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Life-cycle cost analysis of building components and materials used in hospitals

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ABSTRACT: Sustainable development and increasing requirements on the economic, environmental and social performance of buildings are causing growing demands on building design. Regarding the current situation in hospitals, the increasing demand for technical equipment is leading to a shortened service life of the installed building products as the refurbishment cycles decrease rapidly. These circumstances reflect an urgent need for life cycle design in hospitals. This paper focuses on life cycle design regarding construction products of walls, floors and ceilings. In this context a new model for estimating life cycle costs has been developed and is based on normative regulations, dynamic calculation algorithms as well as on specific requirements of hospitals. The new model allowes a quick estimation of life cycle costs for different building components and a practical applicability is shown by the evaluation of a hospital in Graz, Austria.

1 INTRODUCTION

Sustainability and increasing demand of the economic, environmental and social performances of buildings require higher demands on quality and the development of buildings. To asses the sustainability performance of buildings, it is necessary to consider the life cycle costs over the entire service life. The sustainability scores or profiles like economic, environmental and social performances of buildings based on indicators resulting from processes in which the relevant measures are identified, analyzed and valued.

The structure of such an investigation has been provided by national and international guidelines, for instance the work of CEN/TC 350 e.g. EN 15643-1, ÖNORM EN 15643-4, etc. see (CEN 2010a,b) and Austrian standards e.g. ÖNORM B 1801-1, ÖNORM B 1801-2, etc. see (ASI 2009, ASI 2011). Regarding the current situation in hospitals, the increasing demand for technical equipment is leading to a lower service life of the installed building products as the refurbishment cycles decline rapidly (Haas et al. 2009). Furthermore, this development plays an important role in the case of the implementation of special functional and technical requirements. These circumstances reflect an urgent need for life cycle design in hospitals.

In Austria a small nnumber of institutions deal with projects regarding sustainability assessment e.g. the "House of the Future" (HAUS der Zukunft 2012) – a comparative analysis and evaluation of innovative building concept models in terms of key ecological and economic figures obtained from the life cycle of individual building concepts or „ÖGNI" which has been certificated more than 34 sustainable buildings accordance with DGNB certification (ÖGNI & Passer 2011). In Styria the biggest hospital association, which goes by the name KAGes, implemented a new sustainable strategy on utilization costs by improving the construction guidelines and introducing ecological revisions.

In this context, an overall approach is needed to combine ecological aspects and life cycle assessments with essential technical and functional qualities. Present implementation concepts for life cycle cost analysis (LCCA) and forecasting models have shown that existing solutions are not applicable in the case of infirmaries.

This paper describes a new model developed in cooperation with KAGes to forecast life cycle costs based on economic cause/effect relations between different materials used in construction and user-related costs of ownership (Halder 2011).

1.1 *Background of the KAGes/Austria*

The sustainable strategy of KAGes was to revise the technical guidelines (TR-PBB); see (KAGes 2009) for standard cross-sections (CS) in regard of 'ecology in hospital constructions'. This revision was based on semi-quantitative and technical-functional developments (Kreiner et al. 2009), and in this context a coarse model was developed to calculate construction products and construction-specific life cycle costs (LCC) for selected cross-sections. The case study focuses on CS of room-closing elements of the general hospital (GH) in Feldbach, considering floors, walls and ceilings constructed under the guidelines of KAGes. These technical guidelines (TR-PBB 004) see (KAGes 1994) are adapted to the requests and particular needs of Styrian hospitals and are, according to the specifications of KAGes, an integral part of the planning process of new projects.

1.2 *The state-of-the-art of LCCA methodologies*

In order to achieve a uniform assessment of the essential phases in the life cycle of a building, national and international institutions attempt to formulate general applications and rules for recurring measures and activities. The European Committee for Standardization (CEN) set up the Technical Committee TC 350 with the aim of developing comprehensive frame convolutes (horizontal norms) for the assessment of the ecological, economic, social, technical and functional characteristics of buildings in 2005 (Passer 2010). For the LCCA, the following standards will provide the approach for the new assessment model to analyze life cycle costs for construction products in hospitals.

ÖNORM EN 15643-4: Sustainability of Construction Works – Assessment of building „Framework for the assessment of economic performance“ (CEN 2010b).

ÖNORM EN 15978: Sustainability of Construction Works - Assessment of environmental performance of buildings „Calculation method“ (CEN 2010c).

ISO 15686-5: Buildings and constructed assets - Service-life planning - Part 5: “Life-cycle costing” (ISO 2008).

In her work, Pelzeter (Pelzeter 2006) analyzed the state of research and developed both scientific and practical foundations for a forecast calculation model of LCC which she, in turn, further developed into a 'holistic approach'. Herzog (Herzog 2005) has developed a multi-methodical model for the assessment of the production costs, maintenance costs and demolition costs, by which LCC can be financially evaluated for material-specific constructions of buildings. Zehbold (Zehbold 1996) has made 'cost accounting more dynamic' in her contribution to calculating LCC of a building. Riegel (Riegel 2004) has developed a new calculation model to forecast and assess utilization cost over the life period of a building and has also identified numerous key factors on the basis of different building models and associated operating costs. Dobernigg (Dobernigg 2000) has discussed national and international considerations about the life cycle of a building and described the life cycle costs of a building in a practical example while also considering the *total construction costs, financing costs, operation costs* and *after-operation costs*.

Data about the service life of building parts and building elements, as well as figures about operation and maintenance costs of administration buildings are contained in the guideline *Sustainable Building*. Furthermore the guideline by the Ministry of Transport and Environment formulates sustainable (protection) targets (BBR 2001).

2 DEVELOPMENT OF THE CALCULATION METHOD

In terms of a comprehensive investigation of life cycle cost analyzes, it is necessary to consider all process incurring costs in the entire lifespan of a building. Therefore a calculation method was developed according to the different guidelines (e.g. ÖNORM EN 15643-4, ÖNORM EN 15978, ÖNORM B 1801-1, ÖNORM B 1801-2 and ISO 15686-5) which makes it possible to record all processes and materials with their respective costs and to determine life cycle costs for a set period of time. Furthermore, with this method it is possible to compare different construction components and to optimize used materials related to their life cycle costs.

2.1 *Definition and boundaries of the assessment*

For the LCCA of this project, the whole life cycle costs were taken into account. Life-cycle costs refer to the total costs of ownership over the building lifetime and include the development, acquisition and operating costs. Whole-life costs commonly refer to “cradle to grave” costs and include all costs of design, construction and acquisition, usage, maintenance, renewal and rehabilitation as well as replacement or disposal.

For the development of the investigation structure of cost acquiring the approach of ÖNORM B 1801-1 (ASI 2009) was chosen and for follow-up costs the structure of ÖNORM B 1801-2 (ASI 2011) was chosen as shown in Figure 1.

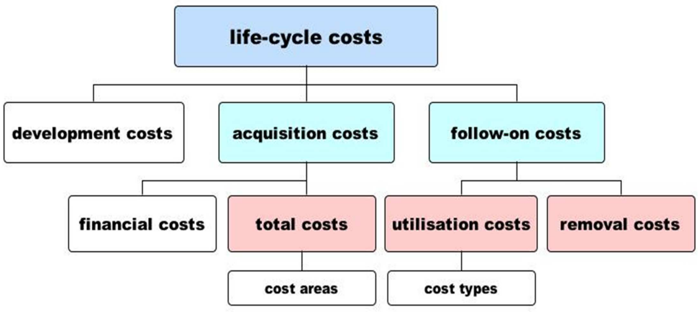


Figure 1. Components of life cycle costs.

Various definitions of “whole” life cycle costs are used by different frameworks and guidelines such as ÖNORM EN 15643-4 and ISO 15686-5. In the present work the term “whole“ contains the whole life cycle ending with the deconstruction of a building and its disposal instate of ending with a change of use.

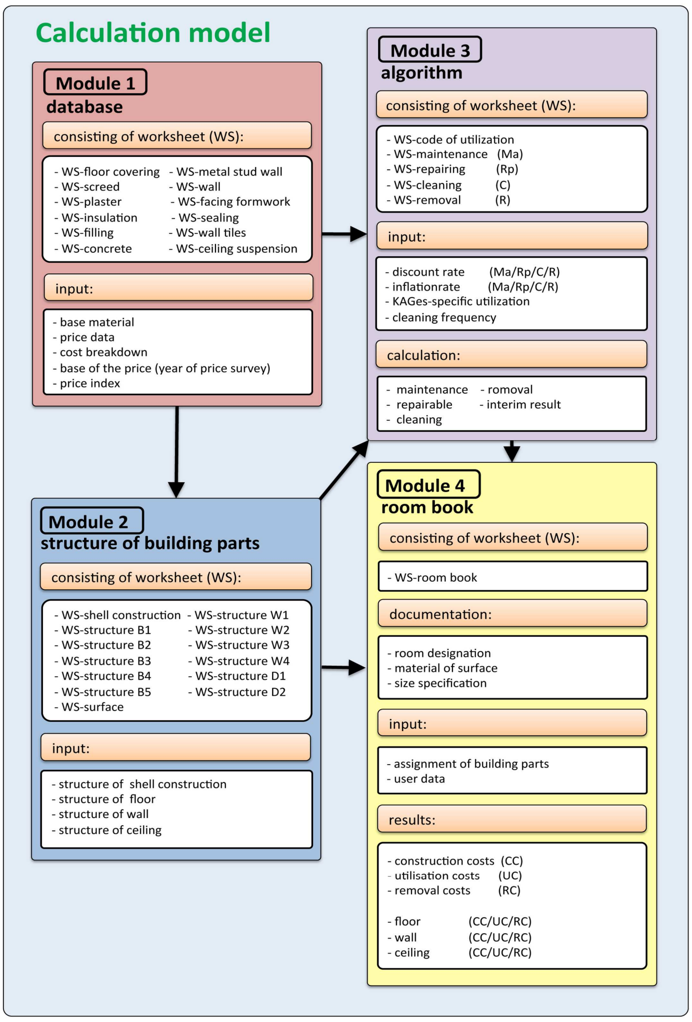


Figure 2. Structure of the calculationmethod.

2.2 *Calculation method of LCC-Analysis*

The life cycle of a building refers to a long period of time and considers all the costs and payments incurred in these life cycle stages. Furthermore time-related price developments have to be considered and these depend on economic, political and general business aspects.

These changing prices for construction activities and services must be considered in a detailed LCCA. For this purpose, the dynamic method of an investment calculation was used to gain practice-related results.

In line with the guidelines ÖNORM EN 15643-4 and ISO 15686-5 the whole-life costs and savings of each option are considered and usually converted into net value costs using discount rates. This discount rate is the rate of interest reflecting the investor’s time value of money and is defined by separating it into two types: real discount rate and nominal discount rate. The **real discount rate** *excludes* the rate of inflation in contrast to the **nominal discount rate** *includes* the rate of inflation. This LCC calculation method is based on the real discount rate. The complexity of accounting for inflation within the present value equation is simply eliminated. By using the real discount rate the calculation results are better comparable that means they can better compared with other projects. For a more realistic result, the inflation rate for construction activities and services have to be included into the (LCCA) calculation method.

2.3 *Structure of the assessment method*

The LCC calculation of buildings consists several complex processes. These comprehensive processes are combined in this project to a LCCA method and divided into four main modules.

Module 1 – Database
Module 2 – Build-up building part (modeling of building part)
Module 3 – Algorithm (Calculation)
Module 4 – Room concept book (results sheet)

To obtain a more detailed breakdown, a further distribution of these four main modules is needed and the structure is shown in Figure 2.
In ***Module 1*** - the correlation of the building materials with the unit prices as well as the layer-concerned subsequent costs can be entered under the materials in the building materials database.
Module 2 - provides the assembling of different standard cross-sections (CS) such as floors, walls and ceilings.
In ***Module 3*** - the set up option for a CS-relevant allocation of the utilization (e.g. cleaning types, categories, maintenance, repair) and the determination of the dynamic calculation parameters (such as calculation interest rate, price increase, inflation etc.) can be entered.

Finally, in ***Module 4*** - all calculation results of the analysis are shown in [€/m2] and are related to rooms.

2.4 *Building Materials Database*

A specially created building material database was developed for the LCCA of GH Feldbach. The required data were taken from the mentioned guidelines (TR-PBB 04) of KAGes, and BKI BAUKOSTEN (Fetzer 2009). With the help of a keyword like long text “1”, pictured in Figure 3, the materials were connected to the layer build-ups. The specification in field "2" shows a detailed description of the accumulated activities and the used materials. The total calculation results removal costs have been transferred to another worksheet and displayed in euro per square meter [€/m2] and space.

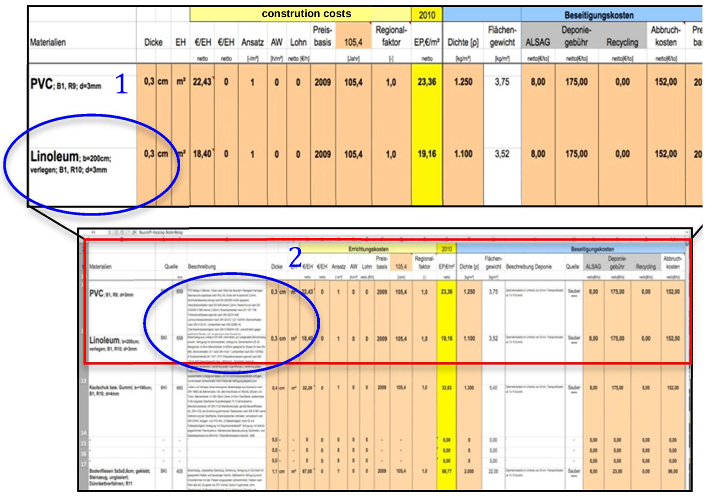


Figure 3. Material database structured by ÖNORM B 1801-1.

The prices of the positions are taken from the „BKI BAUKOSTEN - Positionen 2009" and contain the wage, material, machine and other costs as well as all additional remunerations for entrepreneurs.

2.5 *LCCA categories and parameters*

For the LCCA the following cost categories, shown in Figure 4, are taken into account in this project:

(1) construction costs,
(2) operation costs,
(3) maintenance costs and
(4) removal cost

The calculated construction costs are based on the data compilation "BKI BAUKOSTEN" and the results have been used in this forecasting model. Concerning the removal costs, a practical case study has been developed and is based on existing guidelines.

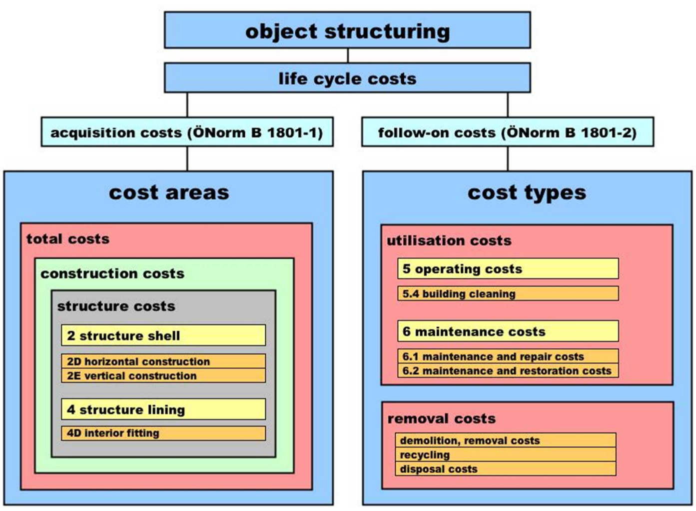


Figure 4. Included costs in the LCCA method.

The LCCA calculation model in this project does not include an analysis of the revenue and profit of GH Feldbach. Only those costs and materials are considered which can be directly associated to the construction, operation and disposal stage.

2.6 *Construction costs*

For a more detailed investigation of LCC a comprehensive documentation of the building costs is necessary. A literature review has shown that there is no database containing material costs for constructions accessible to the public in Austria. As mentioned before the "BKI BAUKOSTEN" has been applied to develop a database for the LCCA model.

The representation structure and the data processing is orientated in the "BKI BAUKOSTEN" on „Standardisiertes Leistungsbuch" (StLB) performance areas of Austrian operating construction companies. According to these performance areas, all positions are described as mentioned in the BKI and have been calculated from finished projects in Germany and contain the following types of costs:

- Salary,
- Material,
- Machines,
- Other (general and administrative costs, etc.)
- Bonuses for entrepreneurs (risk, profit, etc.)

The relation to settled objects makes these statistical parameters comprehensive and realistic. The results of the BKI are composed of German federal average values and can, by means of 'regional factors' and national factors, be converted to Austrian values.

2.7 *Utilisation costs*

The utilization costs are those costs which incur directly in the usage of the building and incur regularly, irregularly or only once.

The main structure of the utilization cost approach shown in Figure 4 is based on the framework ÖNORM B 1801-2 is assumed in the LCCA model and consists of the following costs:

- Maintenance costs - maintenance and repair costs
  - maintenance and restoration costs
- Operating costs - building cleaning

2.7.1 *maintenance and repair costs:*

The maintenance costs are a combination of measures to maintain the functioning state or to regain the latter in the life cycle of a unit. In this project the maintenance costs (maintenance and inspection) are assumed for the construction costs with an annual expense of 0.1%, generated by the ÖGNI (ÖGNI 2011). This annual expense considers only the cost areas of building construction, but not the technical equipment ones. These technical costs cannot be directly allocated to the single construction and are not included in the LCCA model.

2.7.2 *maintenance and restoration costs:*

For the evaluation of repair costs, the maintenance cycles are provided by KAGes. These maintenance cycles are described by a total conversion of the room and function program. These cycles consist of all partial activities of the **removal** of floor constructions without removing the carcass-reinforced concrete ceiling, the non-load-bearing inner wall constructions and the lowered ceilings without raw reinforced concrete ceiling, as well as the **(re)erection** of these building parts. The carcass remains untouched and constitutes the limit of the total system utilization time (Halder 2011).

2.7.3 *Technical service life:*

Using the required utilization and function conditions provided by KAGes, each room and building part service life (SL) is clearly defined. These required utilization conditions are shorter than the lifespan (LS) of the used materials:

LS materials > SL building parts

With this assumption it has to be ensured that the maintenance intervals are not determined by the lifespan of the used materials. They have only to be determined by the room and function program which defines the maintenance cycles.

2.7.4 *Building cleaning costs:*

As part of the utilization costs, the cleaning costs are set to interior spaces and the floor areas. The activities are indicated according to cleaning categories, and depend on the hygiene requirements and the cleaning frequency of GH Feldbach. These categories and frequencies can be changed and adapted in the new LCCA model at any time regarding the room and functional program and are calculated dynamically with price increase factor and calculation interest rate over the building utilization duration.

3 CASE STUDY

For the LCCA a systematic methodology was developed to calculate and forecast LCC for constructions in hospitals. This new approach should support the choice of materials and achieve the most appropriate design options in the early planning phases in a way which is at the same time practical, transparent and flexible enough to be easily adapted to different kinds of buildings. This approach has been applied in a case study on GH Feldbach.

The construction elements accepted into the new calculation model are defined in the guidelines (TR-PBB 004 1994) of KAGes. Figure 5 shows one room of the more than 500 rooms of GH Feldbach considered in the case study.

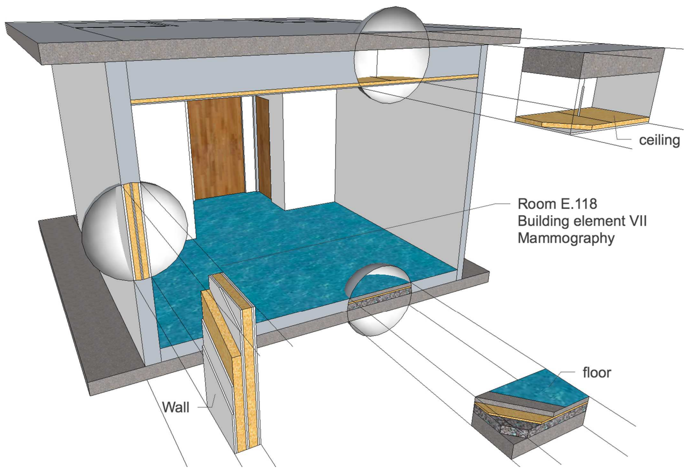
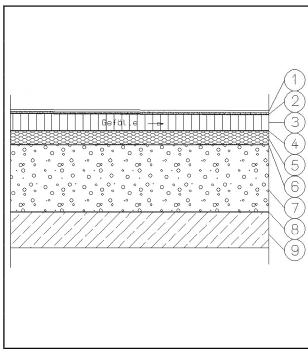


Figure 5. Example of construction elements of GH Feldbach.

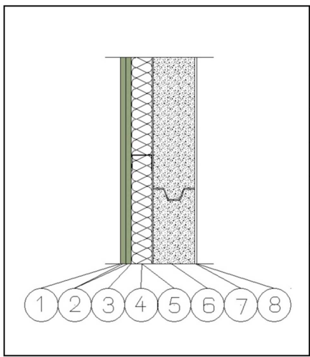
The study will be carried out using the room example “mammography” which is part of the building “Bauteil VII” of GH Feldbach. This section of the building will also be used to determine the removal costs.

Before the case study is explained in detail, the following one-layer build-up of standard cross-sections of floors, walls and ceilings have to be described. Their basic properties are shown in Figure 6-8.



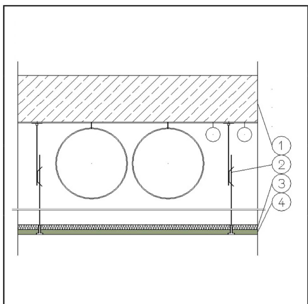
1	glued tiles
2	wet isolation / sealant
3	sloping floating screed
4	pvc-foil
5	extruded polystyrene foam board (xps)
6	pvc-foil
7	cement-bound aggregate (grit)
8	isolation against earth-moist
9	Base plate

Figure 6. Floor layer build-up.



1	coating
2	plasterboard double layer
3	foil
4	mineral fibers board
5	metal stud
6	autoclaved cellular concrete wall
7	putty plaster with plaster reinforcement nets
8	coating

Figure 7. Wall layer build-up.



1	Ceiling (reinforced concrete)
2	suspended ceilings hanger
3	Mineral fibers board
4	suspended ceilings (runners, plasterboard)

Figure 8. Ceiling layer build-up.

These construction build-ups can be modeled individually by the new calculation model and the data needed for this calculation will be automatically taken from the newly developed building material database.

3.1 *Removal costs*

In some guidelines the removal of a building is stated at the beginning of the erection phase and not at the end, e.g. in the Austrian standard ÖNORM B 1801-1 (ASI 2009) as well as German DIN 276-1 (DIN 2008). The main reason for doing so refers the circumstance that the existing building has to be removed before the erection phase of the following building can be started.

For the case study and the newly developed calculation method, the removal phase of a building has been set to the end of the building-life stage. The result of a literature research concerning removal costs has shown that no uniform procedures and information about demolition and retreat costs exist. The demolition costs were modeled by a theoretical demolition object example of GH Feldbach „Bauteil VII“ and verified in cooperation with demoliton companies within the Feldbach area.

Going back to Figure 9, load-bearing structures which are not demolished are indicated by thick lines.

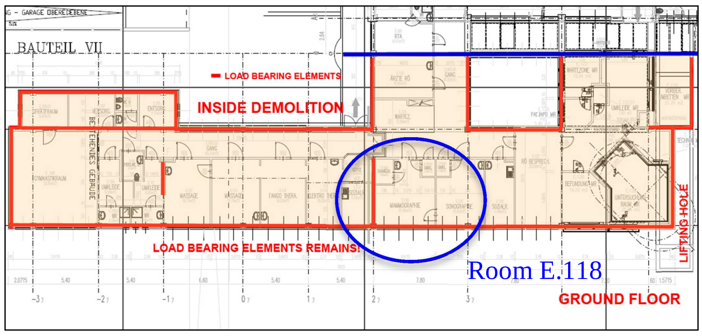


Figure 9. Section “Bauteil VII” of GH Feldbach.

The obtained cost data for the demolition are composed of the wage and machine costs, including additional fees, as well as the transport costs and dumping ground fees (ASI 2006).

4 RESULTS

The results of the LCCA show that it is important to determine the influence of the significant parameters in a first step before pursuing a comprehensive investigation on LCCA because wrongly applied parameters can lead to undesirable results.

For the calculation the utilization of the building system boundary is set at 80 years (Halder 2011) and the discount rate (iz) is assumed at 5.54%. The inflation rate (ir) for maintenance is assumed at 1.82% and the inflation rate (ik) for construction activities is assumed at 3.32% (Halder 2011).

After entering all relevant data for acquisition costs an estimation of the LCC over a given period of time can be carried out.

In a second step, a financial comparison of different build-up variations can be carried out. In Figure 10 two identical ground superstructures are compared under the assumption of the KAGes-specific utilization period of 15 years. The two structures vary with regard to their surface coverings – option 1 (V1) realized in PVC and option 2 (V2) in ceramic slab. Worth to mention is the fact that ceramic slab is the more expensive of the to options in terms of acquisition costs.

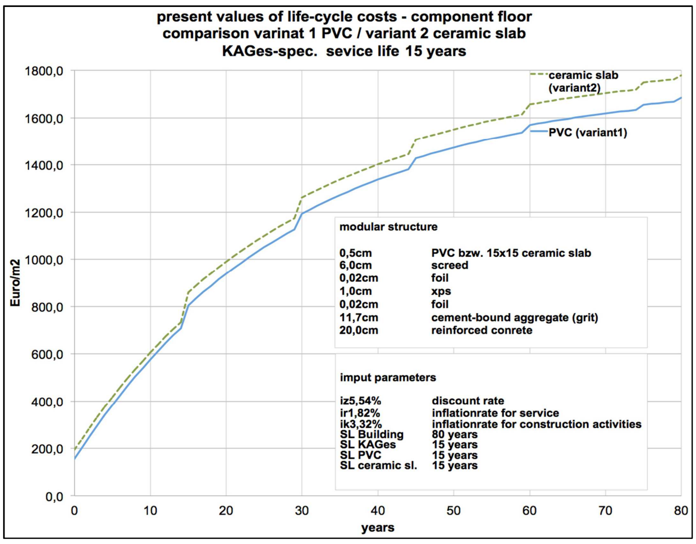


Figure 10. Comparison of variant V1 PVC / V2 ceramic slab (UD V1 = UD V2).

Due to practical considerations we now change the initial parameter life time from KAGes specifications to material life times. Normaly , the life time of ceramic slab is increased to 30 years.

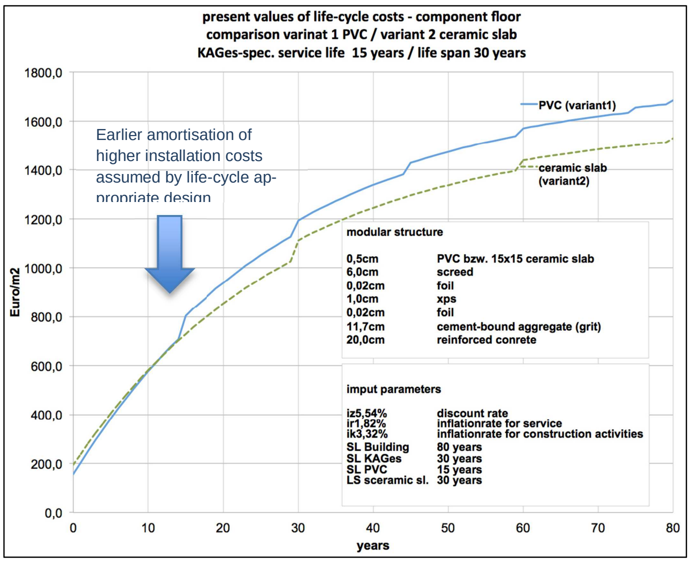


Figure 11. Comparison of variant V1 PVC / V2 ceramic slab (UD V1 ≠ UD V2).

The results of this LCC calculation determines lower life-cycle costs for option 2 even though it comes at higher acquisition costs. The comparison, shown in Figure 11, leads to the conclusion that an amortization of the erection costs for the more expensive option 2 “ceramic slab“ can be achieved after a period of 15 years. It also shows that a decisive reduction of the subsequent costs can be achieved using a well adapted life-cycle planning.

Variant studies enable a better synchronization of the utilization periods and life periods of the different construction components. Through well adjusted life cycle planning and through better use of the employed materials (building part layers) in the planning phase, an earlier amortization of the erection costs and a minimizing of the LCC can be achieved.

5 CONCLUSION

According to the KAGes evaluation on facility costs for hospital buildings, the operating equipment costs are similar to the costs of medical technical equipment and staff costs. This crucial fact allows for major life cycle cost improvements.

The biggest potential for a total consideration of costs of a building consists of the fact that a main part of the total LCC can be influenced in the early planning phase. Therefore not only the erection costs of a building can be influenced, but the subsequent costs as well.

This paper describes a calculation model to analyze and forecast LCC of selected building parts of a general hospital. In order to control the considered costs as precisely as possible, it is necessary to provide a complete documentation of all cost-incurring processes during the utilization period. The total cost revisions considered in the newly developed model have been divided into acquisition processes and subsequent processes according to the standards and guidelines of the ÖNORM B 1801.

With this methodology, in which all relevant parameters for an LCCA are collected, a detailed modeling and calculation can be performed. However the data is obtained, the LCC can only be compared in a meaningful way if the documentation structure of the building part specific costs correspond to standardized and recognized guidelines.

The purpose of such a sustainability assessment is to gather and report information for the purposes of decision-making during the different phases of construction, design and usage of buildings.

As our model shows, the LCC calculation gives significant benefits in the early planning phases and helps to reduce building operation and maintenance costs. This approach is particularly useful when project alternatives, which fulfill the same performance requirements but incur different initial and operating costs, have to be compared in order to select the most affordable solution with maximum savings.

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