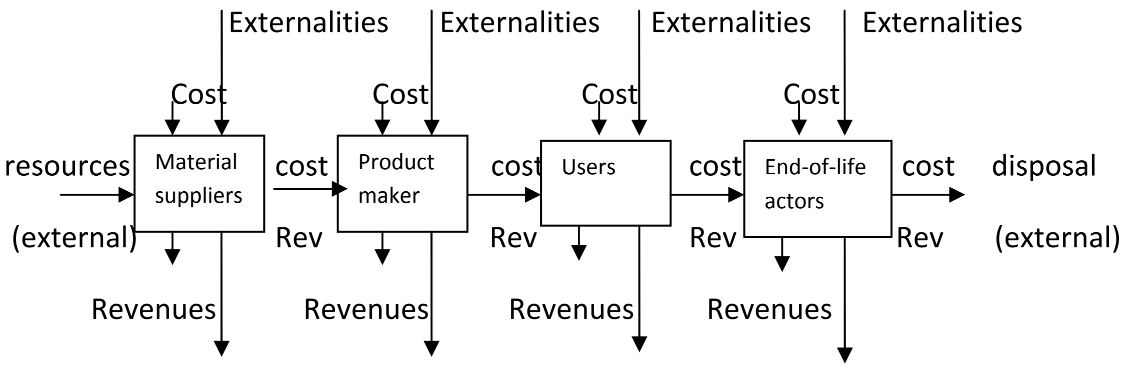


Figure 11 Conceptual framework of environmental LCC (David 2008)

- LCC methodology

LCC methodology is made up of three appraisal levels: strategic, system and detail. The strategic level is mainly for the initial appraisal stage in the pre-construction phase. In this stage, a lot of assumed inputs are used. The system and detail levels are mainly used in the design stage. In these levels, the assumptions made earlier are defined (Pulakka 1999). The life cycle stages considered include pre-construction, construction, operation, maintenance, replacement/ refurbishment and demolition.

3.2 LCC in building sector

Many different tools are available, but no standardized methodology is used. Basically all methods deal with costs, time and interest rate, giving results in Net present value or Net present costs, annual cost or annual equivalent value or payback. In order to have solid grounds for decision making, additional tools are needed for environmental assessments, energy calculations or check of fulfillment of performance requirements.

3.2.1 LCC in planning and design

Life cycle costing can be applied from the very early need analysis design stages to the detailed design of building components. Life cycle costing can roughly be divided in the following three design stages (see in the Figure 12).

- Analysis of functions, setting quality targets and level of energy consumption on the building level;
- Defining the building, its architecture, quality and functional targets on the system level;
- Building design on the component level.

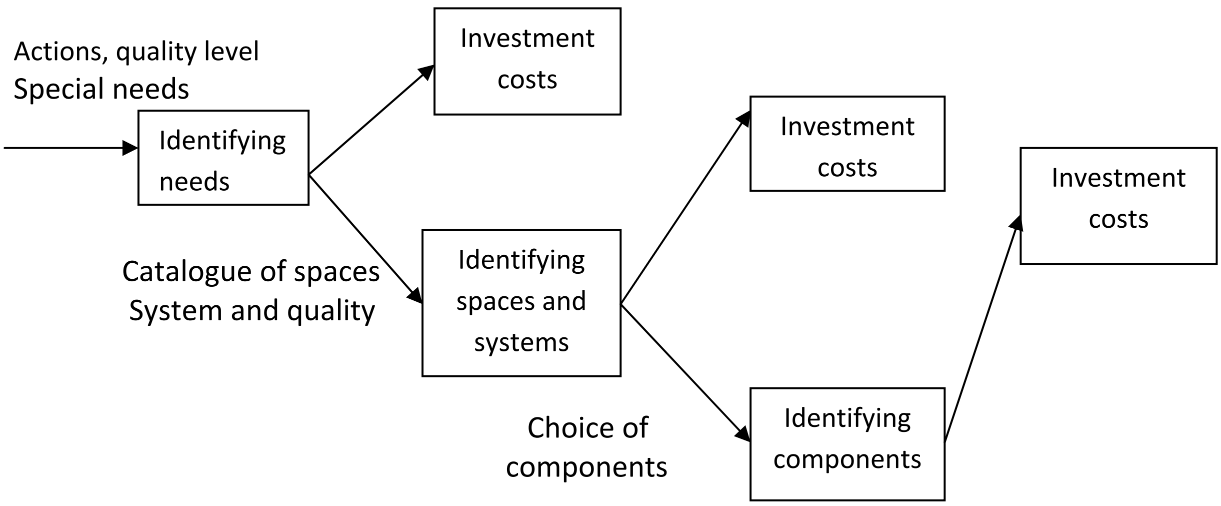


Figure 12 LCC on different stages of building design (Paulakka 1999)

LCC at design stage are depending on available input data. Costs based on experiences statistical information as key number is used as input. Key numbers can be found from statistical treatment of collected data. For instances, energy use or energy costs per sq. m. or cost used for management or maintenance for different building categories.

3.2.2 LCC in construction phase

LCC can be applied in a broad range of circumstance in construction, for example (Guri 2007):

- A single complete constructed facility such as a building or civil engineering structure;

- An individual component or assembly within a facility;
- A portfolio comprising a number of facilities.

It also can be used in the context of existing constructed assets, for instance as a means of assessing future operational budgets or evaluating refurbishment and renewal options. LCC in construction is required in order to (Guri 2007):

- Improve the competitiveness of the construction industry;
- Improve the industry's awareness of the influence of environmental goals on LCC;
- Improve the performance of the supply chain and the value offered to clients;
- Improve long-term cost optimization and forecast certainties;
- Improve the reliability of project information, predictive methods, risk assessment and innovation in decision making for procurement involving the whole supply chain;
- Generate comparable information without creating national barriers and also considering the most applicable international developments.

3.3 LCC calculation

LCC usually requires many cost inputs for calculating the costs for different phases of a project life cycle. The cost variables are usually categorized into groups (Davis 2006).

- ***Acquisition costs:*** site costs; temporary works; design/engineering costs; regulatory/planning costs; construction and earthworks; commissioning costs/fees; in-house administration
- ***Maintenance, operation and management costs:*** rates (operation cost); insurance (operation cost); energy costs (operation cost); water and sewage costs; facilities management (operation /management cost); cleaning (operation cost); security (operation cost); annual regulatory maintenance costs (maintenance cost); maintenance (e.g. repairs, replacement, refurbishment); revenue from ownership or use of the asset (e.g. service charges); demolition; cost of disposal; unanticipated costs resulting from legislation introduced subsequent to completion of the constructed asset (e.g. in relation to environmental, health and safety requirements). Particularly, the maintenance activities usually include inspection, monitoring, testing, condition surveys or inspections, maintenance planning, repairing, refurbishing and partial replacement. The following indirect impacts of maintenance works can also be taken into account: down time (loss of function for a period); the disruption of business activity; the non-availability of a building/ structure; the cost effects of aesthetic condition; the maintenance strategy; external costs/ saving data.

- ***Residual values/ disposal costs:*** The prices for similar assets current on sale in the market; book estimates of the resale value available from the industry or government sources; using accepted practice to assess asset values.

- ***Other cost variables:*** discount rate; inflation; taxes and subsidies; utility costs including energy costs. Environmental cost variables are currently not considered but there will attempts to incorporate LCA in LCC.

3.4 Mathematical and calculation models for LCC

3.4.1 Mathematical format

A mathematical model for LCC contains the mathematical equations that can be applied to quantifying the LCC of building. LCC in construction report, the LCC of a building is suggested to include acquisition cost, operation cost, maintenance cost, replacement costs and disposal costs. The models elaborated make use of NPV (Frank 2004).

$$NPV = IC_0 + CdC_0 + \sum_{t=1}^{n} (MC_t + AC_t) * \frac{1}{(1+i)^t} + DC_n * \frac{1}{(1+i)^n}$$

NPV = Net present value; IC= investment cost; C= construction cost; Cd= dependent cost; MC= maintenance cost; AC= administrative cost; DC= disposal cost; i= interest rate; t= discount rate

3.4.2 Deterministic methods of LCC

The process of deterministic method begins with customer needs and ultimately ends with the customer selecting a satisfied option. The needs of customers are translated to a set of requirements that the proposed, which also should be meet to certain criteria. Once the feasible options fixed, each much be analyzed in the context of life cycle cost, according to following steps (Davis 2006):

1. Generate cost profiles corresponding to each considered options. Each cost profile contains planning, design, construction, maintenance, use and disposal cost estimates calculated over the intended service life of the corresponding facility option.

2. Next, each cost profile is translated to an equivalence measure to support a common and credible basis of comparison among considered options. This involves application of time.

3. The results of the time value of money computations are used to rank the options according to life cycle cost, with the least life cycle cost ranking above all feasible options.

4. The results of LCC procedure are passed on to the infrastructure owner to support decision making.

The deterministic method underlying LCC offers a logical ordering of analytical activities and ranking feasible options to the whole life of building (see Figure12). But this deterministic approach provides little guidance to the engineer and designer attempting to adequately represent the complexity and uncertainty inherent to LCC investigations. Due to this shortcoming, a common extension to the basic method of LCC added the sensitivity analysis and risk analysis (Ehlen 1997; Arrien 2001).

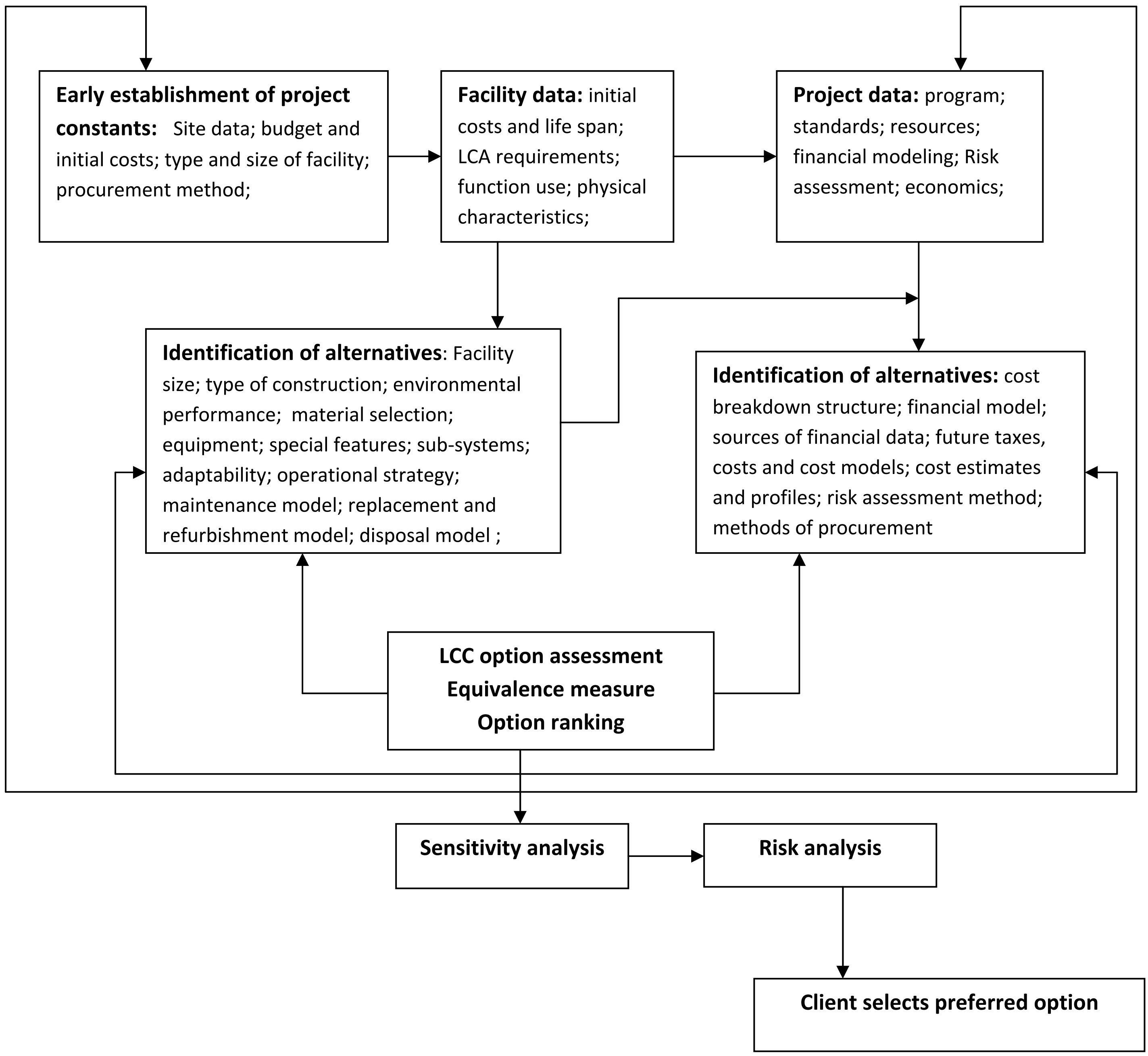


Figure 12 LCC implemental model (Davis Lungdon management consulting 2006)

3.5 LCC in decision making in building sector

The effective implementation of life cycle cost involves utilizing a thoughtful, comprehensive design along with quality material and construction practices with selected environmental considerations. However, environmental friendly materials need higher initial investment but offer low maintenance cost. The biggest difficulty for decision maker is when the project is meeting sustainability goals when analyzing different alternatives with environmental impacts. Level of detail in the LCC calculations and extend of the model can render the LCC process as overcomplicated which can defeat the ultimate purpose of it being the strategy incorporated into the frequent decision making process throughout the life of the facility. Hence, the ultimate goal for carrying out LCC calculations is to aid decision making in (Paulakka 1999):

- Assessing and controlling costs and identifying cost significant items;
- Producing selection of work and expenditure planning profiles.

3.5.1 Difficulties and limitations of decision making during life cycle of building

- Different cycles of ownership during the service life (Nelson A 2002)

Most of developers are only focus in the initial investment needed during the construction and does not take into account operation and maintenance costs of future users. This problem leads to the selection of alternatives with a higher life cycle cost that usually doesn't meet sustainability goals.

- Decision makers are focused on short term analysis

Construction projects have very long service lives. Designers and decision makers must be aware of these characteristic and select alternatives that are economically efficient over long periods of time. Now technology construction methods and materials require usually a higher initial investment.

- Cash flow problem to confront initial investment

In the beginning of the project, there is no sufficient cash flow to afford higher initial investments.

- Environmental impacts have contradictory effects

Environmental impacts generated by projects can cause multiple effects in different variables.

- Uncertainty while estimation future cash flows

3.5.2 Recommendations of decision making during life cycle of building

- Different cycles of ownership during the service life (Nelson A 2002)

One way to solve this problem is education. In respect to private projects, buyer and leaseholders must be educated about the importance of reviewing and estimation the future operation and maintenance costs of the properties they are considering to buy or lease. More awareness on the side of consumers will force developers to select the appropriate alternatives during the design and construction of the project. Consumers will be willing to pay a little more when buying or leasing if they realize that this investment will be compensated by future saving by lower operation and maintenance cost.

- Decision makers are focused on short term analysis

The life cycle cost should be calculated for different service lives and the service life needed to make indifferent the decision between two alternatives must be seen with special interest.

- Cash flow problem to confront initial investment

The use of loans to finance initial investment is a healthy policy, if the future savings during the operation phase of the project will allow the repayment of the loan.

- Environmental impacts have contradictory effects

Decision makers have to analyze carefully their main goals and carefully study environmental impacts of the project in all the relevant variables involved before making a decision.

- Uncertainty while estimation future cash flows

One way to deal with uncertainty is to study the possible scenarios using sensitivity analysis.

Chapter 4 Integration of LCA and LCC in decision making

Life cycle cost and life cycle assessment measure cost and environmental performance of building sector respectively. Though the assessments make analysis from two different dimensions (nature science and social science), both are important in decision making process for the building design and tender selection (See Figure 13). It is necessary to find a feasible way incorporate them together to accommodate both economic and environmental elements.

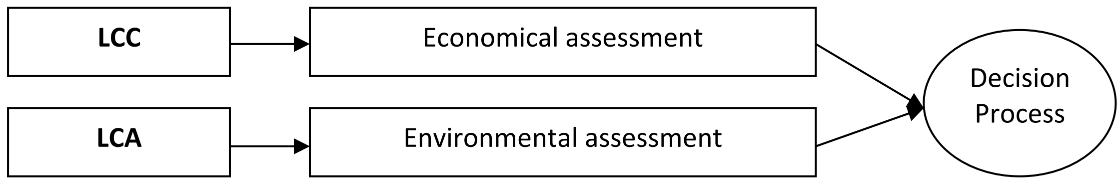


Figure 13 the use of LCC/LCA as tool for decision making process (Jaein 2006)

4.1 Similarities and differences between LCA and LCC

4.1.1 Similarities between LCA and LCC

LCA and LCC are both life cycle technique tools. Hence, the time horizons of their research objectives are same, from cradle to grave. In additional, both of these life cycle technologies need to do calculation through getting data from database. Finally, LCA focus on the environmental impact in the future and LCC concerns on long term benefits. (See Figure 14)

SIMILARITIES	LCA	LCC
Time horizon	Average life of products	Average life of products
Method	Quantity	Quantity
Focus	Future environmental impact	Future economic value

Figure 14 Similarities between LCA and LCC

4.1.2 Differences between LCA and LCC

Compare to similarities between LCA and LCC, the differences between are more obvious. Firstly, data on the complete set of upstream processes are necessary for the calculation of the total environmental impact in LCA, while in LCC it can be reflected in cost; the price can be sum up but the impact cannot. Moreover, the method of LCA is top-down, which means environmental impacts caused by chemical elements of materials are selected from different components of building; While the method to LCC is bottom-up, which means the total cost is sum up by cost of each step during the life cycle. (See Figure 15)

DIFFERENCES	LCA	LCC
Method	Top-down	Bottom-up
Focus	Environmental impacts	Economic value
Scope	Materials and products	Cost

Evaluated environmental impacts	Air, soil, water	Not considered
Cost calculation	Not considered	Totally system cost

Figure 15 Differences of LCA and LCC

4.2 Connection of LCA elements with costs in LCC

4.2.1 Functions of LCA and LCC

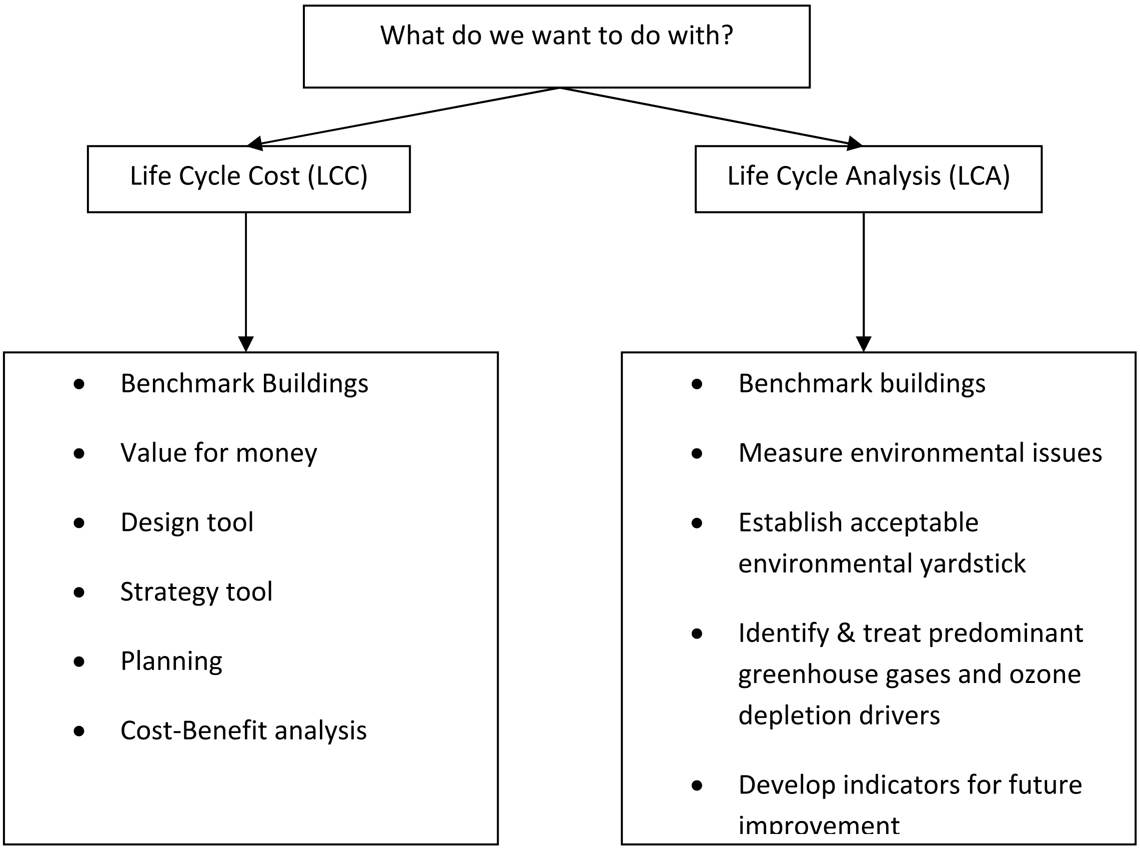


Figure 16 functions of LCC and LCA (ACE 2005)

4.2.2 Integration of LCA and LCC

One way to integrate them together is to convert LCA impacts to cost, which means all the LCC and LCA variables are taken into account in quantifying the cost.

LCC= Capital investment + NPV[(use and maintenance)+ (operating cost)+(repairs+ rehabilitation)+(salvage value)+(environmental LCA factors)+(occupational LCA factors)+(location LCA factors)] (Tupamaki 1998)

In this equation, environmental factors refer to all the environmental impacts from materials and activities in the whole life cycle of building. Occupational factors refer to health, productivity and the other factor shown about people's satisfaction. However, some hidden environmental costs cannot be calculated accurately.

Another way to combine those tools is advocated by (Boussabaine and Kirkham 2004). It incorporates eco-costs into LCA for making decisions on improving environmental performance and investment. The eco-cost forms part of the LCC to evaluate the design alternative (See Figure 17). The eco-cost including as followings (Arup 2002):

- Cost of controlling gas emissions;
- Cost of resources used and energy& water consumption in extraction and production of products;
- Cost of waste disposal;
- Cost of waste treatment, including solid waste and others;
- Cost of eco-taxes;
- Cost of pollution rehabilitation measures;
- Cost of environmental management.

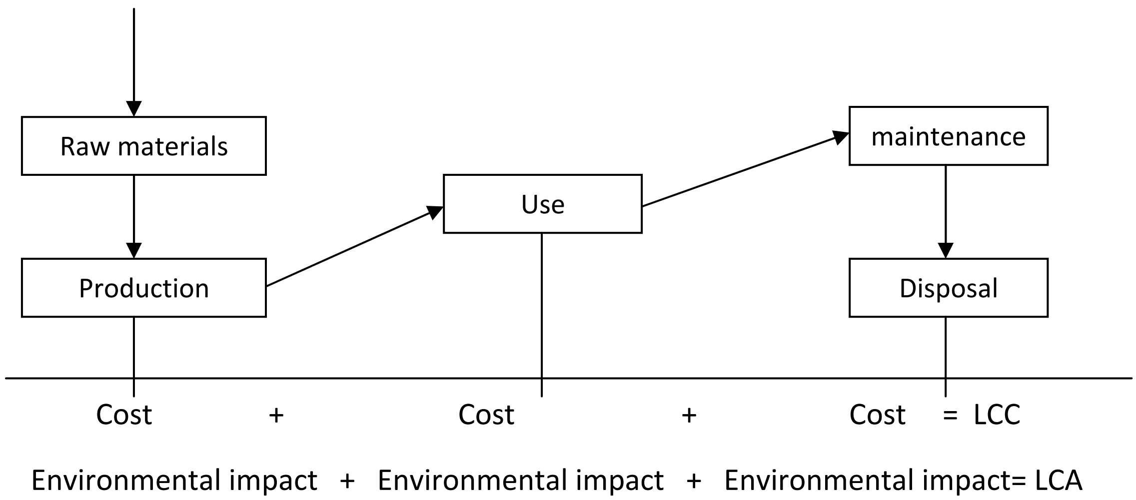


Figure 17 LCC and LCA in building sector (Frank 2004)

4.3 LCA/LCC tool in decision making

4.3.1 The need for LCA/LCC tool

So far, there is no appropriate tool specifically for assessing buildings. Although LCA and LCC have been used in sustainable construction respectively, each of them has limitation needed to be completed. It is necessary to establish an impact and cost database for the dominant range of building and services components and materials. The tool and the database will be made publicly available as an enabling means for promoting sustainable building development (Arup 2002).

4.3.2 Key features of LCA/LCC tool

The LCA/LCC tool developed in the project is a computer program that can facilitate building designers to input the required data to model the building being designed; perform calculations of the environmental impacts and life cycle cost of the building; and to compare the impacts and costs of alternative designs. The outputs can calculated results for different stages in the life cycle of a building, including up to the as-built stage, the operating stage and the end-of-life stage. Separate results can also be retrieved for different parts of a building, such as the environmental impacts of the foundation, the building fabric and the services (Arup 2002). Facilities are provided to allow the user to compare results down to individual elements level.

4.3.3 How LCA/LCC tool implemented in decision making process

The integrated decision making tool includes both LCC and LCA so decision makers of a construction project could use for selecting the most suitable alternative. The integrated decision making tool is V(Value)=F(Function)/(C(Cost)*E(Environmental assessment)) *(*Jaein 2006). We use value engineering and LCC as economic tools and LCA as environmental assessment tool.

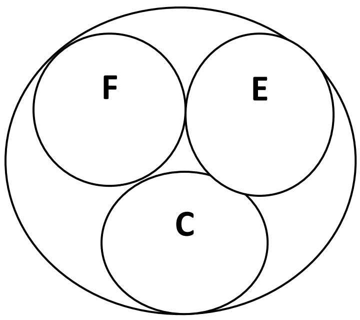


Figure 18 Relation between function, cost and environment

As seen in the Figure 18, we will use VE/LCC and LCA for the decision making process to select the most proper alternative. The integrated decision process is shown in the Figure 19. This process consists of six stages.

STAGE	CONTENTS
Stage 1	Develop alternatives
Stage 2	Analysis function that represent by F
Stage 3	Calculate LCC that represent by C
Stage 4	Calculate environmental performance as E
Stage 5	Value analysis, V=F/(C*E)
Stage 6	Final selection

Figure 19 Decision making process (Jaein 2006)

Firstly, VE and LCC method will be used for economical aspect of the item and then LCA is applied to environmental aspect. Decision maker should consider two aspects simultaneously and same weight to choose the best alternative. The steps are summarized as followings:

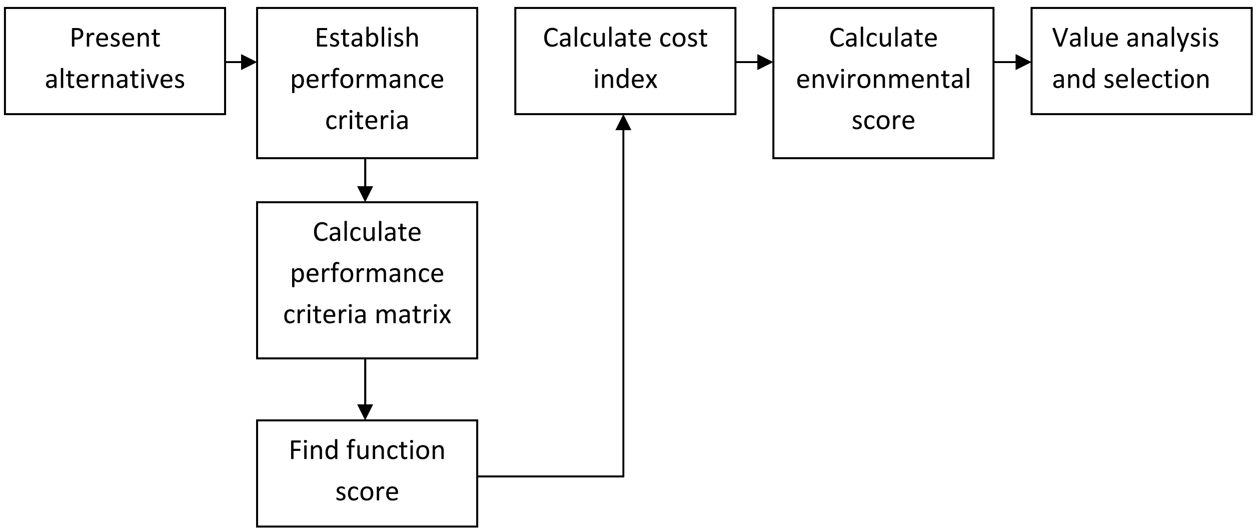


Figure 20 Process of decision making

An environmental performance of a product is determined in design stage, which has been referred before. With this concept, we organized a project performance body that conducts both economical and environmental study with the design and consulting company. Hence, there are two sections join in decision making process. One is design company which plays an important role in selecting the materials and designing structure. They design and make alternatives and provide raw data to consulting company. The other is consulting company, which includes environment consulting company and economic consulting company, and it charges evaluation and feedback.

4.4 The data structure of combination of LCA and LCC

This stage is in LCA commonly subdivided in three phases: production phase, user phase and the demolition and waste handling phase. Because the mainly cost is spend in production phase, the structure primarily handles data in the same phase of the inventory.

When contemplating on how to achieve a suitable data structure for a large LCA of a product system, it is important to recognize that there are at least two conceptual models that have to cooperate. First the one of the production system and second the similar of the analysis tool, the formalized and interpreted model of how global environmental impact occurs. The building production system is a hierarchical system where materials are assembled to products that work with other products to achieve an even more complex product or function. As LCA is a flow analysis method, there was basically no conceptual difference between the production system and the tool, which the production system was to be analyzed with.

This data structure is designed to meet three needs. The first need to meet was to organize LCA data in a pedagogical and easy to find fashion that is customary to building materials industry and technical designers of buildings. The second need was to make the structure expansible and general for data to be added in the future. Finally, the third need to meet concerned the organization of LCA data for production, energy and transport processes in a way that data would: simple, consistent, easy to update, easy to use in inventory process and independent of goal of study.

The system consists of two tables: one table classifying the building products by the technical composition of product, the other table classifying the products by the technical function. The need for a general and expansible structure was granted by the product classification table as well. The categories 0 to 2 belongs to activities connected to the building site, categories 3 to 5 belongs to the building envelop and load-bearing structure, while categories 6 to 9 are related to the specific use the building is designed for. Products and activities are being divided in categories by the classification; independent of what building actually is being built, thus making it general and expansible for all types for buildings, components and materials. The third need holds components of assistance of such LCA issues as keeping system boundaries and quality of inventory data.

The complete data structure that organizes the inventory data for the first inventory phase for life cycle analysis of building sector is presented in Figure 3. Here structural components for LCA data of modes of transportation and energy waste have been introduced. These data sets were handled as general data that were available anywhere in the inventory when no other more specific data were available.

Demolition	Project data	dismantling	D of Furnishing equipment	D of Walls, beams	Other demolition	D of Elevator	Cut in reinforcement	Construction for installation	Temporary construction
Ground	summary	Clearing , demolition moving	Excavate filling	Ground reinforcement, drainage		Cables, culvert,tunnels	Roads, area	Garden	Ground equipment retaining wall
Building substructure	summary		Excavate filling	Ground reinforcement, drainage	Cons, substructure	Culvert, tunnels		Foundation ground	Completion
Frame	summary	Walls	columns	Precast	System of beams		Stairs, shafts	Cooper : roof-frame	Completion
Roof	summary	Roof-frame	Roof-framing	Roof cover	Bases of a roof	Completions for schaks,	plates	Terrace	Completion

						roof hatch			
Façade	sum mary	compl etion		facing		Window s, doors, gates			Compl etion
Completion s/room-formation	sum mary		Sub-floor	Internal walls	Ceiling	Internal doors, window sections	Internal stairs		Compl etion
Internal layers/roo m	sum mary		Layers floors stairs	Layers-walls	Layers-ceiling	paintwo rk	White goods	Decora tion joinery	Compl etion
Installation	sum mary		proce ss		Sewag e, heat	Air ventilati on	Electrici ty	Transp ort	Compl etion
Joint work	sum mary								

Figure 21 the Swedish SBEF table as organizing component of the data structure for LCA-inventory data for the production phase which meets the need of a customary too grid for information

		Original cost	Original cost	Proposed cost	Proposed cost
Initial costs	Factor	Est. costs	PW. costs	Est. costs	PW. costs
1. Demolition costs	7				
2. Ground work	7				
3. Building substructure	5				
4. Frame	6				
5. Roof	7				
6. Façade	2				
7. Room-formation	5				
8. Internal layers	6 4				
9. Installation	1				
10. Joint work					
Total initial cost					
Replacement costs					
20 yrs (periods)					
Total replacement costs					
Annual costs					
1. Energy consumption 2. Maintenance 3. Value-rental					
Total annual costs					
Total PW costs					
Life cycle present worth savings					
Return on initial investment					

Figure 22 life cycle cost worksheet

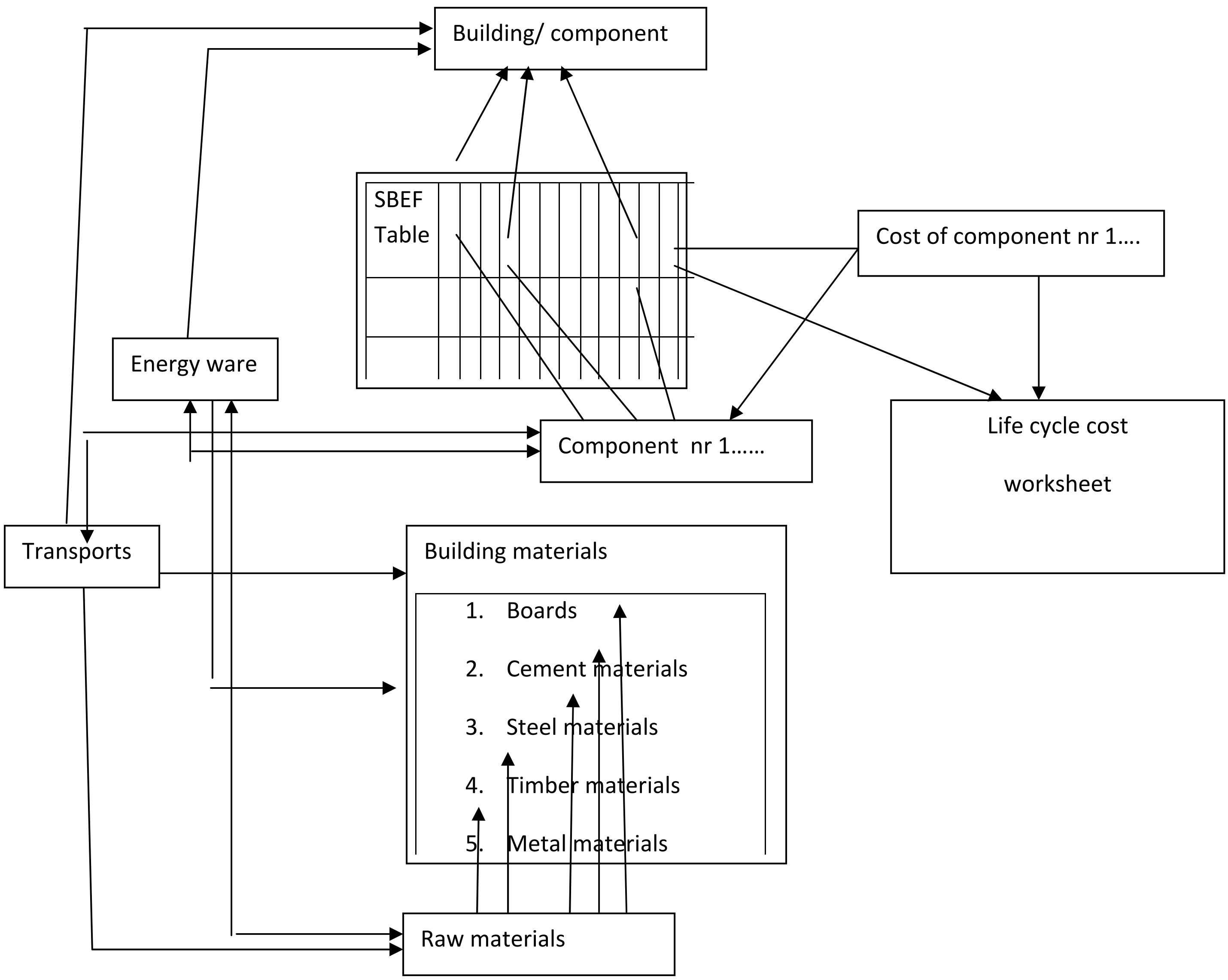


Figure 23 the complete data structure that organizes the inventory data for the first inventory phase for life cycle assessment of building

Chapter 5 Conclusion

Making environmental decision is complex. There are several tools available today that intend to simplify this complexity and support the decision maker in making environmental considerations in a building investment situation. However, as argued here several of these are insufficient for the problems environmental decision-making is afflicted with. To solve some problems future efforts in the development of decision support tools must be necessary (Pernilla 2003).

1. Further development of tools that integrate environmental and economic dimensions (LCA and LCC) (Epsiten 1996). However, in order to raise the decision makers' trust in the result of LCA and LCC, data provided should be availability and reliability. Joint platform of definitions and groupings must be developed.

2. Extend the system boundaries by complementing LCC and LCA (Sterner 2002). However, if too mechanically used by the decision maker this approach has shortcomings in recognizing the decision maker's cognitive skills.

3. Improve the understanding of environmentally related decision making and use of tools. This approach acknowledges that individuals in making decision use cognitive skills which are influenced by both personal values and perceived benefits.

Success in making it understandable for a wider adoption of life cycle technology in the building sector seems to be limited (Larsson 2000). In fact, the situations we facing with are data insufficient, contractual agreements insufficient, too laborious analyses and standardizations insufficient. However, life cycle perspective is good since it extend the system boundaries and incorporates some future costs. For example, integration of LCC and LCA should take future economic and environmental effect into account which can avoid risk in long run. Approaches 1 and 2 build on the notion that decision makers are rational and use decision support tools to evaluate options in order to make an optimal choice.

With more focus on environmentally responsible behavior in building sector, less tool production and more understandable decision making are required. Hence, how to implement the life cycle tool in decision making process becomes more important. As a complement to developing tools, according to approaches 1 and 2, it is necessary to develop a wider understanding of how decision making takes place. What's more, approach 3 considers the decision maker's situation and behavior and thus recognizes the importance of other decision processing aspects in addition to making a rational choice among alternatives (Pernilla 2003). In a word, developing the life cycle tools in decision making process should bring big influence to building sector. Approach 3 is the extension research from 1 and 2, which help working people in different phase of building sector involve in the decision making.

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