Parametric Life-Cycle Assessment and multi-objective design optimization

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Introduction

This paper presents an integrated approach for implementing parametric life-cycle assessment in a
project's early phases, coupled with multi-objective design optimization, considering material cost
and embodied carbon emissions.

Objectives

The key objectives of this poster are summarized below:

- Examine the degree at which changes in a project's size can influence its embodied carbon emissions.
- Implement carbon as a parameter in early design stages.
- Use pre-set carbon benchmarks based on which a project's size can be determined.
- Couple early design add-ons such Carbon Designer (One Click LCA) with Grasshopper to obtain a complete bill of materials.

Methodology

Following the development of the Grasshopper script for the building, One Click LCA's (OCL) add-on "Carbon Designer" was used to obtain a full BoM for the case study. One Click LCA's Grasshopper plugin was chosen due to the software's large construction materials database. The materials from Carbon Designer were then transferred in Grasshopper. For simplicity, geometries not drawn were not transferred in Grasshopper. The materials included are shown below:

- Ready-mix concrete, normal-strength, generic, C40/50 (5800/7300 PSI), 0% recycled binders in cement (400 kg/m3 / 24.97 lbs/ft3)
- Concrete ground slab assembly, incl. insulation, 550mm (EPS Insulation, Ready Mix Concrete C30/37 with 10% rec. binders, Plastic Vapour control layer, Reinforcement Steel 90% recycled, Self levelling mortar, for floots)
- Steel roof assembly, U-Value 0.13 W/m2K, 300mm (Steel sheets 60% recycled, Plastic vapour control layer, Glass wool insulation panels, Reinforcement steel (rebar) 90% recycled)
- Concrete roof tiles avg. thickness 22.4mm
- Triple glazed window, incl. wood-alu frame (3x float glass single pane, wooden decking, aluminum profile for windows and doors)

Costs were derived through OCL's Life-Cycle costing add-on and for simplicity there were entered using surface as the intensity denominator. Octopus was then used since it allows multi-objective evolutionary optimizations. Through Octopus, cost, area and carbon emissions were examined simultaneously and optimized trade-off solutions were provided. Additionally, the carbon benchmarks were obtained from OCL's Carbon Heroes Benchmark feature.

The design was then uploaded in One Click LCA to convert it into a full model by adding the geometries not drawn in Grasshopper (i.e., doors, beams, foundations and load bearing internal walls).

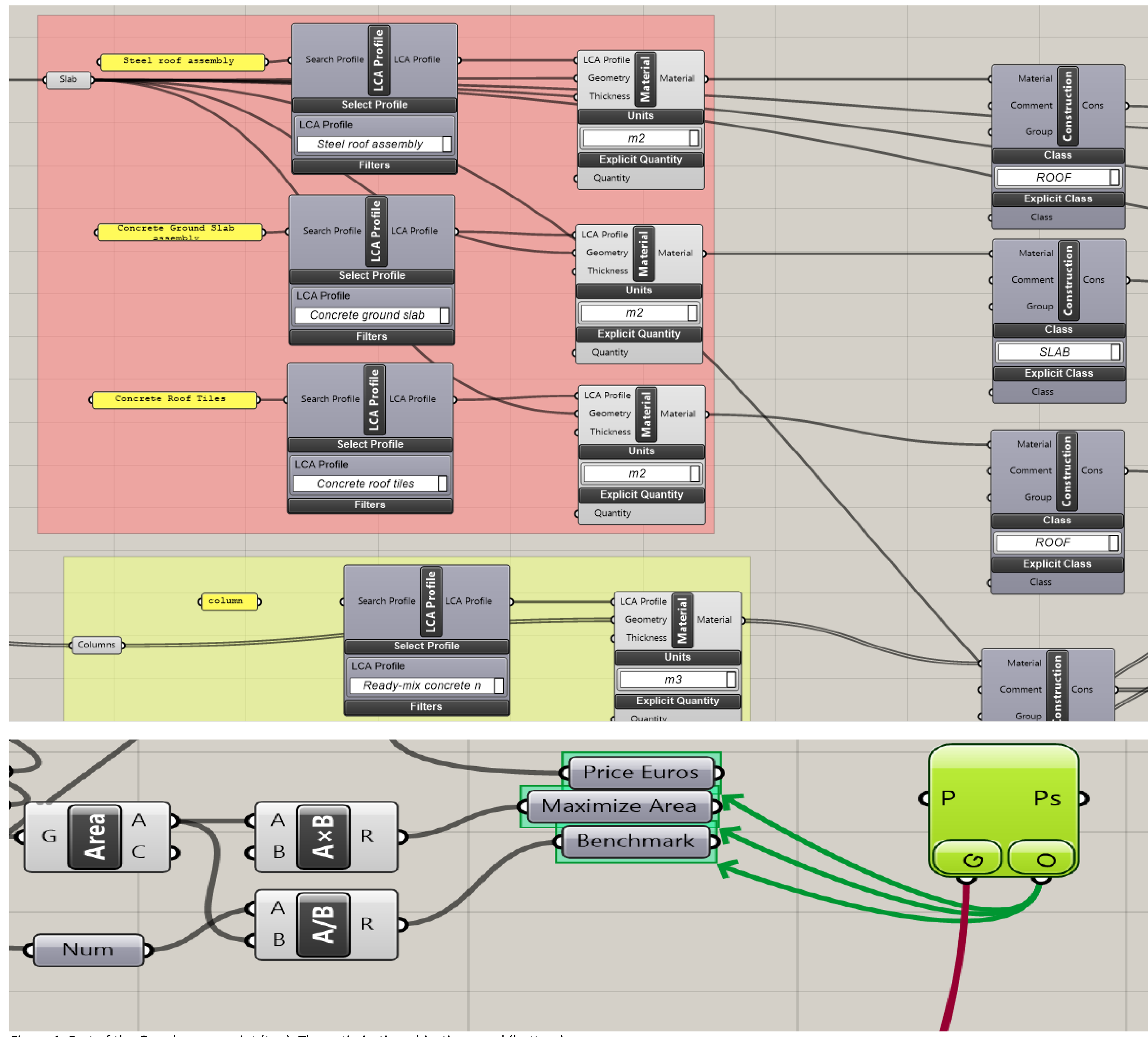

Figure 1. Part of the Grasshopper script (top). The optimization objectives used (bottom)

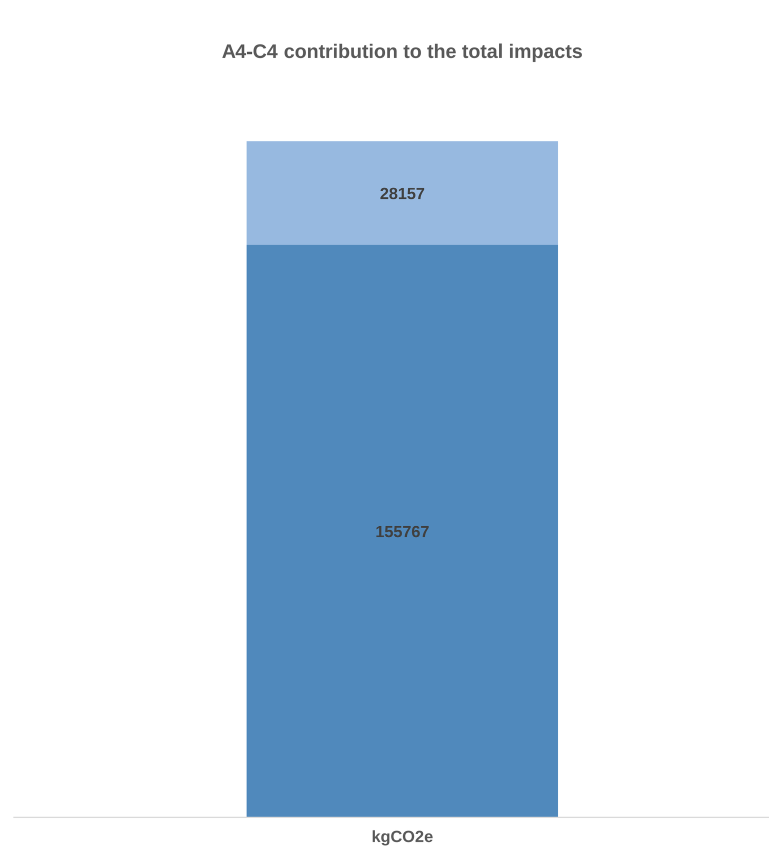

Figure 2. Contribution of A1-A3 emissions against A4-C4 to the design's entire carbon footprint.

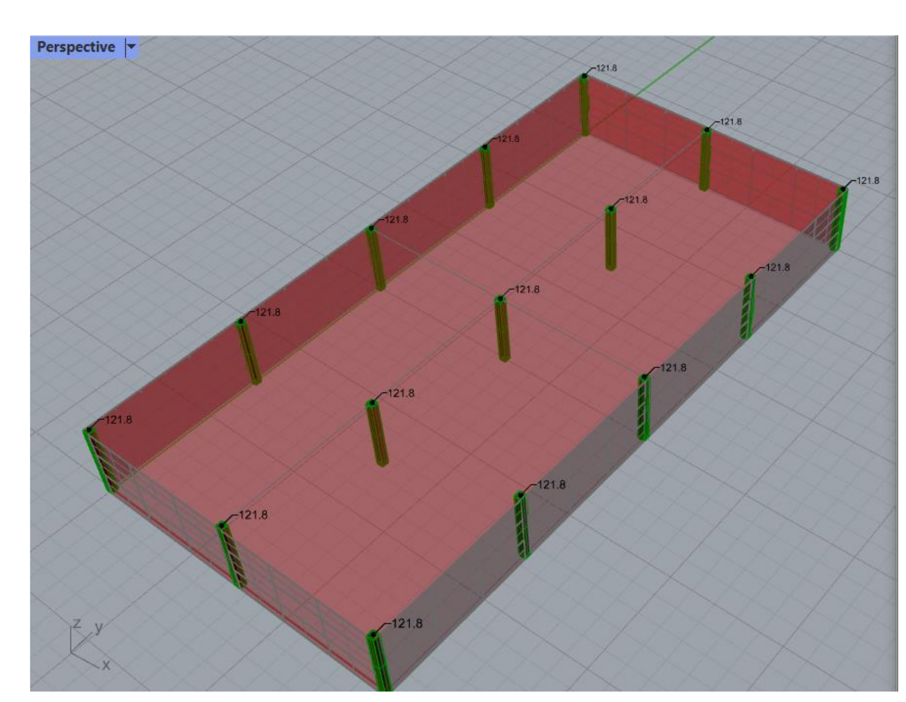

Figure 3. The 3D model coloured according to the carbon intensity of each element (columns shown here).

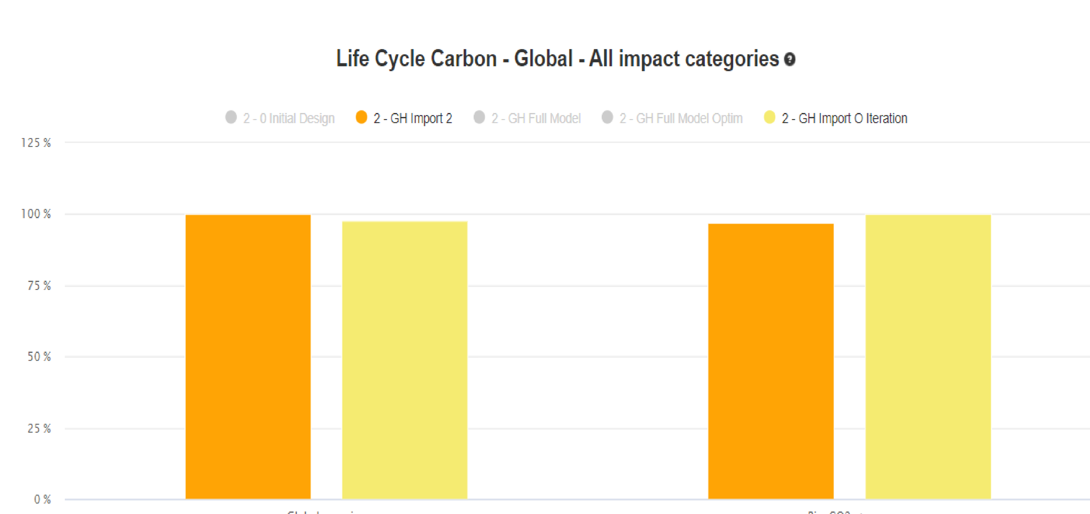

Figure 4. Comparison Between two iterations produced in Grasshopper.

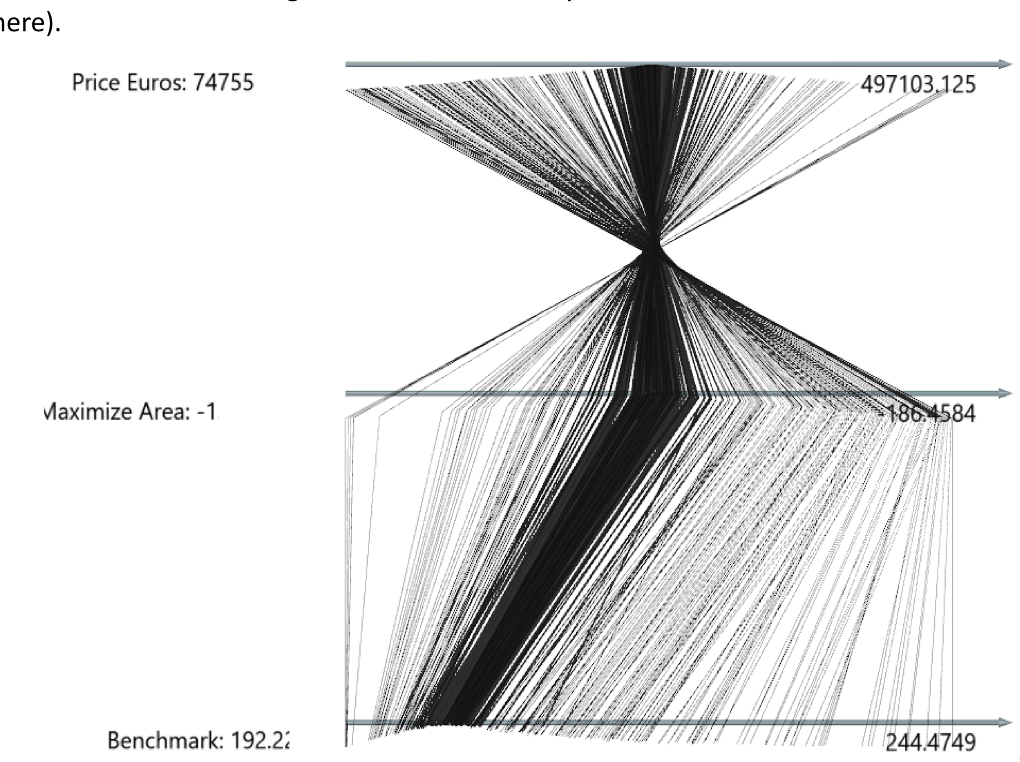

Figure 5. Octopus solutions illustrating the trade-offs between each. The algorithm converged at ~800 m2 and 250.000 Euros price.

Key Results

- The original design ended in Band B of Carbon Heroes Benchmark.
- By examining additional iterations of the same area range, it is possible to reduce carbon intensity by additional 3% (+-2% threshold).
- Using solely Grasshopper & Carbon Designer in tandem with any carbon benchmarks, it is possible to construct an entire bill of materials.
- Increasing the amount of recycled binders from 10% to 20%, can reduce emissions by up to 6%.
- By converting the LCA profiles given in parameters and not static values and subsequently using them as parts of the genome, it is possible to find suitable iterations using the most optimal materials combination (due to increased simulation time, only a limited number of attempts were performed).
- Material optimization techniques resulted in 18% reductions in emissions (only generic materials used).

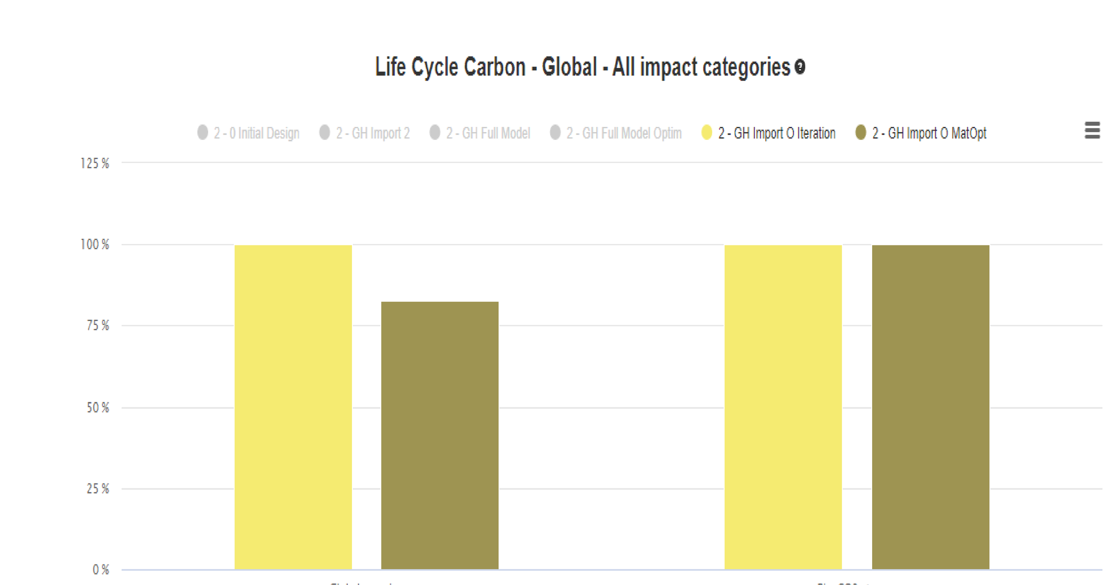

Figure 6. Comparison of the final iteration against a design that implemented early material optimization choices (only generic materials used).

Conclusions

- The results of this case study showed that early stage optimization in Grasshopper can yield up to 10% reductions in CO2e using the right material combination and shape affecting parameters.
- Carbon Designer can assist in developing a full bill of materials which can then be entered in Grasshopper.
- Any carbon benchmarking figures can assist in estimating the project's size.
- It is possible to obtain a full material list and design options early on and move to the next stages fully informed.