

ASSESSMENT OF THE RECYCLING POTENTIAL AND ENVIRONMENTAL IMPACT OF BUILDING MATERIALS USING MATERIAL PASSPORTS – A CASE STUDY

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Abstract

Concerns about increasing global consumption of non-renewable resources as well as shortages of primary raw materials and reduction of space available for final disposal of wastes are raising important issues for the society. Additionally, the minimisation of resources consumption belongs to the main concerns of EU, resulting in development of strategies for maximizing recycling rates in order to minimize environmental impacts and energy consumption caused by extraction of primary materials. For enabling high recycling rates and low environmental impacts of buildings, detailed knowledge about the embedded materials as well as their characteristics in the building stocks is crucial.

In this paper, we will present the concept of the Material Passport (MP), used for evaluation of the recycling potential and environmental impact of materials embedded in buildings. A Material Passport assesses all materials including their quantitative and qualitative properties, thus significantly supporting recycling and optimisation of environmental impacts. Further, the Material Passport serves as design optimisation tool and it enables the generation and comparison of variants thus supporting the decision making process.

The assessment method and data structure for generating a Material Passport will be demonstrated on a case study. The focus is twofold - on assessing the recycling potential and environmental impact of single materials, as well as of the entire building. The assessment methodology is based on coupling of digital tools and digital building catalogues and eco-databases. The assessment of the concrete construction as case study demonstrates that the recycling potential of the building is about 50%; whereas the LCA analysis shows that the main environmental impact is caused by concrete as material. Thereby the Proof of Concept for the BIM supported MP as decision support tool was generated.

Keywords: Material assessment, data structuring, recycling potential, Material Passport

1. INTRODUCTION

The construction industry is the world's largest consumer of resources and responsible for 25-40% of global carbon emissions [1]. Only 20-30% of Construction and Demolition Waste is recovered, whereby many of the discarded materials have the potential to be recovered for different purposes. These purposes can be fertilizer additive, gravel and road-building materials. Increasing the reuse and recycling of materials, would improve the resource efficiency significantly [2]. The strategies for increasing recycling rates and reusability of building elements and materials in construction is a part of a larger concept: Circular Economy (CE). CE aims to maintain the value of products, materials and resources in the economy as long as possible in order to reach a low carbon and resource efficient economy [3].

In order to enable the increasing of recycling rates, detailed knowledge on the material composition of buildings is needed. Recycling is amongst others depending on features of construction such as accessibility and separability of building elements and materials. As constructive features are defined in early design stages, design-centric tools for architects and planners to enable the evaluation and optimisation of the recycling potentials and environmental impacts in the early design stage are currently lacking. In order to fill this gap, we propose a digital design-centric tool: Material Passport (MP). The MP provides knowledge on the material composition of buildings. It also gives qualitative and quantitative information about the embedded materials, their recycling potentials and environmental impacts.

This paper is structured as follows: in Section 2 the methodology, including relevant parameters, used digital data repositories, the data structure will be introduced, followed by the description of the case study in Section 3. In Section 4 the obtained results of the assessment conducted using MP will be presented, which will finally be analysed and discussed in Section 5.

2. METHODOLOGY AND DATA

2.1 Methodology for the MP compilation

The proposed methodology for compiling the MP consists of a digital workflow (Fig. 1), where eco-data repositories and digital building component catalogues are coupled with the BIM based tools. The workflow starts with modelling in BIM software, for which we provide a building component catalogue based on the Austrian Institute for Building and Ecology (IBO) [4]. The catalogue, integrated in a BIM template, consists of exterior and interior walls, ceilings, roofs as well as floorings. After the building has been modelled with components out of the catalogue, the relevant data, as shown in Fig. 1, is linked to BuildingOne [5] Tool. The eco- and recycling-data, which is obtained from IBO/eco2soft [6] is linked to the materials in BuildingOne, which serves as data management and assessment tool, where the final MP-results are generated.

BuildingOne enables the creation of various parameters, which can be assigned to materials of building components. The main reason, why BuildingOne is used, is that a parametrization of individual materials/layers is not possible in a consistent way in BIM, or would lead to big data sizes. Apart from that, it is capable of conducting the MP-related assessment, which is not the case in BIM. Moreover, it serves as the main tool where all the information is gathered, the assessments carried out and the MP created. Through linking recycling-data (e.g. grade 2: 50% recycling, 50% waste) to the parameters obtained from BIM (material, thickness etc.) in BuildingOne, the total share of recycling and waste is assessed. For obtaining the

environmental impacts of the building, eco-data (GWP=Global Warming Potential, AP=Acidification Potential, PEI=Primary Energy Intensity) is linked to the parameters gathered from BIM.

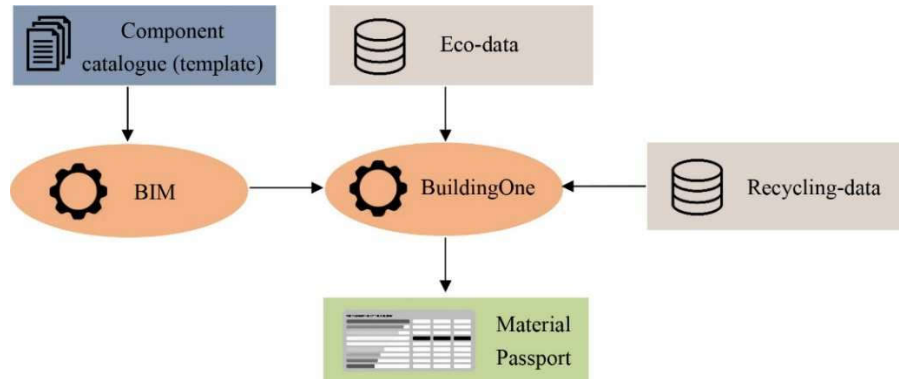


Figure 1: MP-workflow

2.2 Relevant parameters and databases

The relevant parameters for the MP were defined through knowledge gathered in former projects, as well as through interviews with experts from the AEC (Architecture, Engineering and Construction) industry.

The MP displays the total mass, share of waste and recycling, the recycling potential as well as the GWP, AP and PEI of the building. Therefore, various input parameters are necessary, which are provided by different databases. Due to data inconsistencies, such as varying nomenclature and units between various databases, one single database for all the indicators was taken into consideration.

As IBO offers on the one hand digital building catalogues and on the other recycling relevant data, as well as data for assessing the ecological impacts, it was chosen as the main database for the MP workflow. IBO considers three main environmental impacts (GWP, AP, PEI), which are included in the MP-assessment. Relevant parameters among others are the name of the materials, their density, environmental impacts, lifespan, area, thickness, recycling potential and connectivity. All relevant parameters and their sources are displayed in Fig. 2.

2.3 Data structuring

The MP-relevant input parameters are gathered from various sources, as shown in Fig.2. We differentiate between material-specific data, layer-specific data and evaluated data.

IBO is the main source for material-specific data, whereby the eco2soft tool, provided by IBO, was used. Eco2soft offers the possibility to generate as well as import building components from IBO. Parameters obtained from eco2soft are the material, density, GWP, AP, PEI, lifespan and disposal potential. In this paper, only non-renewable PEI was considered; the renewable PEI is not included in the assessment.

As certain building component characteristics, such as the connectivity of two enclosed materials, influence e.g. the lifespan and the recycling potential, the components require an additional evaluation process; which we conduct in MS Excel. Here the data for building components from eco2soft is gathered, analysed regarding above mentioned characteristics and evaluated. If e.g. the outer layer of a wall has a longer lifespan than the inner layer backing it, then the initial lifespan of the outer layer becomes shorter, because the two layers have to be

exchanged together. The recycling potential is originally the disposal potential, but depending on the connectivity. Since two materials, which are glued to each other are difficult to separate, the initial disposal potential needs to be downgraded, as proposed by IBO. The recycling potential is a grade from 1-5, proposed by IBO. Grade 1 stands for a recycling potential of 75% and 25% of waste, whereby grade 5 means that 0% of the material is recyclable and 125% are waste (additional 25% in waste for auxiliary materials required for disposal).

In order to assess the area, thickness and volume of the materials, the Building Information Model (BIM) is used. Thereby the model accuracy plays a crucial role; in terms of geometry as well as for proper classification - a wall has to be modelled as a wall element; and materials have to be chosen from the developed template (see 2.1).

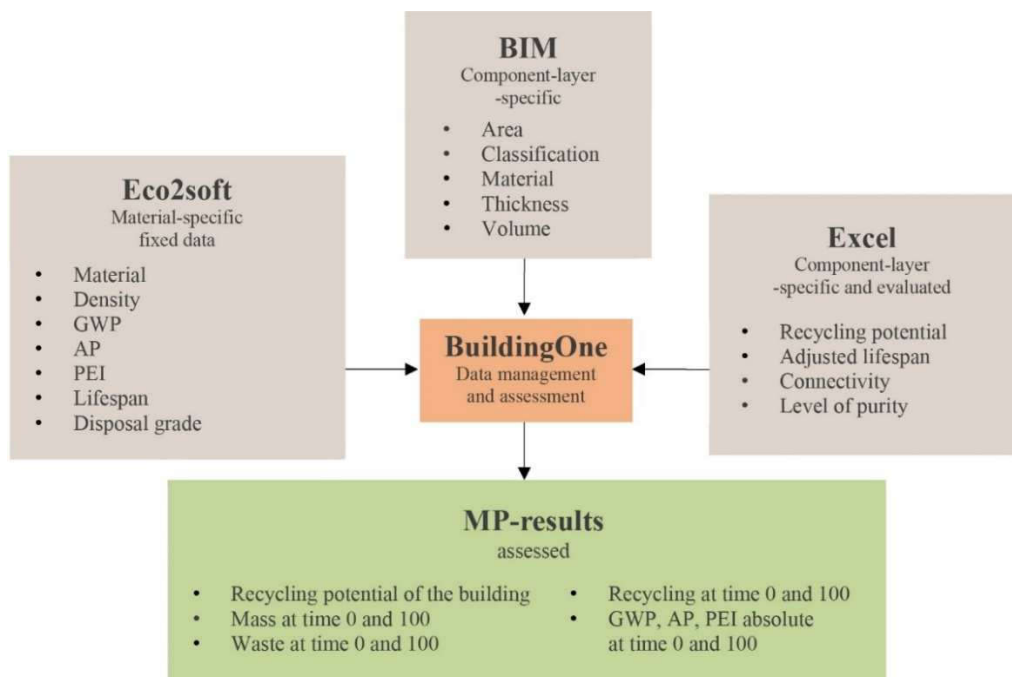


Figure 2: Data structuring

3. CASE STUDY

The MP concept was tested on a case study, which is an office building as concrete construction (Fig. 3). The conceptualised building was modelled with components from the component catalogue template in BIM. It consists of three storeys: one entrance floor with an open space area as well as sanitary facilities and the first and second floor, where office rooms as well as shared spaces are located. The load-bearing elements of the whole building are out of concrete with a thickness varying from 20 to 29 centimeters for exterior walls, ceilings, the basement and roof. The insulation of the outside walls are out of EPS (expanded polystyrene), whereas the roof has a mineral wool insulation and the basement a foam-glass insulation.



Figure 3.: Use case

Following building components were considered in the assessment:

- Exterior walls: I-O (Inside to outside); gypsum filler, concrete, EPS (expanded polystyrene) and silicate plaster
- Interior walls: cement finish plaster, perforated brick, cement finish plaster
- Roof: O-I (Outside to inside); PE (Polyethylene) sealing sheeting, PP (Polypropylene) fleece, timber, air layer with timber beams, PE roof underlay, timber, mineral wool between timber beams, concrete, gypsum filler
- Floorings: 2 variants; 1: solid parquet, internal chipboard, mineral wool; 2: solid parquet, cement, PE sealing sheeting, mineral wool, chippings, PE sealing sheeting
- Ceilings: flooring variant 1+ concrete with gypsum filler underneath
- Basement: flooring variant 2+ concrete, PE sealing sheeting, foam-glass, polymer bitumen sealing sheeting, lean concrete, building paper, sand and gravel, PP fleece
- Glass façade: post and beam out of aluminium, triple glazed glass panels
- Columns: concrete

Not included in the assessment are the windows, doors and staircases. The materials are assigned to groups:

- concrete: concrete, cement, lean concrete
- sand, gravel: sand, gravel, chippings
- timber: timber, timber beams, solid parquet, internal chipboard, building paper
- brick: perforated brick
- mortar and plaster: silicate plaster, cement finish plaster, gypsum filler
- glass: glazed glass panels, foam glass
- various plastics: PE sealing sheeting, PP fleece, PE roof underlay, PP fleece, polymer bitumen sealing sheeting
- mineral wool: mineral wool
- XPS/EPS: EPS
- aluminium: aluminium

4. RESULTS

The application of the MP-method enables the assessment of the total material composition, the recycling potential and the environmental impacts, as it was demonstrated on a case study. The displayed results are for time 0, and therefore for the time when the building is erected. Time 100 stands for the end of the life-cycle, where all materials, which have to be exchanged depending on their lifespan, in course of the years, are considered, however are not shown in this paper.

Fig. 4 displays the material composition of the office building, whereby it is noticeable, that concrete has a share of 82.5% of the total mass of the building. Since concrete is the load-bearing element, having a high density which leads to a high mass, this is an expected result. The second biggest share is represented by sand and gravel (8.4%). Other materials do not have a significant impact to the total mass distribution.

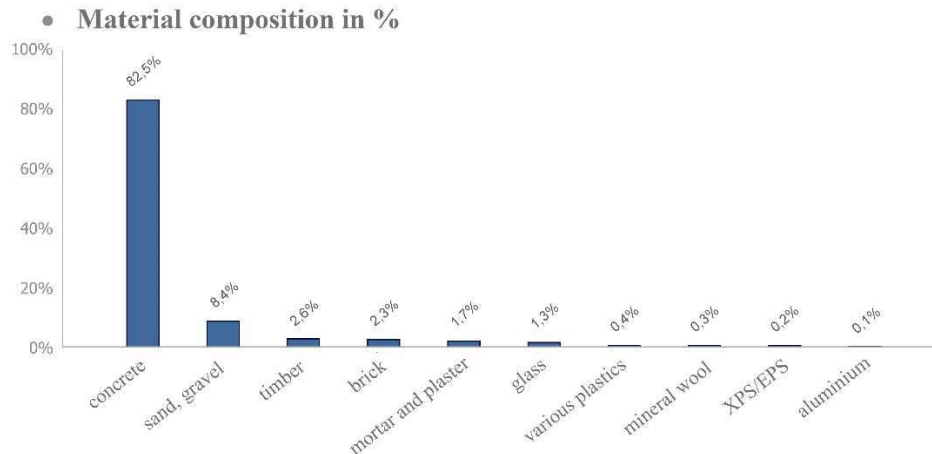


Figure 4: Material composition of the building

Results on building level, where all materials embedded in the building are added up, show, that a total mass of the building adds up to 1338 tonnes whereas 48% of the building materials can be recycled and 52% are waste (Fig. 5). The LCA results are displayed in Fig.6, whereby the level of PEI is significant, as it accounts for about 3000 GJ. The levels of GWP and AP do not have a considerable impact in comparison with PEI.

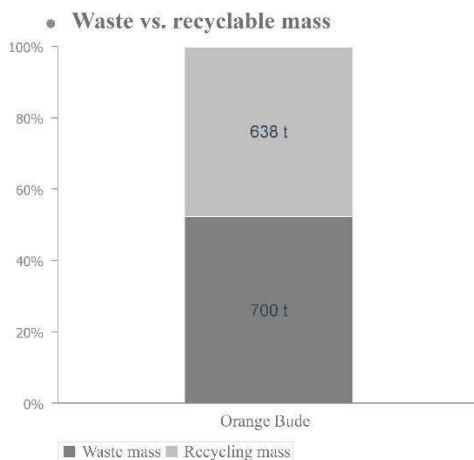


Figure 5: Waste vs. recyclable mass

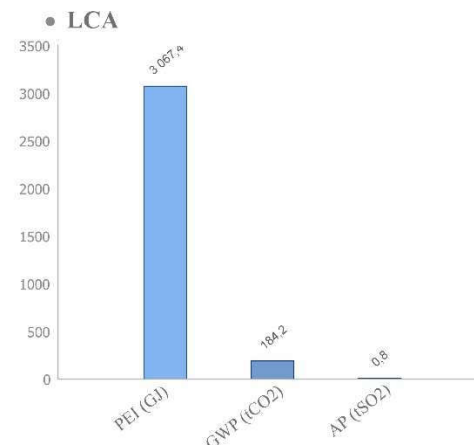


Figure 6: LCA- results

Fig. 7 displays the results on material-level are displayed, whereby the share of recycling is opposed to the share of waste potential for each material. It is evident that concrete has a share of about 50% to 50% for recycling and waste, as well as that concrete leads to the largest amount of waste, causing about 600 tonnes of waste, whereby the waste generated by the entire building adds up to 700 tonnes. Sand and gravel have a high recycling potential, since it is easy to reuse these materials. The other materials except concrete do not have a significant influence to the total recycling potential of the building.

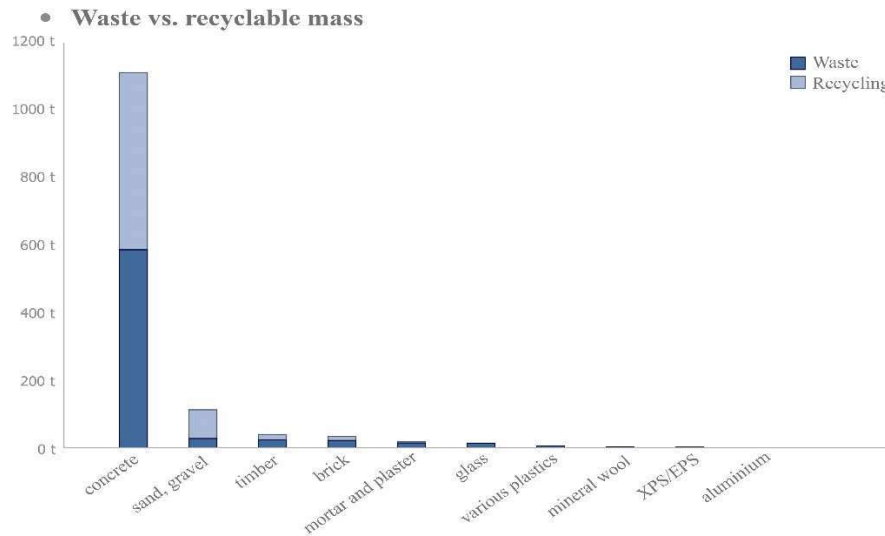


Figure 7: Waste vs. recyclable mass of materials

The vast mass of concrete is also reflected in the LCA-results (Fig. 8), since concrete accounts for about 1200 GJ of PEI. Hence, more than half of the total PEI is caused by concrete. Timber and brick lead to 300 GJ of PEI each, followed by XPS/EPS which accounts for 250 GJ of PEI. If the PEI per kilogram of concrete and e.g. timber is compared, it can be seen that concrete has a lower PEI per kilogram than timber (concrete: 1.14 MJ per kilogram; timber-spruce: 2.5 MJ per kilogram). Therefore, the vast amount of PEI in case of concrete is mostly due to its large mass. The large PEI per kilogram of timber is mainly caused by the energy required for drying wood. The CO₂ emissions of concrete accounts for 175 tonnes of CO₂, which is almost the same amount that is caused by the total building. It is also mentionable, that timber has a negative value for GWP, since timber is absorbing CO₂ from the air and sets free O₂. As the AP has no mentionable impact, it has not been further analysed.

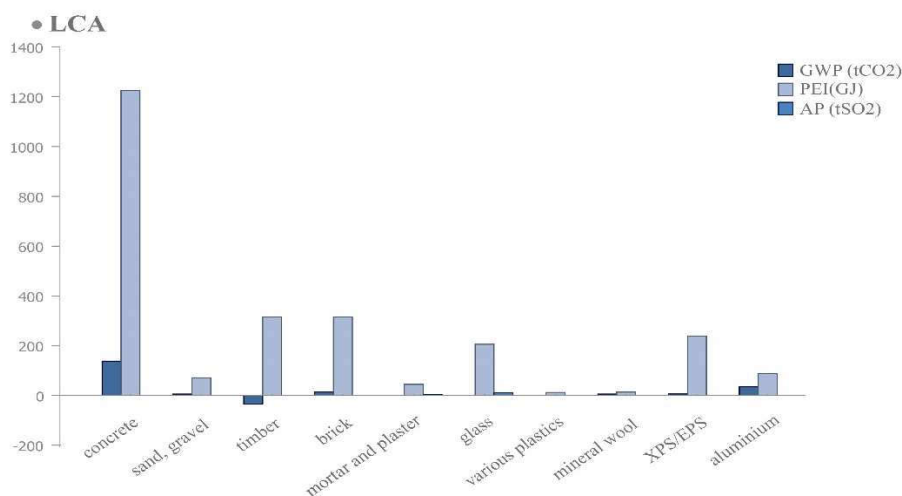


Figure 8: LCA -results of materials

5. DISCUSSION AND CONCLUSIONS

In this paper the methodology for generating a Material Passport using BIM based digital tools and data repositories was presented, focussing on the assessment of the recycling potential as well as the environmental impacts using LCA methodology. Therefore, a case study, which was conceptualised and modelled in BIM, was conducted for the Proof of Concept of the developed workflow, thus applying MP-method and evaluating the results.

The first results of the MP assessment show the percentual distribution of the materials embedded in the building. Thereby it was identified that concrete accounts for about 80% by mass of the entire building. The building displays a total recycling potential of 48%, meaning that 638 tonnes are recyclable and 700 tonnes count as waste. The large mass of concrete is reflected in the waste amount as well as in the LCA-results, since concrete causes 600 tonnes of waste and accounts for 1200 GJ of PEI. The results demonstrate that the main burdens are caused by the huge mass of concrete. Thus the application of the MP methodology implies on possible optimisation, by reducing the thickness of the concrete layer, through an accurate structural analysis. A further possibility is changing the load-bearing elements and using timber instead of concrete, which would lead to less waste, since timber has a lower mass than concrete. What should not be neglected is that timber has a very high PEI. Therefore, it is important to strike the right balance between the various impact factors.

Through the case study we demonstrated the advantages of the Material Passport for the assessment of all materials including their masses and other significant characteristics such as CO₂ emissions and its role as an important decision-tool regarding choice of materials and construction-types already in the early design stages, where the optimization potential is the highest. However, new construction rate across Europe is around 2%. New methods for capturing the existing stocks are necessary in order to make use of the secondary materials. Laser- and Ground Penetrating Radarscan Technologies, which capture the geometry and materials of existing buildings, and further embedment of data into GIS, could support the development of a secondary raw materials cadaster, which plays a crucial step towards enhancement of Circular Economy strategies.

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