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Concept for a BIM-based Material Passport for buildings

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Concept for a BIM-based Material Passport for buildings

M Honic[1], **I Kovacic**[1] **and H Rechberger**[2]

[1] Vienna University of Technology, Institute for Interdisciplinary Building Process Management, Vienna, Austria
[2] Vienna University of Technology, Institute for Water Quality and Resource Management, Vienna, Austria

meliha.honic@tuwien.ac.at

Abstract. Minimisation of resources consumption belongs to the main concerns of EU, resulting in the development of strategies for maximizing recycling rates in order to minimize environmental impacts and energy consumption caused by extraction of primary materials. Detailed knowledge about the embedded materials as well as their characteristics of building stocks is crucial in order to enable high recycling rates and low environmental impacts of buildings. In this paper, we will present the results of the funded research project BIMaterial: Process design for a BIM (Building Information Modelling) -based Material Passport. The concept of the BIM-based Material Passport is used for evaluating the recycling potential and environmental impact of materials embedded in buildings. The BIM-based Material Passport assesses all materials including their quantitative and qualitative properties, thus significantly supporting recycling and reduction of environmental impacts. Further, the BIM-supported Material Passport serves as design optimization tool and enables the generation and comparison of variants thus supporting the decision making process. The main aim of this research is to generate 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 the methodology for the semi-automated generation of the BIM-based Material Passport will be proposed.

Keywords: Material Passports, resources efficiency, recycling potential, BIM

1. Introduction

The demand for natural resources will increasingly rise due to the expected population growth up to 9 billion in 2050 [1], accordingly leading to a significant amount of waste. Therefore the main challenge in future will be to deal with the upcoming waste, as well as the supply of sufficient land, material and natural resources. The construction sector is the largest consumer of raw materials, with civil works and building construction being responsible for 60% of the raw materials extracted from the lithosphere [2] as well as for 40% of energy-related CO2 emissions [3]. In order to minimize the consumption of raw materials, the upcoming of waste and environmental impacts, maximizing recycling rates is the main strategy, as proposed by the European Union`s (EU) action plan for Circular Economy (CE). CEs aim is to reach a resource efficient and low carbon economy by maintaining the value of materials and resources in the economy as long as possible [4]. Creating circular solutions is also the main goal of the EU funded project Buildings As Material Banks (BAMB), where creating a Material Passport (MP) is part of it [5].

For enabling high recycling rates, it is necessary to have detailed knowledge about the existing stock and embedded materials. At present, we lack knowledge on the exact material composition of the existing building stocks, which is the main obstacle for enabling high recycling rates. Building Information Modelling (BIM) as emerging tool has the potential to support a life-cycle optimization of the built environment [6], since BIM offers modelling and analysing of new constructions as well as building stocks. A Material Passport thereby serves as a basis, as it consists of the detailed material composition of buildings.

In this paper the results of the funded research project BIMaterial will be presented, whereby the main aim of the research is to develop a method for a semi-automated generation of an MP with the use of BIM. The method consists of coupling BIM, which serves as a knowledge base for geometry and material properties, with a database for the assessment of the recycling potential and eco-indicators. The BIM-based MP enables an optimization of the building design regarding resources use, recycling and environmental impacts and represents a novelty, since there exists no similar BIM-based method according to our knowledge. The main results are the method, developed workflow and final MP–document, which will be presented in this paper.

2. What is the BIM-based Material Passport?

A Material Passport is a qualitative and quantitative documentation of the materials composition of a building, displaying materials embedded in buildings as well as showing their recycling potential and environmental impact. The BIM-based MP is moreover an optimization tool in early design stages and acts as an inventory at the end of the life-cycle of a building, therefore serving as a basis for a secondary raw materials cadastre. Through knowledge gathered in previous projects, as well as through expert interviews, the content of MP as well as the vital characteristics were defined. These are the type, amount, allocation and quality in terms of recyclability and environmental impact of materials, as well as the separability of two enclosed materials. The separability of two enclosed materials is an important information, since materials which are glued to each other are difficult to separate and lead to unclean fractions.

3. Framework for the BIM-based Material Passport

The framework is based on a prior research from Markova and Rechberger [7], whereby two approaches were tested, which are the bottom-up top-down approaches. For the BIM-based MP a mix of these two approaches was used, by starting with the element level. Figure 1 shows the developed framework, which consists of four levels: the building-, component-, element- and material-level. Through up- and down-scaling, one particular component, element or material can be reached. In the building-level, all components existing in a building, such as the slabs, exterior walls, are added up. The component level sums up all elements with the same construction such as slab 01a, slab 01b and slab 01c to the component slab 01. The element-level displays all layers/material such as layer 1, layer 2 etc., which exist in that element. Further, each element is characterized through the Globally Unique Identifier (GUID) in BIM-Software, which is a unique 22 character-length string, automatically created in BIM. The GUID enables the parametrization and allocation of elements in buildings. Through downscaling from the element-level, the material-level is reached, where properties for the MP are linked to each material.

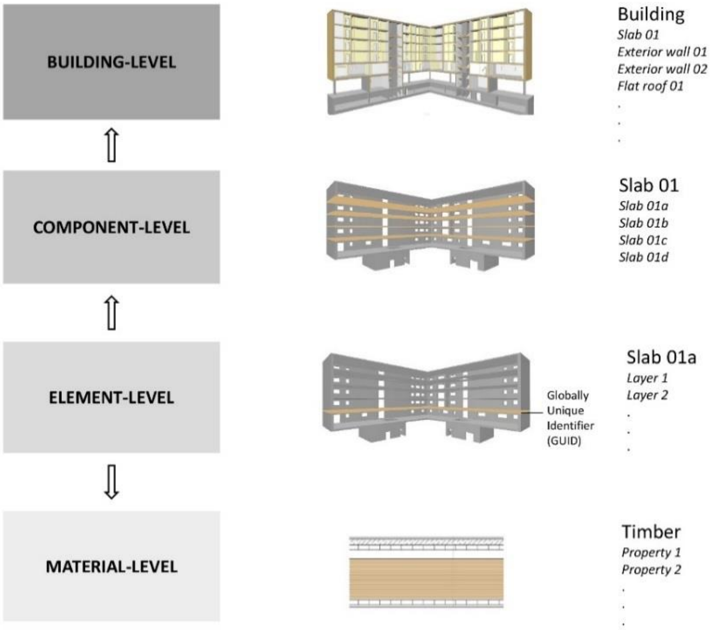

Figure 1. Framework for the MP.

4. Scope of the BIM-based Material Passport throughout the life-cycle

The BIM-based MP has varying purposes throughout the life-cycle, as displayed in figure 2. Four stages were considered for the MP, whereby the focus of this paper is on the conceptual and preliminary design stage (MPa and MPb).

In the conceptual design stage, the MPa serves as a rough analysis and optimization tool, where variant studies are carried out, in order to decide about the most suitable construction in terms of the recycling potential and environmental impact. This stage has the largest impact on the life-cycle performance regarding recycling and waste as well as the environmental impact.

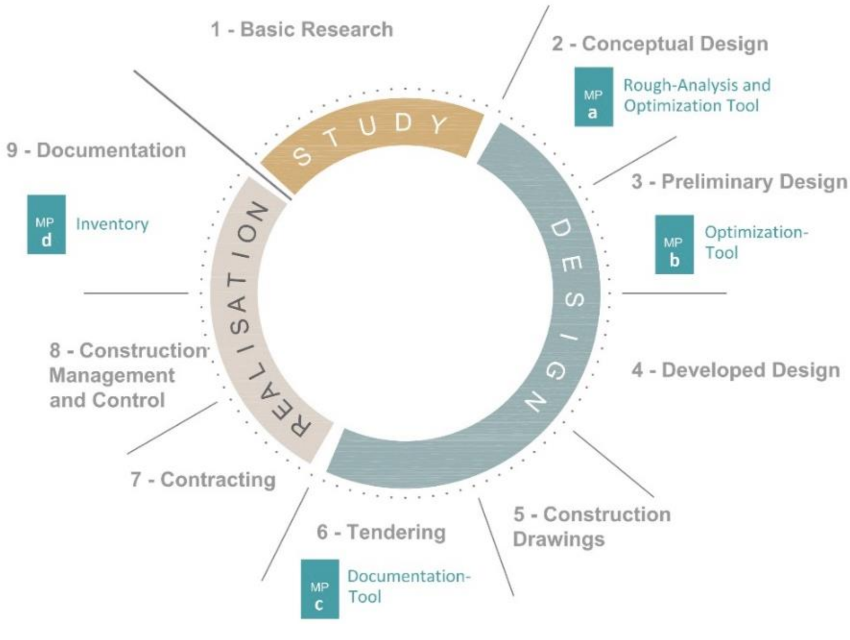

Figure 2. Scope of the MP.

In the preliminary design stage, the MPb acts as an optimization tool, whereby the specific layers and their thicknesses can be changed. The MPc is addressing the tendering stage, where the exact material composition is assessed. The MPd is a final document representing the material inventory of a building, which also serves as a basis for a secondary raw materials cadastre and is delivered at the handover to the operation.

5. Method and data

The main results obtained from the BIM-supported MP is the total material composition of the building including the masses and the recycling grade (from 1-5), which contrasts the share of recyclable materials with the share of waste created by the building. Apart from that, the BIM-based MP assesses the element-based disposal indicator, which is displayed in the BIM-model in colours from green to red (green: very good, yellow: average, red: bad disposal grade). The BIM-supported MP also shows the environmental impact of the building, expressed in Global Warming Potential (GWP), Acidification Potential (AP) and Primary Energy Intensity (PEI). All results are obtained on building-, component-, element- and material-level.

All above mentioned data, the method as well as the building elements, which were used for the templates, were obtained from the Institute for Building and Ecology (IBO) [8]. The recycling grade for the building is assessed based on the provided recycling grades and densities for each material. The masses are calculated through linking the provided densities from IBO and the volumes from the BIM-model. A material with recycling grade 1 stands for 75% recycling and 25% waste, whereby a material with grade 5 leads to 0% recycling and 125% waste (the additional 25% are due to auxiliary materials required for disposal). The separability plays a crucial role for recycling, since it is difficult to separate two enclosed materials which are glued to each other without having unclean fractions. Therefore the IBO-methodology proposes to downgrade a material which is glued to the enclosed material. By linking the recycling grade and the masses of each material and up-scaling the recycling grade for the entire building is assessed. Apart from that, the MP shows a disposal grade for each element in the BIM-model. The disposal indicator is area-weighted and considers the volume, disposal grade (from 1-5) and the recycling grade of each element. IBO also proposes a simplified LCA (Life Cycle Assessment)-method, whereby the LCA-results are obtained through linking the material-specific environmental impacts (GWP in $kgCO_2/kg$, AP in $kgSO_2/kg$, PEI in MJ/kg) to the masses of each material. The building elements are taken from the IBO passive house catalogue, which provides detailed material compositions as well as thicknesses of layers for walls, slabs, roofs and basements. For the template we integrated variants out of timber, concrete and brick from the IBO catalogue.

6. Workflow for generating the Material Passport

For the compilation of the BIM-based MP we developed a workflow, which is based on coupling of the BIM-Model with the material inventory and analysis tool BuildingOne (BO) [9]. BIM-Software is used for modelling the building and BO for matching of MP-relevant data to materials and subsequently for carrying out the necessary assessments. As BO has a bi-directional connection to the BIM-model, it enables an automated synchronization of model changes (e.g. change in height or thickness of a wall is automatically updated in BO through synchronization). Figure 3 illustrates the proposed workflow for the generation of the BIM-supported MP.

The building-model is created in BIM, based on a modelling guide and with pre-defined building elements, which are provided in a template. The modelling guide defines the requirements for the MP-model, e.g. that all building elements must have the right classification (wall has to be modelled as a wall) and that the building has to be modelled depending on the stage (MPa: mono-layered elements, MPb: multi-layered elements, see 6.1). The control tool (Solibri Model Checker) [10] is used to check the model in order to be error-free and suitable for the MP-assessment. Thereby the control tool also tests if the pre-defined elements are used in the BIM-model. After generation of the appropriate model, model-data, including building elements and their layers, volumes, thicknesses as well as single elements such as pipes, are exported to BO. BO is originally used as building information system for property management. In our research it was mainly utilized for parametrization of materials, since this is not possible in a consistent way in BIM. Thereby the MP-relevant data (recycling potential and LCA-data), which is obtained from IBO, is assigned to the materials of the pre-defined elements in BO. The pre-defined elements in BIM and BO have the same designation, through which matching elements from BIM to those in BO is enabled. Through assignment of e.g. the volume (from BIM) of an element, to the related recycling grade (in BO) of that material, that specific material is assessed. Through this assignment the assessment of the recycling potential and environmental impacts is enabled. Due to the connection of BIM and BO, model changes are synchronized automatically and assessments are recalculated. The final result of the MP is obtained from BO, displaying the total material composition of the building, including the share of recyclable materials and waste, as well as the environmental impacts, which are expressed in GWP, AP and PEI.

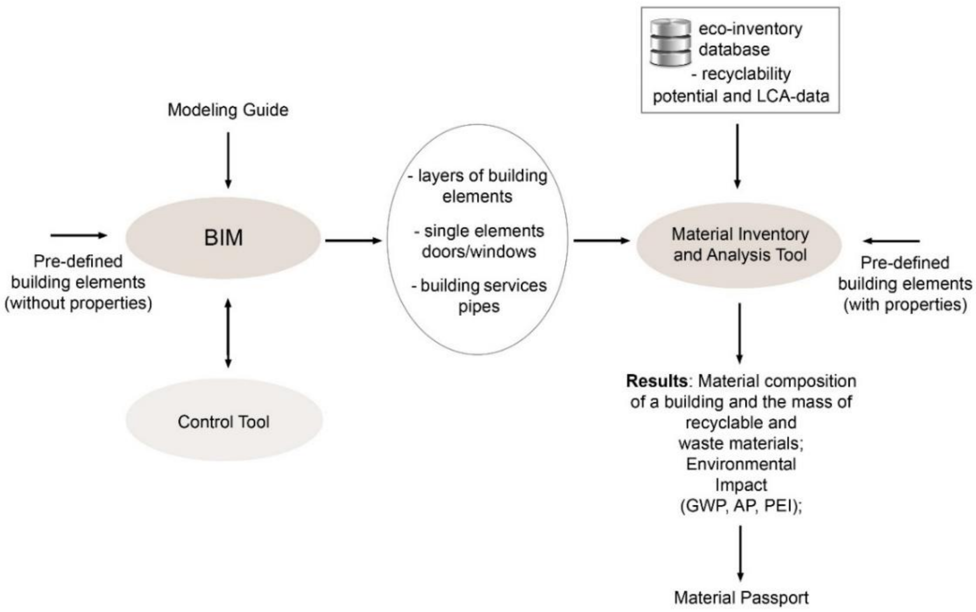

Figure 3. Workflow for the compilation of the MP.

6.1. Modelling methodology

The generation of the stage-oriented and BIM-based MP requires a specific modelling methodology. In this paper the focus is on the early design stages, where small changes can have a big impact to the recycling potential as well as the environmental impacts.

6.1.1. MPa. In the conceptual design-stage. the BIM-model is created with mono-layered elements and matched with elements in BO, as shown in figure 4. In this stage it is vital, that the geometry is modelled accurately, since the area obtained from BIM is considered in BO for the assessment. Apart from that, it is important that each element in BIM has the right classification, which means that a wall has to be modelled as a wall and a slab as a slab. In this stage it is possible to carry out variant studies, where e.g. a variant in timber construction is compared to a variant in concrete construction. MPa is therefore an important decision-support tool.

6.1.2. MPb. In the preliminary design stage. the model is generated with multi-layered elements, which only have information about the material, thickness and volume of each layer. In this stage, it is important to use the building elements provided in the template, in order to make matching with the elements in BO possible, since these elements have the same designation, as shown in figure 5. In this stage, small changes as for example, optimizing the thicknesses of layers or replacing a layer by another material is possible. The main role of the MPb is optimization.

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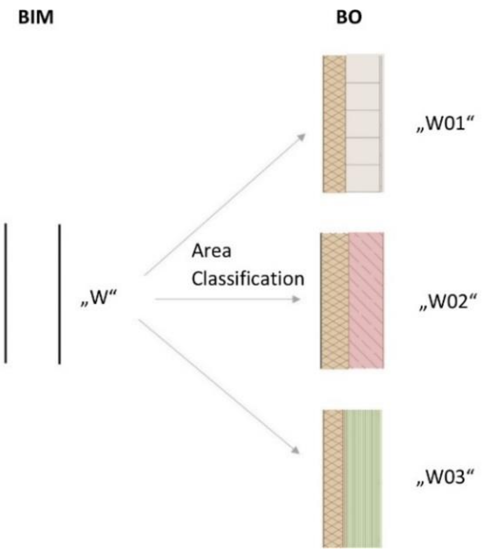

Figure 4. Modelling methodology for the MPa.

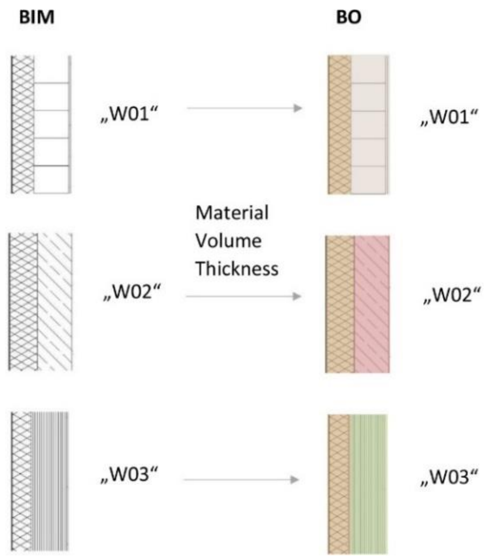

Figure 5. Modelling methodology for the MPb.

7. Result: MP-document

Based on a case study, which is an office building consisting of three storeys, the developed workflow was tested. The conceptualised building was planned in concrete construction and already modelled with mono-layered elements in BIM, as shown in figure 6. For a first analysis, these mono-layered elements were assigned to pre-defined elements in BO. In this phase it was important, that the geometry and classification of the elements was correct in order to achieve accurate results and enable the assignment of elements. After creating variants of the MPa, the most suitable variant in terms of recycling and environmental impacts for this use case was chosen. In a further step, the mono-layered elements were replaced by multi-layered and pre-defined elements in BIM and the thicknesses of the pre-defined elements were adapted to the thicknesses of the pre-existing model. Through the bi-directional data-synchronization, the changes on the model were easily updated in BO. Figure 7 displays the results of the office building out of concrete construction. The building has a total mass of 1338 tonnes and a recycling grade of 2.5, whereby 48% (638 tonnes) of the materials incorporated is recyclable and 52% (700 tonnes) leads to waste.

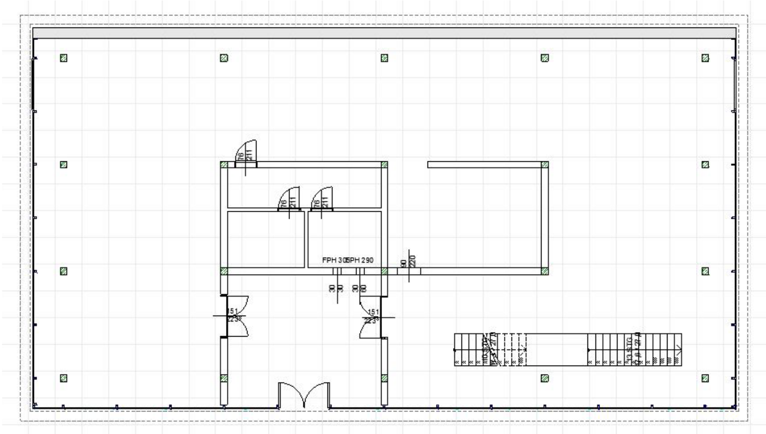

Figure 6. Pre-existing model of the use case.

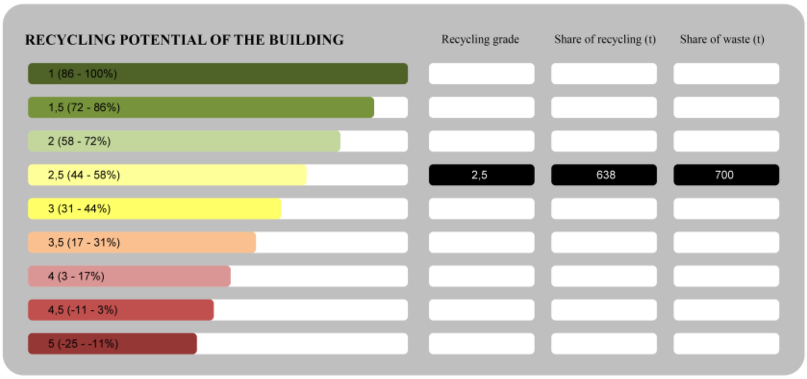

Figure 7. Recycling grade of the use case out of concrete.

Two variants of the same building were assessed and the MPb created. Figure 8 and 9 show the disposal indicator of each element. The variant displayed in figure 8 is out of concrete and the variant in figure 9 out of timber construction. It is significant, that the exterior walls of the timber variant have a better disposal indicator, than the concrete variant. However, the flat roof of the timber variant has a worse disposal indicator than the flat roof out of concrete, mainly due to the mineral wool insulation in the timber roof, which was obtained from the IBO-catalogue.

Figure 8. Concrete variant.

Figure 9. Timber variant.

In figure 10 the LCA results for the concrete variant are displayed, whereby the level of PEI is significant, as it accounts for about 3000 GJ. As concrete is the load-bearing element, it has the biggest influence in the results. The PEI for one kilogram concrete accounts for 1.14 MJ (IBO). As concrete has a high density and therefore a large mass, the total PEI results are high. The levels of GWP and AP do not have a considerable impact due to their low initial impact per kilogram (GWP=0.13 $kgCO_2/kg$; AP=0.0003 $kgSO_2/kg$; IBO) in comparison with PEI.

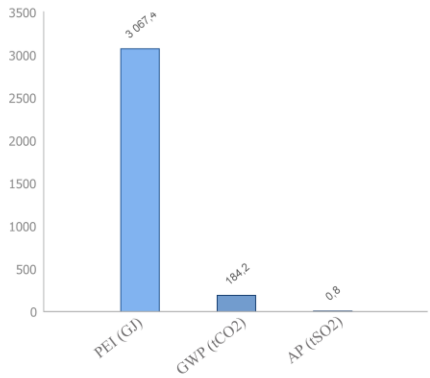

Figure 10. LCA-results.

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8. Discussion and conclusion

In this paper we presented the results of the research project BIMaterial. The BIM-based MP has diverse roles along a building`s lifecycle. In early design stages it serves as an optimization tool, whereby in later stages it acts as a documentation and inventory of building stocks.

During the research several obstacles were faced, such as lack of standards and structures for material properties in data repositories. Due to the inconsistent nomenclature in different databases, this research is restricted to one main database provided by IBO. Apart from that, the parametrization of materials is not possible in a consistent way in BIM, wherefore the material analysis and inventory tool BO needs to be used, which requires a specific expertise. Further, in early design stages the material composition is not defined yet, which requires the use of pre-defined building elements, in order to make an assessment in these stages possible. However, the use of pre-defined elements leads to a restriction of creativity for architects. In later planning stages, know-how regarding materials and sustainability is required by designers in order to be able to conduct a material assessment, which often is not the case. Therefore an auditor or additional competencies would be necessary to compile the BIM-based MP.

The focus of the presented BIM-supported MP is the optimization in early design stages, however, new construction rate across Europe is around 2%. A future research addresses the development of an integrated set of methods and tools (BIM to GIS) to generate a material cadastre for cities by using laser-and ground penetrating radar scan technologies.

The MP represents a central milestone towards standardized, BIM-generated MPs, which should become a standard procedure for certified structures and buildings and is a necessary future completion to the Austrian Mineral Resource Plan as well as a vital contribution to implement circular economy solutions within AEC industry (Architecture, Engineering and Construction).

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