

Working Paper Proceedings

15th Engineering Project Organization Conference
with
5th International Megaprojects Workshop
Stanford Sierra Camp, California
June 5-7, 2017

BIM Based Material Building Pass as Tool for Enhancement of Circular Economy in AEC Industry

Iva Kovacic, TU Wien, Austria

Meilha Honic, TU Wien, Austria

Helmut Rechberger, TU Wien, Austria

Proceedings Editors

Ashwin Mahalingam, IIT Madras, Tripp Shealy, Virginia Tech, and Nuno Gil, University of Manchester



© Copyright belongs to the authors. All rights reserved. Please contact authors for citation details.

BIM BASED MATERIAL PASSPORT AS TOOL FOR ENHANCEMENT OF CIRCULAR ECONOMY IN AEC INDUSTRY

Iva Kovacic¹, Meliha Honic² and Helmut Rechberger³

ABSTRACT

The concept of “Urban Mining” - based on reuse or recycling of secondary materials contained in urban stocks, and in consequence minimisation of primary resources consumption paired with increased recycling rates and waste reduction – is fundament of circular economy in AEC. The implementation of circular economy involves participation and consensus of numerous stakeholders along AEC value chain, ranging from material and building product manufacturers and logistic; till designers, planners and facility managers. The complexity of such actor network, as well as sometimes opposing interests in the industry requires for tools which would allow modelling and prediction of material and waste flows; both as design and decision support instrument. We propose a Material Passport (MP) as such tool, as qualitative and quantitative documentation of the material composition of, and the material distribution within, a building structure.

New computational tools such as Building Information Modelling (BIM), bear large potentials for automated compilation of MP, as information-rich building elements and components build extensive BIM-based material knowledge-base.

In this paper, a modelling framework for creation of BIM-based MP will be presented; through coupling of BIM with material-inventory and analysis tool and various eco-inventories, thus enabling generation of both MP and life cycle assessment of a building in various design stages for varying Levels of Development.

Thereby the proposed framework allows use of MP along the value chain of AEC industry for various stakeholders such as material industry, architects, building owners and public policy; with multiple purposes as design-optimization tool in early design stages for of material and resources efficient design; as material-repository for an feasible end-of-life demolition of structures and recycling of applied materials; as a document of material assets of real estates and finally, if applied extensively, as the informational basis for a secondary raw materials cadastre, which in return is the basis of sophisticated recycling plans.

¹ Associate Professor, Institute of Interdisciplinary Construction Process Management, Vienna University of Technology, Austria, Phone +43 (1) 58801 21526, iva.kovacic@tuwien.ac.at
² Project Assistant, Institute of Interdisciplinary Construction Process Management, Vienna University of Technology, Austria, Phone +43 (1) 58801 21543, meliha.honic@tuwien.ac.at
³ Professor, Institute of Water Quality, Resources and Waste Management, Vienna University of Technology, Austria, Phone +43 (1) 58801 22645, helmut.rechberger@tuwien.ac.at

KEYWORDS

Material Passport, Resources Efficiency, LCA, Urban Mining, BIM

INTRODUCTION

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 labelled “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 to 50 years, a significant increase in solid waste generation is to be expected within the next decades. 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 material, 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.

We thereby propose material passport (MP) as a knowledge-base for material composition of a building, giving qualitative and quantitative information on relevant raw resources and their recycling or reuse potential within a building, as one of the tools for supporting circular economy principle in the AEC. The design and planning tools, which allow information management along life cycle, such as BIM and GIS bear large potentials for generation of such MP.

In this paper, we will present a methodology for creation of Material Passports (MP) supported by BIM (Building Information Modelling). Thereby BIM is used for modelling and information management of building coupled with several data repositories regarding environmental and end-of-life information of materials and building elements. This research is a part of ongoing funded project BIMaterial: Process-Design for BIM based material building pass⁴. A requirement specification for development of automated BIM-based MP app is the final aim of the project.

The use of such material building pass along the building’s life cycle is multifold: as design tool in the early design stages for optimization of material efficiency, prediction and optimization of upcoming waste and recycling rates; as material data

⁴ Project funded by Austrian Research Promotion Agency, Project Number: 850049

repository, providing information for recycling and reuse at the end of life; and finally as an element of urban material cadastre at the macro level of city.

However, the automated process of generation of MP is facing several challenges, many of which are related to complex actor network of industry, planners and designers and finally environmental consultants and auditors; further on data inconsistencies and technical issues regarding BIM modelling. In this paper we will focus on the proof of concept for generation of MP using BIM, as well as its implementation as design-optimisation tool.

This paper is structured as following: we will start with literature review placing material passport within life cycle assessment methodology and in broader scope in circular economy principles; we proceed with the modelling methodology for BIM supported MP and demonstrate proof of concept for the modelling framework, and finally we conclude with identification of challenges and obstacles; and discussion of broader meaning of MP in the field of circular economy.

LITERATURE REVIEW

The principles of circular economy are based on moving away from linear economic models based on (unlimited) extraction of raw materials and production, consumption and disposal of goods and products where large quantities of easily accessible resources and cheap energy are a premise; towards circular economic model conserving resources and energy through reuse of existing resources within the economic sphere (European Environment Agency 2016).

Circular economy has its roots in the 1970ies, where Meadow et al. (1972) illustrated for the first time in the public at large that the resources are limited and depleting. Concepts such as industrial ecology, based on systemic view on more effective use of material and energy flows (Frosch and Gallopoulos, 1989), partly originating in “biomimicry” concept by Benyus (1997) which uses principles from nature for problem solving of engineering problems, and environmental economics (Tietenberg et al. 2016) stand in close relationship with principle of circular economy. New ideas in dealing with waste are introduced by Graedel and Greenville (2002) – who explore symbiotic use of waste within industrial systems closing ecological loops; or Cradle to Cradle concept by McDonough and Braungart (1999). Not only are the processes being re-thought, but also new economic models are developed, such as ‘Performance Economy’ (Staehl, 2002), based on concept of usage instead of ownership – consumer pays a fee for the use of a product.

With increasing number of world population living in cities and related growth of megacities; the need for primary resources is increasing through increased construction activity; with simultaneous growth of material stocks, as megacities provide sufficient amount of secondary resources (Brunner, 2011). Thereby the concept of “Urban Mining”, as recycling and reuse strategy of these material stocks, paired with waste reduction - is also promising economic benefits on larger scale; and is as such crucial element of circular economy in AEC. Circular economy principle in AEC can thereby be seen as a method for management of adaptive complex systems, involving multiple spheres of impact – primarily anthroposphere, but through reduction of environmental impacts from construction also geosphere, biosphere,

atmosphere and hydrosphere. The implementation of circular economy concept involves participation and consensus of numerous stakeholders along AEC value chain, ranging from material and building product manufacturers and logistic; till designers, planners and facility managers. The complexity of such actor network, as well as sometimes opposing interests in the industry requires for tools which would allow modelling and prediction of material and waste flows; both as design and decision support instrument.

The generation of **Material Passport** as well as the issue of efficient use of material resources stands in close relationship with life cycle assessment (LCA) methodology as analysis of environmental impacts caused by buildings or building components along their life cycle – from production of materials, over construction, use and finally demolition and re-use. The crucial factor for the Material Passport is the mass in tonnes and the share in % of recyclable and waste materials. Until recently particular focus in ACE industry was optimisation of mostly operational energy, less so on embodied energy (for production, transport, maintenance and demolition of materials). In order to achieve sustainability, assessment of the environmental performance of buildings and their sub-components based on evaluation and optimization of both embodied and operational energy and emissions is required already in the planning phase (Srinivasan et al. 2014). However, the optimisation of efficient use of materials and resources was much less in focus of research. The need for more integrated approach in optimization of building performance in terms of both energy and of resources consumption, has been recognized by the decision makers, planners and investors (König et al. 2009).

A life cycle assessment (LCA) methodology focuses on evaluation of the total environmental impacts of buildings over their entire life cycle. Two main streams can be identified in LCA methodology - aggregating and analyzing the flows of primarily resources and materials throughout the lifecycle of products (from cradle to grave, or even better from cradle to cradle); or the second stream - Life Cycle Energy Assessment (LCEA), which is an evaluation of the energy use and consumption over different stages of building life cycle, expressed as primary energy consumption from nature or secondary energy as actual consumed energy (Chau et al 2015; Fey et al 2000).

Carrying out an LCA for buildings is still a challenging task due to the lack of information about the used materials and their production processes, whereas the LCA of manufactured products is often more effortless, because of existing knowledge about the standardized production processes (Ramesh et al. 2010).

Potentials of BIM-use for life cycle analysis in the design stage has been of increasing interest in the research community, as BIM bears large potentials in terms of process-automation and data management. Azhar et al. (2011) undertake a thorough analysis of BIM fitness for sustainability assessment using LEED rating analysis, establishing a procedural framework between the environmental analysis that can be carried out using BIM model, and LEED credit requirements, however they conclude that the automation of the workflow is not possible, due to the lack of LEED features integrated in the software.

Significant efforts have been invested in automated modelling and analysis of operational energy; much more so than with analysis of material resources or embodied energy.

Especially interesting is so called BIM to BEM approach – transfer of building information models to building energy modelling for follow up thermal simulation. Model exchange in this area has been especially troublesome, since commercial BEM software such as Energy Plus or similar do not support IFC interface, but a proprietary gbXML interface, which makes the transfer particularly troublesome. Researchers such as O’Donnell et al. (2014) propose a workflow for BIM to BEM based on IFC interface, via so called BIM Model View Interface, allowing semi-automated model exchange. Schlueter and Theselling (2009) develop a proprietary tool for energy performance analysis in design stage for Autodesk Revit software platform.

However, there is a lack of holistic and integrated methods and tools, which would allow optimization of both resources and energy. Geyer and Buchholz (2012) provide a holistic and innovative urban system model framework, described as Parametric Systems Modelling (PSM) and based on the System Modeling Language (SysML). SysML supports geometry-based CAD, is design-oriented modelling approach, which considers multidisciplinary information and parametric interdependence. However, the resulting system-model is a non-geometric model, which shows the interdependences of buildings and environment as flow chart and displays energy, water and CO₂ emission-flows and dependencies.

Generating knowledge and data on the material consumption of buildings on urban level is one of the greatest challenges, as several studies show. Kohler and Hassler (2002) analyzed the material flows of the German building stocks and coupled statistical data (top-down) with analysis of buildings building elements and materials (bottom-up). Lichtensteiger and Baccini (2008) explored the urban material storages in Switzerland with the use of the so-called ARK-Haus Method, whereby buildings were categorized according to their age and typology. The “Christian Doppler Lab for Anthropogenic Resources” (CDL, 2017) at TU Wien used a similar approach, whereby buildings and infrastructure were analyzed in terms of recyclability (Kleemann et al. 2016). Markova and Rechberger (2011) proposed a concept for the generation of a MP in order to support Circular Economy. Thereby two approaches were performed on three use cases - the top-down and bottom-up approach. In the top-down approach, the building was firstly divided in functional elements, like the façade and the roof; and further on dissected down to the lowest level – the specific material in a building element. In the bottom-up approach the layers of building components were up-scaled to the whole building, whereby the location and the separability of the materials was documented.

Various projects are currently taking place in European context, drawing attention to the topics of Circular Economy and resource efficiency, as for example BAMB (Buildings as Material Banks), a Horizon 2020 project with 16 participants from 8 European countries. The aim of the project is implementing Circular Economy in the AEC industry; in order to increase the life cycle value of materials. Buildings with flexible and adaptable design can be integrated into concept of Circular Economy, whereby the materials should persist in their value (through reuse). Thereby, on the

one hand, waste should be minimized, and on the other hand, the use of primary resources should be optimized. However, the automated generation of a MP with the support of BIM is not aimed within this project.

The study “Building Passport” (German: Gebäudepass) (Reisinger et al, 2014) deals with the development of basic principles for the standardization of Material Passports for buildings as information-systems for material composition following two aims: Implementation of a building material-data sheet and Use of BIM as a building materials-information-system. The study concludes that that the development of a BIM-based material information system in the long term displays more potential than the material information management using data sheet.

Although BIM shows large potentials as optimization and documentation tool of material composition of a building, a method for an automated creation of a BIM-supported MP is still lacking. A BIM-Model contains a wide range of information needed for an MP and further on LCA, assumed that it is generated appropriately. As the tools and methods for an automated creation of a MP are still lacking, the current research addresses innovative approach in this field.

METHODOLOGY

One of the main aims of the research project BIMmaterial is to explore the potentials of BIM models for automated generation of material passport, and further on to develop a framework for modelling and optimisation of resources-efficient design.

Material passport is used at various stages with multiple purposes (as decision support, data-repository, document on material value of a building) along the life cycle of a building, as well as with varying perspectives and interests of various stakeholders utilizing MP, which have to be considered when conceptualizing a modelling framework for BIM based MP.

Multiple stakeholders using various aspects of MP – material industry providing necessary information on materials, designers for design optimisation, building owners as document on material composition and economic value of materials incorporated in the building, and finally construction and demolition companies gathering knowledge on separability and accessibility of materials for economic exploitation in terms of reuse or demolition and finally city municipality in terms of exploitation of secondary raw materials.

The initial step in the project was therefore basic research, in order to capture varying stakeholder interests, which was the foundation for the requirement definition for the MP. Thereby the scope of necessary information was defined, which on the one hand included expert-interviews (demolition companies, material recycling union, material industry) and on the other hand was based on the knowledge generated by „Christian Doppler Lab for Anthropogenic Resources” (CDL, 2017). The MP should address resources and material efficiency along the life cycle of a building, and will thereby be developed for four stages:

- in the early design stages, it serves as decision-support tool for optimization of material efficiency, prediction and optimization of upcoming waste and recycling rates;

- in tendering stage for exact documentation of material composition of the building;
- as material inventory, providing information for recycling and reuse and material value of a building at the end of the life-time;
- finally, as an element of urban material cadastre at the macro level of city.

In further step, the BIM-modelling methodology was established. BIM-Software (ArchiCAD or Revit) is used for generating a detailed model, whereby a modeling-guide is developed, defining the requirements and Level of Development for a MP-Model according to the design stage. A control tool (Solibri Model Checker) is used to ensure that the BIM-Model is error-free.

In order to carry out material and life cycle assessment we couple BIM-Software with material inventory and analysis tool BuildingOne (BO); which is used for calculations and for linking of eco-indicators from various eco-inventories however, for the proof of concept only eco-indicators from an Austrian eco-inventory (IBO) will be used:

- GWP (Global Warming Potential)
- AP (Acidification Potential)
- PEI (Primary Energy Intensity)
- Recyclability Potential (includes separability and accessibility of building components); expressed through weights in IBO database

We use one eco-inventory in order to achieve data consistency. Inconsistent data, nomenclatures and varying LCA methodologies represent a major problem when using data from different databases. Therefore, it is beneficial, that the eco-inventory provides all indicators needed for LCA and MP.

BO offers a bi-directional data exchange to the BIM-Software and an automated synchronization of data. In BO, the building components are 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. The workflow is tested with two BIM-Software Tools (ArchiCAD, Revit).

As a result, a MP consisting of the information about all materials and their recycling potential existing in the building is obtained; as well as LCA assessing eco-indicators GWP, PEI and AP.

Finally, the proposed framework will be tested on real use cases to test the usability and for verification; and in final step a Roadmap for implementation of MP for various stakeholders will be issued.

In Figure 1 research methodology and steps are presented, from basic research and definition of requirements over model building and modelling framework till roadmap for MP.

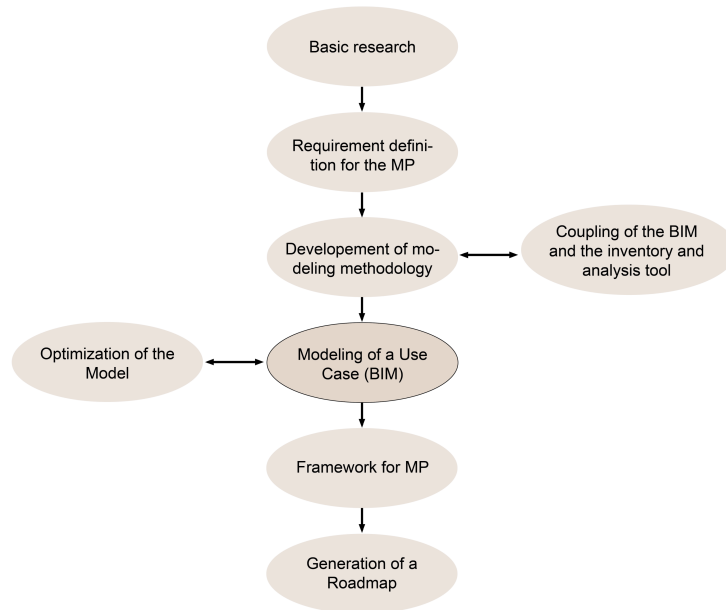


Figure 1: Research Methodology

MODELLING FRAMEWORK – PROOF OF CONCEPT

The proposed modelling framework for the generation of BIM based MP was developed on a case study of five story cross laminated timber housing block, in conceptual design and preliminary design stage.

Upon initial creation of BIM architectural model in Archicad 19 BIM-Software platform, we exported the materials and building elements into Building One where materials were matched with proper nomenclature and eco-indicators from eco-inventories, upon which life cycle assessment of the environmental impacts of the materials and building elements as well as the separability and recyclability were assessed (Figure 2).

The process was carried out for conceptual design stage with lower Level of Development (single-layered elements such as walls and slabs) and for preliminary design stage with higher LOD (multi-layered elements).

In the first phase of the research, a data exchange between BIM-Software and the material- inventory and analysis tool BO was tested, whereby the properties needed for a Life Cycle Assessment (LCA) were generated in BO. The results show that the data exchange between the BIM-Software and the tool works properly. Based on the insights of the study, requirements for generating a BIM-based MP and a proper workflow (Figure 2) were generated.

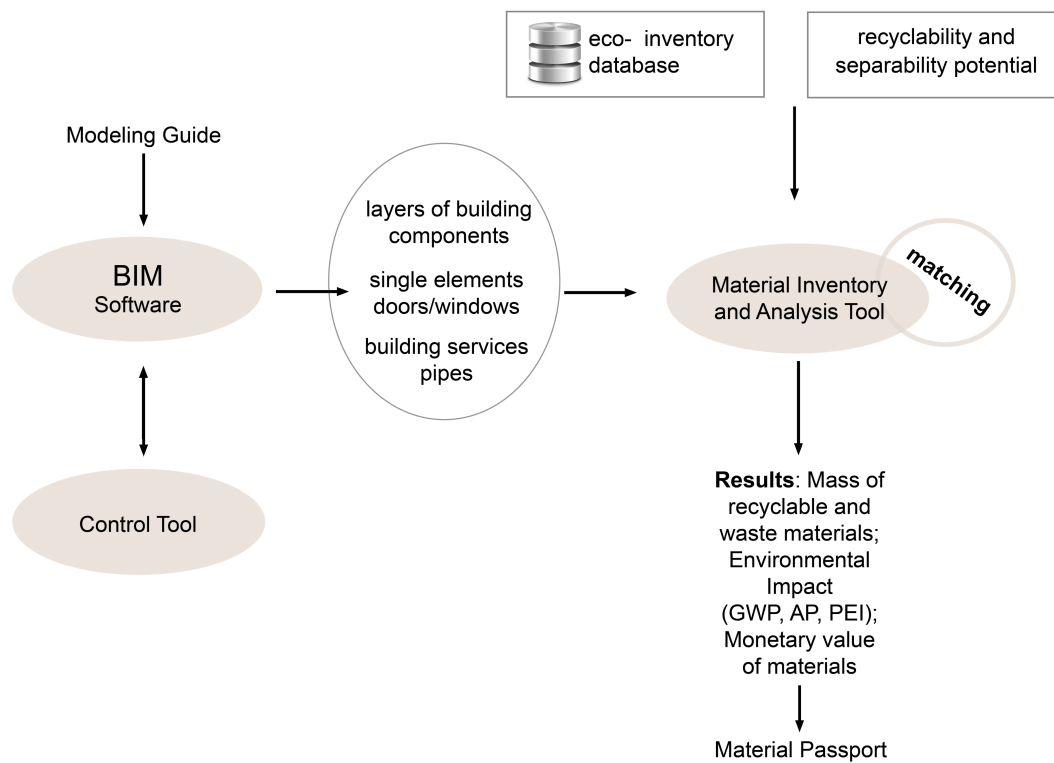


Figure 2: Modelling and Assessment Framework

For the compilation of the Material Passport a scheme was developed (Figure 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 (2011) 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.

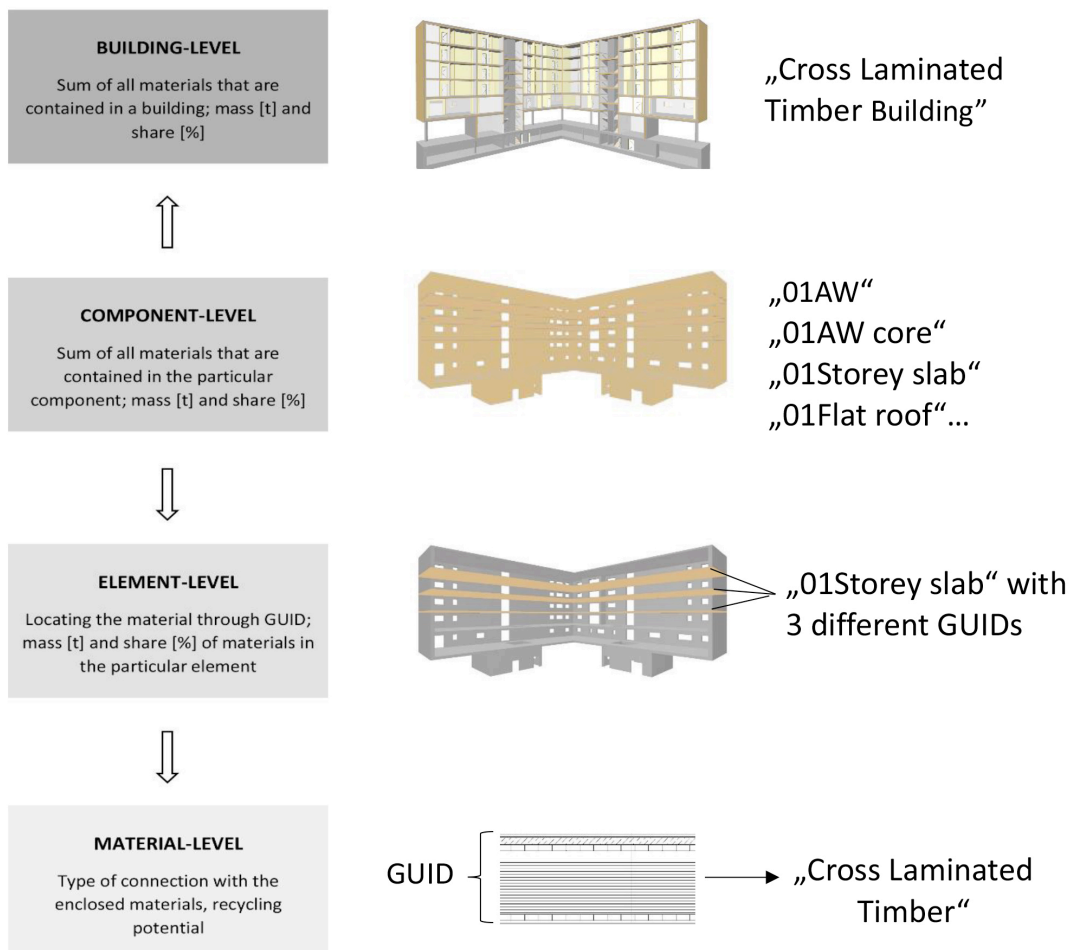


Figure 3: Structure of MP starting with element as primary level, thus allowing segregation of data (down-scaling) for material-level analysis; and aggregation for upscaling for analysis of components and finally whole building.

The GUIDs (Globally Unique Identifier) 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. 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. (Figure 5).

Material	Share	Sum of Mass [t]
Cross Laminated Timber	35%	585,13
Synthetic substances	0%	5,77
Bitumen	0%	4,83
Sawn timber	1%	21,09
Wood fiberboard	1%	11,99
Wood fiberboard, insulation	5%	91,56
Massive parquet	2%	37,61
Plasterboard	5%	82,45
Plaster/mortar	6%	106,16
Rock wool	1%	24,18
Gravel	4%	64,57
Grit	19%	323,09
Screed concrete	14%	235,59
Glas	6%	100,30
		1694,32

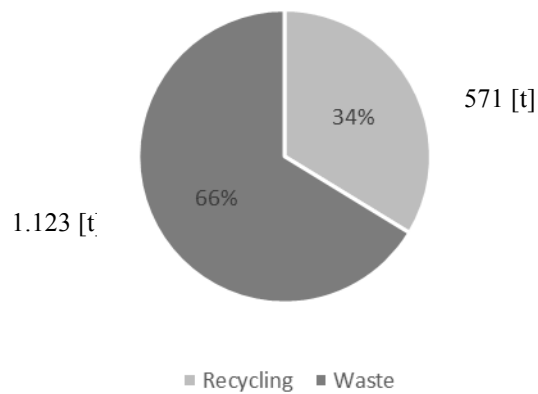
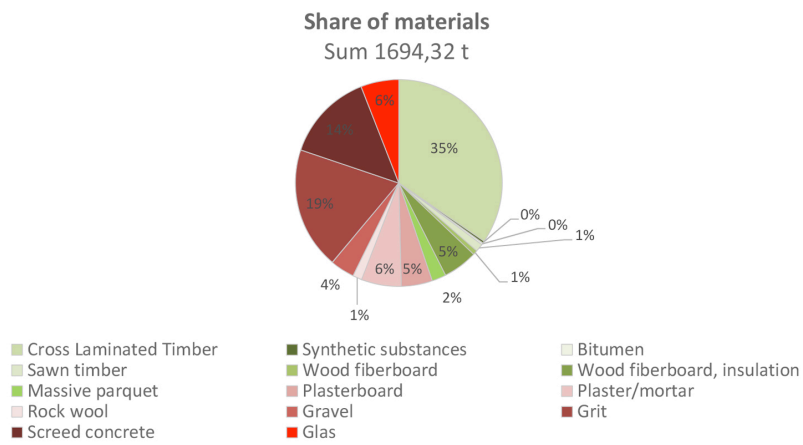


Figure 5: Material Composition Assessment

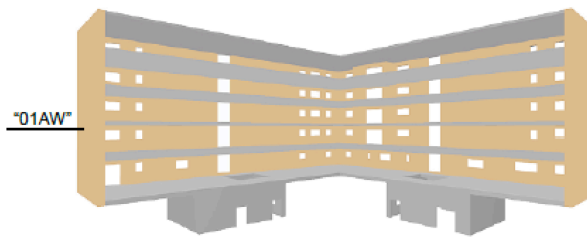
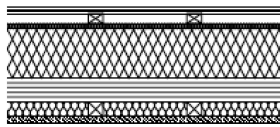
DISCUSSION

Throughout the modelling process several challenges were encountered, mostly regarding the diverging degrees of accuracy regarding the development of design in various design stages and of LOD required for compilation of MP.

Further on the inconsistent nomenclature of materials and constructions in various data repositories, templates and eco-inventories is identified as one of the largest challenges for compilation of both automated MP and LCA.

Outside wall

"01AW"



Thickness [m]	Layers	Corresponding materials from IBO
1	0,024 Außenverkleidung	Brettsper Holz
2	0,04 Holz Fichte Lattung (40/60) (10%)	Schnit Holz Fi rau h. luft trocken
3	0,022 Holz faser dämmplatte	Holz faserplatte, porös 250 kg/m ³
4	0,2 Holz faser dämmung	Holz faser-Dämmplatte 160 kg/m ³
5	0,1 Brettsper Holz	Brettsper Holz
6	0,06 Holz Fichte Lattung (60/60) (10%)	Schnit Holz Fi rau h. luft trocken (10%)
7	0,06 Mineralwolle (90%)	Steinwolle MW-W (90%)
8	0,025 Rigips Feuerschutzplatte	Gipskartonplatte (Flammschutz)
0,471		

Creating multi-layered elements in Archicad

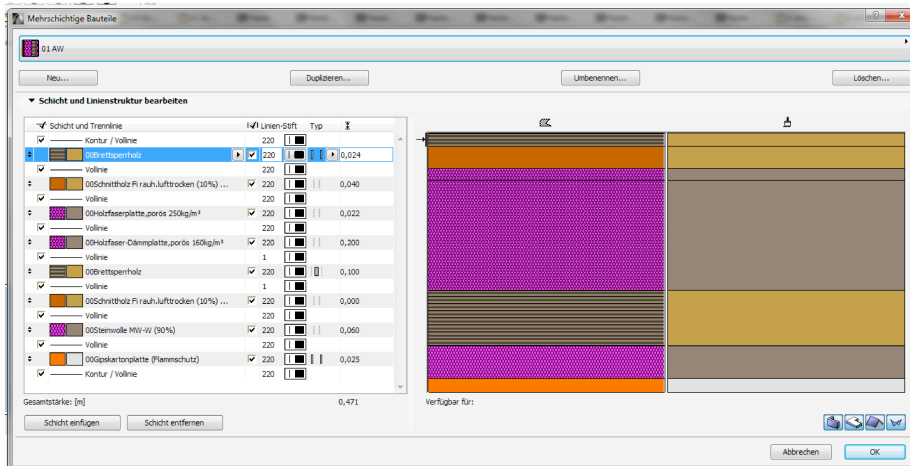


Figure 5: Modelling of Material-Layers and Data-Matching

The designers use various building catalogues and data-inventories as support for creation of building elements and constructions, particularly so when designing light weight construction such as timber. For creation of building elements such as walls, slabs, and roof we used the Austrian catalogue Cross Laminated Timber (CLT) database dataholz. However, this catalogue does not provide eco-indicators, or material information regarding recyclability, separability and accessibility, therefore this information needs to be extracted from further inventories (IBO catalogue). As various inventories have inconsistent nomenclature of materials, automated data-transfer and matching to the eco-indicators is hardly possible (Figure 5).

It was also detected, that there exists a general problematic in BIM-Software when modelling multi-layered elements, due to lacking possibility to define properties for each layer/material within a building component.

Further problem regards the varying LOD and stage-dependent modeling – various design stages employ BIM models of varying LOD; thereby in the earliest design stages – Conceptual Design – material or building element information is hardly available and often held at very abstract level. The question arises how to generate an MP from such abstract and information-poor model. However, as the Conceptual Design stage has large impact on latter building performance in terms of material and resources efficiency, a MP plays crucial role as decision-support tool in this stage.

Starting with Preliminary Design, there is higher LOD required, therefore each building component has to be defined in BIM, which enables matching to the eco-inventory data in Building One. From this phase on the general multi-layered elements are defined, only individual layers can be changed (e.g. the thickness of a layer) (Figure 9).

Due to the formerly described problems – too low and abstract LOD in Conceptual Design Phase for generation of MP; and need for material matching due to data-inconsistencies in latter design stages – we propose a methodology based on pre-defined element and component catalogues; based on IBO data-inventories (eco2soft and baubook).

Thereby in the Conceptual Design stage, the architect creates an abstract BIM model (single-layered elements) and exports it to the BO tool. In the BO tool compilation of MP is carried out and the “MP consultant” will choose the “pre-calculated” building elements from the catalogue in collaboration with designer team; and in this way carry out a variant study (Figure 6).

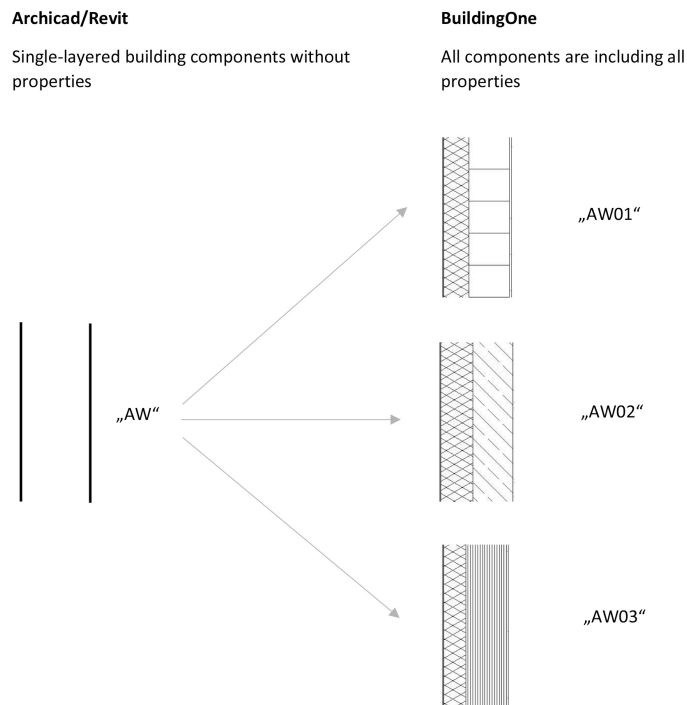


Figure 6: Modelling in Conceptual Design Stage

In more developed design stages, the designers and architects will be able to work with templates of building elements created upon IBO catalogue, and export these in BO in order to avoid material-matching and data-inconsistencies (Figure 7).

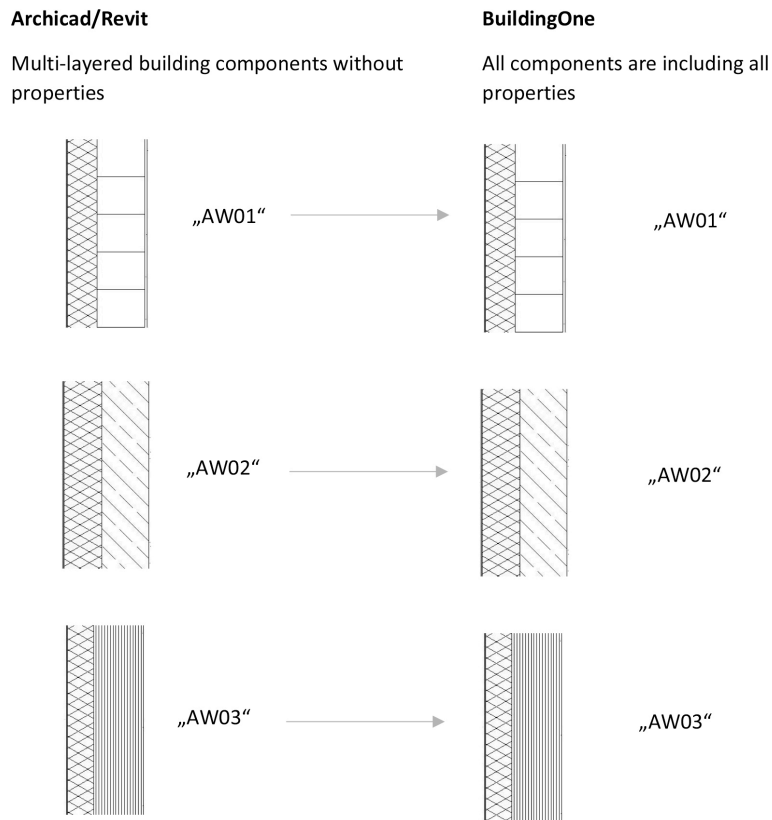


Figure 7: Modelling in Preliminary Design Stage

There are some challenges regarding the proposed strategy, as designers often perceive templates or pre-fabricated catalogues as too limiting; further on the IBO catalogue is extensive containing 150 elements, but not extensive enough, so inclusion of further data repositories would be advisable for the future. However, as IBO stands in close relationship with policy makers it is conceivable that the IBO catalogue and all the resulting certificates such as MP and energy certificate will be demanded for assessment of public projects.

Further issue regards the collaborative process and the level of knowledge required for compilation of MP or conduct of LCA. Usually architects and planners lack the extensive knowledge on material properties regarding the environmental impact or on LCA methodology assessing environmental impacts. Therefore, in order to support the design team, we propose the “MP specialist”; as consultant for compilation of MP, for design of templates, building catalogues or simply advisor for choosing the optimal variants in terms of material efficiency.

Figure 8 shows the various stakeholders involved in the process of compilation and utilisation of MP. In order for functioning workflow and efficient use of MP along the value chain, modelling conventions and consistency of the data in the repositories must be achieved. Thereby coordination among designers, building industry and public policy is needed. Further on, higher knowledge level among designers on resources efficient design and LCA will be required in order to generate but more over utilise full potentials of MP as design-optimisation tool. Finally, an MP consultant, similar to building certification consultant such as LEED should support the process, through management of building catalogues and compilation of material passport.

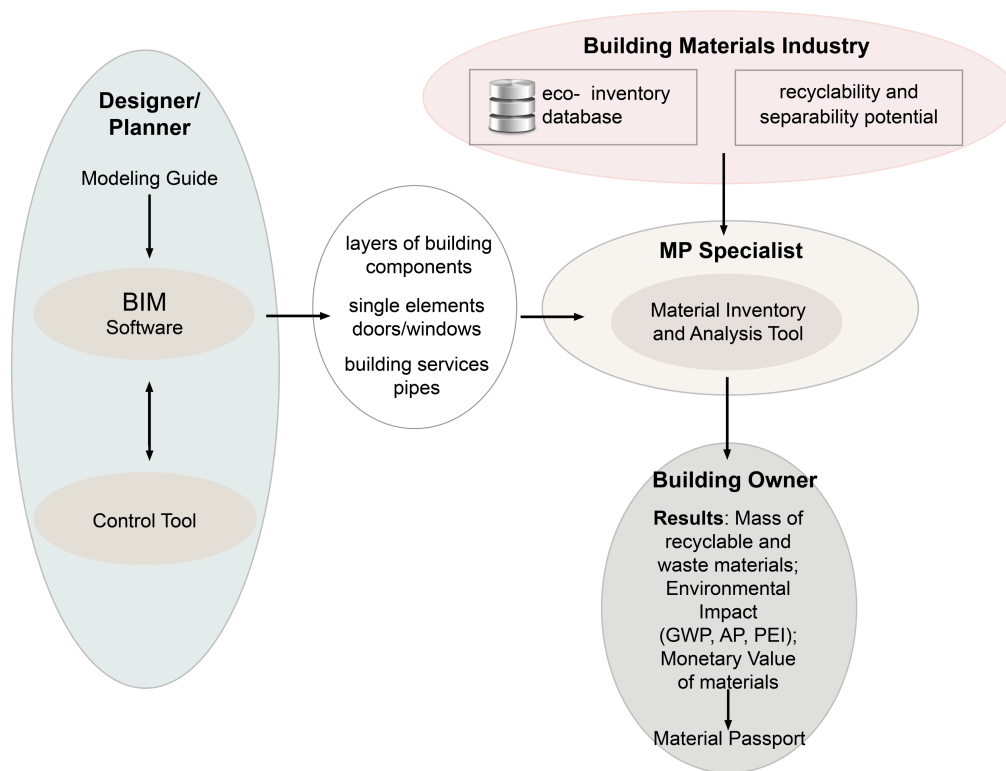


Figure 8: Modelling Framework and Stakeholders

CONCLUSION

In this paper, we presented ongoing research within research project BIMaterial, in which the potentials of BIM for generation of automated MP are explored.

Thereby we see MP as means towards successful implementation of Urban Mining strategies, and moreover as multifold instrument along building's lifecycle – as design-optimisation tool, material-inventory and as a document on material assets of real estates or building stocks.

Using a case study of cross laminated timber housing block, modelled in BIM software, and coupling of various available eco-data repositories containing eco indicators such as GWP, AP PEI, and further on life duration and recycling potential to Building One – as assessment and material-inventory tool with bi-directional interface to BIM platform; a proof of concept for BIM based MP was generated and several challenges regarding the compilation of automated MP were identified. In general, the problems regard the inconsistent data in the eco-data repositories, as the databases use varying metrics or LCA methodology, making the results not comparable.

Further on, as the level of development 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 characterised 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.

Through the case study we have demonstrated how MP can be generated and used as optimisation tool in the early design stages, which are crucial for latter building performance. However, in the further course of research the MP should also be tested on pilot projects in later life cycle stages, such as tendering and operation, in order to identify full potentials of possible need for improvement of MP framework.

An MP should finally increase recycling rates, by optimised design and more efficient use of material resources. For higher recycling rates, it is vital to have detailed knowledge about the composition of construction wastes, which are also captured in MP. The recycling potential is highly dependant on accessibility and separability of materials. The way how the layers are connected (e.g. glued or screwed) plays important role. Recyclability changes over time, as it is a function of technological development and resource markets. Thereby the challenge for the evaluation of recyclability is determination of the recycling potential factor, which changes over time; and further on rethinking of the design process away from the composite materials towards light construction allowing easy deconstruction.

MP acts as decision-support tool for planers for the optimization of resource efficiency in early design stages. However, new construction rate across Europe is around 2%. Thereby new methods need to be developed to capture material composition of existing buildings and building stocks. Material passports hence should become a standard procedure for certified structures and buildings, and contribute to the development of a secondary raw materials cadastre.

The aim of the project presented in this paper is to develop and test an integrated set of methods and tools that can finally be used to establish a material cadastre for a city. Such material information is instrumental to design effective recycling strategies, consisting of concepts and technologies, as required for the realization of a pronounced circular economy. Often referred to as Urban Mining, such strategies would significantly reduce the consumption of primary resources and the generation of waste that has to be landfilled. Both reductions have the potential to significantly reduced impacts on all environmental spheres. The exploitation of secondary resources produces fewer emissions into atmosphere and hydrosphere and requires less land use than the according primary production. Lower amounts of materials to be landfilled also contribute to lower emissions and land use. However, Urban Mining also contributes to make a region less dependent on import and extraction of primary resources – thereby in Europe and especially Austria, which are heavily dependent on imports of raw materials the implementation of Urban Mining is a means to make a society less vulnerable to regional or global supply problems. The European Union has identified secure supply of raw materials as a major challenge and considers internal recycling as one of three strategies to guarantee it. We consider cities (urban areas) and Urban Mining as an eminent contribution to achieve this.

We therefore argue that compilation of MP would be a useful decision-support tool for the AEC industry supporting successful implementation of circular economy principle along value chain within AEC.

REFERENCES

- Azhar, S., Carlton, W. A., Olsen, D. and Ahmad, I., (2011). "Building information modeling for sustainable design and LEED® rating analysis," *Automation in construction*, 20(2), 217-224.
- BAMB, Buildings As Material Banks, <http://www.bamb2020.eu/>, accessed April 2017.
- Brunner, Paul H. (2011). "Urban mining." *Journal of Industrial Ecology*. 15.3. 339-341.
- Benyus J., (1997). "Biomimicry: Innovation Inspired by Nature", New York: Harper Collins.
- BuildingOne, OneTools, <http://www.onetools.de/de/buildingone>, accessed: April 2017.
- CDL, Christian Doppler Lab for Anthropogenic Resources, <http://iwr.tuwien.ac.at/en/home/research/overview-research/>, last access May 2017
- Chau C.K., Leung T.M., Ng W.Y. (2015). "A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings". *Appl Energy*; 143, 395-413.
- Dataholz, Holzforschung Austria, Katalog bauphysikalisch ökologisch geprüfter Holzbauteile, <http://www.dataholz.com/>, accessed April 2017.
- European Environment Agency, (2016). "Circular economy in Europe. Developing the knowledge base," European Environment Agency Report.
- Graedel, T. and Greenville J.,(2005). *Greening the Industrial Facility. Perspectives, approaches and tools*. New York: Springer.
- Fay R, Treloar G, Iyer-Raniga U. (2000). "Life-cycle energy analysis of buildings: a case study". *Build Res Inf*; 28(1), 31-41.
- Frosch, R. and Gallopoulos, N. (1989). "Strategies for manufacturing," *Scientific American* (September).
- Geyer, P., Buchholz, M., (2012). "Parametric systems modeling for sustainable energy and resource flows in buildings and their urban environment", *Automation in Construction*, 22, 70-80.
- IBO, Austrian Institute for Building Biology, eco2soft, <https://www.baubook.info/eco2soft/>, accessed April 2017.
- Kleemann, F., Lederer, J., Aschenbrenner, P., Rechberger, H. and Fellner, J., (2016). "A method for determining buildings' material composition prior to demolition," *Building Research and Information*, 44(1), 51-62.

- Kohler, N., and Hassler, U., (2002). "The building stock as a research object", *Building Research & Information*, 30(4), 226-236.
- König H., Kohler N., Kreißig J. and Lützkendorf T., (2009). "Lebenszyklusanalyse in der Gebäudeplanung," Institut für internationale Architektur-Dokumentation. München: *DETAIL Green Books*.
- Lichtensteiger, T. and Baccini, P., (2008). "Exploration of urban stocks" *Journal of Environmental Engineering and Management*, 18(1), 41-48.
- Meadows, D., Meadows , Randers, J., Behrens W. (1972). *The Limits to Growth*. New York: Universe Books.
- Markova, S. and Rechberger, H., (2011). "Entwicklung eines Konzepts zur Förderung der Kreislaufwirtschaft im Bauwesen: Materieller Gebäudepass und Design for Recycling für das Bauwesen, " *Endbericht*, Technische Universität Wien.
- McDonough W. and Braungart M., (2002) *Cradle to Cradle: remaking the way we make things*. New York: North Point Press.
- O'Donnell, J. T., Maile, T., Rose, C., Mrazović, N., Morrissey, E., Regnier, C., Parrish, K. and Bazjanac, V., (2014). "Transforming BIM to BEM: Generation of Building Geometry for the NASA Ames Sustainability Base BIM," Lawrence Berkeley National Laboratory.
- Ramesh T., Prakash R., Shukla K., (2010). "Life cycle energy analysis of buildings: An overview," *Energy and Buildings*, 42, 1592-1600.
- Reisinger H., Buschmann H., Walter B., Lixia R., Daxbeck H. (2014) „Erarbeitung von Grundlagen für die Standardisierung von Gebäudepässen als Gebäudematerialinformationssystem“ (Development of Framework for Standardized Material Passports as Material Building Information System), UmweltbundesamtGmbH, Wien.
- Schlueter, A. and Thesseling, F., (2009). "Building information model based energy/exergy performance assessment in early design stages", *Automation in Construction*, 18, 153-163.
- Stahel W.R., (2010). *The Performance Economy*. 2nd ed. Hampshire: Palgrave Macmillan.
- Srinivasan, R. S., Ingwersen, W., Trucco, C., Ries, R. and Campbell, D., (2014). "Comparison of energy-based indicators used in life cycle assessment tools for buildings," *Building and Environment*, 79, 138-151.
- Tietenberg, T. H., and Lewis, L., (2016). "Environmental and natural resource economics," Routledge.