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Development of LCAbyg: A National Life Cycle Assessment Tool for Buildings in Denmark

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Abstract. In the autumn of 2014, the Danish government presented a national strategy for the building sector. Sustainability was mentioned as one of five focus areas for the future political work within the sector. Subsequently, the development of a national Life Cycle Assessment tool for buildings was initiated, and the first version of LCAbyg was launched in 2015. The primary goal behind the development of LCAbyg has been, with judicious, intuitive and transparent visualization of LCA results, to increase building designer's awareness of the life cycle impacts of buildings, and to understand where, in the building life cycle, reductions of environmental impacts can be achieved. This paper describes the principles of the LCA tool in terms of the required input data for the building assessment, the calculation methods within the model and how the LCA results are presented to the user. The paper furthermore demonstrates how the tool enables the user to perform comparisons of different construction solutions and material uses, and elaborates on how the predefined visualization of results qualifies the designer to identify hotspots and to understand and mitigate the major impacts throughout the building's life cycle.

1. Introduction

A Danish governmental building strategy from 2014 introduced sustainability of buildings as one of five focus areas for the future political work within the sector [1]. The strategy mentioned the possibility to introduce a voluntary sustainability class as part of the Danish building regulation, and addressed the need to develop harmonised LCA and LCC tools for buildings. With reference to the government's strategy, the national building authorities funded the initial development of a set of life cycle tools for environmental and cost evaluation in the building sector. The first versions of the tools, LCAbyg and LCCbyg, were launched in spring 2015 [2] [3].

The aim with the LCA tool development was, in the first place, to provide the Danish building sector with a harmonised LCA tool for buildings, a tool that was free-of-use, and that could support the development of sustainable buildings in Denmark. Secondly, the aim of the tool development was to present the complex results of a building LCA in a transparent fashion that assists the users in understanding the impacts related to the building life cycle, and the environmental consequences of choosing different construction types and materials. Thus, a significant part of the tool development was related to communication of LCA method and interpretation [4].

This paper presents the structure of the current LCAbyg tool (version 3.2), the applied calculation principles and the dissemination of results to the users of the tool. An outlook to future development is furthermore provided.



2. Tool structure

Figure 1 describes a brief overall model structure of LCAbyg. The tool can be divided into three main parts: 1) User input, 2) Calculation tool and 3) Presentation of the results to the user.

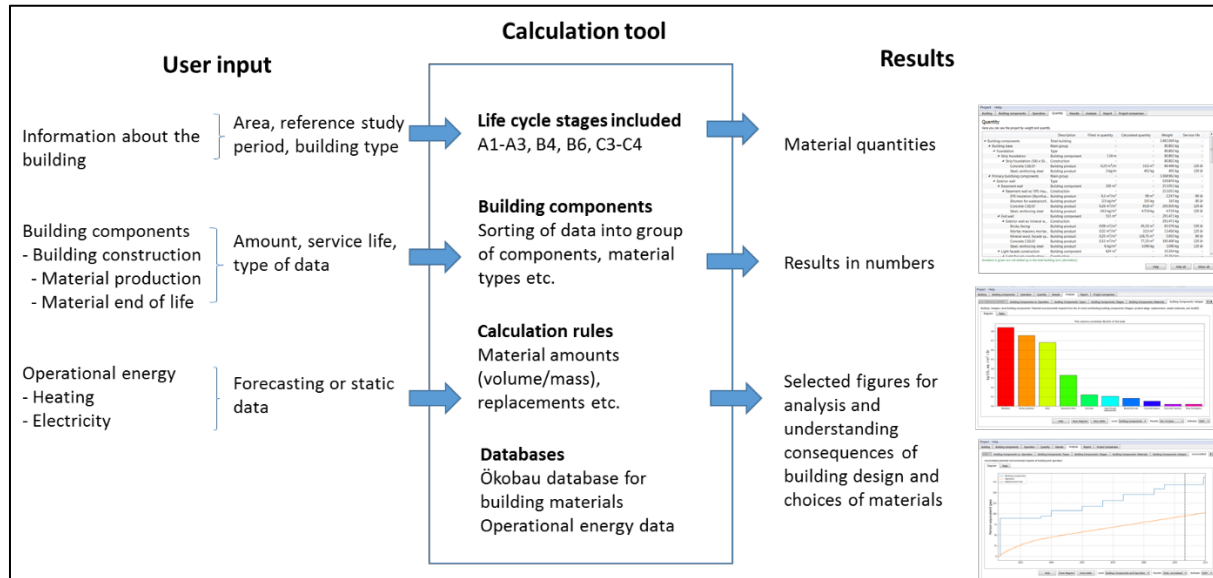


Figure 1. The overall structure of the LCAbyg tool.

2.1. User input

As shown in figure 2, the tool is divided into 8 tab pages. The user input takes place in first three tab pages, namely 1) Building, 2) Building components and 3) Operation.

In Building, the user fills in general information about the building, such as brief description of the building, address, building type, area, year of commissioning and reference study period (RSP).

The Building components, holds the major workload required by the user. Here the user inserts all the information about the building components. It can be seen in figure 2 that a building modelled in LCAbyg consists of a selection of building components. Each building component consists of one construction, that either can be selected from a construction catalogue within the tool or new construction defined by the user. A construction consists of one or more building products (materials), which each consists of a material production stage (A1–A3) and material end of life stage (C3–C4).

When selecting constructions or materials used in the construction, the user can, as shown in figure 2, enter the database and perform quick comparisons of the environmental impacts of possible solutions.

The third tab page for user input relates to the operational energy consumption for electricity and heating. LCAbyg includes two possible energy scenarios for the operational energy consumption; 1) static energy data based on the energy supply as in year 2015 and 2) a forecasting scenario based on the politically agreed goals for energy supply until year 2050.

2.2. Calculation tool

The calculation part involves important assumptions influencing the final results of the building LCA. This chapter includes a brief description of selected important factors influencing the results.

2.2.1. Life cycle stages. The tool includes the following life cycle stages (and modules):

- Product stage (A1–A3)
- Use stage (B4:Replacement, B6: Operational energy use)
- End of life stage (C3 Waste processing, C4: Disposal)

A construction consists of one or more building products (materials), each consisting of a material production stage (A1-A3) and material end of life stage (C3-C4), which are grouped together in the building product database. When the user chooses building constructions for the building, this package of data for the building products is automatically included.

Data on the building product service life is included there as well, which then defines the amount of replacements during the RSP. There are assumed limits to the replacements near the end of the RSP. Hence, the tool calculates no replacements in the last 10 years up until the end of the assumed service life that defines the RSP [5]. Furthermore, no replacements are calculated if a building material's service life exceeds the remaining RSP of the building by 2/3rd. This means that a material with 60 year service life is not replaced in an office building with RSP of 80 years, but is replaced once in a residential building with RSP of 120 years. . The calculation of the end-of-life impacts from replaced materials during use stage are allocated to the B4 use stage according to the EN 15978 standard.

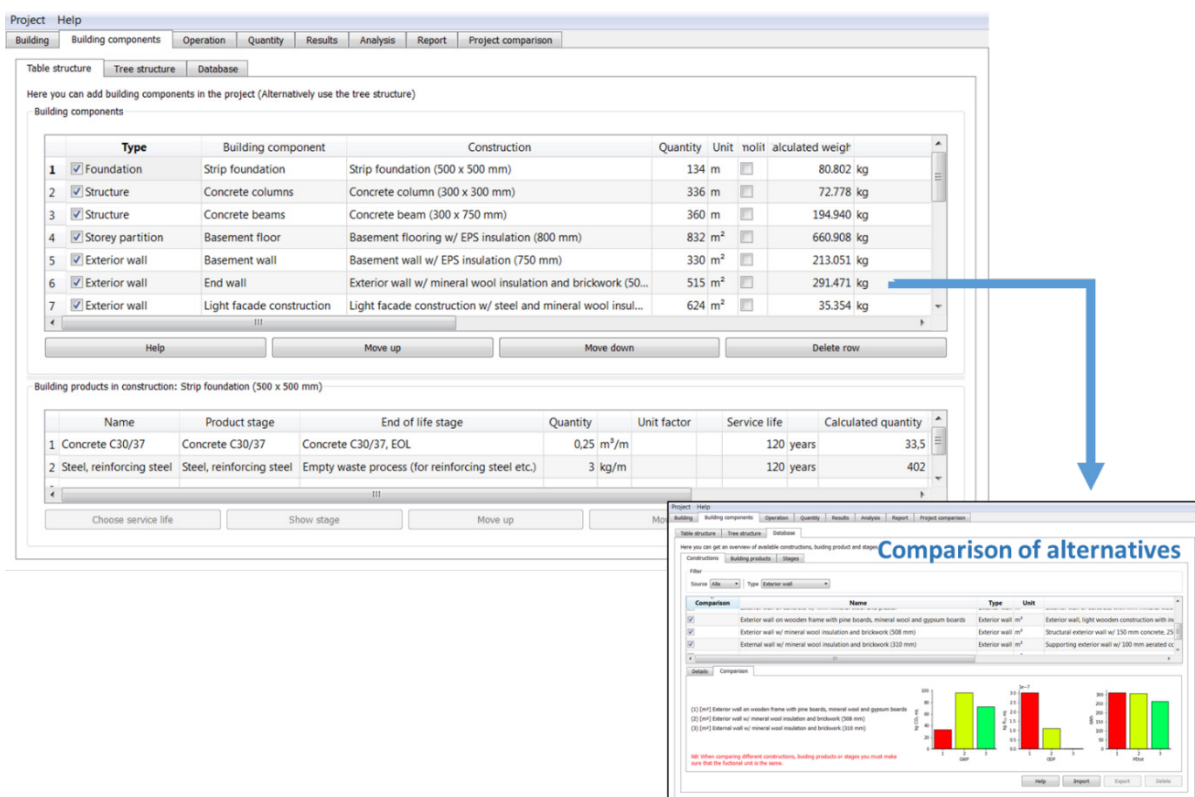


Figure 2. User input: Building components and comparison of different component alternatives.

2.2.2. Building components/sorting data. An important part within handling the data entered into the tool is sorting the data in different levels and groups in order to create the results and figures. This structure of the data and calculations was already presented in section 2.1.

2.2.3. Building material data. Ökobau is a free-of-use German national life cycle impact assessment (LCIA) database specifying impacts and resource uses associated with a specific reference flow. Due to lack of a Danish national database, Ökobau was evaluated as an acceptable alternative after initial assessment on its representativeness for use in Denmark. LCAByg operates with a slightly adapted version of the German Ökobau database, and the current version of LCAByg (version 3.2) operates with Ökobau version 2016.

The Ökobau database can be supported by EPD data, where the user can enter EPD data for building materials in LCAbyg. The amount of EPDs available for building materials in Denmark is currently slightly increasing, but is still behind neighbouring countries such as Norway, Sweden and Germany.

2.2.4. Operational energy use – forecasting or static data. The data on operational energy in LCAbyg represent the Danish energy grid and includes data for the average Danish electricity production, natural gas for heating and district heating, which were developed for LCAbyg [6].

The tool allows the user to choose between the use of static energy data based on dataset from year 2015 and forecasting of electricity and district heating according to the political goals until year 2050. The forecasting scenario is based on estimation of the expected development of the energy composition in 5 data points (2015, 2020, 2025, 2035 and 2050) and the corresponding expected environmental impacts. Table 1 gives an example of the values for one selected impact category (GWP). The recommended reference study period in building LCA in Denmark is from 80 to 120 years depending on building type. Therefore, a building LCA scenario calculated in 2018 represents a period ending in 2098-2138. In the forecasting scenario, data for 2050 is used for the remaining years after year 2050.

Table 1. GWP for the forecasting scenarios for five data points (year) [6]

	2015	2020	2025	2035	2050
Electricity kg CO ₂ -equiv./kWh	0.352	0.201	0.169	0.031	0.024
District heating kg CO ₂ -equiv./MJ	0.052	0.031	0.028	0.020	0.016

2.2.5. Environmental impact categories. LCAbyg includes the following 7 environmental impact and resource use categories: Global warming potential, Ozone depletion, Photochemical ozone formation, Acidification, Eutrophication, Abiotic depletion potential for fossil resources and Abiotic depletion potential for non-fossil resources. The tool includes the following three energy resource categories: Use of primary energy renewable, Use of primary energy non-renewable and Use of renewable secondary fuels. The use of primary energy is however in the results grouped into one category, namely Total use of primary energy.

2.3. Results

The result part of the LCAbyg covers five out of eight tab pages of the tool. Considerable effort has been assigned to the development of the result part of the tool in order to create the intuitive and transparent visualization of the LCA results wanted to communicate complex results in simpler form to the building designers. The goal was to use selected figures to increase building designer's awareness of the life cycle impacts of buildings, and to understand where, in the building life cycle, reductions of environmental impacts can be achieved. The result part consists of the following sheets:

- Quantity: An overview of the project's materials use in weights, quantities and service lives. The overview can be unfolded at different levels of details.
- Results: Detailed numeric results of all impact categories, which can be folded out in different levels of details (main group of building components, type of building components, constructions, building products and stages).
- Analysis of the results with several selected figures: Operation vs building, Building components: (types, materials and two different hotspot analysis), Accumulated environmental impacts over the RSP, Operation and Comparing projects.
- Report. Standardized report with calculation entries and LCA results of the project.
- Project comparison: Possibility to compare different projects.
- Selected figures and results predefined for LCA for the Danish DGNB certification

In order to get the full understanding of the results of the building LCA, it is recommended that the different outputs of results are used interactive (shuffle around) to get deeper understanding. In the following sections, the thoughts behind the educational approach related to the communication to designers are illustrated briefly.

2.3.1. Quantity of materials in the building. This sheet gives a valuable output in order to quickly get an overview of the quantities resulting from the data entered for the building components. This sheet allows for checking obvious mistakes in the volumes, masses or densities inserted into the model. As shown in figure 3, the details of the data can be folded out into more details. The list also provides an overview of the replacements expected due to the length of the service life.

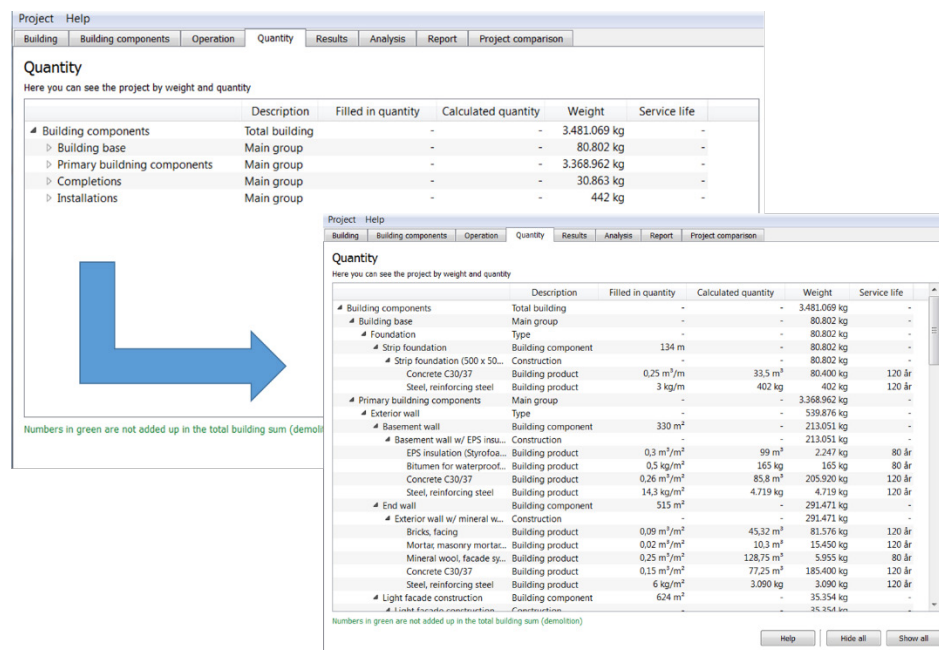


Figure 3. Results: Quantities of materials in the building.

2.3.2. Analysis with figures. Figure 4 below shows some of the figures that are available for the analysis to support the detailed numerical results. The results can be viewed as divided into life cycle stages or into 6 materials categories defined in the Ökobau database (insulation, metal, mineral, other, synthetic and wood). The hotspot analysis is performed for either the 10 most important building components or 10 most important building products, sorted and showing how much they cover of the total environmental impact for the impact category selected in the figure.

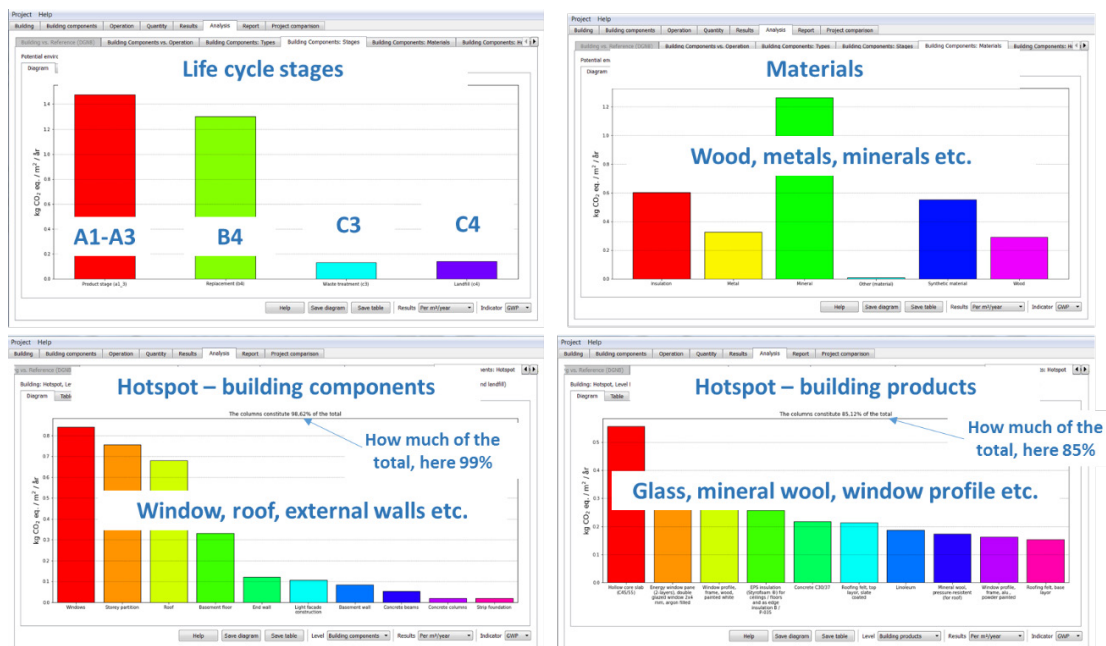


Figure 4. Examples of the figures for analysis of results.

It is important for the designer (or the decision maker) to view the environmental impacts over time in order to understand and evaluate the effects of different material choices with different service life. Figure 5 shows the results presented accumulated over time. Here also different level of details can be visualised. Figure 5 shows first GWP from operation (orange line) versus embodied (blue line) over 80 years. For this office building, the embodied GHG emissions are about 2/3 of the total GWP from the calculated case. The smaller figure shows when the level of details has been increased for the embodied impacts, showing the building component types (foundation, exterior wall, interior wall etc.). The black vertical line marks the last 10 years where there is no replacement.

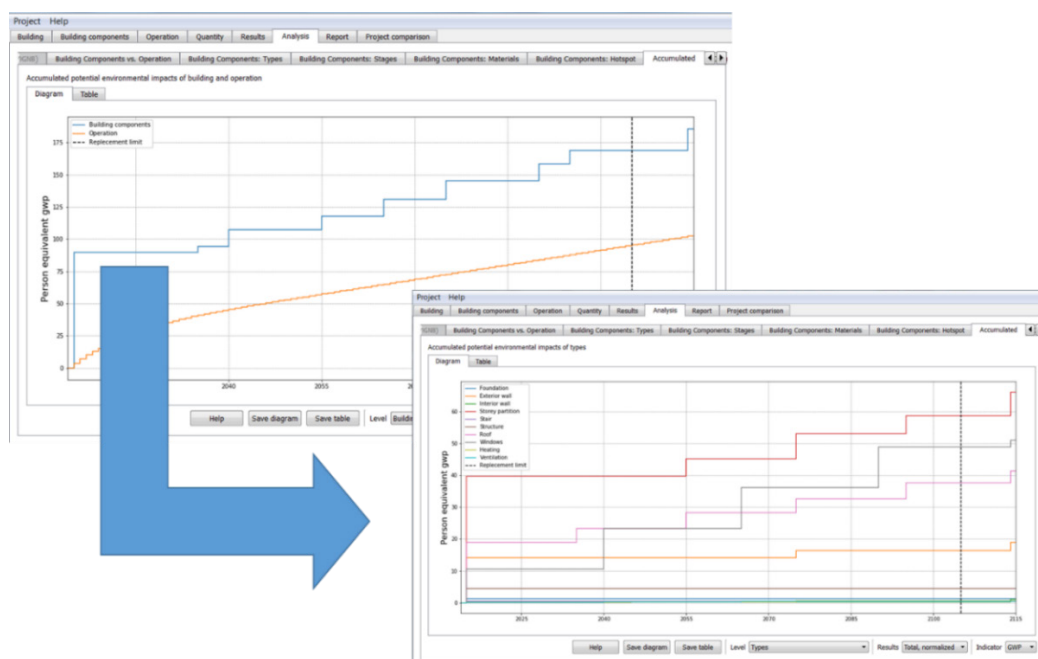


Figure 5. Results accumulated over the reference study period.

3. User interpretation of LCA results

The previous chapter gave a brief introduction to the structure of the tool, calculation and the output. As mentioned, the primary goal behind the development of LCAByg was to increase building designer's awareness of the life cycle impacts of buildings, and to understand where, in the building life cycle, reductions of environmental impacts can be achieved. Based on the authors' experience from development of several specific LCA tools for buildings [2], road constructions [10] and waste management [11], it is decisive to focus on simplifying the process as much as possible [8] and finding ways of communicating complex LCA results to the users (and decision makers). Therefore, a notable effort was allocated to assisting the users' possibilities to perform comparisons of different construction solutions and material uses within the tool. Furthermore developing predefined visualization of results that were believed to qualify the designer to identify hotspots and to understand and mitigate the major impacts throughout the building's life cycle.

The intention with the specific selection of ways to present the results was to encourage the user to shuffle around between the numerical results and the figures in order to understand the environmental impacts related to the building project evaluated. Figure 6 is similar to figure 5 above, showing the accumulated GWP over time. Here the information from expanding the level of details (in figure 5) and from the Quantities (figure 3) were added and used to understand the reasons for increasing embodied impacts over time. The user can from this information continue an iterative process to find ways to lower impacts, e.g. by changing the initial construction and material selection.

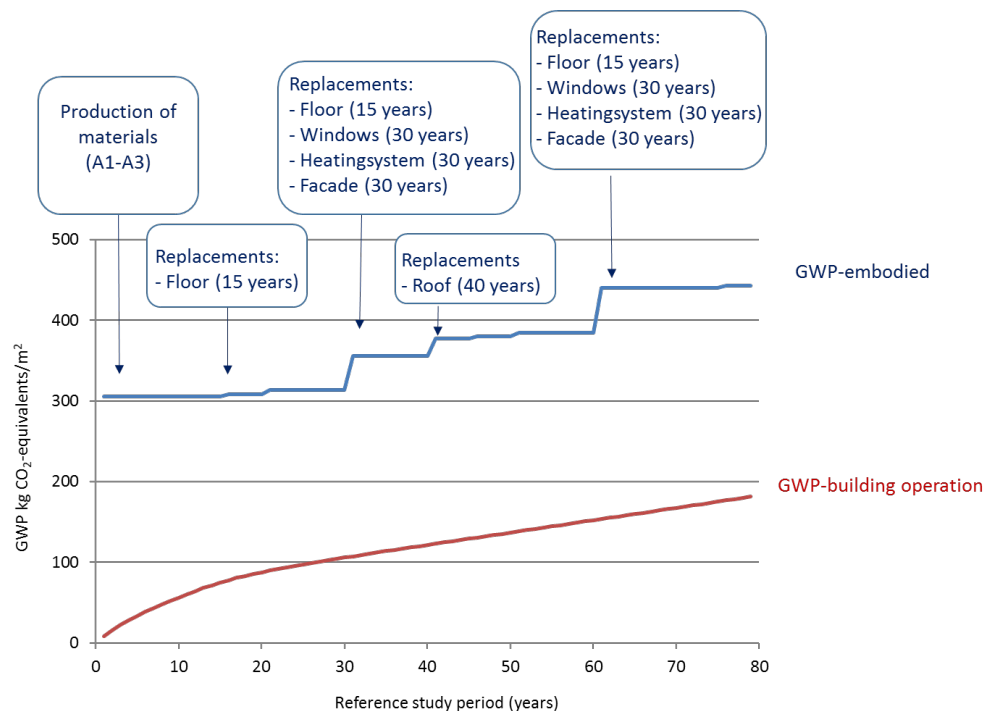


Figure 6. Results accumulated over the reference study period (data exported to Excel), supported by information from Quantities of materials.

4. Further developments of the LCAByg tool

The LCAByg tool is subject to ongoing adaptations of method and functions. Since launching the original version of the tool, several projects in which adaptations of the tool were executed to improve user experience and expand functions, for instance to include benchmarks on Danish reference buildings [7]. Recent development projects concern a simplified approach to user inputs with the aim of easing LCAs at early stages of the building design. The changes to the tool entailed the development of

a comprehensive catalogue of construction examples used in practice. An underlying principle of a layers structure enables the user to model a building with predefined layers of building element [9]. The building element ‘Outer wall’ for instance consists, as a default, of three layers; 1) outer surface, 2) supporting construction with insulation, 3) inner surface. All layers contain ‘typical’ amounts of use per m² of the specific building element and for all layers, a range of layer variations exists in terms of materials and amounts used. At all times, the predefined layers can be edited by the user if more specific data is available on type and amount of materials. The new development enables a user to obtain a comprehensive LCA model of a building based on just schematic information about the building layout and assumed choices of typical construction solutions.

Future developments of the tool may concern the integration of product specific environmental declarations (EPDs), which in the current version is entered manually by the user. Additionally, broadening of the scope to include more life cycle stages could be investigated (e.g. by including stage A4 and A5) as well as the current focus on circular economy (e.g. by including module D).

Finally, it is well known that several commercial or freely available LCA tools exist and which are under constant development. And some which are based on approach using Building Information Modelling (BIM) to assess a range of construction options in early design stages. Future development of LCAbyg will undoubtedly be inspired by those tools or work towards integration of tools.

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