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ENVIRONMENT AND ECONOMY – AN ALLIANCE OF MUTUAL BENEFITS IN RESIDENTIAL BUILDING

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Abstract

Different environmentally and economically driven stakeholder interests in the building context are often seen as concurring concepts that are mutually exclusive. Owing to the fact, that the methods of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are getting increasingly important in the predesign evaluation of a building's lifetime performance, it is about time to determine positive effects in the combination of both aspects. In order to clarify, which factors influence the environmental impact, as well as the life cycle costs of a building throughout its lifetime, the authors compare the LCA and LCC results of twelve recently constructed Swiss residential buildings, and identify the most significant building elements (e.g. roofs, ceilings, walls etc.) and life stages (construction, replacement, operation and deconstruction). The investigation shows for both the life cycle costs and the environmental impact of a building, that the most important building elements in this sample are ceilings, windows and external walls. The most important life stage, from a cost aspect, is the initial construction. As all buildings from the sample follow the state-of-the-art energy regulations in Switzerland, they induce comparably low costs during their operational stage. Nevertheless, for some of the inspected buildings the environmental impact results show a relatively high significance for the operational stage. The examination of this building sample suggests that in a residential building the alliance of environmental and economic interests provides mutual benefits for both.

Keywords:
Life Cycle Assessment LCA; Life Cycle Costing LCC; apartment buildings

1 INTRODUCTION

In the past, the building industry has concentrated mainly on minimizing the initial construction cost, without taking further expenses or outcomes of design choices on the ecological effect of a building during its lifecycle into account. In result, the lion's share of structures in existing building stocks today are vigorously wasteful to operate and cause environmental impacts related to resource depletion and fossil fuel consumption.

As of late, more thorough building regulations and an adjustment in client requests have become effective. Attributable to discourses about climate change and the way that the building sector represents around 40% of all primary energy usage for building operation [1], life cycle thinking and improving buildings from an ecological and in addition an economic point of view, have turned into an important issue during the planning process. Therefore, in recent years, scientists have proposed complementing Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) approaches for a more sustainable evaluation of buildings during their lifecycle [2].

Building characteristics

Building	01	02	03	04	05	06	07	08	09	10	11	12
Number of accommodation units	111	2	3	4	132	3	89	6	4	10	22	10
Type of construction	massive	hybrid	light-weight	massive	hybrid	light-weight	massive	hybrid	hybrid	massive	massive	hybrid
Energy reference area A_E [m^2]	12.430	350,40	374	622,20	20.400	408	13.441	1.121,90	510,10	1.120	2.966	1.170

Fig. 1: Main characteristics of the buildings.

LCA and LCC approaches are especially gaining importance in the predesign assessment of a building's lifetime performance. The thought of a combined LCA and LCC approach is not new, but recent [3]. As different environmentally and economically driven stakeholder interests in the building context are often seen as concurring concepts that are mutually exclusive, it is about time to determine positive effects in the combination of these two counterparts. For this purpose, it is crucial to understand which factors mainly influence the environmental impact as well as the life cycle costs of a building throughout its lifetime.

Therefore, in this paper, the authors compare the LCC results with the LCA results of twelve recently constructed Swiss residential buildings and examine mutual similarities with regard to the most significant building components and life stages of the buildings.

2 DATA AND METHODS

The methodological approach for the LCA in this study is based on the international standard ISO 14040 [4] and 14044 [5], while the LCC approach follows the international standard ISO 15686-5 [6] and its adaptation for Switzerland “Leitfaden LCC – Planung der Lebenszykluskosten” [7]. The LCA results and all building characteristics as well as the LCA modelling specifications have been published in [8] and [9]. These building characteristics were then used for determining the life cycle cost. An overview of the twelve buildings and their most important attributes is shown in Figure 1. For the display of LCA results, the impact indicator GWP 100a for $CO_{2eq.}$ emissions has been utilized (IPCC 2007 GWP 100a V1.02 [10], referring to a time horizon of 100 years for emissions).

The LCC approach required characterizing the general layout and system boundary of this study in accordance with the LCA model, by means of setting up the expenses for the different life stages (initial construction, maintenance, end-of-life and operation).

The LCC results were calculated by splitting the building into building components (floors, ceilings, external walls, internal walls, columns, roofs, exterior doors, windows). Each of these components contained data about the materials and amounts utilized. Likewise, preliminary works (excavation and backfill) and building installations (heating and ventilation system) were considered. The operational stage of the buildings was tended to by including the annual energy demands for heating, domestic hot water, ventilation energy and household electricity. In order to be able to compare the LCA and LCC results, it was a prerequisite to define a common functional unit, to which the results of the environmental impact assessment as well as the cost assessment allude. In compliance with [8], this functional unit has been determined to be 1m² of energy reference area AE (referring to the heated floor space) per 1 year in the total lifetime of the building of 60 years (1m²/a).

The modelling of the LCC has been conducted in a seven-step approach, which is illustrated in Figure 2. The currency utilized for the calculation of the life cycle costs of the twelve buildings is Swiss francs (CHF). As all twelve buildings have been built within a similar time frame, it has been assumed for the following calculations that all the buildings have been constructed in year 0, go into operation in year 1 and are being demolished and disposed of in year 61. The base date for discounting future costs is set at the start of the operation at the beginning of year number 1.

The first step during the LCC calculation was to model each building element using cost reference values from the Swiss EAK catalogue [11] or BTK catalogue [12]. Cost reference values were accumulated per square metre for the initial construction as well as for the replacement and the disposal of each particular building element. The individual unit costs established during step 1 were then multiplied by the surface areas of each particular element for computing the total cost per element in step 2. This was done separately for the initial construction, replacement and demolition of each building element. Subsequently, the total costs for the replacement and the demolition established in step 2 were multiplied by their individual discount factor in order to estimate the present value in

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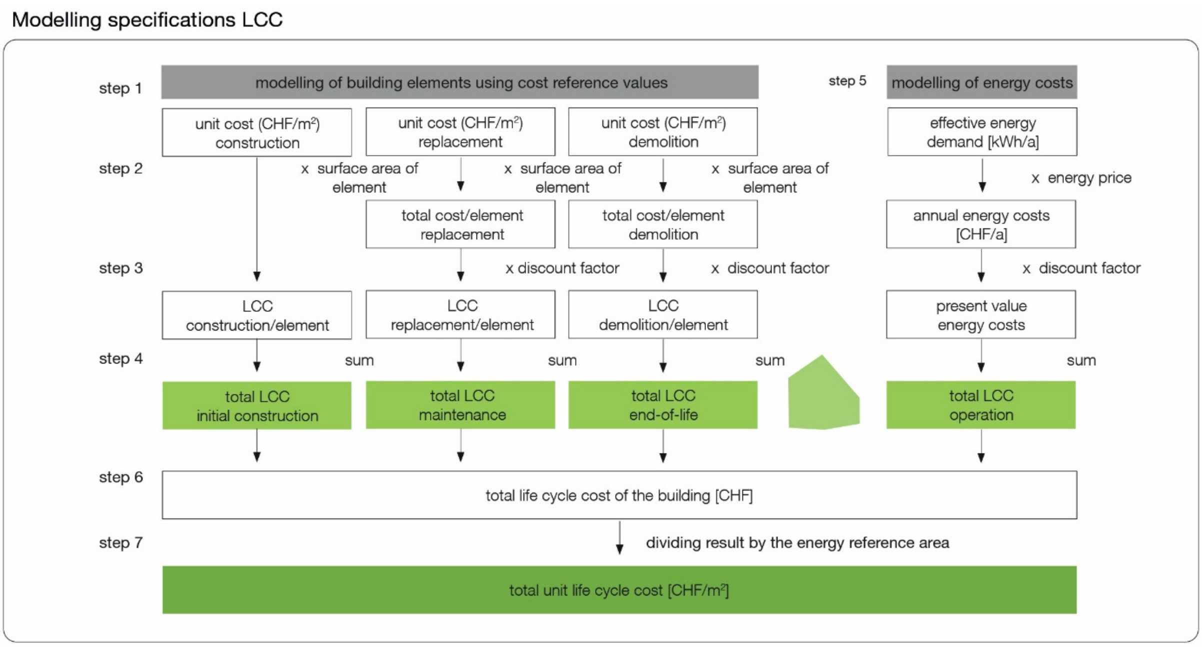

Fig. 2: Modelling specifications for the LCC approach.

step 3. The individual discount factor depends on the time at which a payment occurs. The initial construction costs do not need to be discounted as it has been assumed that they occur on the defined base date. In step 4, the initial construction cost and the present value of replacement and disposal costs for all the different building elements were added up to the total life cycle cost of the initial construction, maintenance and end-of-life separately. In step 5, the evaluation of the energy costs for the operation phase of the buildings was done as follows: The effective energy demand was used for the calculations and in those cases, where a building has a heat pump, the total energy demand was converted into the effective energy demand and divided by the assumed COP-Value of the heat pump (=3,5). Afterwards, the effective energy demand was multiplied by the energy unit price (CHF/kWh), resulting in the annual energy cost. The annual energy cost was then multiplied by its individual discount rate (depending on the year of its occurrence), which resulted in the present day value of the energy cost for a particular year. Finally, the life cycle cost for operation was computed by adding all the present values of the energy costs together. Afterwards, the total life cycle cost of each building was calculated in step 6 by adding the initial construction, maintenance, end-of-life and operation costs together. The final step was to divide the total life cycle cost from step 6 by the energy reference area, resulting in the total unit life cycle cost in CHF/m².

3 RESULTS

A comparison of embodied $CO_{2eq.}$ emissions and life cycle costs, as depicted in Figure 3 demonstrates a similar tendency for the LCA and LCC results of the twelve buildings. Regardless of their type of construction, the most relevant life phase for most of the buildings is the construction stage, while the least important phase is the deconstruction / end-of-life stage. However, the buildings 7 and 10 have their most relevant impact on embodied $CO_{2eq.}$ emissions in the operation stage.

As all buildings from the sample follow the state-of-the-art energy regulations in Switzerland, they induce comparably low costs during their operational stage. Nevertheless, for the buildings 7 and 10, the results for embodied $CO_{2eq.}$ emissions show a relatively high significance of the operational stage. This is mainly due to the comparably high environmental impact regarding $CO_{2eq.}$ emissions of the energy carrier, which is natural gas (building 7) and district heating with natural gas (building 10). Most of the other buildings contain a heat pump powered by the Swiss electricity mix (which mainly consists of renewable energy) and therefore have a significantly lower impact with regards to $CO_{2eq.}$ emissions during their operation phase.

For this sample, the embodied $CO_{2eq.}$ emissions of the end-of-life stage contribute 4-14% to the overall LCA results, while the end-of-life stage has nearly 0% impact on the overall LCC results of all the buildings.

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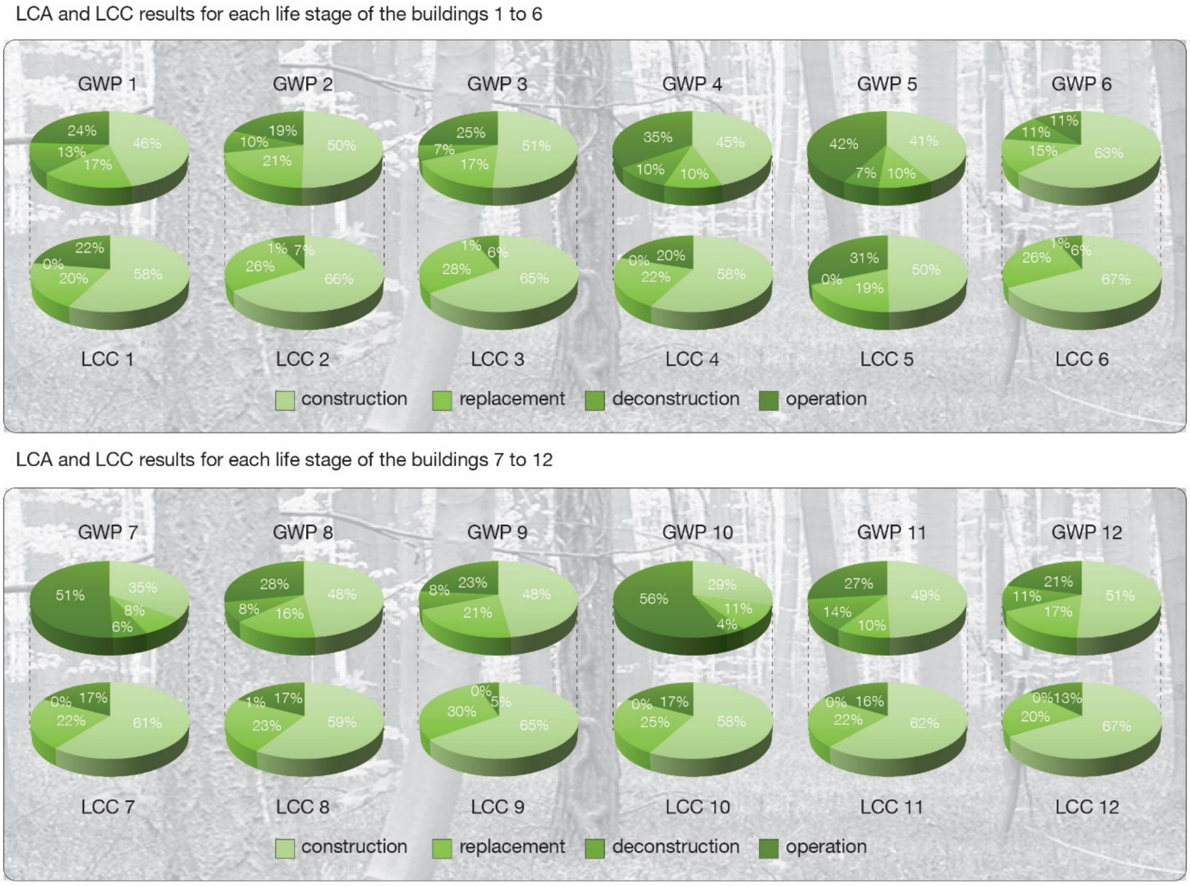

Fig. 3: Comparison of the shares of LCA and LCC results for each life stage of the twelve buildings.

When comparing embodied $CO_{2eq.}$ emissions and initial construction costs, the most relevant building components, regardless of the type of construction but regarding both LCA and LCC results of the 12 buildings, are ceilings, external walls and windows, as Figure 4 indicates. Additionally, for the buildings 1, 4 a nd 6, the roofs have a significant impact on the overall results, while the inner walls contribute significantly to the results of the buildings 9 and 12.

4 DISCUSSION

It was stated in the introduction that in order to show mutual benefits in a combined use of the LCA and LCC approach, it is important to understand, which factors mainly influence the environmental impact, as well as the costs of a building throughout its lifetime. The results section has shown significant similarities in the LCA and LCC results of the twelve analysed residential buildings, both on the overall building level with its life stages and on the building element level. Furthermore, these similarities were observed in all the various types of construction (light-weight, hybrid and massive constructions). This means that there appears to be a strong link between environmental and economic choices in building design in general.

This finding contradicts the assumption that different environmentally and economically driven stakeholder interests in the building context are concurring concepts. Consequently, in order to fully establish trade-off effects and mutual benefits of ecological and economic decisions, it seems inevitable to investigate both LCA and LCC aspects in a holistic approach. As in this example only residential buildings and solely one environmental impact indicator (GWP 100a) were utilized for the assessment, further research should investigate, if similar results are derived from other types of buildings (e.g. office buildings) as well as alternative indicators (e.g. non-renewable primary energy).

5 CONCLUSIONS

The examination of this building sample suggests, that in residential building the alliance of environmental and economic interests provides mutual benefits for both. The joined use of LCA and LCC empowers the estimation of the environmental impact and cost of a building at different phases of its lifetime, looking at alternative options and recognizing the ecologically and also economically most sensible long-term solution.

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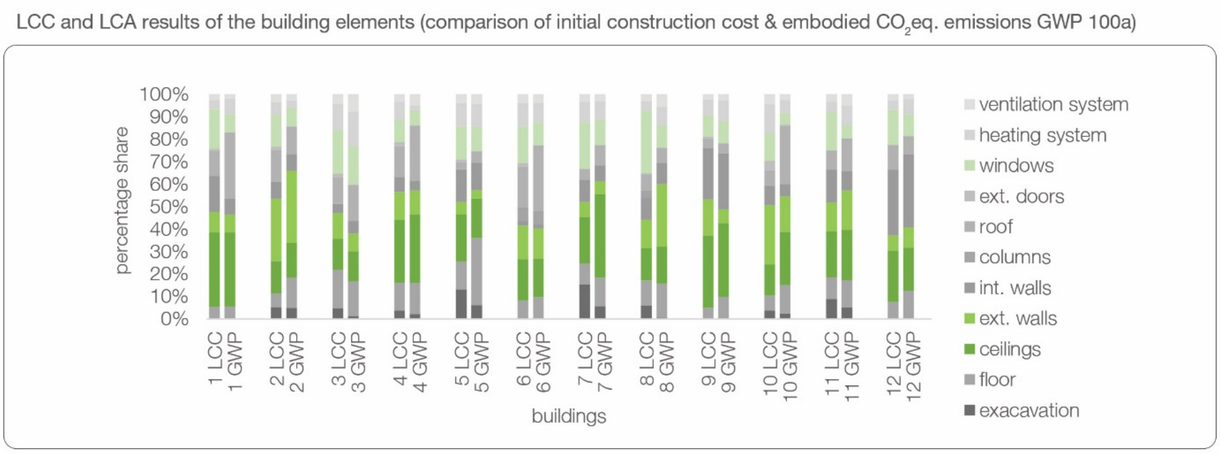

Fig. 4: Comparison of the shares of LCC and LCA results for each building element.

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