BIM*ATERIAL*

Process-Design for a
BIM-based
Material Passport

short report

BIMMATERIAL

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ABSTRACT

European Architecture, Engineering and Construction industry (AEC) consumes a significant rate of materials such as steel, aluminum, copper and plastics, thus creating a large reservoir on secondary raw materials in buildings. One of the main strategies of the European Union is to maximize recycling rates in order to minimize environmental impacts and the energy consumption caused by extraction of primary materials. To enable circularity, and in consequence high recycling rates, information about the existing stock is necessary. The early design stages play a crucial role in the waste reduction, the reusability of the building elements as well as in the increase of the recycling potential. New digital design tools such as BIM enable data management along life-cycle, thus bearing large potentials for generating a Material Passport (MP).

The proof of concept demonstrated potentials of the MP as instrument along a building's lifecycle – as **design-optimization tool**, **material-inventory** and as a document on material assets of real estates or building stocks, and finally enabling successful implementation of Urban Mining strategies. This project is a central milestone towards standardized, BIM-generated Material Passports. In this project, we developed a concept for the compilation of the MP, as well as a workflow for the semi-automated generation of a MP by coupling BIM to the Material Inventory and Analysis Tool Building One and eco-inventory databases. The proposed methodology allows the assessment of embedded materials in buildings as well as simultaneous LCA.

STARTING POINT

Building stocks and infrastructures are the largest material stock of industrial economies. As research findings in Regional Substance Flow Analysis indicate, these total material stocks on the global scale are about as large as primary resource stocks in nature. It is of long-term importance to maintain or frequently recycle these urban stocks, and in consequence to minimize the use of primary resources and thus the dependency on imports. Often, this strategy is labeled "Urban Mining". The only way to respond to the challenge of landfill shortages can be the consequent increase of recycling rates. For higher recycling rates, it is vital to have detailed knowledge about the composition of construction wastes. Recyclability changes over time, as it is a function of technological development and resource markets. Recyclability is also determined through design – it is dependable on constructive criteria defining accessibility and separability of building elements (or its parts).

The early design stages play therefore a crucial role in the waste reduction, the re-usability of the building elements as well as in the increase of recycling potential, through the choice of materials, construction and assembly method – therefore the planners and architects bear large responsibility. Design-centric methods and tools, allowing planning-optimization and compilation of the deconstruction concepts in the design phase are necessary. New digital tools such as BIM (Building Infromation Modeling) bear large potentials for the documentation and assessment of the material composition of buildings and accordingly for the generation of a Material Passport (MP).

METHOD

The method for the compilation of a Material Passport (MP) is based on coupling of various digital tools and was tested on use cases and optimized accordingly (*Fig. 1*).

The analyzed building is modelled with BIM-Software (Graphisoft Archicad[1] or Autodesk Revit[2]) based on a developed modeling guide. The modeling guide defines the requirements for the MP-model, such as the stage-oriented modeling (preliminary design stage: MPa and conceptual design stage MPb). The control-tool Solibri Model Checker[3] checks the quality of the model and makes a general BIM-test, so that e.g. no element exists twice. Additionally, the control-tool checks if the model is suitable for the generation of an MP. After checking the model, data from BIM is transferred to the material inventory and analysis tool (BuildingOne[4]). The bi-directional connection between BIM-Software and the material inventory and analysis tool enables an automated synchronization of data in both directions. Moreover, BuildingOne enables the parametrization of each layer with e.g. recycling-relevant data and eco-data, which is currently not possible in a consistent way in BIM. BuildingOne also delivers the final results of the MP, where the detailed material composition, the share of waste and recyclable materials as well as the environmental impacts are shown.

As modelling of new building components is a time consuming process and additionally data for recycling and ecological impacts is not available in a consistent way, for the proof of concept phase, standardized

[1] *Graphisoft, Graphisoft Archicad 21. https://www.graphisoft.at/archicad*
[2] *Autodesk, Autodesk Revit 2018. https://www.autodesk.com/products/revit-family/overview*
[3] *Solibri, Solibri Model Checker. https://www.solibri.com/products/solibri-model-checker*
[4] *Onetools, BuildingOne. http://www. onetools.de/de/buildingone*

components from the baubook-catalogue[5] of IBO[6] (Austrian Institute for Building and Ecology) were used. The components from baubook consist of recycling- as well as eco-data, which is why there are used as source for the MP-generation. Selected components are provided as Archicad- and BuildingOne-Template, which enable modeling of buildings and the generation of MPs.

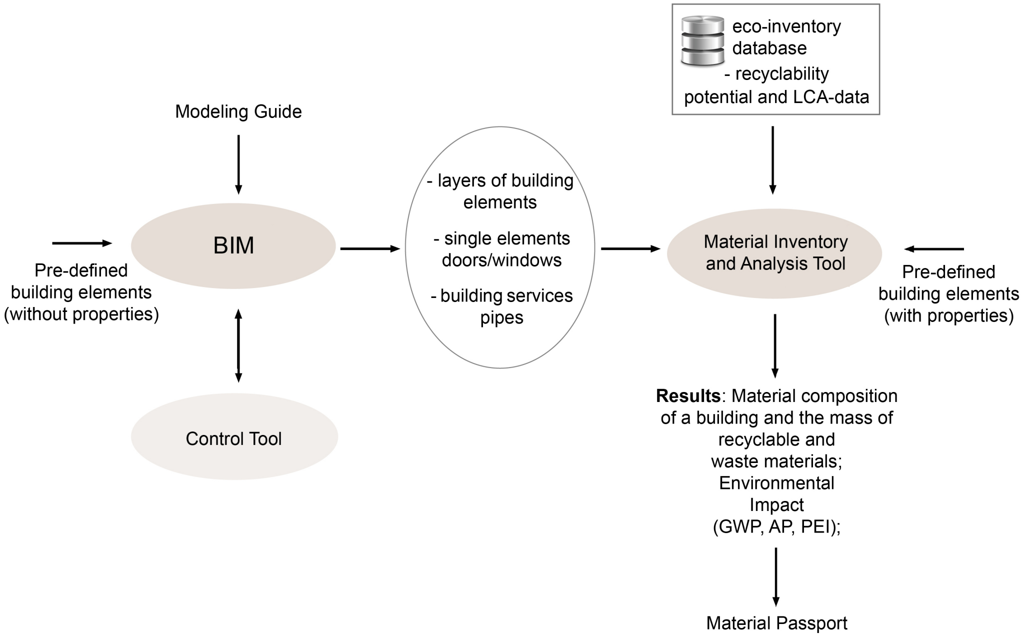


Figure 1: Method for the semi-automated generation of a BIM-based MP

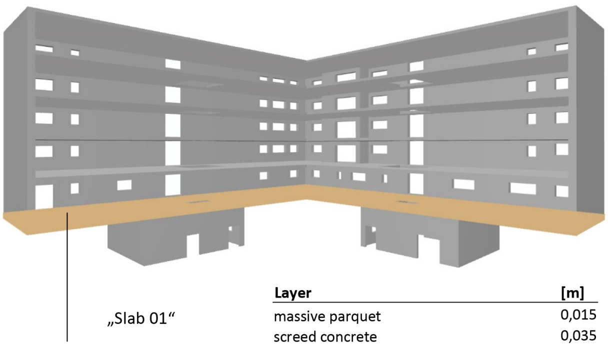
[5] *Baubook GmbH, Passivhaus Bauteilkatalog. https://www.baubook.at/phbtk/*
[6] *IBO, Austrian Institute for Building and Ecology https://www.ibo.at*

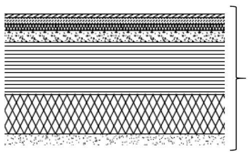
RESULTS

CONCEPT OF THE MATERIAL PASSPORT

The content of the MP is illustrated in *Fig. 2* and described in the following:

- Quantity of the materials embedded in a building (in tonnes)
- Share of recyclable and waste materials (in % und tonnes)
- Allocation of the materials in the building
- Separability of two enclosed materials
- Ecological impact of the building (LCA= Life Cycle Assesment)





Layer	[m]
massive parquet	0,015
screed concrete	0,035
bitumen felt	0,001
rock wool footfall sound insulation	0,03
chippings	0,06
fleece (PE)	0,0015
cross laminated timber	0,26
PE sealing sheeting	0,0015
wood fibre insulaiton board	0,2
lime-cement plaster	0,06

Figure 2: BIMaterial

The **scheme of the MP** is illustrated in *Fig. 3.* and consists of four levels: Building-, Component-, Element- and Material-Level. Through up- and downscaling the scheme enables an evaluation within the diverse levels and shows in which level exists the highest optimization potential.

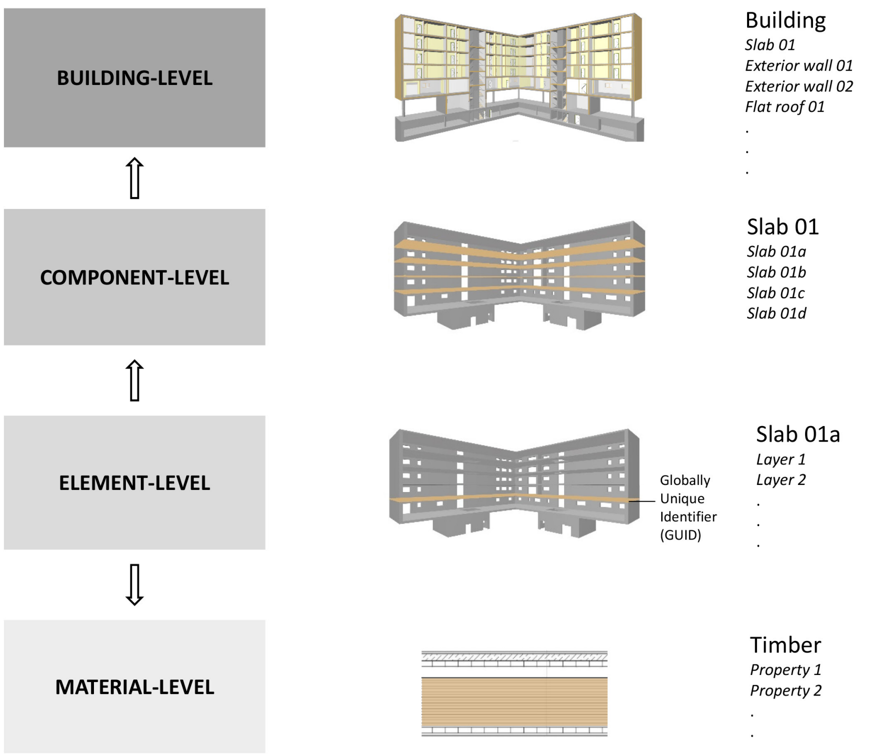


Figure 3: Scheme of the MP

Within the project we focussed on the proof of concept in the conceptual design stage (MGPa) and in the preliminary design stage (MGPb). The functions of the MP throughout the entire life-cycle are illustrated in *Fig. 4* and described in the following:

MGPa: Conceptual design stage, as rough analysis and optimization tool, creation of variant studies and selection of the best variant

MGPb: Preliminary design stage, as optimization tool, adjustments of layer thicknesses and single materials

MGPc: Tendering stage, as documentation tool, acquisition of the tendering-related material composition

MGPd: Dokumentation, as inventory and documentation of the actual ("as-built") material composition of the building and as basis for a secondary raw materials cadaster

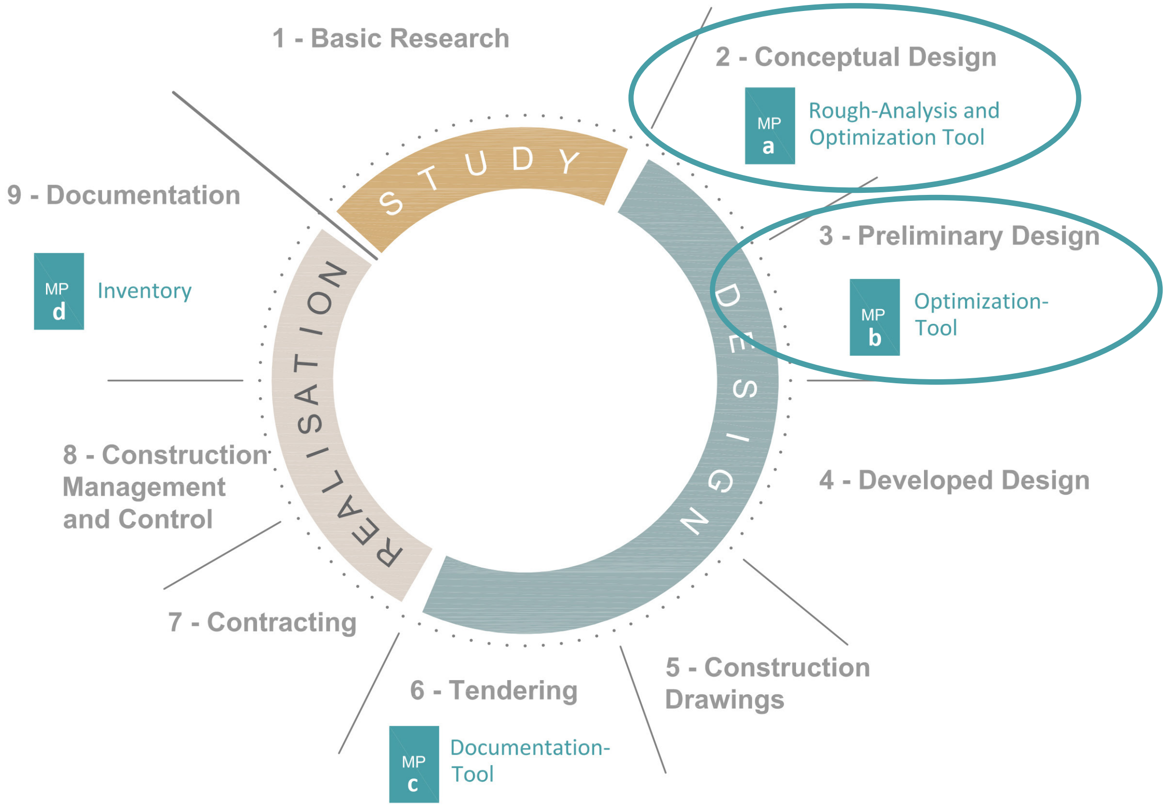


Figure 4: MP throughout the life-cycle stages (on the basis of BKI=Baukostenindex, German database for cost estimations)

WORKFLOW FOR THE GENERATION OF THE MP

DIGITAL TOOL-CHAIN: BIM – BUILDINGONE – ECO- AND RECYCLING-DATA

The first step in the development of the workflow was the creation of a tool chain *(Fig. 5)*. Thereby BIM mainly serves as modeling-tool, for which a component catalogue from baubook is used. Data from the BIM-model is transferred to BuildingOne, where eco- and recycling-data from IBO is linked to the components. In BuildingOne the whole assessment is carried out and the final MP-document is generated.

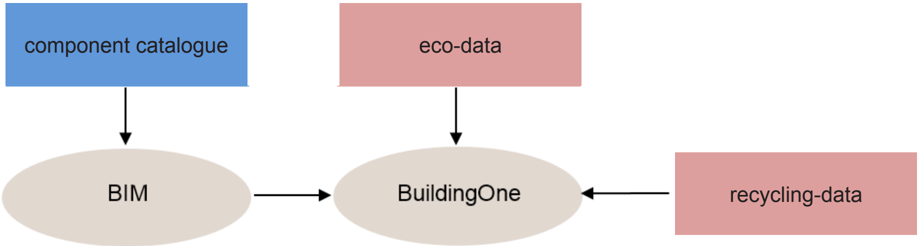


Figure 5: Tool-chain for the generation of the MP

PARAMETER-DEFINITION

The MP provides the following results:

- all materials embedded in a building,
- their masses,
- share of recycling and waste,
- their ecological impacts (GWP, AP and PEI).

The shares of recycling and waste are expressed as recycling grades from 1 to 5. Thereby grade 1 stands for 75% recycling and 25% waste and grade 5 for 0% recycling and 125% waste.

Based on the IBO-method the proposed disposal indicator was also integrated in the MP-assessment. The disposal indicator is area related and considers the accruing volume, the disposal grade and the recycling potential of the entire building.

In order to achieve the above mentioned results, various parameters are required, which mostly originate from different databases. All paramteres are gathered in BuildingOne, as illustrated in *Fig. 6.*

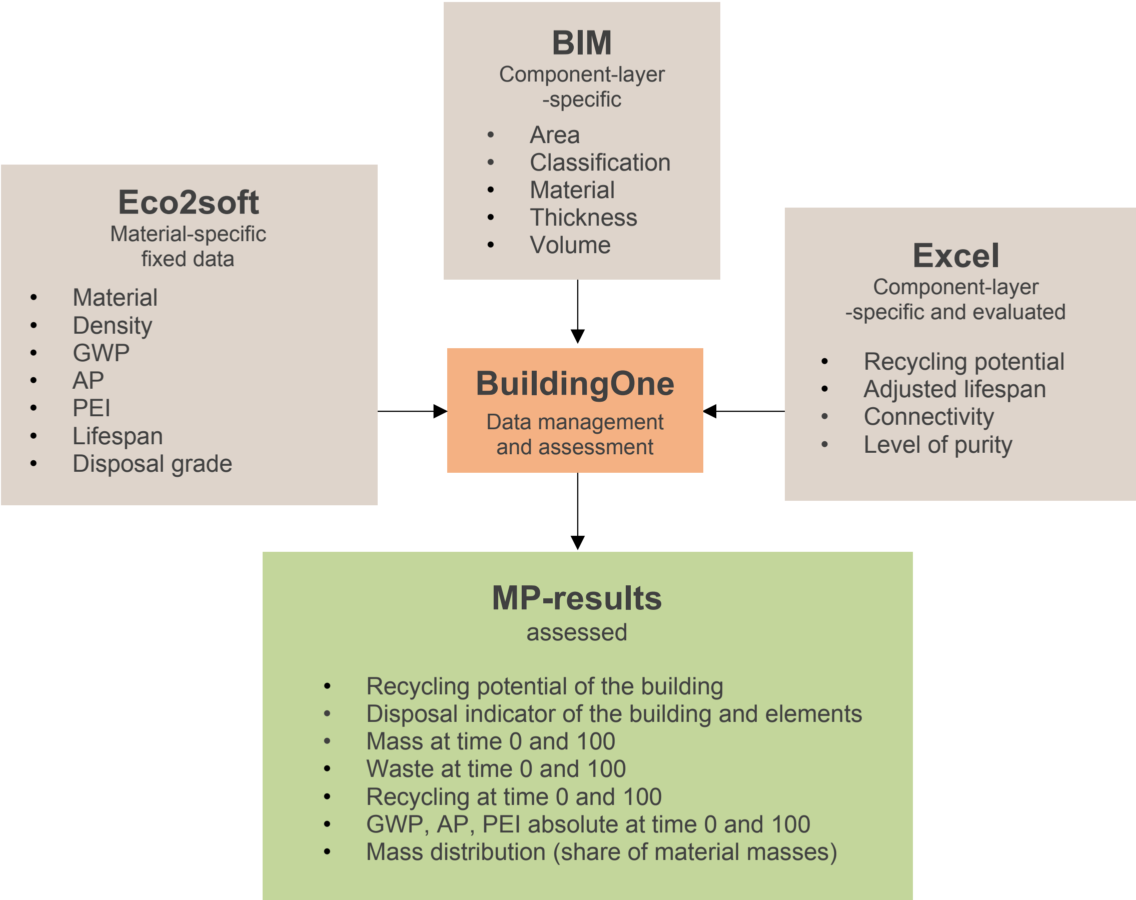


Figure 6: Parameter-structure for the generation of the MP

MODELING METHODOLOGY FOR MPa

BIM-Software
mono-layered elements
without properties

BuildingOne
multi-layered elements
with properties

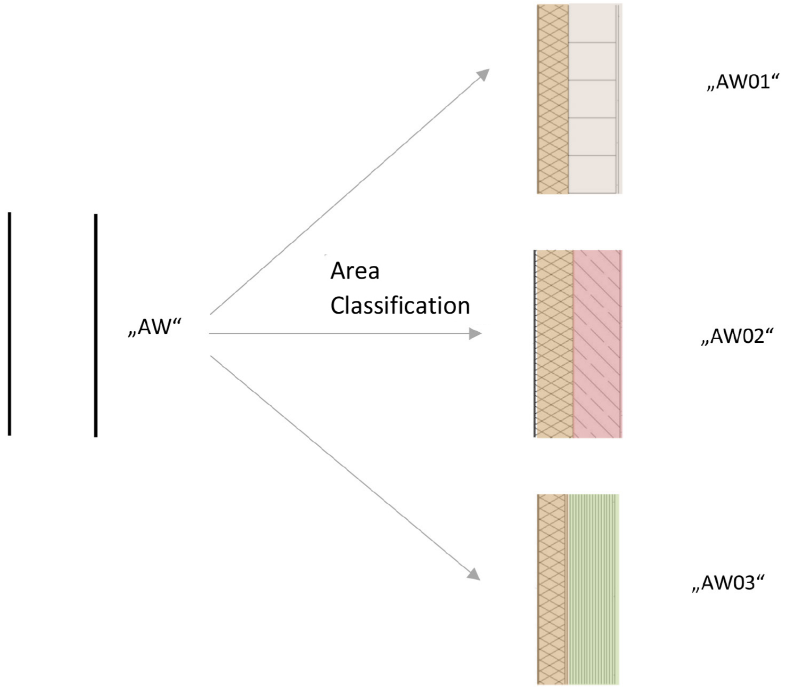


Figure 7: Stage-oriented modeling-MPa

MODELING METHODOLOGY FOR MPb

BIM-Software
multi-layered elements
without properties

BuildingOne
multi-layered elements
with properties

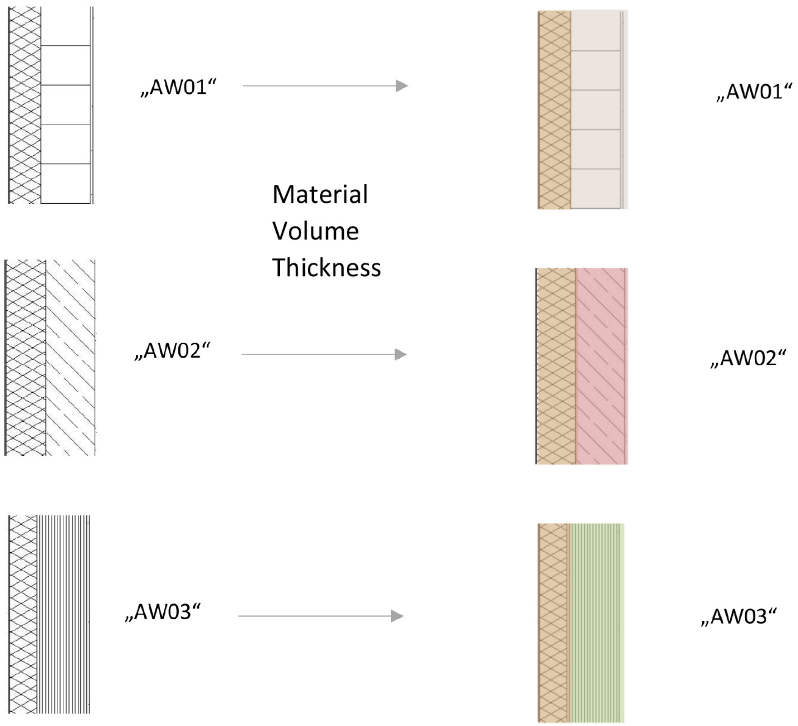


Figure 8: Stage-oriented modeling-MPb

For the creation of the component catalogue, a specific method was used, which is displayed in *Fig.* 9. The catalogue is based on the baubook catalogue from IBO, which consists of diverse components. For the component catalogue characteristic components out of cross laminated timber, concrete and perforated brick were selected. In total the component catalogue consists of five exterior walls, two exterior walls with ground contact, three basements, three interior walls, four slabs and four roofs.

The method for the creation of the component catalogue is based on coupling of various tools. These tools are eco2soft[7] (tool from baubook with components from the baubook catalogue), MS Excel, BuildingOne and Archicad.

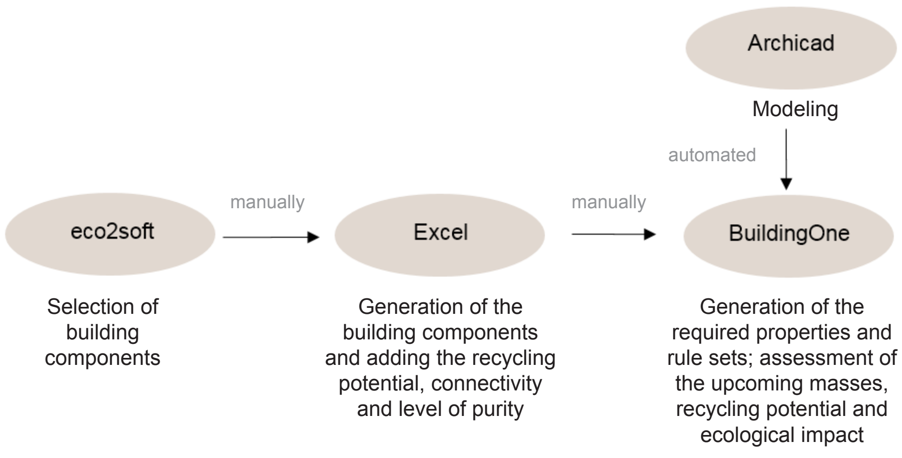


Figure 9: Generation of the component catalogue

[7]*Baubook GmbH, eco2soft – LCA for buildings. https://www.baubook.info/eco2soft/*

USE CASE: CONCRETE VARIANT

The concrete variant consists of reinforced concrete walls, slabs and basement. The interior walls are non-load bearing vertically perforated brick walls. *Fig. 10* reflects the disposal indicator (1-5) of each element, which was calculated in BuildingOne and transferred back to the BIM-model. Therby disposal indicator 1 (dark green) means, that this element has a high potential to be reused or recycled. Disposal indicator 5 (dark red) means that a lot of waste will accrue. The colors in the model are in accordance with the colors of the recycling potential in the MP document *(Fig. 12)*.

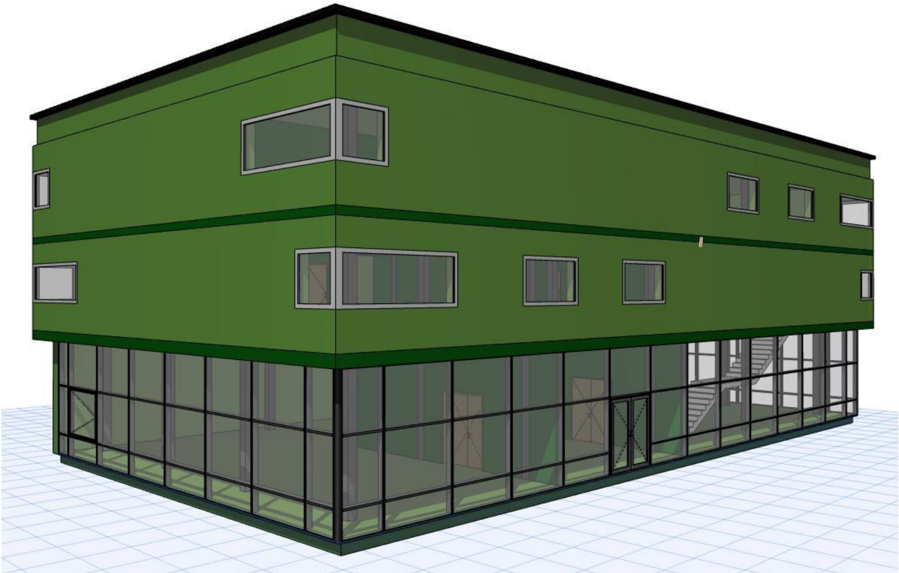


Figure 10: Use case - concrete variant

USE CASE: TIMBER VARIANT

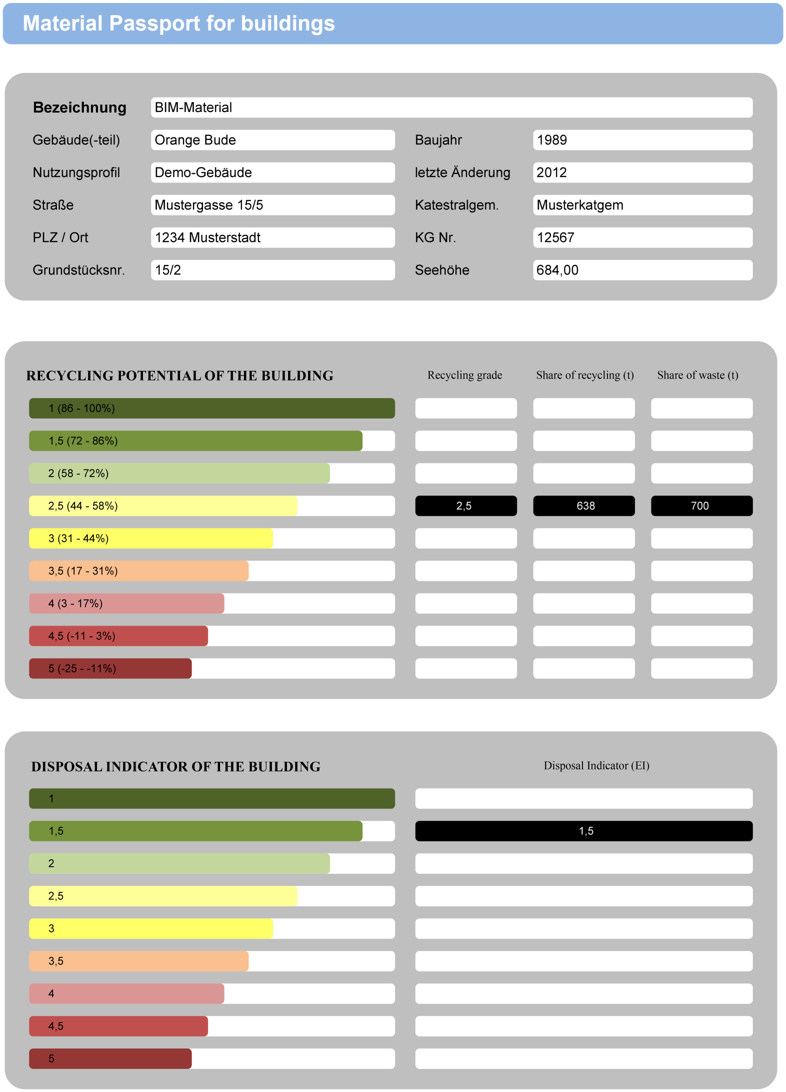
The timber variant consists of cross laminated timber walls and a solid timber flat roof. The basement and the interior walls are the same as in the concrete variant. *Fig. 11* reflects the disposal indicator (1-5) of each element, The solid timber roof in the timber variant has a significantly worse disposal indicator (3.15) than the roof in the concrete variant. The poor disposal indicator is mainly caused by the thick rockwool insulation.

Figure 11: Use case - timber variant

MP DOCUMENT

In the following the **MP document** of the **concrete variant** is shown, which is an automatically generated document from BuildingOne. This document gives information about the recycling potential, disposal indicator, exact material composition and ecological impacts within the different levels (building-, component- and material-level). The recycling potential describes what amount (in %) of the building is recyclable and how much waste accrues throughout the whole life-cycle, thus directly comparing recycling and waste. The disposal indicator, proposed by IBO, is area-weighted and considers the disposal grade, recycling potential and accruing volumes. The recycling potential and the disposal indicator are both expressed as grade from 1-5, whereby the recycling potential considers all building components, whereas the disposal indicator only takes into account the building envelope (except windows and doors in exterior walls), the interior walls and slabs.

The results show that the building out of concrete has a recycling grade of 2.5, which stands for about 48% recycling potential. The disposal indicator of the building is 1.5. On building-level it is evident that the largest mass is represented by concrete (82.5%). Moreover, the PEI (Primary Energy Intensity) accounts for a significantly high amount. *Fig. 12-16* illustrate the developed MP document with the MP-results.



Material Passport for buildings

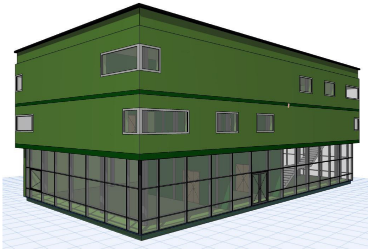
Bezeichnung	BIM-Material		
Gebäude(-teil)	Orange Bude	Baujahr	1989
Nutzungsprofil	Demo-Gebäude	letzte Änderung	2012
Straße	Mustergasse 15/5	Katestralgem.	Musterkatgem
PLZ / Ort	1234 Musterstadt	KG Nr.	12567
Grundstücksnr.	15/2	Seehöhe	684,00

RECYCLING POTENTIAL OF THE BUILDING	Recycling grade	Share of recycling (t)	Share of waste (t)
1 (86 - 100%)			
1,5 (72 - 86%)			
2 (58 - 72%)			
2,5 (44 - 58%)	2,5	638	700
3 (31 - 44%)			
3,5 (17 - 31%)			
4 (3 - 17%)			
4,5 (-11 - 3%)			
5 (-25 - -11%)			

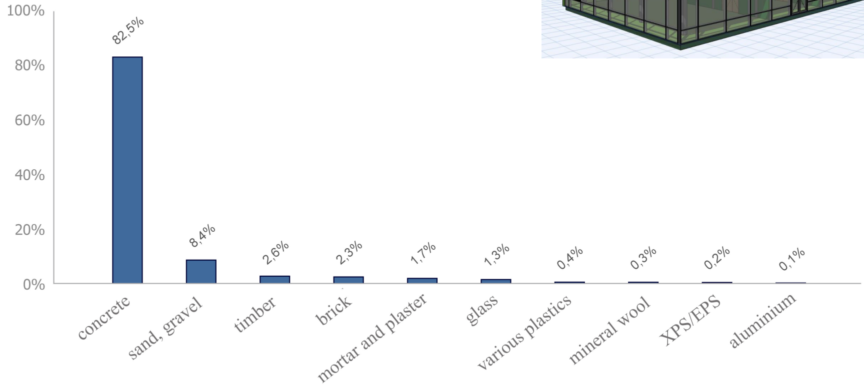
DISPOSAL INDICATOR OF THE BUILDING	Disposal Indicator (EI)
1	
1,5	1,5
2	
2,5	
3	
3,5	
4	
4,5	
5	

Figure 12: MP document p.1

BUILDING LEVEL



- **Material composition in %**



- **Accruing masses throughout the life-cycle (t)**

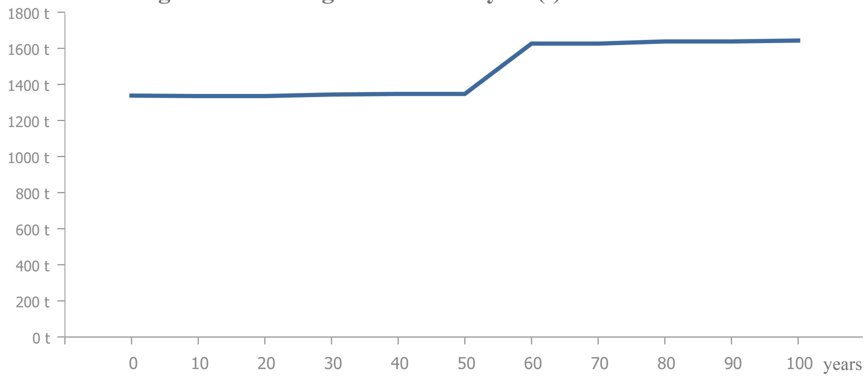
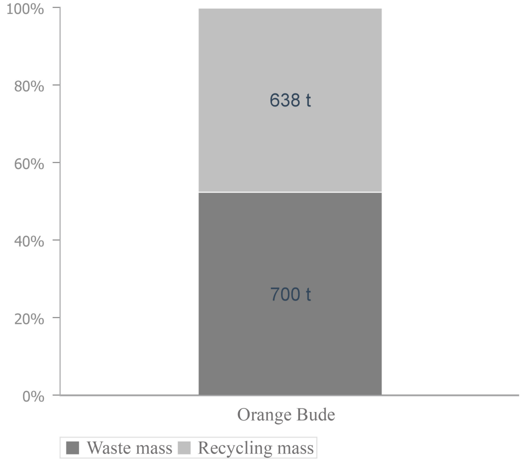


Figure 13: MP document p.2

- **Waste vs. recyclable mass**



- **LCA**

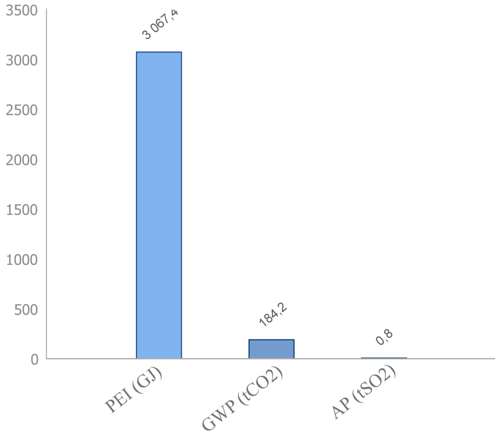
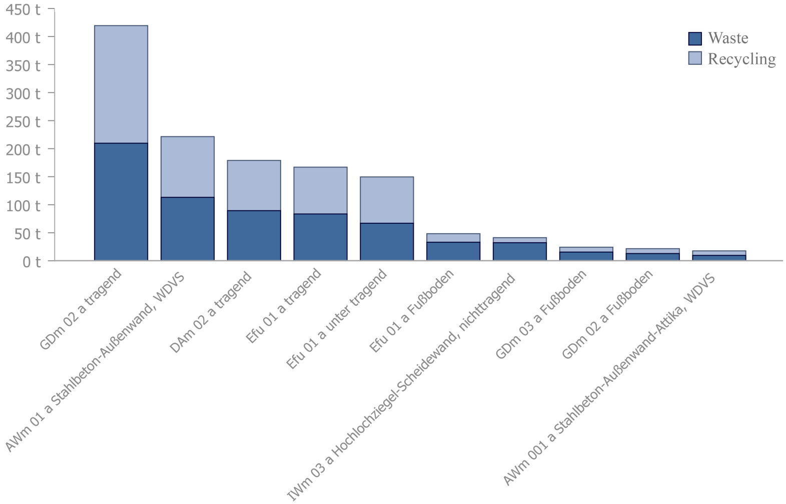


Figure 14: MP document p.3

COMPONENT LEVEL

- **Waste vs. recyclable mass**



- **LCA**

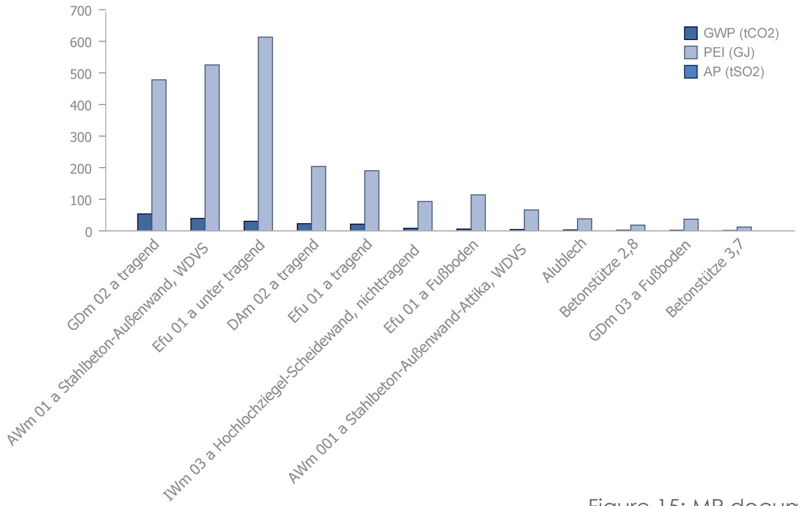
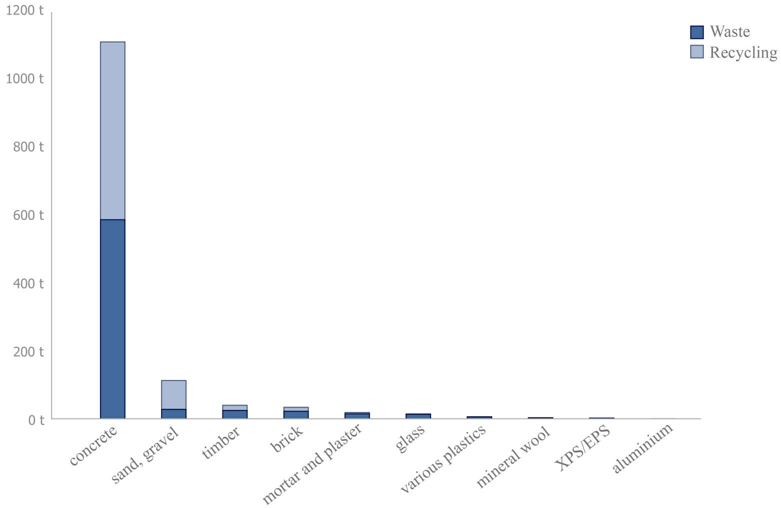


Figure 15: MP document p.4

- **Waste vs. recyclable mass**



- **LCA**

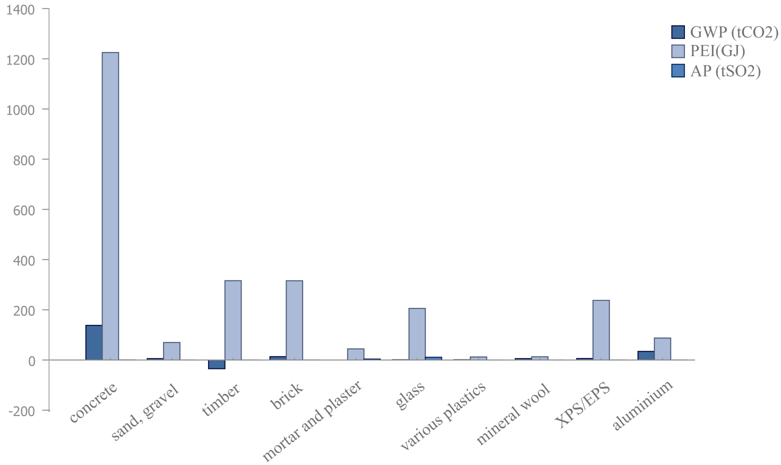


Figure 16: MP document p.5

FRAMEWORK

The generation of the BIM-based MP is based on a tool-chain, which consists of BIM-Software, a control tool and a material inventory and analysis tool. The compilation of the MP is enabled through the templates for BIM-Software, the control-tool and the material inventory and analysis tool. The templates are composed of all required rule sets and serve as basis for the compilation of the BIM-based MP. Through using the material inventory and analysis tool template, there is no need for a manual parametrization of layers, as the parametrized layers are directly taken from the template. Thereby the modeling guide serves as support for the MP-suitable modeling in BIM.

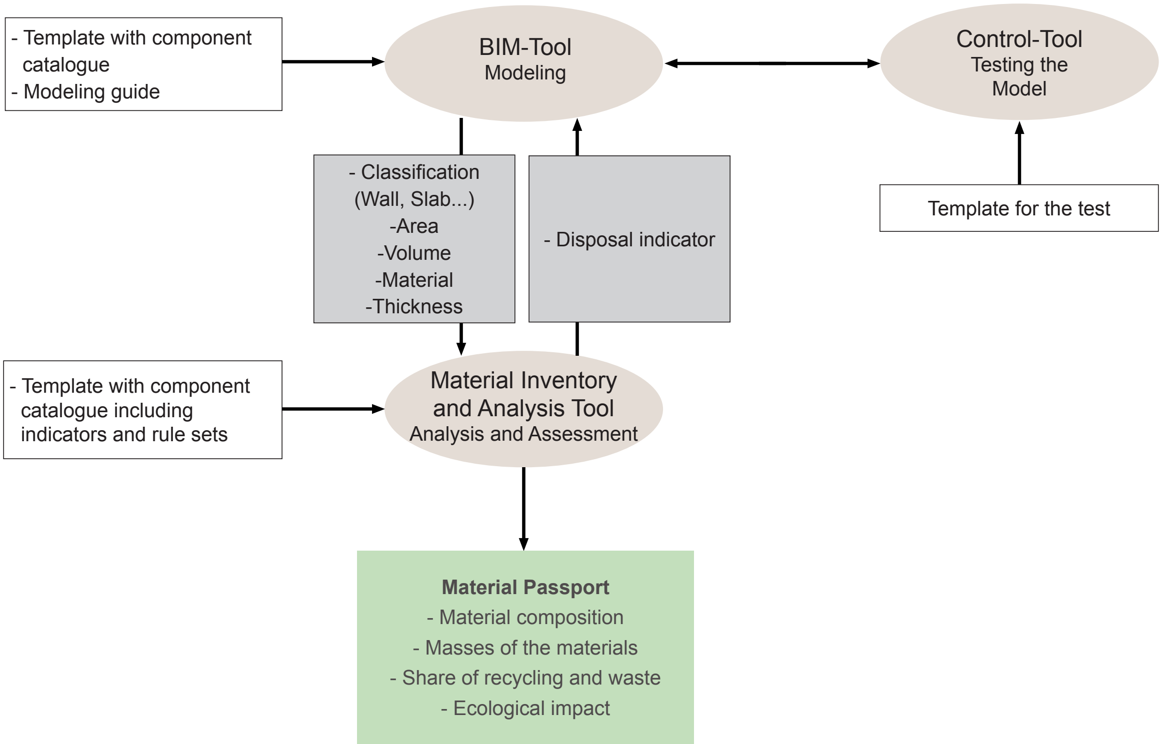


Figure 17: Framework for the generation of an MP

CONCLUSIONS

Within the research project BIMaterial, mainly the semi-automated generation of a Material Passport was investigated, as well as if the MP has potential to serve as basis for a secondary raw materials cadaster. The proof of concept shows, that the developed method for the compilation of a BIM-based MP is possible. Apart from that, the proof of concept presents large potentials for the generation of information rich secondary raw materials cadasters through future embedment in platforms such as GIS (geographical information system). This finding lead to the follow-up project SCI_BIM, in which the enhancement of resources- and energy efficiency is enabled through coupling of various digital technologies and methods for data- capturing (geometry and material composition) and -modeling (as-built BIM).

It can be expected that the existence of a BIM-based MP for short-term is a basic prerequisite for the optimization of the design and for long-term enables effective recycling, in particular, when we consider the increasing material complexity of buildings nowadays. The existence of a BIM-based MP, which is complemented with a deconstruction concept, should become a standard for certified buildings and later serve as cornerstone for the development of a secondary raw materials cadaster. There exists demand to further automate the process, wherefore new research cooperations towards developement of BIM software with the project team will follow.

BIMMATERIAL

Long report of BIMaterial
(ISBN 978-3-200-06012-8):
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SCI_BIM

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