INTERNATIONAL DESIGN CONFERENCE - DESIGN 2014
Dubrovnik - Croatia, May 19 - 22, 2014.

COMPARING LCC WITH LCA TO ASSESS PSS SUSTAINABILITY: THE CASE OF THE ECO-BOX

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Keywords: life cycle costing (LCC), life cycle assessment (LCA), product/service-systems, sustainable building, life cycle design, holistic sustainability assessment

1. Introduction

Product/Service-Systems (PSS) strategies are increasingly proving to be a source of competitive advantage and environmental improvement for engineering companies [Matzen 2009]. As a research phenomenon, PSS originated in the field of sustainable design research, with the main hypothesis that a PSS approach should allow for the decoupling of functionality, user satisfaction and financial income on the one hand, from the overall environmental impact of the function-delivering technology on the other [Mont 2002]. By its very nature, PSS implies greater responsibility on the provider (often the producer) over an extended life cycle period, in order to first calculate, then effectuate and finally measure the economic and environmental benefits of the technology (often embodied in products) via the PSS offering [McAloone et al. 2011]. Understanding the importance of thorough and current insight into the product's life cycle for successful PSS provision, the two main life cycle elements of *environment* and *cost* can be analysed and subsequently optimised using Life Cycle Assessment (LCA) and Life Cycle Costing (LCC), respectively.

LCA assesses environmental performance of a product or system by measuring environmental impacts associated with different stages in a product or system's life cycle [European Commision 2010]. LCC supports the selection of the most preferred cost-oriented alternative solution for a product or system [Christensen et al. 2004] and can be used to highlight trade-offs, which could be between design and operation cost [Hydraulic Institute 2001]. Although the LCA and LCC are supported by numerous studies and literature, separately, there are very few studies that show the two approaches operating together in an integrated or comparative approach. Furthermore the strategic implications of LCA and LCC approaches often seem to be contradictory [Bierer et al. 2013]. However, considering that the goal of PSS approaches seems to be to deliver sustainable as well as cost-efficient solutions, both approaches (LCA and LCC) need to be integrated to show the trade-offs and support decision making.

This paper describes an integration of LCA and LCC investigation for an exemplar PSS case study. The case study focuses on a temporary building named Eco-Box which which offers both the physical environment for providing public and private services such as office space and marketing purposes for the city district. The Eco-Box is based on a PSS concept where suppliers guarantee taking back the building materials after use, in order to ensure reuse and thereby improve sustainability. This extends the ownership and responsibility of the supplier to the entire life cycle [Tan 2010]. The temporary building serves the purpose to satisfy the dynamic needs we have for buildings and office spaces. Eco-Box is believed to be a sustainable construction, because of its focus on limiting waste and utilising materials, even after demolition.

2. Comparing LCC and LCA

LCC and LCA both consider impacts attached to life cycle stages, support decision making, and are iterative processes of improvement with more insights and better data. Despite these similarities, there are radical differences in the purpose and approach between LCA and LCC due to the fact that they arise from two different disciplines [Langdon 2007]. Table 1 shows how the two approaches compare to one another [Norris 2001], highlighting the similarities and differences [European Technical Contractors 2003], [Langdon 2007].

Table 1. Comparing LCC and LCA, adopted from [Norris 2001]

	LCC	LCA
Purpose	Determine cost-effectiveness of alternative investments and business decisions, from the perspective of an economic decision maker such as a manufacturing firm or a consumer.	Compare relative environmental performance/effectiveness of alternative product systems for meeting the same end-use function, from a broad, societal perspective.
Activities which are considered part of the life cycle	Activities causing direct costs or benefits to the decision maker during the economic life of the investment, as a result of the investment.	All processes causally connected to the physical life cycle of the product; including the entire pre-usage supply chain; use and the processes supplying use; end-of-life and the processes supplying end-of-life steps.
Flows considered	Cost and benefit monetary flows directly impacting decision maker.	Pollutants, energy, resources and inter-process/system (technosphere-ecosphere) flows of materials and energy.
Units for tracking flows	Monetary units (e.g. euro, dollars).	Primarily mass, energy & other physical units.
Time treatment and scope	Timing is critical. Present value (discounting) of costs and benefits. Specific time horizon scope is adopted, any costs or benefits occurring outside that scope ignored.	Impact assessment may address a fixed time window (i.e. specific temporal system boundaries) of impacts (e.g. 100yr time horizon for assessing global warming potentials) but future impacts are generally not discounted.
Usage	Supports decision making processes.	Supports decision making processes.
Process	Iterative	Iterative
Summary: Similarities	Similarities: Both approaches utilise similar data/modelling approaches, particularly with regard to: - Quantities and specification of materials. - The service life of the materials. - The maintenance and operation implications (assumptions on use). - End-of-Life proportions related to recycling, sale value and disposal. Both approaches include similar level of analysis, specifically with regard to: - Assesses long term impacts. - Analysis with diverse range of inputs. - Using similar input data. - Consider operation and maintenance. - End-of-Life opportunities are considered. - Assesses alternatives and base. - Decisions based on performed analysis.	
Summary: Differences	- Focuses mostly on the market cost. - Results are obtained based on costs and the results are used to support investment decisions.	- Takes production into account with for example associated energy. - Decisions are based on potential environmental impacts by considering multiple impact categories.

Some recommendations to use LCA and LCC together have been defined by different researchers [Wood and Hertwich 2012]. As such, integrating LCC and LCA is a holistic combination that will answer questions regarding the sustainability of a building, since this mixture will consider the economic and environmental aspects [European Technical Contractors 2003]. It is asserted that LCC and LCA must only be used together by defining a common system boundary and functional unit [Hunkeler and Rebitzer 2005]. A comparison will be supported by defining objectives that are linked and still makes sense for both methodologies [Reich 2004]. Both LCC and LCA consider different alternatives, but the inputs in the two assessments must be the same to facilitate comparison of the economical end environmental results [Wood and Hertwich 2012].

Nevertheless, the LCC and LCA results for the Eco-Box could not be fully compared due to differences in framework, modelling, availability of data and requirements. Parallel modelling of LCC and LCA was especially complicated since different data were available for the two assessments. Thereby it led to the inclusion of different life cycle stages in the LCC and LCA models. While the LCA could use mostly real data, the LCC had to be based on rough cost estimates and uncertain assumptions. Therefore, the two assessments also had different levels of uncertainty.

3. Comparing LCA and LCC for PSS

In order to make the LCC and LCA study comparable a common functional unit was defined for the Eco-Box case, introduced above, since both assessments consider different alternative life cycles and support decision making processes. Even though the performed study was about combining two capabilities with each other, LCC and LCA still have flow similarities. The unit of analysis was the physical system of the PSS, including material, transport, operation and end-of.life.

The LCC and LCA were based on the same four scenarios. The four scenarios were based on two physical designs and two ownership approaches. The two designs included an initial design (Design 1) and an altered design (Design 2), based on environmental sustainability (ecodesign) as well as changes in the available budget, supplier base and intended use of the product. The ownership approaches included a PSS approach, including leased materials, and a non-PSS approach, in which materials were bought, i.e. no reuse of any material and no extended supplier responsibility. Table 2 shows the total solution space unfolded by combining the PSS and non-PSS solutions with Design 1 and 2.

Table 2. Four scenarios

	Non-PSS	PSS
Design 1	Non-PSS design 1	PSS design 1
Design 2	Non-PSS design 2	PSS design 2

Figure 1 shows an illustration of how LCC and LCA were applied in this case study. First of all the same goal and scope were defined. The modelling was carried out separately, but in parallel, which is indicated by the arrow in the middle. Finally, a comparison of the two assessments was carried out.

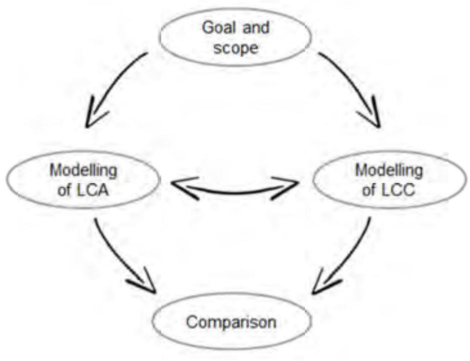

Figure 1. Applying LCC and LCA together in practice

The modelling went through several iterations in an attempt to align the LCC and LCA. The aim was to compare as many life cycle stages as possible, but in the end only a few life cycle stages were comparable and common, namely: production; operation; and end-of-life.
Only in these life cycle stages, were the data available and assumptions comparable for both the LCC and the LCA. Even though other life cycle stages were the same in the LCC and LCA, they could not be compared, since they had different data inputs and assumptions. This would not lead to a fair comparison, since a comparative study must have the same basis, system boundaries and inputs [Hunkeler and Rebitzer 2005].

4. Results

4.1 Overall findings

Figure 2 shows the aggregated LCA and LCC score of the four scenarios defined in Table 2. The results of the LCC are displayed on the x-axis while the results for the LCA are displayed on the y-axis. On studying Figure 2, a PSS approach seems to lead to improved economic and environmental sustainability of the building. The results also reveal that PSS2 has environmental and economic benefits, compared to the other three alternatives. This is a surprising result as Design 2 included less budget and less structural flexibility.

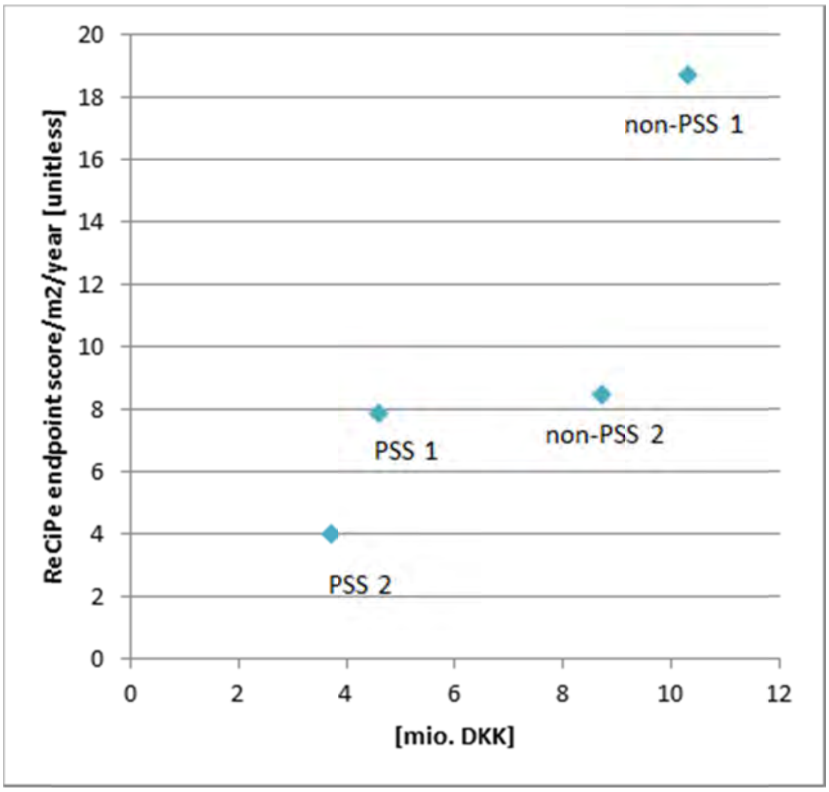

Figure 2. LCC and LCA comparison of four scenarios

Table 3 summarizes the LCC and LCA results for the four scenarios defined in the study as a sum of the three above-mentioned life cycle stages, production, operation and end-of-life. It shows that the more environmentally friendly solutions also are consistently less costly, within the common system boundaries. In other words, the four scenarios show the environmental-economic synergies of the ecodesign and product/service-system approach. The non-PSS 1 scenario is therefore least preferable and the PSS 2 scenario is most preferable. By comparing these two extremes, a 64% cost reduction and 79% environmental score reduction were achieved by using the second design with a product/service-system approach, compared to the first design with a conventional procurement approach.

Table 3. Results of four scenarios

	LCC results	LCA results
	Monetary value in mio. DKK	ReCiPe endpoint score
Non-PSS 1	10,3	18,7
PSS 1	4,6	7,8
Non-PSS 2	8,7	8,5
PSS 2	3,7	4
Reduction (from Non-PSS 1 to PSS 2)	6,6 (64%)	14,7 (79%)

The usage of the results is limited to the life cycle stages forming the basis for comparison. Also by looking at the LCC and LCA studies separately, different pictures are gained. This is caused by the differences in data inputs, system boundaries and modelling procedure, even though uncertainties in the modelling have most likely influenced the outcome. A broader comparison is therefore needed to measure the joint environmental and economical sustainability of the building.

4.2 Results distributed across life cycle stages

Distributing the results to the three compared life cycle stages, Figure 3 shows the results for the LCC analysis and Figure 4 presents the resuls of the LCA. For both LCC and LCA it can be seen that using a PSS approach and going from the first design to the second design improves the economic and environmental performance. What is clear is that the material production varies considerably. In all the scenarios for both LCC and LCA the material production contributes significantly more than the other life cycle stages to the total life cycle impact. This means that changing the design of the building and its various building materials has a significant impact on the overall result. The different design parameters set by the stakeholders will therefore greatly influence the sustainability of the building, which is something the stakeholders should be aware of, especially when the material production is so much higher than the other life cycle stages.

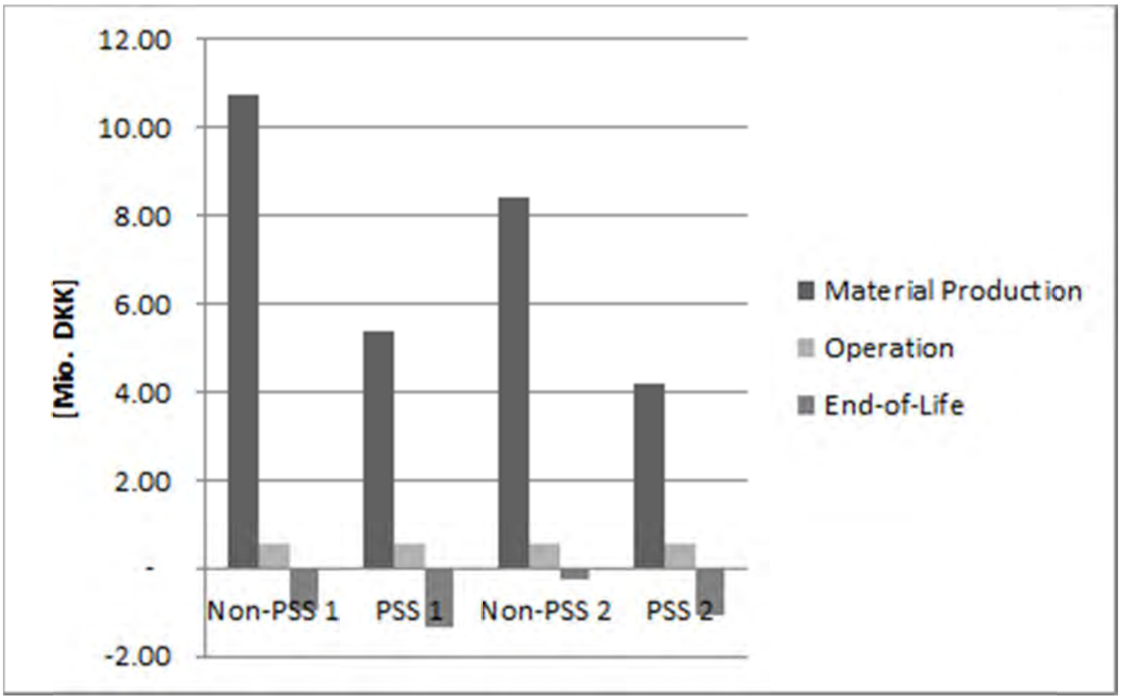

Figure 3. LCC results distributed across life cycle stages

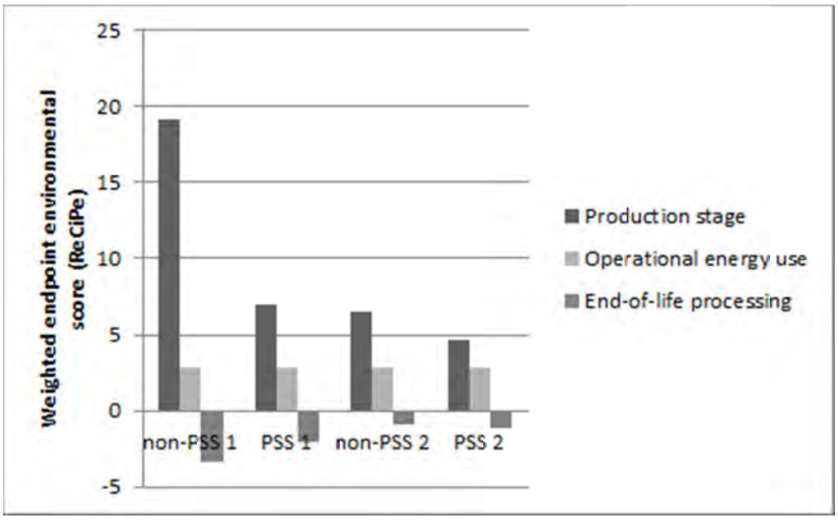

Figure 4. LCA results distributed across life cycle stages

Table 4 illustrates how much impact material production covers in both LCC and LCA, where it can be seen that most of them are around 100%. The reason is that the end-of-life has a negative value, since energy is restored in LCA and deposits are received in LCC. This secures that material production covers a major part of the total results and the different design parameters and considerations will have a significant impact on the overall result, both economically and environmentally. The major impact of the material production also creates low sensitivity of operation and end-of-life on the total life cycle impact score, shown in Table 3.

Table 4. Contribution of material production

Material productions coverage		
	LCC	**LCA**
Non-PSS 1	104%	103%
PSS 1	117%	90%
Non-PSS 2	97%	78%
PSS 2	114%	73%

Remarkably, the results for operation were not higher for both assessments, since operation usually covers a major impact for buildings. This leads us to conclude that temporary buildings do not have a significant impact in the operation phase, even when taking into consideration that maintenance was not included in the two assessments. The reason for this is that maintenance will most likely have a low impact, considering the limited lifetime of Eco-Box and the fact that most of the building materials have a longer lifetime than the Eco-Box.

On studying the end-of-life stage for both assessments, it was discovered that Design 1 gave better results in terms of economy and environment. The reason for this is that Design 1 uses more materials that give better end-of-life income, such as steel and aluminium. Design 2, on the other hand, uses more wood than metal, thus resulting in less income at end-of-life, but yielding a better overall environmental performance.

5. Improvements in comparing LCC and LCA

It appears that there are many benefits of comparing LCC and LCA and literature shows an urge for such a comparison, in order to reach sustainability. However, actual comparisons seem to be infrequent. It is remarkable that existing literature provides only brief information about how such comparisons should be performed, with recommendations being general in nature and quite obvious.

5.1 The flexibility of LCC

During this study it was discovered that LCC lacks consensus and standards, with many approaches having been applied by different researchers. This led to a more open and simpler goal and scope definition for the LCC of this study, compared to the LCA. In general it can be said that LCC studies are more flexible, but less consistent. Current standards and recommendations for performing LCC mainly consist of standard values that are useful for screening, whilst recommendations for LCA are more specific. Guidelines for LCA are more detailed than for LCC and include, for example, recommendations of which life cycle stages to include and which to exclude, according to the purpose of the particular study. LCA standards generally have more detailed calculation method guidelines, which are non-existent and still under development for LCC. Throughout the study it was discussed that LCA practitioners have been able to define international standards and guidelines to perform LCA, leading to consistency in performing LCA. The same is needed for the implementation of LCC, which must gain similar international standards and guidelines. At such a stage it will be easier to compare the LCC and LCA results.

5.2 Learning from LCA

Since common standards are lacking for LCC, an idea could be to use the same LCA framework, in order to make them comparable. One way could be to follow for example the ILCD Handbook [European Commision 2010] consistently or any other international guideline to perform LCC. The reason for this is that ILCD has a detailed handbook on performing LCA with a detailed description on how to define the goal and scope and how results should be treated, assessed and interpreted. It could of course be confusing to use an LCA guideline to perform LCC, but by turning the mind from environmental impacts to cost impacts will most likely reveal how it should be performed and how the recommendations should be treated. Thereby a more consistent comparison between LCC and LCA could be gained and concurrent integrated analyses made possible.

Moreover, the further development of tools integrating environmental and economic impacts are needed in order to facilitate a consistent and proper comparison between LCC and LCA. Likely to be included is the expansion of system boundaries to complement the comparison of LCC and LCA. In the case described in this paper, the system boundary turned out to be very different considering the LCC and LCA for the Eco-Box. LCC can learn something from LCA, when it comes to the definition of system boundaries, as it was noted in the performed literature study on LCC that there are many ways to define system boundaries. Another example is the need to have the same functional unit in LCC and LCA to be able to compare [Hunkeler and Rebitzer 2005]. The LCC literature does not directly describe about the need for a functional unit, but something similar is proposed to be used. In order to be able to compare LCC with LCA a common functional unit is necessary, which is also why a functional unit was defined for the LCC in the Eco-Box case.

Currently the best solution could be to use an LCA guideline for LCC, since no standards for LCC are defined and guidelines to perform LCC and LCA together do not exist. By having the exact same flow and focus the generation of a more comparative study between LCC and LCA ought to be possible, since the foundation and frameworks are the same and only allow focus on the same inputs.

6. Conclusion

The comparison performed for the Eco-Box showed the importance of having the same product system and inputs in order to initiate a comparison of the environmental and economical results. It is proposed to ensure alignment between the assessments to make the results comparable [Wood and Hertwich 2012]. When dealing with sustainability one has traditionally assessed the environmental aspects, but sustainability is more than environment and to gain a broader sustainable picture, a fusion between LCC and LCA can be performed. However, this appears to be a very new area which is hardly touched upon in the literature, even though some recommendations can be found. The third aspect of sustainability, namely the social element, is fully acknowledged but was not dealt with in this study.

The performed assessment for the Eco-Box had many obstacles, because two different assessments had to be performed in parallel and the results had to be compared. Due to the differences in assessments it was not possible to perform a holistic comparison. However, fragments of the results could still be compared, since they had the same inputs. Some common results were therefore gained, but the comparison has certainly scope for enhancement. LCC needs and lacks international standards and guidelines like LCA that also must be as detailed and comprehensive as LCA, in order to make a more proper comparison.

It would therefore be interesting to let the LCC assessment follow an LCA guideline, to secure same basis and alignments throughout the two assessments and thereby secure a proper comparison, since international LCC standards do not currently exist. This will most likely be good for the comparison, but is currently only a suggestion that is based on the performed assessment for the Eco-Box construction. A proper guideline to use LCC and LCA together in a concurrent and integrated fashion would be optimal for allowing comparisons that are useful in the design process.

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