Design Optimisation via BIM Supported Material Passports

Stefan Schützenhofer[1], Meliha Honic[2], Iva Kovacic[3]
[1,2]Institute of Interdisciplinary Construction Process Management - Intergrated construction Planning and Industrial Building, Vienna University of Technology
[3]Institute of Interdisciplinary Construction Process Management - Integrated construction Planning and Industrial Building, Vienna University of Technology
[1,2,3]{stefan.schuetzenhofer|meliha.honic|iva.kovacic}@tuwien.ac.at

Scarceness of resources, lack of waste sites, dependency on imports, increasing urbanization thus increasing consumption of resources and upcoming of waste are current challenges in built environment. Reduction of both, energy and resources consumption, should thereby be the primary aims for sustainable design. Even though by 2020 70% of the building waste has to be either recycled or reused , resources efficiency is less considered than energy efficiency in the design stage of buildings. Previous research has shown, that the generation of Building Information Modelling (BIM)-based Material Passports (MP) is possible and can for example be used for optimization in early design stages. In the current curricula the energy design is well represented in the courses of building science, however, optimization of resource efficiency and recycling potentials are still lacking. The focus of this proposal is the implementation of the developed BIM-based Material Passports in teaching for optimization of design proposals, thus enhancing the awareness for recyclability and reusability in construction among students of architecture and civil engineering.

Keywords: *BIM in education, Material Passport, Sustainability in education, Environmental sustainability, Integrated Planning*

INTRODUCTION

Scarceness of resources, lack of waste sites, dependency on imports, increasing urbanization thus increasing consumption of resources and upcoming of waste are current challenges in the built environment.The Architecture, Engineering and Construction (AEC) industry is responsible for 60% of global raw material extractions (Bribian et al., 2011), 40% of CO2 emissions (WGBC 2016) and a significant proportion of waste. In Austria, construction waste accounted for about 17% (BAWP 2017) of total waste in 2015 (about 40% of the total amount of waste, if excavated materials are not considered), although there is a strong local divergence here. However, not only the proportion of "construction waste" is very high in urban areas but is often but is often similar in size as the mass required for the construction of new buildings (Brunner 2011). Reduction of both -

energy and resource consumption - should thereby be primary aims for sustainable design. Even though by 2020, 70% of the building waste (non-hazardous) must be either recycled or reused (EU-WRC 2008), recycling is currently a less considered design objective than energy efficiency. Material management therefore plays a crucial role in creating a more sustainable future. Not only valuable primary resources are saved through recycling andcascade use in accordance with the (EU-CL 2015), but the limited volume of landfill space is also preserved. However, the (AWG, 2002), which represents the national implementation of (EU-WRC, 2008), only defines a very vague criterion in this respect to when components must actually be reused or recycled: "Recyclable materials need to be recovered if this is ecologically expedient and technically possible and if it does not involve disproportionate costs." (AWG, 2002) P. 29, §16 pt. 7.1 (translated to English). Therefore, it is essential to know which materials will be available and how the Ecological Footprint of these materials changes due the use of secondary raw materials. Only through knowledge of the effects of stakeholders' actions a conscious decision-making process is possible. Therefore, it is essential to impart knowledge already during the education of planners, architects and engineers who are responsible for the creation of the built environment. Raising awareness offers a suitable action at the social level (Filho et al. 2019; [5]). The research questions that will be addressed are the degree to which MPs can be used for such optimization and how the optimization process affects architectural and structural design quality, as well as the cost. Thereby, the research objective of this paper is to enhance the awareness and competences of students from architecture and civil engineering for recyclability and reusability in construction. Through simulation of a design to deconstruction process supported by Building Information Modelling (BIM) in teaching, BIM-based Material Passports were used for optimization of design proposals. A further expected impact is introducing the knowledge of resource efficiency in architectural and civil engineering curricula. Therefore, the curricula of civil engineering, architecture and environmental engineering were examined and searched for suitable contents. In a further step, a course, which offers students the opportunity to deal with the topic, was established. The examination of the curriculum of civil engineering at the TU Vienna shows one compulsory course with explicit teaching content in the bachelor's programme and four in the master's programme, whereby their completion is optional. The faculty of architecture at TU Vienna offers bachelor's theses on this topic, and in the master's programme also four optional courses. The environmental engineering programme delivers four courses in the baccalaureate and four in the master's programme. Due to the new curriculum of environmental engineering at TU Vienna, the master's programme is not accessible yet, but will be in one or two years. Measures which can be found in the literature include (mandatory) material documentation, as well as a life cycle assessment / recycling evaluation. In the current curricula the energy design is well represented in the courses of building science and building physics in both teaching and research. However, the design tools for optimization of resource efficiency as well as material and recycling potentials are still lacking. This paper is structured as following: first, a digression of the data and tools used as well as the origin of the data is given. This includes which parameters, such as eco- and disposal indicators as well as cost indicators for cost calculation, are needed to create a Material Passport For cost calculation, parameters are provided ranging from single element layers and layer packages, like layers of floor constructions, to facade elements. Next, it is shown how the calculation process of the Material Passport and cost calculation works, and how their results are linked to obtain conclusions about the necessary monetary input to improve the sustainable performance of the buildingmodel. In a further step this is shown through a BIM-model given to the students as an example and analysing the results afterwards.

METHODOLOGY

Through research led teaching the students of civil engineering will implement BIM-based Material Passports with 5D BIM assessment and conduct optimization upon delivered predesigns by students of architecture. Using qualitative evaluation and feedback,the optimization potentials and design tradeoffs will be explored, thereby developing the strategiesfor recycling and reuse of building elements and materials already in the early design stage. The models were created by architecture students in a previous semester. The theme of this course was to design a building for social housing, considering aspects of sustainability, prefabrication and modularity.The use of BIM already during this design process was of particular interest, as it allows to consider how much waste avoidance could have been achieved with another design. However, the focus of this course is not only the material optimization, but also the consequences on costs. For this purpose, masses and quantitiesare readout from the BIM model, including all relevant components with their geometric parameters,as well as their material structure and reference quantities such as areas, lengths and numbersof units. This element/component information is then combined with the relevant parameters (life cycle assessment and recycling evaluation - IBO[3, 4]; costs - BKI [1]). It is important that suitable materials and structures as well as databases are found and that these areassigned (matched) to the existing data generated from the BIM model. Due the lack of data regarding eco-indicators and disposal indicators of windowsand doors in the data sources used , a consideration of these parts was not possible. For example, the influence of replacing plastic windows by wood-aluminium windows can unfortunately not be taken into account.

Data and tools

"Material Passports are digital sets of data which provide the necessary information about materials,products and components for a circular use of ." (BAMB 2019) In order to process planning tasks, suchas the creation of an MP, or the calculation of construction costs, certain data, such as cost parameter per unit (depending on the planning phase you needdifferent parameters) or material parameters, like the density, are required. It is important to have an extensive as possible databases (from the same source). Due to different approaches or calculation models during data collection and the creation of databases,it should be avoided to use different data sources for the same purpose. To fulfil the task demanded in this course, necessary data was collected on the one hand from [4] (Austrian Institute for Building and Ecology), more exactly baubook-eco2soft [3] for sustainability aspects, and on the other hand for the cost calculationcharacteristic values from the [1] (Baukosteninformationszentrum Deutscher Architektenkammern), more exactly the data of 2017 for residential buildings.Even if these data is catptured in Germany, it has been shown that this data fits good enough for further calculation in Austria. Therefore, the different tax level unddifferent cost group classification must be considered. To generate the Material Passport, the calculation is based on (EI10 2018b and OI3 2018a), linkedwith the data from [3]. (EI10 2018b and OI3, 2018a) are guidelines on how to deal with the data from[3], for example which recycling quota must be assignedto the respective disposal indicator. The calculation of building indexes like in those guidelinesis waived, but the disposal indicator is applied on building level. Furthermore, in this paper the totalamounts of the parameters Global Warmth Potential (GWP), Acidification Potential (AP), and Primary Energy, Non-Renewable Resources (PENRT), as well as the total mass of waste and recycling material of the entire life cycle are described. When looking at the material results (EI 10 2018b), an evaluation is made according to the school grading system and a correspondingrecycling quota. The result depends on how much of the whole building can be recycled.The data was provided as the BIM model, in the form of the native ArchiCAD files and in IFC format, atemplate (Excel) for creating and calculating the MP, and a template (Excel) for calculating the costs during the planning phases (cost framework; cost estimationand cost calculation according to ÖNORM B 1801-1). The data for the creation of the MP can be seen in eco2soft. This is an online calculation tool, in whichcomponents can be created and modelled, thus enabling the calculation of an entire building model. An extensive material database is available, which containsguideline values for general material designations, but also data of explicit products. In the field of Baukosteninformationszentrum Deutscher Architektenkammern, the chapters for ”Wohnbauten”of the 2017 edition were made available in digital form. Using data which is not completely up to date is a common strategy in the field of cost calculation.

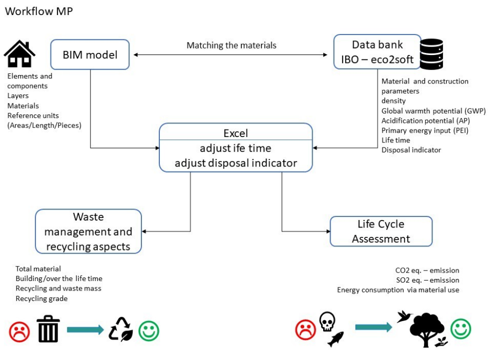


Figure 1
Workflow for the Material Passport

Relevant parameters

The data required from (eco2soft, 2020) are divided into the areas of waste and recycling management relevant parameters, and life cycle assessment relevantones. Information about density and life time of the component layers and materials is required forboth areas. Further, the material parameters GWP [kg CO2 equ/kg], AP (kg SO2 equ/kg] and grey energy - PENRT [kJ/kg] are required to calculate the environmental impact. For the calculationof the material management aspects, the disposal classification is also necessary. The data used to consider the impact on costs resulting from the optimizationstep (BKI 2017 Bauteile-Neubau, chapter - Ausführungsvarianten). This step is only possiblewith cost parameters in a certain level of detail, because with these data the material change of a single shift can be considered in part. However, since the data for precast and elementary components are not very high, the use of the data from 2020 might be more useful.

Calculation Methodology

MP. After determining all necessary data, like layer structures, materials, ecological data, disposal characteristics and others, and matching the materials of the databases with the materials of the BIM materials . The scheme of the calculation is level based, where the building is divided into four levels: the Building-Level, which consists of the massand the amount of all materials in the whole building; the Component-Level, which is the sum of all materials existing in a particular component; the Element-Level, which represents materials of one particular element and where each element is identifiedthrough the Globally Unique Identifier (GUID a fixed 22 character length string) (e.g. “01Storey slab_-Regelgeschoß”), which is automatically assigned in BIM-Software, and the Material-Level, whereby the mass, type of connectionwith the enclosed materials and the recycling potential is described for one specific layer/material.The first step is to calculate the mass produced at layer level per unit. For example 14.8 kg/m^2 for a2cm thick solid parquet layer. By taking into account the existing surface area and service life, the mass incurred during construction and the planned servicelife, for example 100 years, can now be calculated. It must be considered that the life expectancy calculated must be adjusted to reflect reality.This is the case, for example, if the outer layer has a longer life than the inner layer. Furthermore,this is also necessary for the disposal classification. Bonding, for example, often reduces the recyclability. Therefore, a downgrading of the bonded layers mustbe carried out. With the total masses identified in this way, it is now possible to determine the future recycling and waste masses that will be produced.The environmentally relevant emissions result from the use of these materials. In a further step, one can see to what extent these emissions areinfluenced using secondary raw materials obtained from the recycling process (figure 1).

Figure 2
Workflow for cost calculation during the planning phase

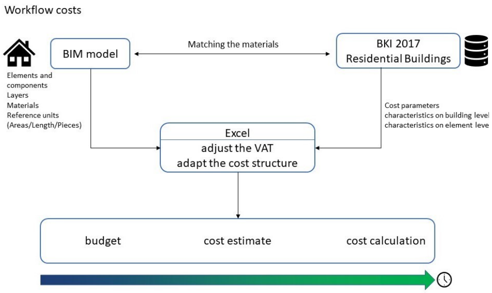


Figure 3
Workflow to link the environmental sustainability potential, with the change of consequent environmental cost

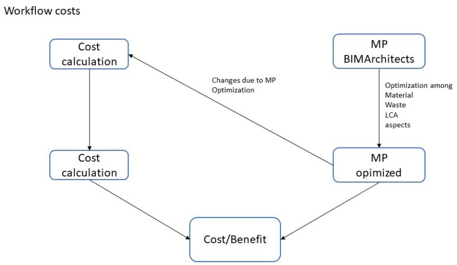
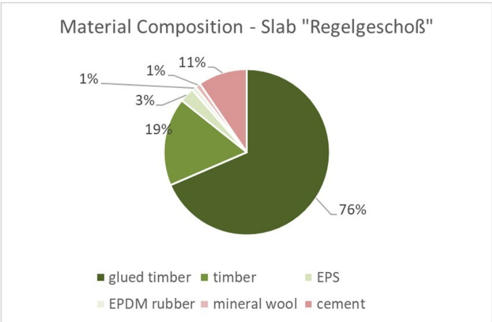


Figure 4
Material composition on component level



Costs. The costs which were used for further consideration correspond to a cost calculation. Since data from Germany was used and structured according to DIN,some adaptations had to be made. The cost groups must be changed and restructured, the value added tax (VAT) difference has to be taken into account,and since the data is from 2017, they had to be adjust using a cost index. Even if the data basisis not consistent here, students are requested to research non-existing data concerning refabricationelements themselves (figure 2).

Optimization and Evaluation

After the MP was created and the cost calculation was made, the MP had to be optimisedand the resulting changes were compared to the costs. As sustainable aspects were required in the creation of the BIM models, but were not the only focus, there is some optimisation potential. Improvements can be achieved in different ways. For example, by changing a layer thickness, by changing a material (e.g. changing from plastic to wooden windows),by changing a construction (e.g. changing from bitumen sealing to water-repellent concrete), orthe targeted use of material according to mechanical aspects (hollow core slabs, ribbed slabs). Based on these optimisation proposals, an MP-optimised and a cost-optimised calculation can be made. Subsequently, the monetary use is to be compared with the ecological improvement (figure 3). However, as this is a multi-criteria assessment, it is alsopossible that the improvement of one parameter has negative effects on another.

RESULTS OF THE USE CASE

Material Passport

Material EI10. In figure 4 the results of one particular building component is shown. This component represents the ceiling of the standard storey, and thus represents aconsiderable proportion of the flat components. The main structure is a Cross Laminated Timber (CLT)-plate with a thickness of 18cm. Because of the goodperformance of CLT, and the share in the total mass of the component (75%), the component is performing good as well. More than 50% of the total component masscan be recycled (figure 5). This is because of the high amount of wood in this component. But wood isn´t just performing good under the aspect of the ability to be recycled,but also the ecological performance is good as well.

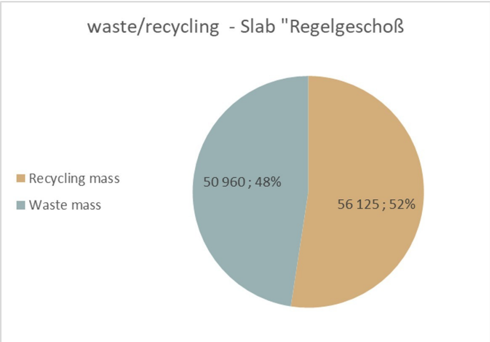


Figure 5
Waste and Recycling mass on component level

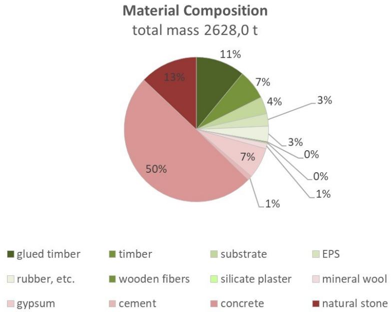


Figure 6
Material composition on building level

Figure 7
Waste and Recycling mass on building level

On Building-level, you can see the big influenceof concrete structures, as well as cement containing building parts. Just two floors of concrete (cellar and ground floor as well as the balcony structures) in combination with gypsum plaster, which makes the recycling process of concrete more complicate, and the disposal indicatormust be downgraded, producing half of the building mass, and change the recycling rate under 50% (figure 6 and7). Thus, the building has disposal grade 3, according to the disposal index on material level and adaptation on building level (figure 8).

Ökobilanz OI3. In figure 9 the results of the life cycle analysis (LCA) are shown, whereby the calculation of a single key figure according to (OI3 2018a) was waived. The scale of the individualeco-indicators was adjusted to make the results more transparent. For example, the result ofGWP100 is given in 10 kg CO2equ.

Costs

See table 1 for the results of the cost calculation, structured according to (ÖNORM B1801-1). BWK are the costs of the physical building, BAK are the costs of BWK with the costs of for example work you have to do on the building sight to be able to build and create outdoor facilities. Relevant to link the costs to the Material Passport is the BWK.

Evaluation and Optimization

Ideally, an improvement will be achieved in both the eco-indicators and the material balance. More essential, however, is that interactions between the different areas can be shown, depending on the optimization measures, and based on this a discourse about good and less good, maybe even bad measures becomes possible (figure 10).

Table 1
Cost calculation results

Cost group ÖNORM	DIN		Buidling costs	Construction costs	Establishment costs	Total costs
00	100	Property				0
01	200	Disclosure		100 180	100 180	100 180
02	300	Building shell	3 217 532	3 217 532	3 217 532	3 217 532
03	400	Building technology	1 296 442	1 296 442	1 296 442	1 296 442
04	300	Building extension	1 378 942	1 378 942	1 378 942	1 378 942
05	600	Furniture		53 036	56 908	64 523
06	500	Outdoor facilities		276 967	297 186	336 952
07	700	Fees			695 541	695 541
08	770	Service charges			0	0
09		Reserves			126 462	126 462
		total EURO netto	5 892 917	6 323 099	7 169 193	7 216 574
		+ 20% Umsatzsteuer	1 178 583	1 264 620	1 433 839	1 443 315
		total EURO brutto	**7 071 500**	**7 587 719**	**8 603 031**	**8 659 889**

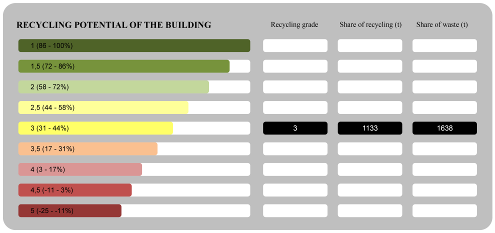


Figure 8
Disposal grade of the building

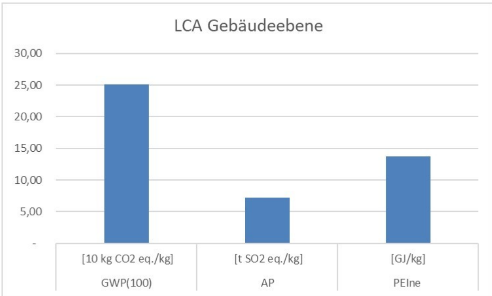


Figure 9
eco indicators on building level

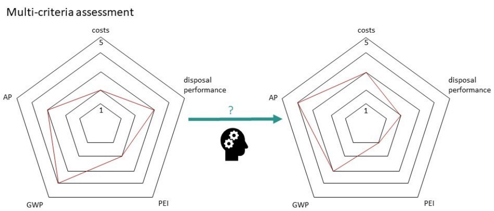


Figure 10
multi-criteria analysis

CONCLUSION

The aim of this lecture is to create awareness of the students, to the problem of high material consumption and lack of waste sites, and the growing importance of doing something against these problems. In order to overcome these problems, the use of technical tools such as BIM is suitable for documenting the necessaryinformation in the construction sector and for taking optimization steps based on this information.Therefore, during a course the Material-Passport was presented, which shows the information required to perform which calculation steps and howBIM can be used to support this. The optimization step of the Material Passport and the determinationof the conclusion on costs enables not only a holistic view, but also creates an awareness of which measures have positive or negative effects on different areas. Since models of students of architecture are used as a basis for planning, a situation which is common to practice is created and which should underline the importance of an integral planning approach. The implementation of the MGP in this form in teaching is not only an attempt to create awareness for sustainability aspects already during the education, but also offers the opportunity to give students an insight into the current state of research. In addition, results have shown that creative approaches to solutions in theuse of BIM are sometimes created in the course. The results of the calculation, especially the costs and improvement of environmental factors, in addition to further data like the demolition, disposal and recycling costs can be used as an aid to decision-making in future demolition projects after validation for correctness, and thus be applied in the implementation of the (ARR 2002) - see above - guidelines. In a further step, the consideration of reuse should also be embedded in the process presented, as this is stillabove recycling in the waste hierarchy. Another suitableuse of the Material Passport would be to generatea Material Cadastre, especially in big cities, becausethere the material balance is mostly given as

REFERENCES

AWG 2002, Österreichisches Parlament 2002 (2018) 'AWG - Abfallwirtschaftsgesetz 2002', *Gesamte Rechtsvorschrift für Abfallwirtschaftsgesetz 2002 (02.10.2018)*

EU-WRC 2008, European Parliament 2008 'Directive 2008/98/EC of the european parliament and of the council of 19 November 2008 on waste and repealing certain Directives', *Council on waste and repealing certain Directives*

EU-CL 2015, European Commission 2015 'Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions', *Closing the loop-An EU action plan for the Circular Economy*, Brussels

BAWP 2017, Bundesministerium für Nachhaltigkeit und Tourismus 2017 'Bundes-Abfallwirtschaftsplan', *Teil 1*

Bribián, IZ, Capilla, AV and Usón, AA 2011, 'Life cycle assessment of Building materials: comparative analysis of energy and environmental impacts and evaluation of the co-efficiency improvement potential.', *Building and Environment*, 46 (5), pp. 1133-1140

Brunner, PH 2011, 'Urban Mining - A Contribution to Reindustrializing the City', *Journal of Industrial Ecology*, 15, pp. 339-341

World Green Building Council, WGBC 2016 'Global Status Report', *(2016)*

Filho, WL 2019, *Aktuelle Ansätze zur Umsetzung der UN-Nachhaltigkeitsziele*, Springer Spektrum, Berlin, Heidelberg

Honic, M, Kovacic, I and Rechberger, H 2019, 'Improving the recycling potential of buildings through Material Passports (MP): An Austrian case study', *Cleaner Production*, 217, pp. 787-797

Markova, S and Rechberger, H 2011 'Entwicklung eines Konzepts zur Förderung der Kreislaufwirtschaft im Bauwesen', *Forschungsber. Technische Universität Wien (TU Wien) Institut für Wassergüte, Ressourcenmanagement und Abfallwirtschaft, Fachbereich Abfallwirtschaft und Ressourcenmanagement*

OI3, IBO - Österreichisches Institut für Bauen und Ökologie, IBO 2018 'Leitfaden zur Berechnung des Oekoindex OI3 für Bauteile und Gebäude', *2018*

EI 10, IBO - Österreichisches Institut für Bauen und Ökologie, IBO 2018a 'Leitfaden zur Berechnung des Entsorgungsindikators EI Kon von Bauteilen und des Entsorgungsindikators EI10 auf Gebäudeebene', *2018b*

[1] https://bki.de/;BKI,BaukosteninformationszentrumDeutscherArchitektenkammern;10.04.2020

[2] http://www.bamb2020.eu/;BAMB*2020,BuildingAsMaterialBanks;13.04.2020

[3] https://www.baubook.info/eco2soft/;Eco2soft,2020.baubook-eco2soft;13.04.2020

[4] https://www.ibo.at/;IBO,2020.IBO-□□sterreichischesInstitutf□¼rBauenund□□kologie;13.04.2020

[5] https://sustainabledevelopment.un.org/?menu=1300;UN2020,UnitedNations,UN-SDG(SustainableDevelopmentGoals);03.04.2020