

linking Rhino 3D and OneClickLCA

Development of a Grasshopper script which enables carbon footprint assesment in the early stages of architectural planning

report by NOMAD architects

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Tallinn, Estonia

Development of a Grasshopper script which enables carbon footprint assesment in the early stages of architectural planning. Linking Rhino 3D and OneClickLCA

March 2021

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Abstract

The aim of the paper is to describe a method for implementing carbon footprint information about various designs in the prefabricated building market which would inform the client on environmental impacts of certain decisions as well as help planners to develop designs which align with multiple sustainability goals.

This paper describes two developed Grasshopper files which enable fast life cycle assessment of Rhino 3D models. It allows the user to link Rhino 3D with existing LCA softwares, such as OneClick-LCA. Furthermore the developed Grasshopper files enable carbon footprint estimations for the used materials even in the most early design phases.

Lastly, the paper suggests further improvement possibilities of the Grasshopper files to enable even more accurate life cycle assessments which would take in account location and function specific information.

Keywords

LCA, carbon emissions, Rhino 3D, Grasshopper, OneClickLCA, prefabrication, emission optimization

1. Introduction

Building life cycle assessment (LCA) has become one of the major methods to evaluate the sustainability of buildings. It allows to measure the building's environmental impact in terms of global warming, water pollution, resource depletion by quantifying and evaluating material and energy inputs. The inputs are usually analysed in life cycle stages of a building such as material extraction and manufacturing, use stage as well as end of life with disposal scenarios. (Davila & Reinhart, 2013)

As some studies have shown, the buildings embodied emissions from the materials might even exceed the emissions of the operation (Hestnes, 2017, 17). This points out the importance of assessing the material and design choices which happen at the early stages of building designing. With prefabricated and modular housing options on the market, the possibilities to pre-evaluate and improve the environmental impact of buildings at the early design stages have increased. In particular, the use of digital modeling tools helps to sketch and compare multiple design ideas in a short time.

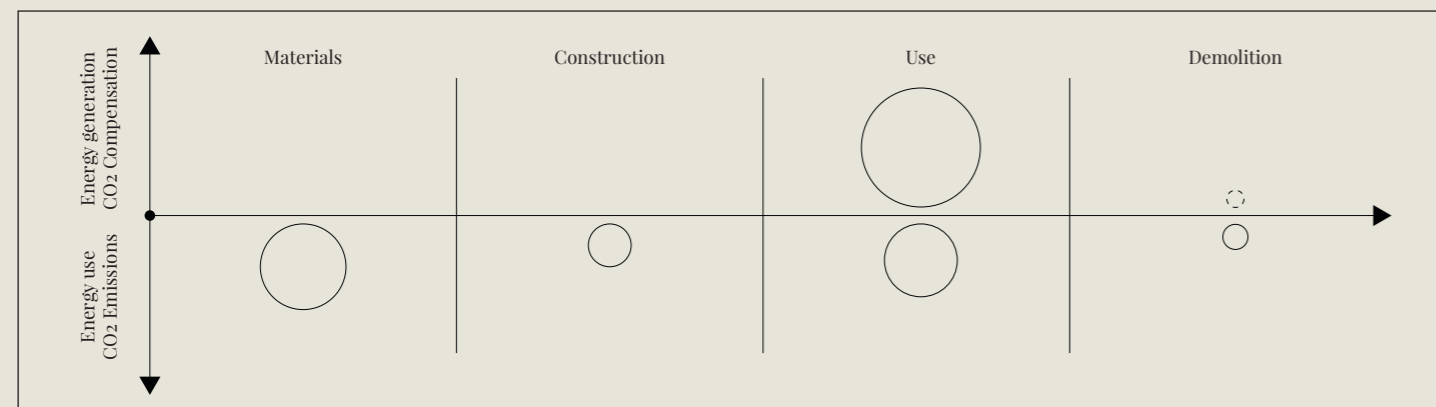
Although the popularity and requirements of building integrated modeling (BIM) softwares is increasing in the building industry, a computer-aided design (CAD) software such as Rhino 3D by Robert McNeel & Associates has close to no limitations in the freedom of design while at the same time offering plug-in software extension such as Grasshopper which enables parametric design functions. This causes the soft-

ware to be very appealing for the creatives in the field of architecture. Yet, Rhino 3D does not have a simple, open source and established workflow to extract the building information for the purposes of carbon emission calculations which softwares with BIM formats might offer.

At the same time, an online platform Configurator by Creatomus Solutions OÜ, which offers interactive 3D house configurators for modular housing, has a well integrated workflow for designers between the Rhino 3D software environment and the Configurator platform. It allows the client or developer to select various predefined options for the housing design and create customized versions of the same product while at the same time being able to track the building area, costs and various other parameters and in this way guide the decision making. If a new parameter could be integrated on the platform, which would represent to the client the carbon footprint of the building and demonstrate the environmental impacts of choices made by customizing the house, it would help to get an optimal base for responsible decision making in architecture.

The work was developed on the example of 369 Pattern Buildings by Renee Puusepp, Egle Vogt, Lauri Läänelaid, Marianna Zvereva, Eero Tuhkanen, Kristo Kalbe and on the building system based Musterhaus 369 project. This allowed the workflow to be tested on an actual architectural project and to become potentially implemented for further use.

Fig. 01 Illustration of the emissions balance of a zero emission building



2. Using Grasshopper to enable carbon footprint estimations of Rhino 3D models

The following sections will describe two developed Grasshopper (GH) tools. The text will explain the workflow of the tools while at the

same time additional background information will be introduced.

2.1 Linking Rhino 3D and OneClickLCA to estimate carbon footprint of buildings and building components for the Creatomus Configurator

The GH tool developed in this work allows to create and extract information from a Rhino 3D model in a very simplified form of a BIM model where additionally to 3D geometry, information regarding the building and its components is stored (Autodesk, 2018, 3). The tool gathers volumetric and area information of different material layers and adds the information regarding building material in form of an IFC name, building element location according to class and additional user specific information. The gathered information is automatically saved into an Excel file which allows it to be integrated in

OneClickLCA for the life cycle assessment. The results can be inserted in the Configurator by Creatomus Solutions OÜ to showcase the environmental impact of architectural choices in realtime to the user.

The GH file is solely based on the basic version of GH and open source plugins. It consists of three main parts: a base component for inserting material information which can be duplicated, a simple table head structure for improved orientation and the extraction component which transfers the data from GH to Excel.

Fig. 02 Representation of an LCA workflow between Rhino 3D and Creatomus Configurator

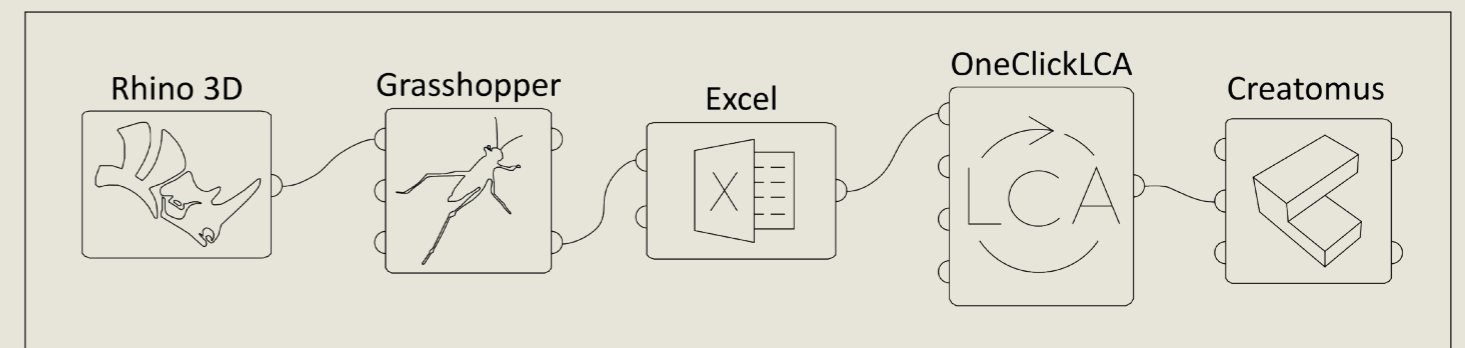
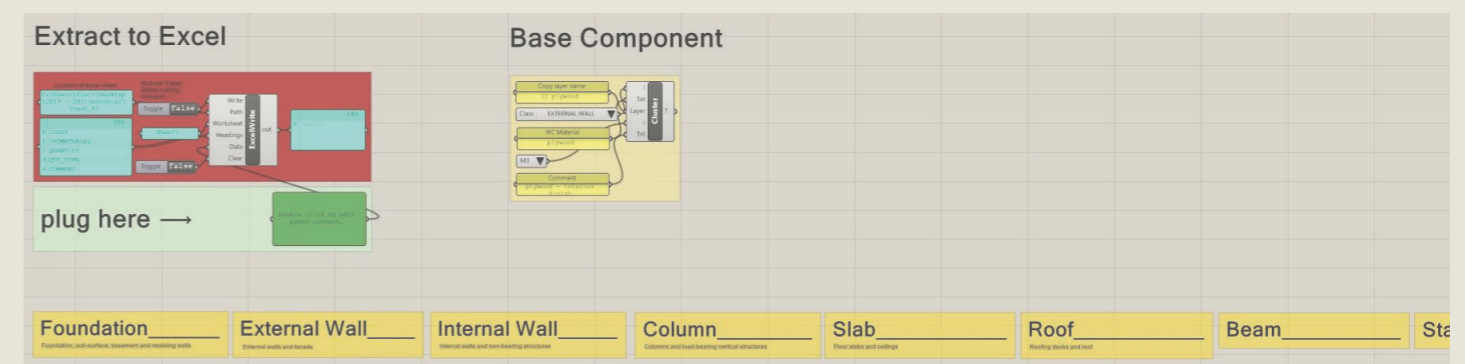


Fig. 03 Main parts of the Grasshopper file



In order to add materials for later LCA assessment the Base Component has to be copied and dragged beneath the right material classification written in the table heads which include all major material classifications used in the platform OneClickLCA (foundation, external wall, internal wall, etc.).

By inserting a layer name from Rhino into the panel “Copy layer name” the included geometry is loaded into GH with the component “Layer Reference”. The layer name has to be unique in order to work for the GH-file and all included geometries have to be either surfaces or closed

volumes. The volume and area of the geometry is calculated in GH and automatically sorted. If surfaces are loaded, the result for its volume is invalid and can be removed with the component “Clean Tree” to only receive the information regarding the area. If volumes are inserted, results for volume and area are calculated. With “List Item” only the first line of result is retrieved. If two results exist the volumetric data is retrieved as it stands in the first line. If surfaces are uploaded and the invalid result for volume is removed, as described earlier, the result for surface area will move in the first line of results and is retrieved.

Fig. 04

Base Component for material information

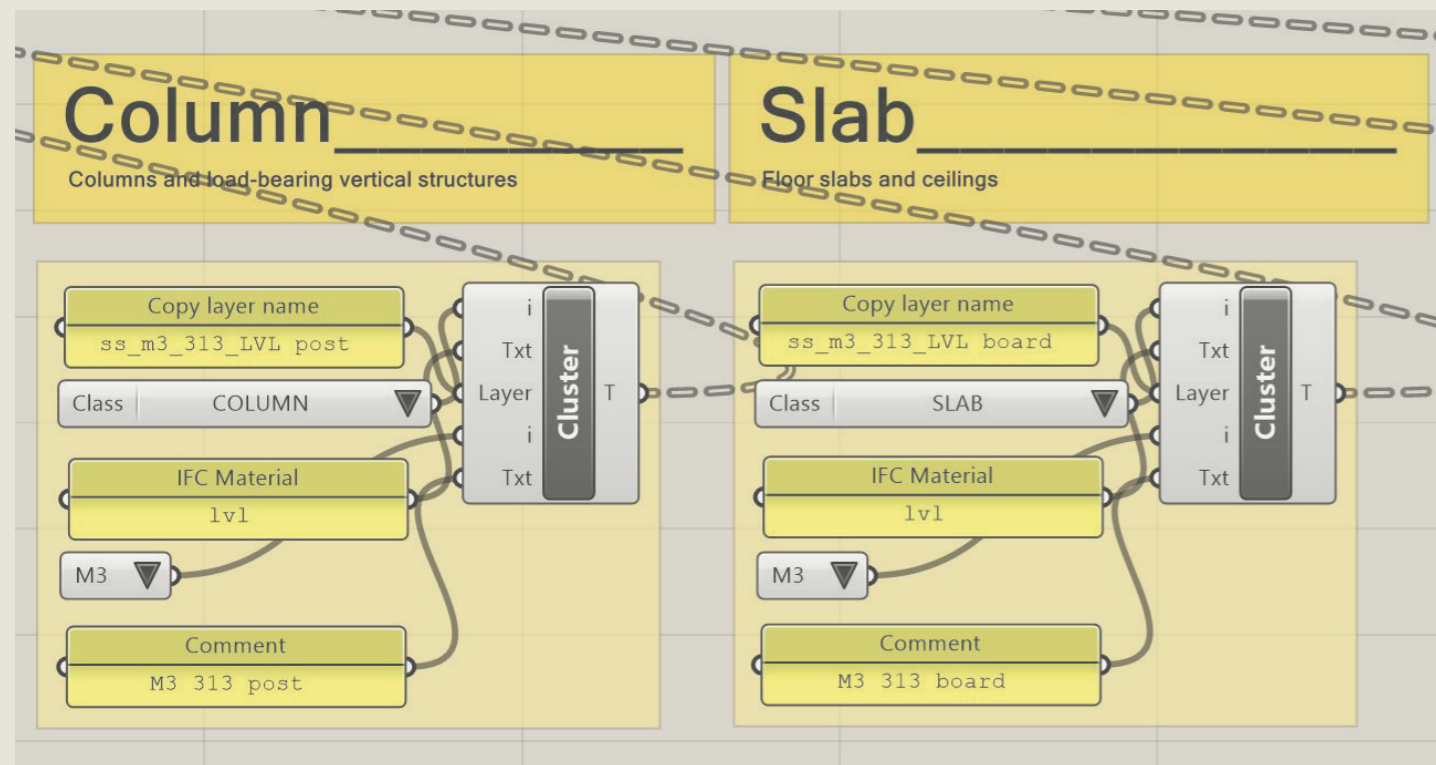
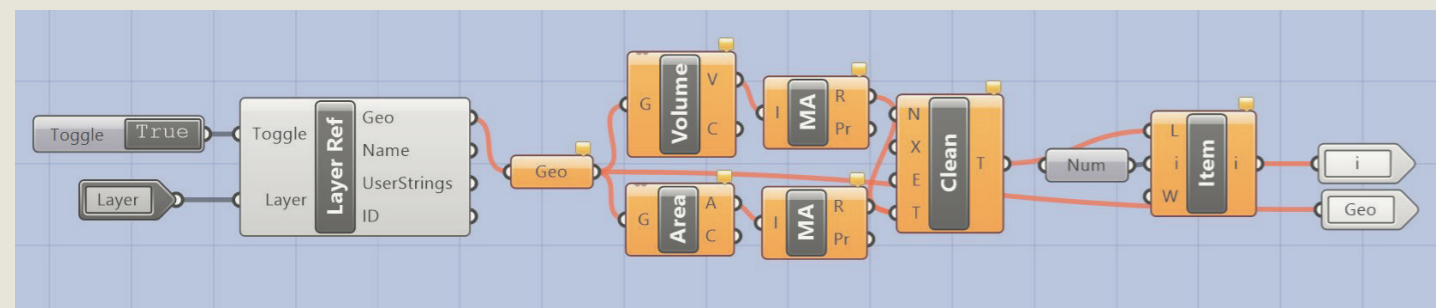


Fig. 05

Automatic detection of volumes or surfaces



In the value list “Class” the user can choose from predefined material classification (should be the same as in table heads) to specify the IFC class which will be used for this material in OneClickLCA.

In the panel “IFC material” can be added a material label which will be used to select possible materials from the OneClickLCA material database later on. Use specific material labels if known (eg. Concrete – Insitu Nwt – C20/25) or general labels (eg. Concrete) if the exact material should be chosen in OneClickLCA. The second value list is used to define the quantity type for OneClickLCA. “M2” for square meter and “M3” for cubic meter is used. The selection has to be in accordance with the uploaded geometry.

The last panel “Comment” has the purpose to help the user later on in OneClickLCA and give some additional input like material location, intended product and material type, etc.

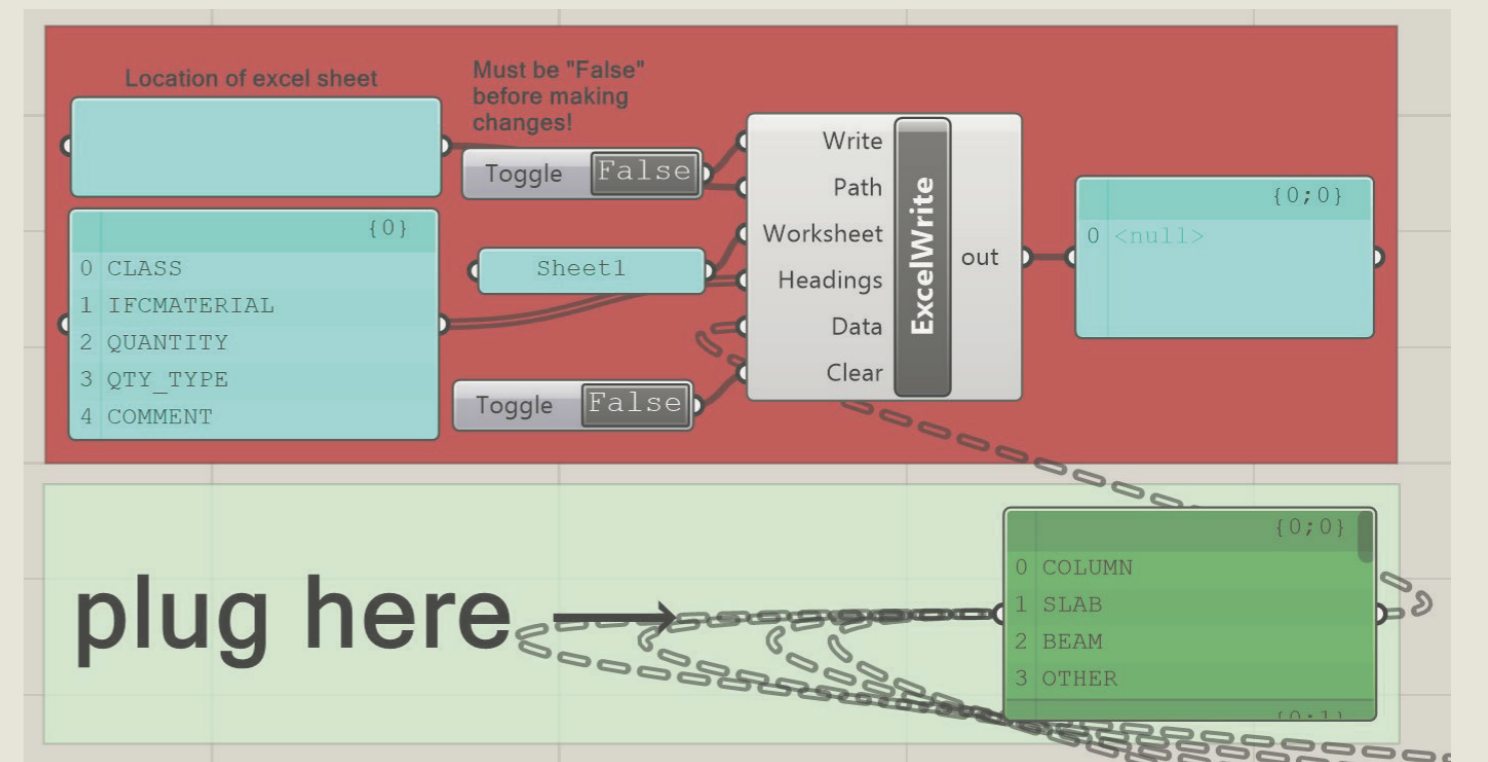
All filled information from the Base Components is joined into a single data list in the “Extract to

Excel” component. The “Excel Write” component from the GH-plugin Lunchbox is used to export the data to Excel.

Further on, the resulting Excel file can be imported in OneClickLCA for estimation of the carbon footprint or other environmental impact of the uploaded buildings or building components. One option is to use the results to create a component library which includes carbon footprint data for a square meter or number of different building components can be created (eg. carbon footprint for 1 m² of exterior wall, floor plate, foundation or carbon footprint per modular building component, etc.), which can be used later on for simplified emission assessment in Rhino. Otherwise, the GH tool can be used to assess the emissions of specific architectural options, which can be added on the Configurator by Creatomus Solutions OÜ and showcased live to the user, assisting in the decision making.

Fig. 06

Extract to Excel component



2.2 Simplified carbon emission estimation in Rhino 3D as base for design optimization

The bespoke component library can be used to fastly assess building designs in regards to greenhouse gas emissions with the help of a second GH file which shows simplified LCA results in the Rhino viewport.

This GH-tool consists of three main parts: base components for inserting material and building component information, a processing component which sorts and displays the information on the Rhino viewport and a component to customize preview settings.

Fig. 07
Workflow to estimate building carbon footprint in the early design phase

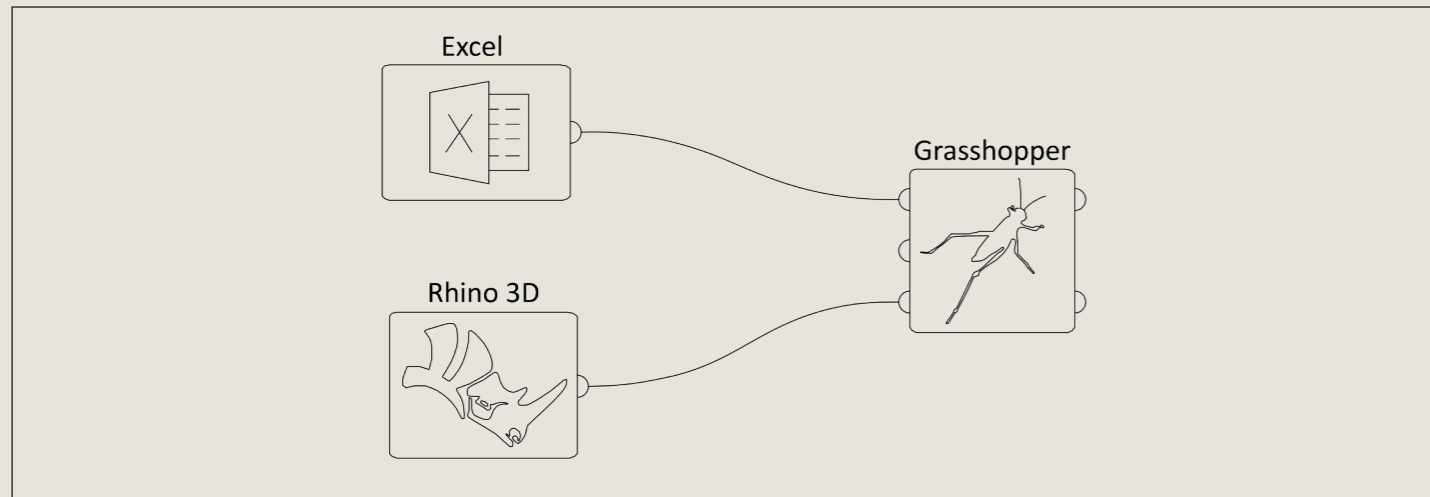
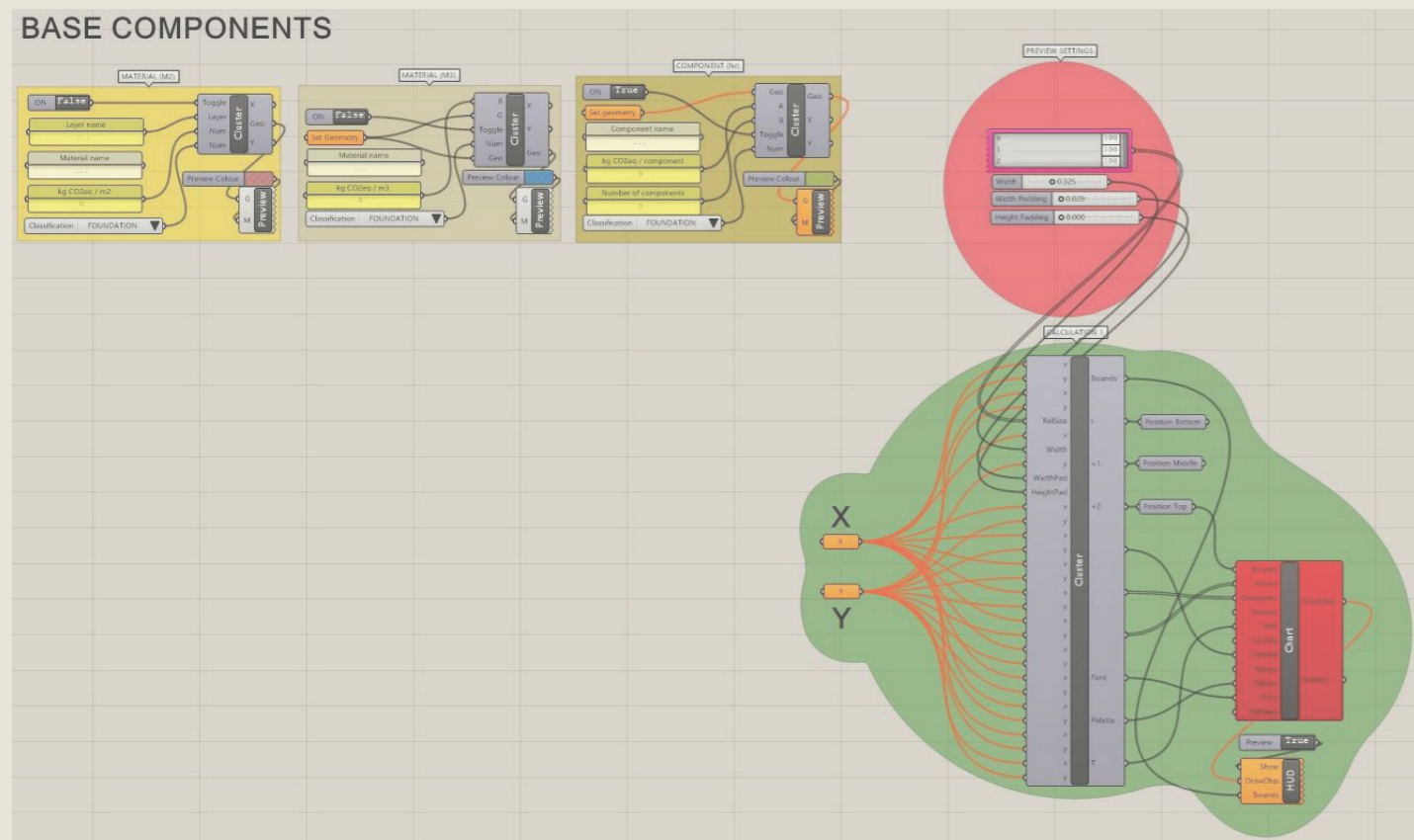


Fig. 08

Main parts of the Grasshopper file



To conduct a simplified LCA directly in Rhino one has to have prepared a component library that holds useful generic data for various building components, such as carbon emissions per square meter of component.

The “Base Components” are used to insert this information into GH and link it to specific layers. Consequently, areal or volumetric data is multiplied with the listed carbon intensity of the

building component. Therefore, the building model in Rhino can be drawn very simplified and has to contain only simple surfaces or volumes representing the assessed, more complex building components of the component library. Three different Base Components are included in the file which can be used depending on the provided quantity type of the component (“M2” - square meter, “M3” - cubic meter, “Nr.” - number of components).

Fig. 09
Base Components for component and material emission input

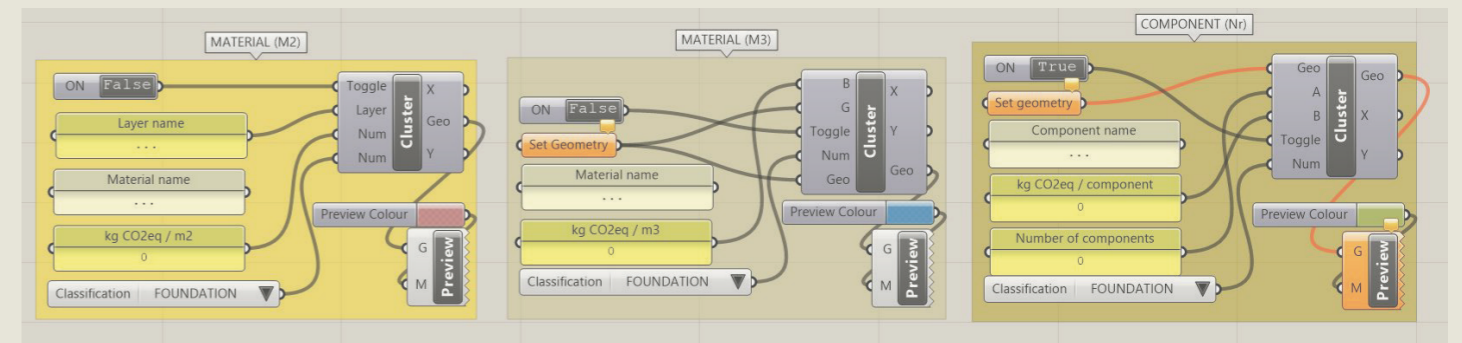


Fig. 10
Component library in MS Excel

| # | A | B | C | D | E | F | G | H | I |
|----|---------------------------|------------------|----------------|---------|---|----------|-------|-------------|-------------|
| | MATERIAL / COMPONENT NAME | SHORT NAME | CLASSIFICATION | VERSION | COMMENT | kg CO2eq | m2 | kg CO2eq/m2 | kg CO2eq/m3 |
| 1 | MATERIAL / COMPONENT NAME | SHORT NAME | CLASSIFICATION | VERSION | COMMENT | kg CO2eq | m2 | kg CO2eq/m2 | kg CO2eq/m3 |
| 2 | PB module M3 313cm | ss_M3_313cm | PB modules | A | 75% of emissions are from steel | 1470 | 9 | 163 | |
| 3 | PB module M3 313cm B | ss_M3_313cm_B | PB modules | B | LVL post and beams to glulam. LVL plate to CLT. 91% of emissions from steel | 1217 | 9 | 135 | |
| 4 | PB module M3 345cm | ss_M3_345cm | PB modules | A | 75% of emissions are from steel | 1500 | 9 | 167 | |
| 5 | PB module M3 345cm B | ss_M3_345cm_B | PB modules | B | LVL post and beams to glulam. LVL plate to CLT. 91% of emissions from steel | 1243 | 9 | 138 | |
| 6 | PB module M6 313cm | ss_M6_313cm | PB modules | A | 65% of emissions are from steel | 1918 | 18 | 107 | |
| 7 | PB module M6 313cm B | ss_M6_313cm_B | PB modules | B | LVL post and beams to glulam. LVL plate to CLT. 86% of emissions from steel | 1474 | 18 | 82 | |
| 8 | PB module M6 345cm | ss_M6_345cm | PB modules | A | 65% of emissions are from steel | 1945 | 18 | 108 | |
| 9 | PB module M6 345cm B | ss_M6_345cm_B | PB modules | B | LVL post and beams to glulam. LVL plate to CLT. 86% of emissions from steel | 1490 | 18 | 83 | |
| 10 | PB module M9 313cm | ss_M9_313cm | PB modules | A | 57% of emissions are from steel | 2358 | 27 | 87 | |
| 11 | PB module M9 313cm B | ss_M9_313cm_B | PB modules | B | LVL post and beams to glulam. LVL plate to CLT. 82% of emissions from steel | 1710 | 27 | 63 | |
| 12 | PB module M9 345cm | ss_M9_345cm | PB modules | A | 57% of emissions are from steel | 2364 | 27 | 88 | |
| 13 | PB module M9 345cm B | ss_M9_345cm_B | PB modules | B | LVL post and beams to glulam. LVL plate to CLT. 82% of emissions from steel | 1714 | 27 | 63 | |
| 14 | external wall A | exw_A | external wall | A | highest share of emissions of all building classifications | 2519 | 31,05 | 81 | |
| 15 | external wall B | exw_B | external wall | B | stone wool replaced with wood fibre (STEICO), external cladding replaced with Swedish thermo wood | 1657 | 31,05 | 53 | |
| 16 | window A | exww_A | window | A | | 4967 | 31,05 | 160 | |
| 17 | window B | exww_B | window | B | same product but better emissions wood-aluminium window | 3515 | 31,05 | 113 | |
| 18 | external door A | exwd_A | door | A | high emissions | 4066 | 31,05 | 131 | |
| 19 | dry partitional wall A | iwdp_A | internal wall | A | | 982 | 31,05 | 32 | |
| 20 | dry partitional wall B | iwdp_B | internal wall | B | stone wool replaced with wood fibre (STEICO) | 748 | 31,05 | 24 | |
| 21 | dry internal wall A | iwdi_A | internal wall | A | | 512 | 31,05 | 16 | |
| 22 | dry internal wall B | iwdi_B | internal wall | B | stone wool replaced with wood fibre (STEICO) | 364 | 31,05 | 12 | |
| 23 | wet partitional wall A | iwvp_A | internal wall | A | | 1528 | 31,05 | 49 | |
| 24 | wet internal wall A | iwwi_A | internal wall | A | | 990 | 31,05 | 32 | |
| 25 | roof A (560mm) | r_A | roof | A | | 1145 | 27 | 42 | |
| 26 | roof B (560mm) | r_B | roof | B | stone wool replaced with wood fibre (STEICO) | 649 | 27 | 24 | |
| 27 | roof A (700mm) | r_A2 | roof | A | | 1492 | 27 | 55 | |
| 28 | roof B (700mm) | r_B2 | roof | B | stone wool replaced with wood fibre (STEICO) | 768 | 27 | 28 | |
| 29 | ceiling A | c_A | slab | A | | 1395 | 27 | 52 | |
| 30 | floor A | f_A | slab | A | | 1395 | 27 | 52 | |
| 31 | underfloor A | uf_A | foundation | A | 60% of emissions from foam glass insulation (always a more sustainable alternative in terms of circular economy than XPS or EPS products) | 2756 | 27 | 102 | |
| 32 | underfloor B | uf_B | foundation | B | replaced insulation plates with foam glass aggregate insulation, concrete replaced by concrete with fly ash | 1319 | 27 | 49 | |
| 33 | strip foundation A | sf_A | foundation | A | | 539 | 6,32 | 85 | |
| 34 | strip foundation B | sf_B | foundation | B | replaced insulation plates with foam glass aggregate insulation, concrete replaced by concrete with fly ash | 414 | 6,32 | 65 | |
| 35 | concrete | concrete | | | | | | | 288 |
| 36 | timber terrace A | timber terrace A | | A | | | | | 367 |
| 37 | timber terrace B | timber terrace B | | B | different product | | | | 330 |
| 38 | timber stair | timber stair | | | | | | | 814 |

In order to add a building component to the carbon footprint estimation in Rhino a Base Component (M2, M3 or Nr.) has to be copied. A Rhino layer can be linked with the component “Layer Reference” (for M2), or geometries set (for M3 and Nr.). Therefore, the layer name in Rhino has to be unique again and include either surfaces or closed volumes.

The panel “Material / Component name” is only informative input for the user to specify and remember used component types of the component library. In the panel “kg CO2eq / m2; kg CO2eq / m3; kg CO2eq / component” is added the respective emission data of the chosen building component. In the value list “Class” the user can choose from predefined material classification (same as in One ClickLCA) to specify to which IFC class the emissions of the particular component will be counted.

A next “Base Component” is copied and filed for each next building component which should be added to the LCA.

The processing component filters the information with the help of the “Expression” components and joins the IFC classes with the fitting carbon data. The component “Conduit Chart” from the GH-plugin Proving Ground is used to write the information as a chart on the Rhino viewport. The file is prepared to showcase one to three different LCA’s simultaneously on the viewport in form of bar diagrams which display carbon emissions per IFC class and the total carbon emissions of the designs.

The “Preview Settings” give the user the option to change size, placement and ratio of the charts.

Fig. 11
The processing component

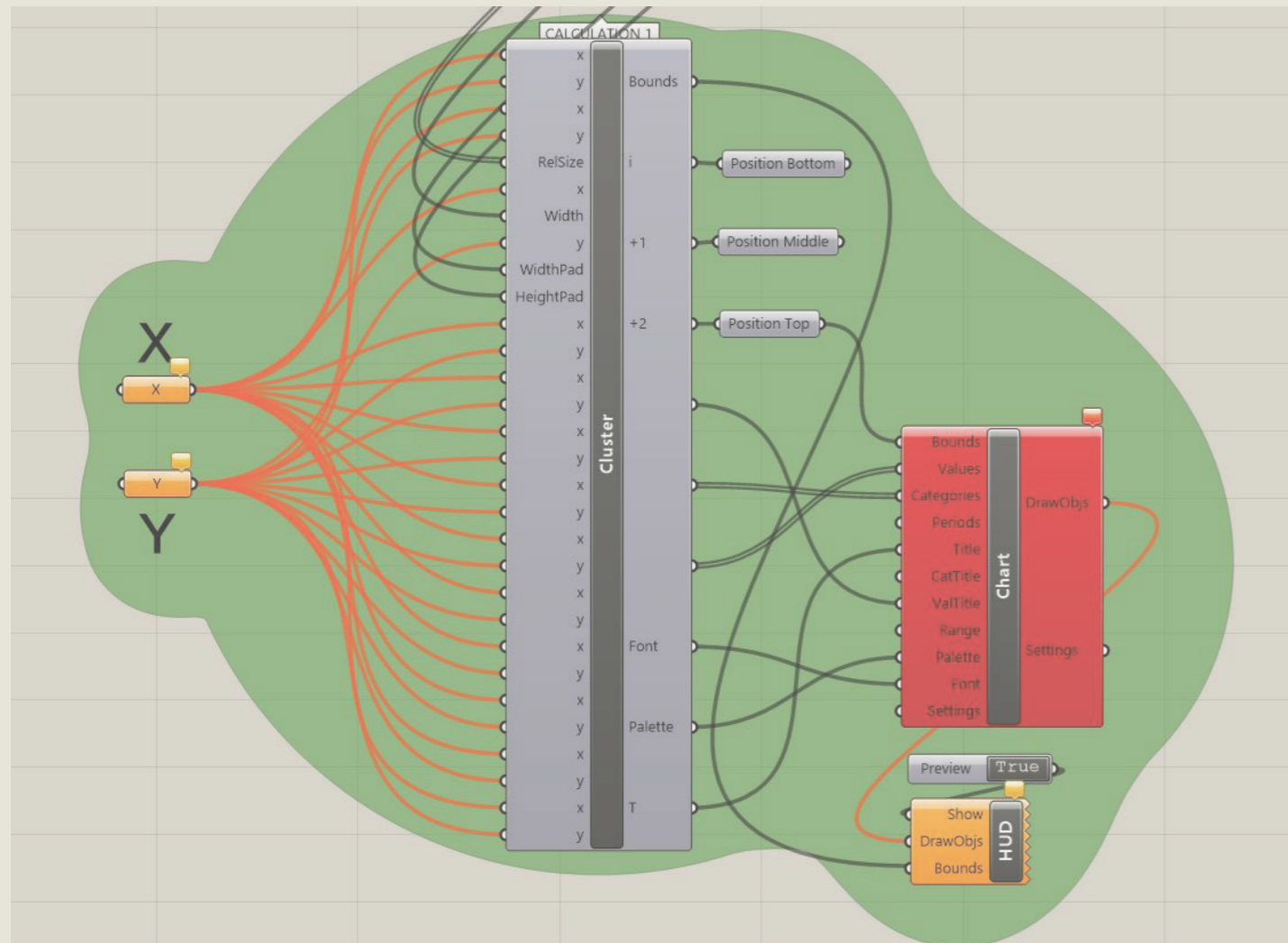
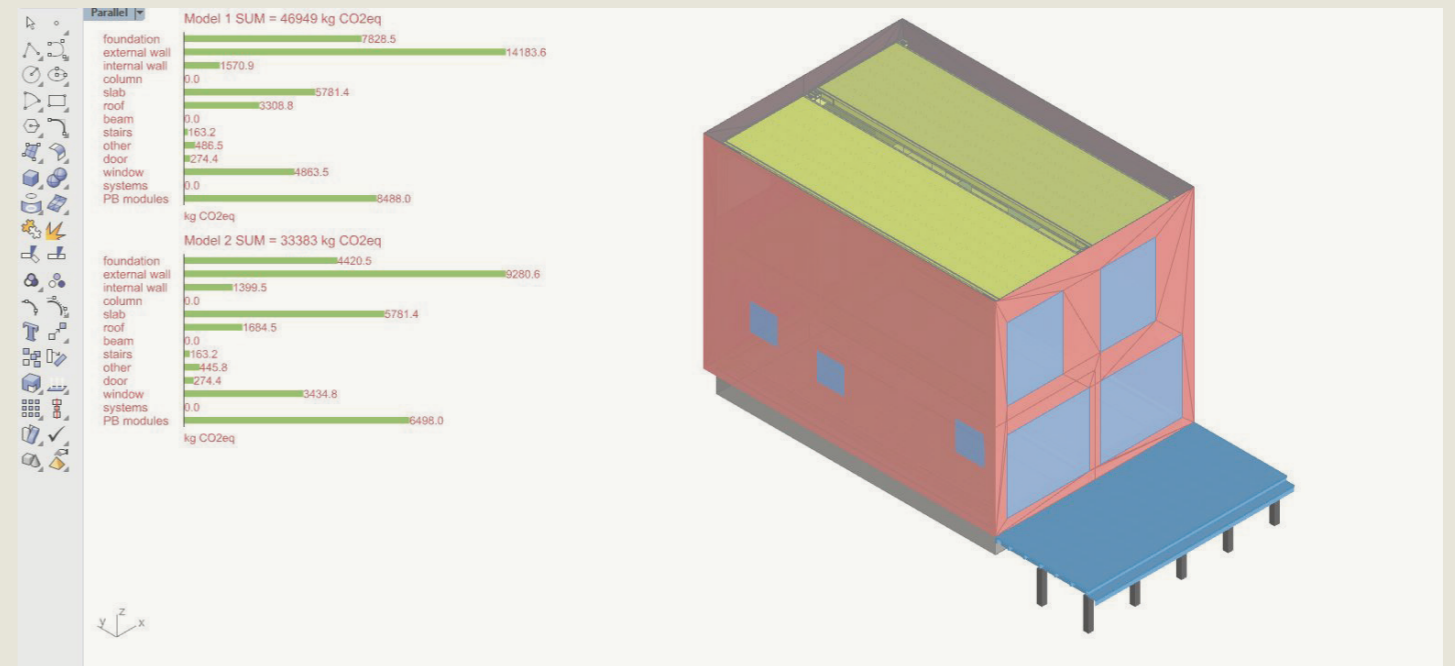


Fig. 12
Preview of emissions in Rhino 3D interface



3. Application of the developed Grasshopper tools

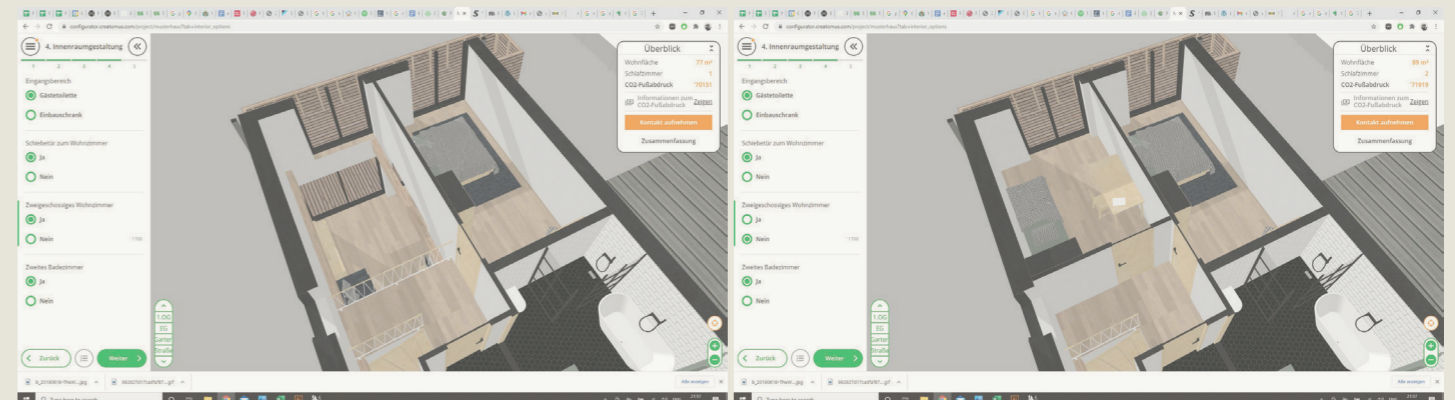
3.1 Showcasing environmental consequences of architectural choices to users of house configurators

Both GH tools were tested on the project 369 Musterhaus, which is available on the Configurator by Creatomus Solutions OÜ.

The platform already has an option to give cost values for each uploaded option which is displayed to the user in real-time. Instead of

cost, one can potentially do the same with the amount of carbon emissions each option is responsible for. In the particular chosen example, the user, among other things, has the option to select a double height living room or a normal height living room and an additional bedroom above.

Fig. 13
Configurable design with open or closed ceiling



During this work, a new Rhino model of the inserted room option was created based on the construction details provided by Harmet Modular Homes and the building information transferred to OneClickLCA with the first GH tool.

The result was 1907 kg CO₂eq for the LCA stages A1 to A4 (material production and transport) and C1 to C4 (end of life). The construction and use stage could not be included in the LCA as the final location of the modular house is unknown.

Fig. 14
Rhino 3d model and GH setup of the configurable ceiling

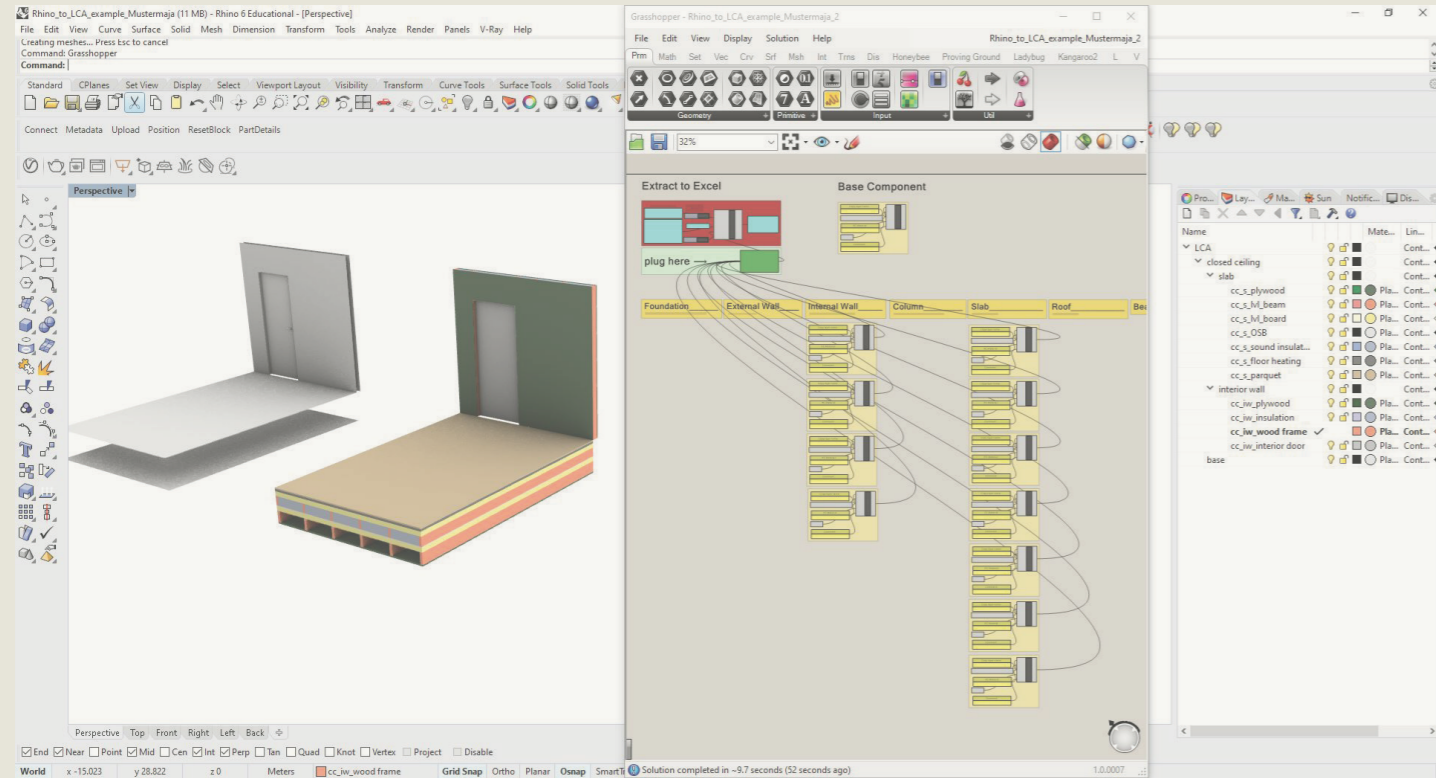


Fig. 15
OneClickLCA emission results for inserted ceiling

| Building life-cycle carbon footprint for Level(s) in compliancy with EN 15978 | | | |
|---|--|---|------------|
| Incomplete lifecycle according to Level(s) definitions (Draft Beta v1.0) | | | |
| Result category | Global warming kg CO ₂ e | Biogenic carbon storage kg CO ₂ e bio | |
| A1-A3 | 1 687,67 | 2 726,66 | Details |
| A4 | 17,34 | | Details |
| A5 | | | Hide empty |
| B1 | | | Hide empty |
| B4-B5 | 0 | | Details |
| B6 | | | Hide empty |
| B7 | | | Hide empty |
| C1-C4 | 202,01 | | Details |
| D | -1 298,39 | | Details |
| Total | 1 907,02 | 2 726,66 | |

The results can be used by the planners to identify the most contributing materials for global warming. In this particular case laminated veneer lumber (LVL) accounted for 60.9% of the total emissions and the parquet flooring for 8.4%.

nated timber (CLT) and the flooring product was changed. The total emissions could be reduced by 7% to 1768 kg CO₂eq. This carbon data was attached to the option in the online house configurator and can now be seen by users as a guide for decision making.

In order to reduce emissions part of the LVL was replaced with less carbon intensive cross-lami-

Fig. 16
OneClickLCA results for most contributing materials in the configurable ceiling design

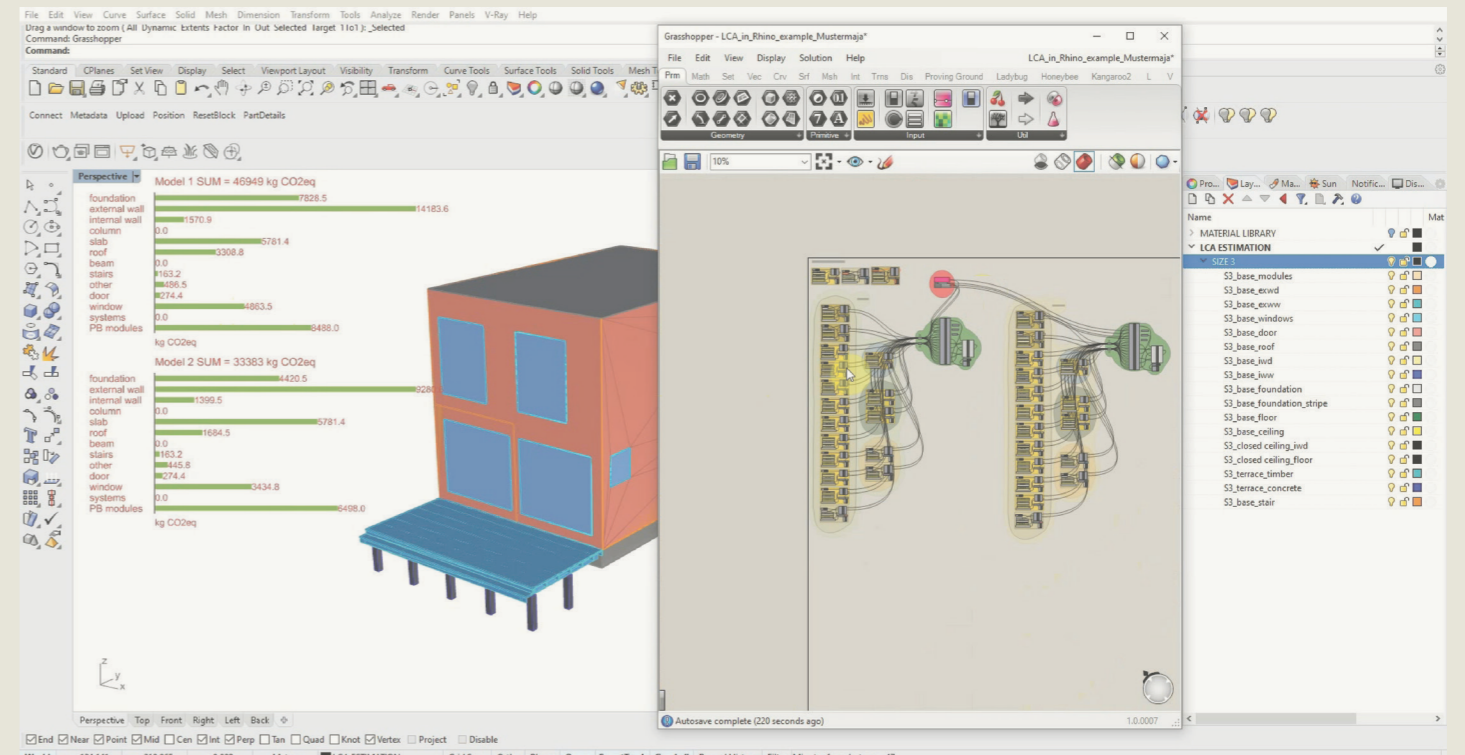
| Most contributing materials (Global warming) | | | |
|--|-------------------------------|--------------------------------|--|
| No. | Resource | Cradle to gate impacts (A1-A3) | Of cradle to gate (A1-A3) Sustainable alternatives |
| 1. | Laminated veneer lumber (LVL) | 1 tons CO ₂ e | 60.9 % Show sustainable alternatives |
| 2. | Parquet from hardwood | 0,14 tons CO ₂ e | 8.4 % Show sustainable alternatives |

3.2 Emission based building optimization in the early design stages

Instead of modeling multiple detailed building options for LCA calculations with, for instance, different spatial arrangements, material layers, window surfaces, etc., the second GH tool can be used by planners to save modeling time in order to assess a larger number of different building options.

For this test a component library, including all the main building components of the Musterhaus, was created based on the construction details provided by Harmet Modular Homes. OneClickLCA was used to add additional less carbon intensive alternatives.

Fig. 17
Comparison of different building designs with the help of the GH tool



The medium sized configuration of the Musterhaus was remodeled fastly with mostly surfaces representing full building layers. The second GH tool was used to link the model with the emission data of the component library. It allowed to estimate simultaneously the carbon emissions of multiple (in this case two) versions of the building with only one simplified model and to showcase the results on the Rhino viewport. For this test was examined a version of the building with the construction based on the details of Harmet Modular Homes and one with emission-optimized building components.

4. Current limitations and possible advancements

Both GH tools only assess information regarding material amounts and resulting emissions. Yet, the user is required to also include energy usage and energy efficiency of a building in order to make valid sustainable decisions. This becomes especially important when using the GH tool for carbon emission estimation in Rhino 3D in the early design phase, since the building layout and volume optimization decisions cannot be done solely on the material emission estimation. The building's overall performance is affected also by the energy efficiency, orientation, solar gains, function, planned user behaviour and further factors which all affect the total emissions of a building. This issue could be solved in future by combining the GH tool with the Honeybee plug-in which enables among other things the assessment of heating and cooling demands. However, Honeybee is developed for use in mid to late stages of design and is rather time-intensive to use (Ladybug Tools LLC, n.d.). A simplified version of Honeybee for fast use in early design stages would supplement the developed GH tools and would allow full LCA's for planners decision making and design optimization from the start of the design process.

Furthermore, to gain more comparable information about a building's carbon footprint, data of gross floor area, number of occupants or esti-

While the preparation of the component library requires time, depending on its complexity, it has the advantage to be reused and extended for further emission assessments and projects. However, the 3D modeling and linking with GH can be reduced to only a couple of minutes. Especially the breakdown of the calculated emissions by IFC class helps planners to identify the most crucial parts of the building for further emission reduction in a fast way. In this case the external walls, foundation and the 369 Pattern Buildings structural systems showed the highest potential for emission reduction.

mated lifetime of the building can be added easily to the equation. In this way the results could be showcased in commonly used formats such as emissions per square meter and year or per occupant and year. The latter allows to evaluate the building's carbon footprint more objectively and equally.

Lastly, the first GH tool was especially developed to link Rhino 3D and OneClickLCA. In order to use the GH tool for other LCA softwares slight reconfiguration of the resulting Excel table or the GH tool itself might be needed. However, it is possible to use also own EPD libraries and freely available EPDs from producers to enable a cost-free workflow.

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Figures

- Nr. 01 based on: Hestnes, A. G. (2017). ZERO EMISSION BUILDINGS (N. L. Eik-Nes, Ed.). Fagbokforlaget.
- Nr. 02 own representation
- Nr. 03–06 screen captures from the developed Grasshopper files
- Nr. 07 own representation
- Nr. 08–09 screen captures from the developed Grasshopper files
- Nr. 10 screen capture from the developed component library in MS Excel
- Nr. 11–12 screen captures from the developed Grasshopper files
- Nr. 13 screen capture: Creatomus Solutions OÜ & NOMAD architects. (2020). 369 Musterhaus. Creatomus Solutions. <https://configurator.creatomus.com/project/musterhaus?tab=index>
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