# Proof of Concept for a BIM-Based Material Passport

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**Abstract**

Building stocks and infrastructures are representing the largest material stock of industrial economies. In order to minimize the use of primary resources and the dependency on imports, "Urban Mining" strategy aims to recycle these urban stocks. For enabling of higher recycling rates detailed knowledge about the composition of building stocks in needed. Recyclability is also determined through design and is depending on constructive criteria defining accessibility and separability of building components, whereby the early design-stage plays an important role. In order to optimize the recycling potential and material composition of buildings, new design-centric tools and methods are required. The so called Material Passports represent such tools, which next to the design optimization would enable circular economy in the building industry. In this paper we will present the results of funded research project BIMaterial: Process design for BIM-based, Material passport. The main aim of this research is to create a BIM-based Material Passport for the optimization of the building design regarding resources use and documentation of materials, thereby using Building Information Modelling as knowledge base for geometry and material properties and coupling to further databases for assessment of ecologic footprint and recycling potentials. Thereby a framework for modelling and methodology for semi-automated Material Passport assessment will be proposed. As the methods and structured data that would allow an automated creation of a Material Passport are still lacking, therefore the current research has an innovative character and closes a research gap in this field.

**Keywords**

Circular economy • Digital tools • Resources efficiency

## 89.1 Introduction

Global material resources consumption is increasingly rising as well as the world's population; thereby the future challenge will be to provide sufficient land, material and natural resources; as well as to deal with upcoming waste.

Building stocks and infrastructures are the largest material stock of industrial economies. 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—a strategy labelled as "Urban Mining". The increased application of construction materials with some delay triggers the equivalent increase in solid waste generation. Considering the average lifetime for construction products to be 40–50 years, a significant increase in solid waste generation is to be expected within the next decades. The only response to the challenge of landfill shortages can be the consequent increase of recycling and re-use rates. For higher

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recycling rates, it is vital to have detailed knowledge about the composition of both building stocks and construction wastes. Recyclability changes over time, as it is a function of technological development and resource markets. Building design has also a strong impact on recyclability, which depends on constructive criteria defining accessibility and separability of building elements (or its parts). Currently we lack knowledge on exact composition and construction of building stocks, representing a major obstacle for optimization of recyclability of build-in materials and thereby increase of recycling rates.

Powerful computational technologies and tools such as Building Information Modeling (BIM) and Geographical Information Systems (GIS) offer large potentials for modeling and analysis of both new construction and building stocks in terms of material composition, and creation of so called material cadaster, for which a Material Passport (MP), as documentation of material composition of a single building builds a fundament.

The main research question is how to efficiently model, analyze, and optimize predict the material flows within a building, particularly with regard to the assessment of material masses and the reduction of landfill waste in order to increase re-use and recyclability?

In this paper we will present the results of funded research project BIMaterial: Process design for BIM-based MP. The main aim of this research is to create a BIM-based MP for the optimization of the building design regarding resources use and documentation of materials, using BIM as knowledge base for geometry and material properties and coupling to further databases for assessment of eco-indicators and recycling potentials. Thereby a modelling methodology and workflow for semi-automated MP assessment will be proposed.

## 89.2 Literature Review

Life Cycle Analysis (LCA) and analysis of resources and material-composition of buildings stand in close relationship. The LCA is a general assessment of environmental impacts of buildings along the life-cycle and considers the environmental impacts of production process, transport, renewal, and finally recyclability or waste management of materials in terms of indicators such as global warming potential, primary energy consumption and further. The most common LCA-method is the process analysis method, whereby the direct and indirect energy inputs in each product process are evaluated. The LCA method is determined by the International Organization for Standardization (ISO) Standard 14040:2006, which describes the principles, the framework and temporal and spatial system limits of the LCA. Further, the main phases of LCA are explained, which imply the goal and scope definition, the inventory analysis, the impact assessment and the interpretation phase.

BIM-use for life cycle analysis in the design stage has been of increasing interest in the research community. BIM as emerging tool bears large potentials in terms of process-automation. Azhar et al. [3] carried out a thorough analysis of BIM-fitness for sustainability assessment using Leadership in Energy and Environmental Design (LEED) rating analysis. Thereby they established a procedural framework for the environmental analysis that can be conducted using a BIM-model, and LEED credit requirements. However, an automated work-flow is not possible, due to lack of LEED features integrated in the software.

Geyer and Buchholz [9] developed an innovative urban system model frame-work that follows a holistic approach, whereby both, energy and resources, are evaluated. This approach is described as Parametric Systems Modelling (PSM) and is based on the System Modeling Language (SysML). SysML is a design-oriented modelling approach, which supports geometry-based CAD. SysML considers multidisciplinary information and parametric interdependence. The results are displayed as flow chart, where energy, water and $CO_2$ emissions and dependencies are shown. However, the resulting system-model is a non-geometric model and the process is not automated.

Accomplishing a LCA is a challenging task, since information about the material composition of buildings and the production process of the materials is lacking. Apart from that, the manual input of life cycle inventory data for every material is an obstacle [6], for which the integration of BIM and LCA software might represent a solution, since it is possible to integrate material specifications and conduct quantity take-offs in BIM [1]. However, there still exists lack of data interoperability between BIM and LCA-tools as well as the problematic of inaccessibility and complexity of LCA inventories and tools [13]. LCA tools have to be built into BIM-software to get standardized implementation of LCA and improve data exchange [8]. Coupling LCA databases to the BIM-tools could also overcome the obstacles.

BIM as information rich model of a building shows large potentials for the automated generation for both LCA and MP. Prins et al. [18] described and evaluated in a research several Circular Economy cases in the Netherlands. One use case was an educational building, which required a renovation. Therefore a resource passport has been created in form of a digital BIM.

BIM has also been identified as tool for minimizing the amount of Construction and Demolition waste (C&D waste) [21]. As C&D waste is growing continuously, it receives big attention from practitioners and researchers around the world [14]. BIM shows big potential for reducing design errors, rework, and unexpected changes.

However, automated generation of MP as well as automated LCA from BIM are still facing numerous challenges. Major challenges are LCA-data accessibility and automated coupling of BIM-models (and object libraries) with LCA inventories. Further on, current LCA inventories are including eco-indicators regulated by ISO. These inventories are generally lacking information on recyclability or separability of materials within building elements or between elements, which is a crucial information for the MP. Although BIM shows large potentials as optimization and documentation tool of material composition of a building as well as for an automated creation of LCA, a method for an automated creation of a MP is still lacking, therefore the current research addresses innovative approach in this field.

## 89.3 Methodology

Based on our previous research [22] through testing of software for semi-automated BIM supported LCA on a case study, we have decided for generation of semi-automated MP through coupling of BIM with the data management and analysis tool BuildingOne (BO). We are using the data management approach of linking the model with the external eco-databases through BO, instead of integrating the data in the model itself.

For the compilation of a MP numerous databases provide data for the composition of construction elements, their recycling potential and eco-indicators. The main obstacle when using data from different databases is the inconsistent naming and structuring of products and materials, which leads to incoherencies in data transfer. In order to guarantee for consistency of data regarding eco-indicators as well as indicators of recyclability and separability, we use only data provided by Austrian Institute for Building (IBO), and their corresponding databases baubook or tools such as eco2soft [10].

In the first step the scope of necessary information was defined, which on the one included expert—interviews (demolition companies, material recycling union, material industry) and on the other was based on the knowledge generated in the project "Christian Doppler Lab". As MP will be compiled at the conceptual-structural level, and is regarding short-term as well as long-term benefits, where as raw material extraction and upcoming of waste should be minimized. The MP should address resources and material efficiency along the life cycle of a building, and will thereby be developed for four stages:

**MPa** is addressing conceptual design phase. This stage has the largest impact on life-cycle performance regarding re-usability of the building elements and materials as well as on upcoming waste. Thereby the optimization potential is the largest at this stage, as is the importance of MP a as design-optimization tool.

**MPb** is addressing the preliminary design phase, as planning-optimization tool and support for design for deconstruction, as well as to compile a deconstruction concept.

**MPc** is completed in tendering stage in order to assess the exact material composition.

**MPd** is representing a final document on material inventory of a building and is delivered at the handover to the operation.

A methodology for modeling is proposed upon national BIM-standard (Austrian BIM-standards ÖNORM 6241-1 and 6241-2), defining Level of Development (LOD) and Level of Detail (LoD) of a BIM-model. The proposed framework defines the necessary LOD along various design stages. Thereby the material matching and coupling with state-of-the art LCA-data inventories is carried out according to the granulation of LOD.

For the compilation of MP a LCA methodology is applied. LCA focuses on evaluating the total environmental impacts of buildings over their entire life cycles. The environmental impacts occur throughout several life cycle stages—production, transport, operation and end-of-life scenarios. The LCA assessment as proposed by building certificates or IBO assesses the three most important indicators as environmental impacts: Global Warming Potential (GWP)—$CO_2$ equivalent, Acidification Potential (AP) and Primary Energy Intensity (PEI), consisting of Non-Renewable and Renewable parts. For the compilation of MP additional indicators have to be assessed such as reusability, recyclability and separability; which are also proposed by IBO.

BO was chosen as powerful database and management tool, enabling bi-directional data exchange with BIM-model, thus all of the geometry or material changes can be carried out either in the model or in the database; as a tool for material-inventory and LCA assessment; and was tested for such use for the first time; as originally the software tool is developed for asset management. Further on BO enables the creation of Rule Sets for the assessment of quantities and LCA, thus supporting automated compilation of MP, once Rule Sets have been created and materials matched. Thereby the properties needed for LCA were generated in the BO tool. The results of the conducted test studies show that the data exchange between the BIM-software and the tool works properly [23]. Based on the insights of the study, requirements for generating a BIM-based MP and a proper workflow were developed. A workflow description will be presented in detail in Chap. 4.

## 89.4 Workflow Design

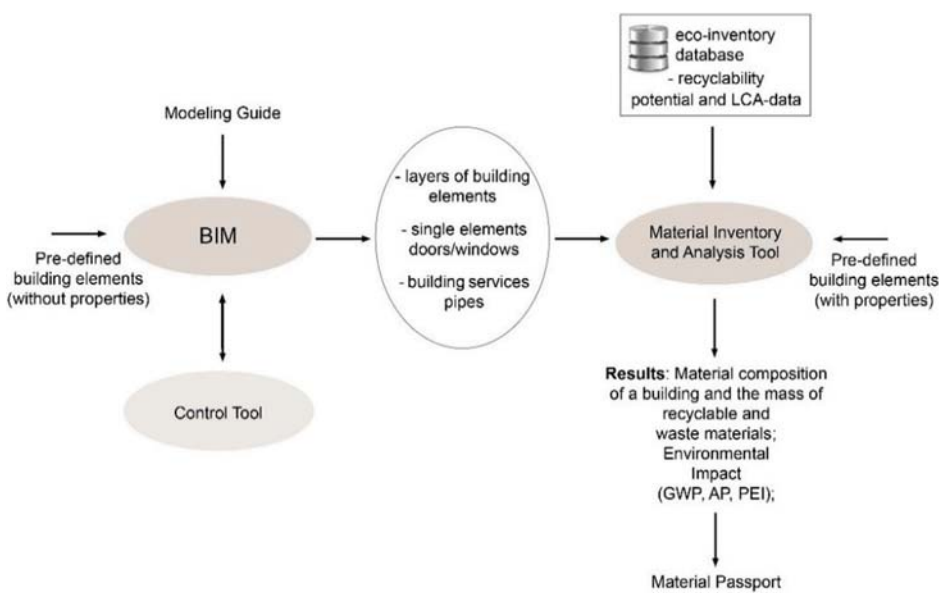
For the generation of MP, we propose coupling of BIM-model with the material inventory and analysis tool BO. BIM-software is used for modeling and BO for matching of eco-indicators to materials and LCA/MP assessment. The workflow is tested with two BIM-software Tools (ArchiCAD and Revit). The material inventory and assessment tool BO offers a bi-directional data exchange to BIM-software and an automated synchronization of data. Figure 89.1 illustrates the developed workflow for the compilation of a MP.

BIM-software is used for generating a detailed model, whereby a modeling-guide is taken into consideration, which defines the requirements for a MP-Model, e.g. that all building elements should be multi-layered (in design stage MP b). A control tool (Solibri Model Checker) is used to ensure that the BIM-model is error-free. In a further step all the required information about building components is exported to the assessment tool (BO), where the materials used in BIM-software have to be matched with the materials existing in the eco-inventory-database in order to conduct the LCA and assess environmental life-cycle impact expressed through indicators such as e.g. the GWP. Therefore, the eco-database requires coupling with the tool (Fig. 89.2). In the assessment-tool, the building components are also parametrized through values for the recyclability and separability in order to assess the total mass of recyclable and waste materials. Due to the direct connection with the BIM-model, all model changes are synchronized automatically and queries are recalculated. Final result is a MP consisting of the information about all materials and their recycling potential existing in the building.

For the compilation of an automated **MPa** "component catalogue", where elements are pre-defined has to be used. The "component catalogue" is outlined in an Excel-file, whereby each layer of an element is attributed with properties like e.g. separability and recycling potential, data that originates from eco2soft database. In a further step, the developed elements are modeled in BIM-software (ArchiCAD or Revit), which are provided as a template. In BO these elements are enriched with further information (property/m$^2$) and summed up in categories such as GWP, AP etc. On material-level, all materials have a characteristic value, which is also summed up on the element-level. Modeling in hybrid-modeling-methodology and mono-layered-modeling-methodology (each layer as wall) is not permitted (assessment for elements would not be possible).

In conceptual design stage (**MPa**), the BIM is modelled with mono-layered elements, which are then in a further step matched with pre-defined elements in BO. In this stage, variant studies can be carried out; as for example a variant in timber compared to a variant out of concrete; thereby MP a serving as an important decision-support tool.

**Fig. 89.1** Workflow



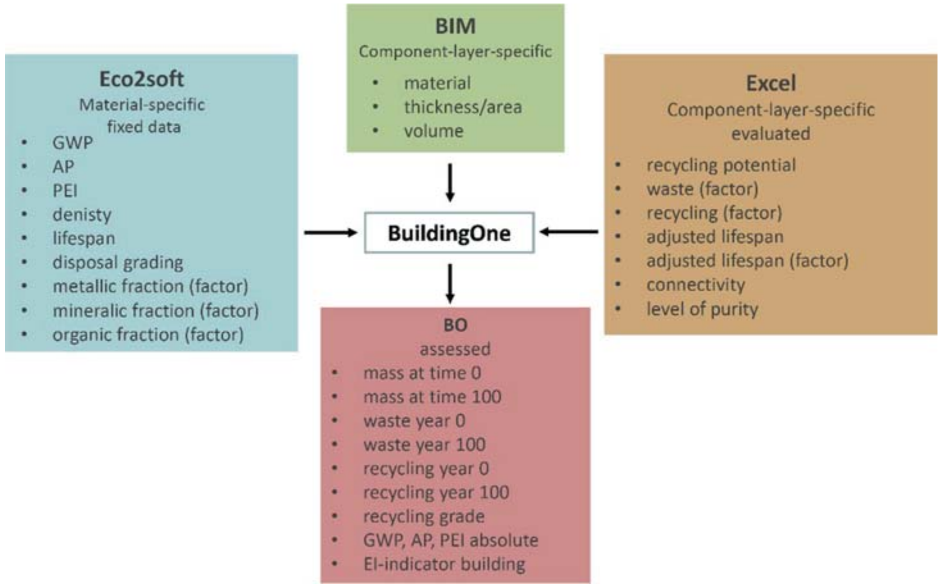



**Fig. 89.2** Data for assessment

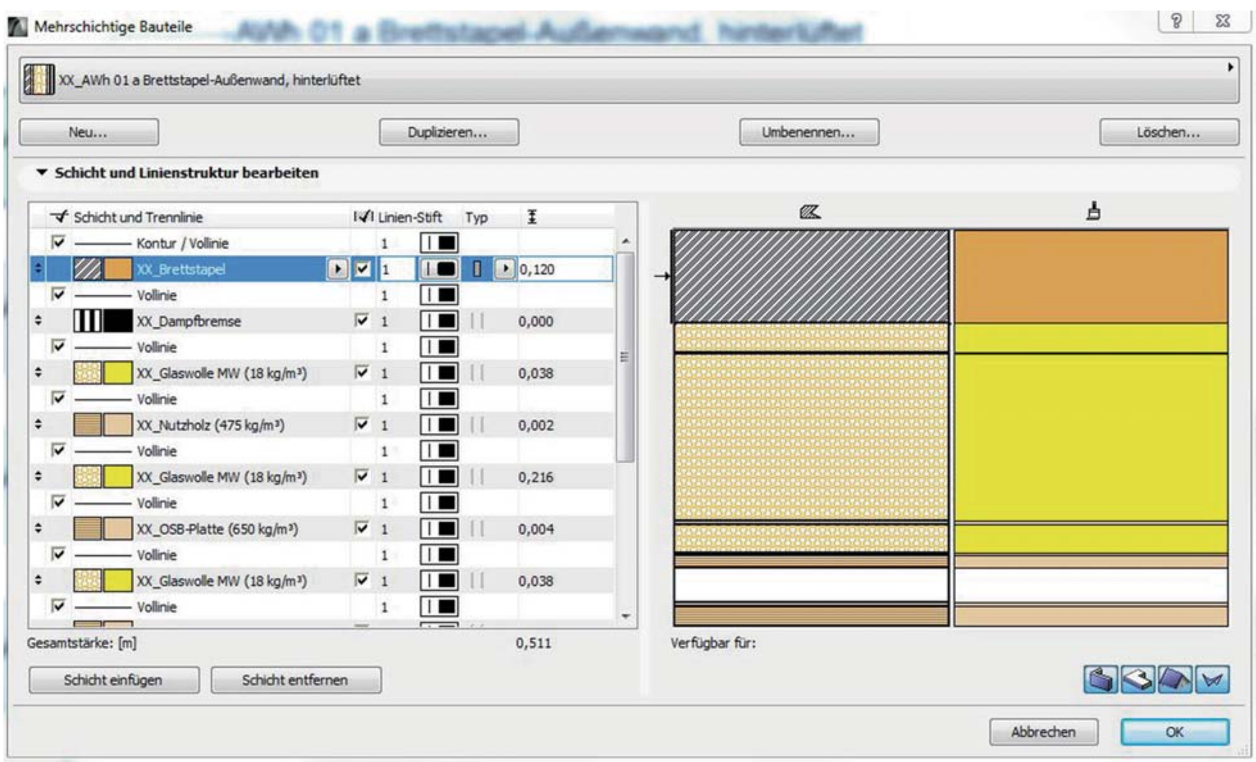



**Fig. 89.3** Pre-defined exterior wall in ArchiCAD, MPb

In the design stage, the model is already created with multi-layered elements, which only have information about the thickness, materials and volume/area. In this stage, it is important to use the elements provided in the template, in order to make matching with the elements in BO possible, as these elements have the same designation (Fig. 89.3). In the design stage small changes as for example, optimizing the thicknesses of layers is possible. The **MPb** serves mainly as an optimization tool.

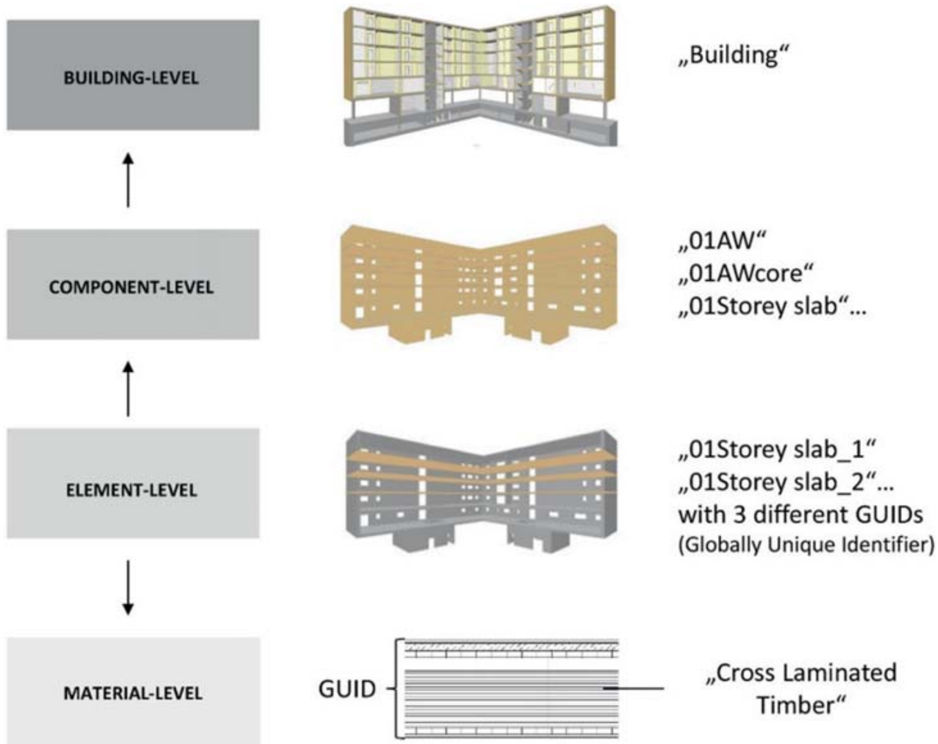



**Fig. 89.4** Scheme for the MP

For the compilation of the Material Passport a scheme was developed (Fig. 89.3), incorporating top-down and bottom-up approach.

Thereby the building is divided in four levels: the Building-Level, which consists of the mass and the share of all materials in the whole building; the Component-Level, which is the sum of all materials existing in a particular component (e.g. slabs); the Element-Level, which represents all materials of one particular element (e.g. slab “01”) and the Material-level, whereby the mass, type of connection with the enclosed materials and the recycling potential is described for one specific layer/material. The scheme is based on a prior research from Markova and Rechberger [15] whereby a mixture of the bottom-up and top-down approach is tested by starting with the Element-Level in this case.

With up-and downscaling we obtain the sum of recyclable and waste material in tones and as a share in % for each material, element, component and building, underlining the weak points regarding recyclability.

The Globally Unique Identifier (GUID) is automatically generated for each building element by BIM-software, thus allowing identification and allocation of every element within “higher” system e.g. building model (Fig. 89.4). In this way accessibility can be parametrised. Accessibility is expressed as sub-indicator of recycling potential indicator.

Finally, the data-transfer and analysis of BIM-model in BO allows extensive assessment and analysis of material composition of a building, such as assessment of all material-quantities, of percentage of mineralic, metallic or organic materials, of recyclable and waste materials over buildings’ life cycle etc.

## 89.5 Conclusion

In this paper, we presented a proof of concept for compilation of BIM supported material passport as multifold instrument along 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.

The problems encountered through conducted research primarily address the processual issues such as lack of standards and structures for material properties in data repositories. Further on, as the LOD of BIM-models in the early design stages is still very vague, exact allocation and attributing of materials is very difficult for the planners. The early design stages are characterized by high level of implicitness, aggregated indicators for building elements of different typologies instead for each material layer, would be therefore necessary. In latter planning stages, high level of expertise regarding materials and sustainability is required by designers in order to be able to conduct material assessment, which often is not the case, therefore an auditor or additional competencies would be necessary to compile MP. The identified limitations of BIM—data handling and allocation in BIM models and lack of standardized object properties regarding material characteristics create a handicap for the implementation of the proposed "passport", therefore further actions towards synchronization of data dictionaries and eco-data repositories are needed for problem-solution.

The future research should address development of an integrated set of methods and tools (BIM to GIS) to establish a material cadaster for a city as well as modelling and prediction of future resources flows.

MPs should hence become a standard procedure for certified structures and buildings, and contribute to the implementation of circular economy principle along value chain within AEC (Architecture, Engineering and Construction).

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