Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling

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Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling

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Abstract. This publication discusses the application of RecyclingGraphs and ConnectionMatrixes in Building Information Modelling (BIM) for the assessment of the ability of structures to be decomposed and their components to be recycled. The assessment of recyclability of designed building parts is a data-rich task which requires expert knowledge and detailed analysis on a small scale, if complete recycling of the material content is desired. Today often only the main content of buildings, such as concrete and steel structures, are recaptured, while components of smaller quantities are lost or in the worst case, if they cannot be separated, lead to deterioration of the main material flows. BIM models will be connected to relevant databases and used in future to support the optimization of building parts for complete recycling through assisted design or even in automated analysis runs and workflows. Structural compositions are described by RecyclingGraphs and ConnectionMatrixes, which's components represent on the one hand material elements and on the other hand the connections between them. Materials are classified in terms of various characteristics, such as their recyclability, their ability to be incinerated and the harmfulness of their deposition. The connections are evaluated regarding their ability to be disassembled and the compatibility of the materials connected. The structures are translated into ConnectionMatrixes and the aspects of the evaluation are assessed individually and in combination. The translation of BIM models of four wall structures into RecyclingGraphs and ConnectionMatrix representations is analysed and potentials of such representations in new BIM-based workflows are discussed.

1. Introduction

The principles of design for recycling have been known for a long time and the stakeholders in the design and construction industry are increasingly aware of the need to preserve resources. In future, resource efficiency of buildings will be required as a necessary quality of building designs, like energy-efficient building today [1]. However, up to now there are still no applicable tools and assessment methods that enables engineers and architects to systematically translate these objectives into constructible designs.

Although there are methods for the evaluation of recyclability, these are often limited to the assessment of the individual material elements in a building structure. If at all, joining techniques and the ability to disassemble are only included in the assessment qualitatively. In product design however methods for the development of recyclable products are now widely applied, also because recycling is more straightforward here due to longer design cycles, higher quantities and more controlled production conditions. With the increasing use of digital planning methods and prefabrication, the development of recyclability is becoming also more feasible in the construction industry. Especially the object-oriented approach in Building Information Modelling (BIM) will give rise to the application of pre-designed elements stored in catalogues of design templates optimized for resource-efficiency, recycling and low life cycle impact. Common to these three new design aspects is that their assessment are highly data-rich tasks that required detailed consideration and a large degree of expertise which is not in the core competence of architects and engineers today. Such new requirements will overwhelm design professionals if not supported by databases and computational tools. The approach presented in this paper will allow the evaluation of resource-efficiency, recyclability and life-cycle impact of structural elements represented in BIM template databases.

As the European Construction Product Regulation (EU-CPR) demands that all new building and building products can be recycled already today, an applicable method for such assessment is needed. Beside the technical, economic and ecological considerations also the assessment of the ability for recycling is required in the development of new materials and structural elements [1].

Akinade, et al. [2] conducted a survey among construction industry stakeholders in the UK how BIM methods can support recycling and resource-efficient design, however most of these approaches address the reduction of construction waste on site (“designing out waste”) and the prediction and management of material flows. The authors identified seven key BIM functionalities to be leveraged for design for recycling [3]. These are “Improved stakeholders’ collaboration”, “Visualization of the deconstruction process”, “Identification of recoverable materials”, “Deconstruction plan development”, “Performance analysis and simulation of end-of-life alternatives”, “Improved building whole life management” and “Interoperability with existing BIM software”. The utilization of pre-designed and optimized design templates in the object-oriented structure of a BIM model is not listed although such applications will effectively support the introduction of structures optimized for deconstruction and recycling into design practice.

2. Building Information Modelling (BIM)

The term “Building Information Modelling” (BIM) refers to an object-oriented and parametric representation of design objects in the field of building design, construction and building operation. Design elements are represented in digital models as geometric, volumetric objects, which are augmented with relevant numerical and textual parameters. As an object-oriented approach BIM allows nested representations with adapted levels of detail. Through a common modelling standard and aligned workflows BIM facilitates the cooperation of the various disciplines in the design process and between the relevant lifecycle phases. BIM is used for coordination between architectural design, structural engineering and mechanical design. In the building’s lifecycle information is passed from design to construction and to facility management.

In the field of resource efficient design BIM models are used for the generation of simulation models for thermal building simulation, load calculations and structural engineering from one common representation. In the context of recycling the application of BIM is often discussed for resource flow management, volumetric waste volume estimation and the prediction of transport and processing requirements [4].

While the main benefit of BIM is often seen in its ability to provide coordination between the disciplines in the design flow, the capacity of the nested object orientation to develop detailed design solutions bottom-up and then to plug them into the top-down design model is not yet utilized for deep analysis of design solutions. Although suppliers of technical installations, such as shading systems or ventilation units, already provide augmented BIM representations of their products to reference to the central BIM model, the detailed representation of for example wall structures with all their constructive and building physical elements and layers is not common today. BIM models are developed to limited level of geometry (LoG) and a limited level of information (LoI) and detailed design information is attached in form of 2D plans and textual descriptions [5,6]. This is partly to reduce the workload of the specialized engineers, who are still reluctant to design, specify and to enter such detailed information into the model [7]. It is also to maintain a workable size of the model since data rich representations become heavy even with today’s computer infrastructure [7].

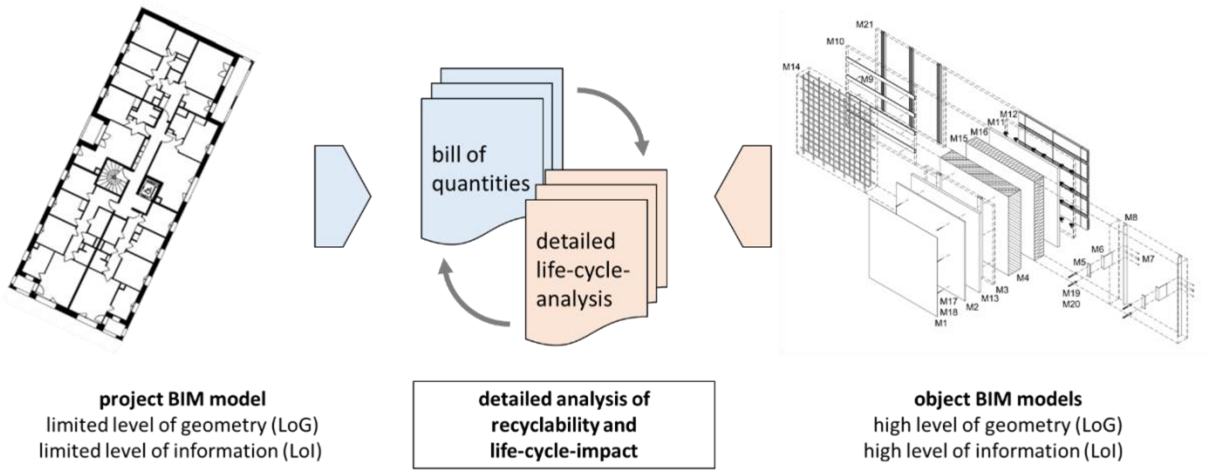

Figure 1. aggregation of detailed analysis results on building level.

3. Description of the method

BIM models contain geometric and volumetric information about the objects in the design. Additional parameters can be attached to these objects, such as material names and properties. However, information on their relationship is usually not included other than through their geometric coordinates and their shape.

Through automatic geometric analysis of the element's geometry and their placing in the model it is possible to identify adjacent elements and to plot a simple recycling graph and connection matrix [8,9] (moving from A to B in Figure 2). Pairs of adjacent elements are then listed as connection datasets. In a next step (moving from B to C in Figure 2) these connections are qualified with relevant parameters indicating the type of connection and other characteristics of the connection such as the ability to be separated and the compatibility of the connected materials [9]. This qualification can be performed by hand or supported by a database of common connection properties of material pairs. However, such information is not yet available in a structured form and will need to be developed to support future design for recycling [10].

Obviously, also the objects in the design can be specified with relevant information on the recyclability and the path of disposal, as well as of other relevant properties for life-cycle assessment and for environmental and economic evaluation. Such information can be retrieved from the available databases and connected to the material elements.

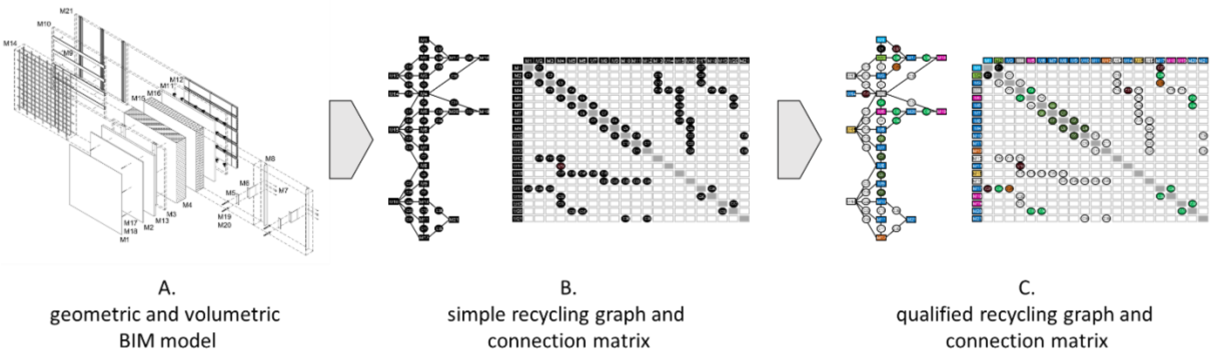

Figure 2. workflow from a BIM model into an analysis model for optimization for disassembly and recyclability. A. geometric and volumetric BIM model, B. simple recycling graph and connection matrix, C. qualified recycling graph and connection matrix.

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In first applications of the method the resource demand (e.g. “mass”, “primary energy consumption”) and the environmental impact (e.g. “global warming potential”) were added to the material element data sets [11] as well as the general ability to be recycled [9]. The connection elements have been modelled with information on the “ability to be disassembled” and the “compatibility for processing” of the two connected material elements [9]. Further information can be added to both element categories for detailed assessment and planning as suggested below.

material elements parameters (examples)
- Mass of material
- Environmental impact for LCA
- Resource demand for LCA
- Durability of material
- Classification of hazards for health
- Classification of hazards for environment
- Economic value/burden after recycling
- Specification of applicable ways of processing

connection elements parameters (examples)
- Ability to be disassembled
- Compatibility of elements for processing
- Worktime for disassembly
- Required tools for disassembly

Qualities such as the “ability to be disassembled” can then be rated on a given scale. The rating in a connection element dataset can thereby also differ depending on the direction to indicate that one member will remain intact, while the other member is destroyed in the process of disassembly. Such information can be depicted in the RecyclingGraph and the ConnectionMatrix by numeric values and by colour codes. Related qualities of the design object can be assessed visually and through mathematical evaluation. Integrated evaluations can be produced by overlaying ratings of individual criteria. In [9] it has been demonstrated that the overlay of the rating of “ability to be disassembled” and the rating of “compatibility for processing” can be used to identify the best process for deconstruction to recover the resources in a given structure.

With the translation of a designed structure into a qualified graph and matrix representation its constructive characteristics become accessible for computational evaluation and based on that for processing for optimization. BIM models can be analysed, and related computer aided algorithms can be implemented in BIM design environments.

In a first step the optimization will be performed by the designer based on depicted analysis results as shown below. In future alternative selections of materials and connection types can be suggested by a computer aided system based on information from material and connection databases, as well as based on learning from the analysis of structures with a proven high degree of recyclability stored in element catalogues.

4. Results

The method has been applied to four different wall structures, which are modelled in detail with all required connection elements and fixtures as well as all functional layers to comply with the requirements of the current German energy code (EnEV 2016). The same wall structures have already been analysed regarding their ability to be recycled in [9] and regarding life-cycle impact and resource consumption including all constructive elements in [11].

In Figure 3 the four wall structures and their ConnectionMatrixes are depicted for the “ability to be recycled” (A), “compatibility for processing” (B) and the “integrated assessment of recyclability” (C = SQRT(A x B). For each material element in the four structures simple indicators are determined to analyse the bonding of material elements. The indicator “number of connections to other material elements” (#) indicates if the material element is connected to multiple neighbours. A value of 1 identifies a material element that is either a coating or embedded in another material. A value of 2 indicates a material element which is fitted in sequence with its neighbouring material elements. A further indicator is the “average rating” (∅) in the categories A, B or C. The rules for the analysis depicted in Figure 4 are given in Table 1.

As a result of modelling and optimization of individual design objects the demolition material flows can be predicted as required for management of removal logistics and recycling. In difference to the assessment based on the bill of quantity alone the quality of the material flow can be assessed from the BIM model already in the design. Not only the volume of a material fraction can be determined, but also which combinations of materials are to be expected and which technology would be necessary to process such material fractions into secondary resources.

Table 1. assessment rules for the assessment of disassembly and processing of material elements

number of connections # of a material element M		
1	M is only connected to one other material element. M is either a coating or M is embedded into another material (such as steel in concrete).	
2	M is fitted between two other material elements. M is either a connection or a separation element fitted in sequence with two neighbours. M might also be bridging between two neighbouring elements (coating spanning over different elements).	
>2	the material element is connected to several other material elements. It is possible that the element is locked-in and disassembly is restricted (might require a certain sequence of work steps)	
average rating ∅ of a material element M (A, B or C)		
1	A	material element M can be disassembled from all its direct neighbouring material elements
	B	material element M can be processed together with all its direct neighbouring material elements, the composition is a mono-material system or a material system that can be processed together without reduction of quality.
	C	material element M can either be disassembled from or processed together with all its neighbours

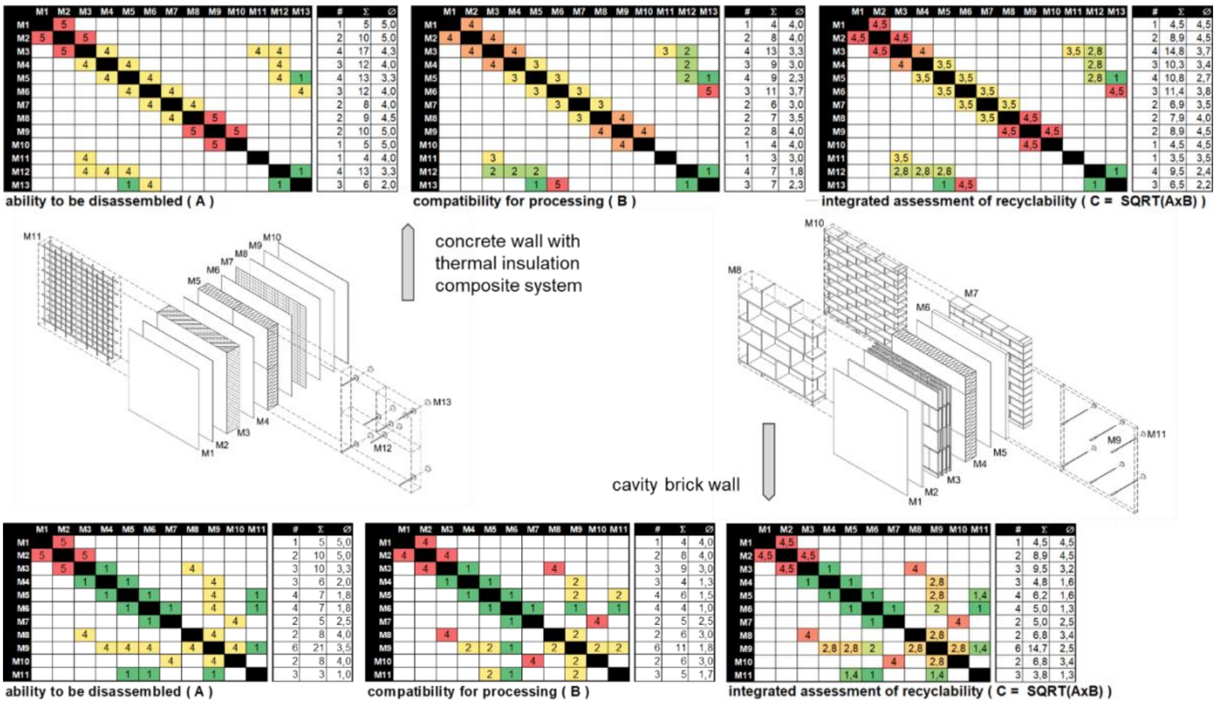

Figure 3. qualified connection matrixes with the properties “ability to be recycled” (A), “compatibility for processing” (B) and the “integrated assessment of recyclability” (C = SQRT(A x B)). (continued next page).

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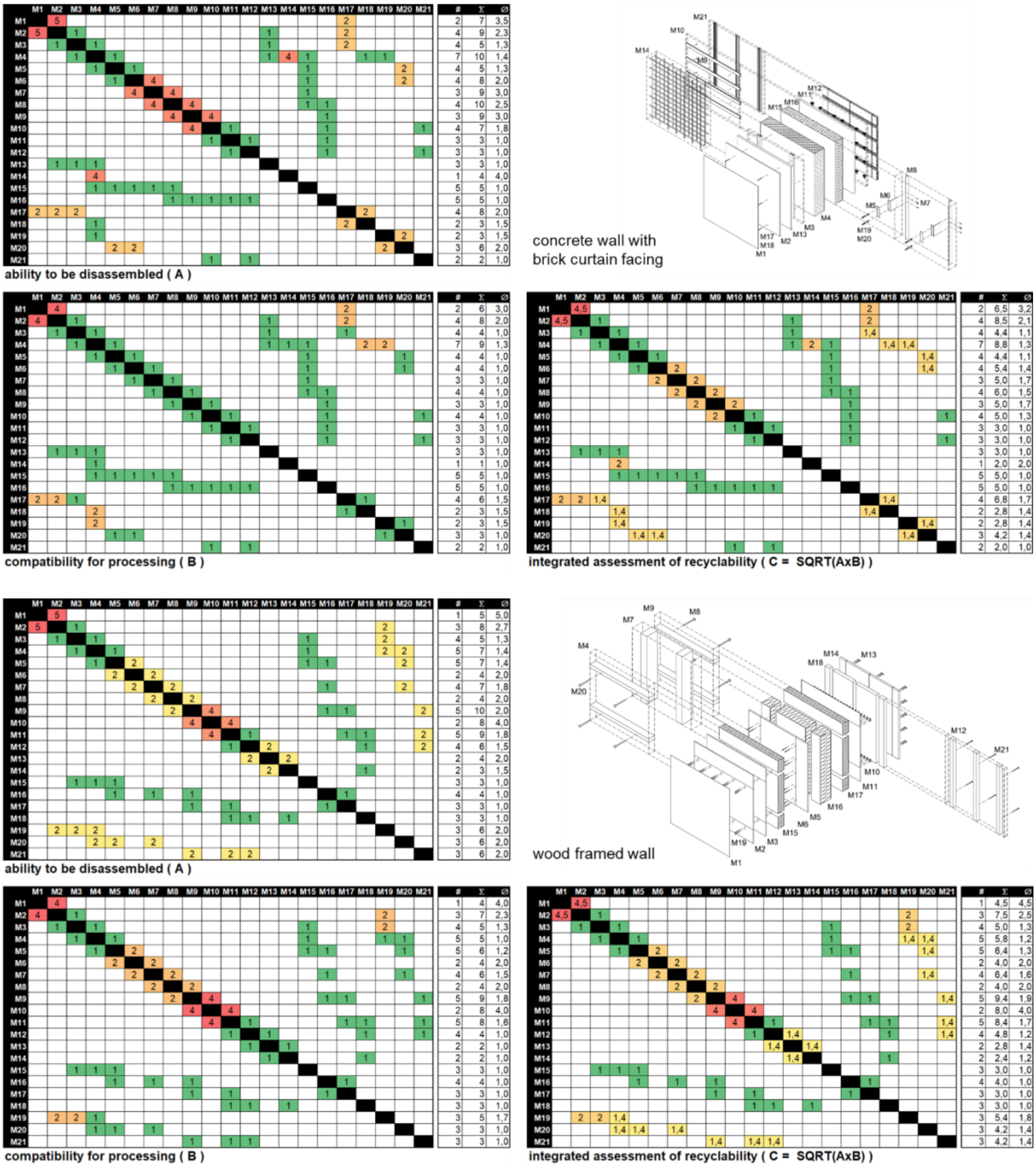

Figure 3 (continued). qualified connection matrixes with the properties “ability to be recycled” (A), “compatibility for processing” (B) and the “integrated assessment of recyclability” (C = SQRT(A x B)).

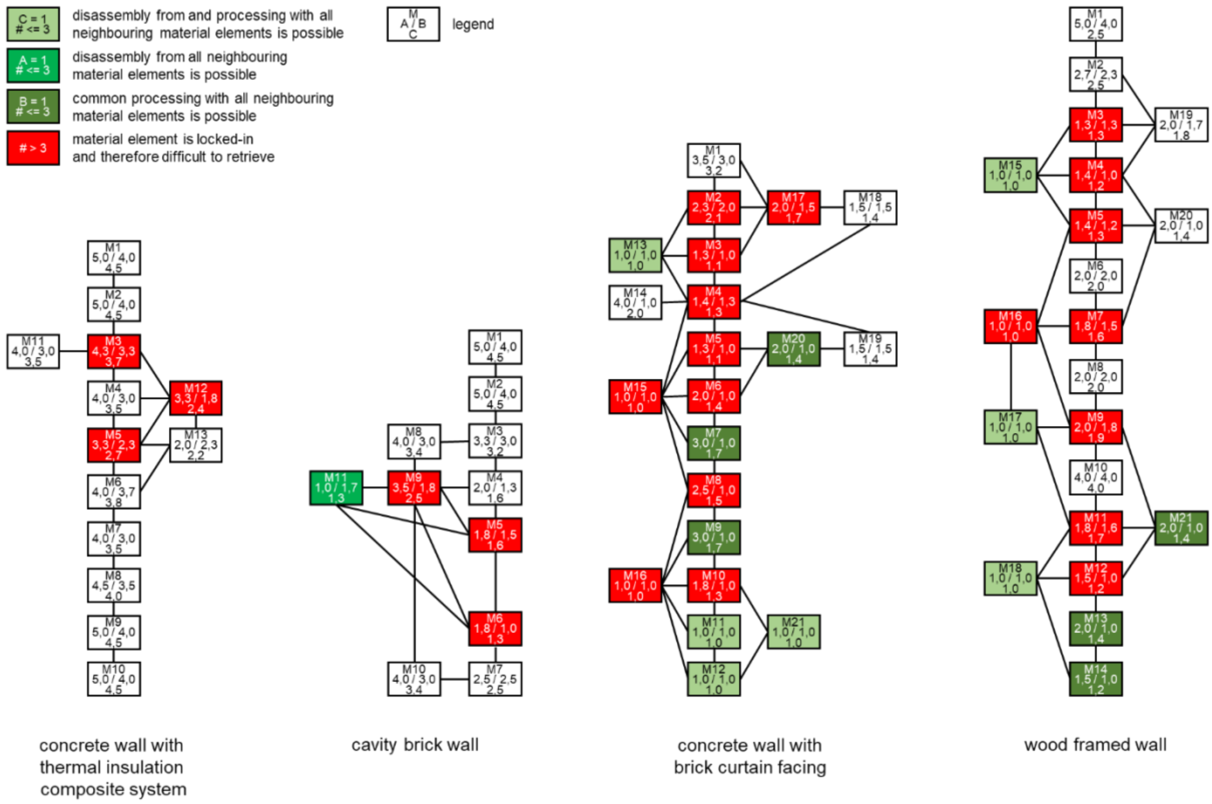

Figure 4. simple rule-based analysis of four wall structures. Colour codes indicate the recyclability of the material elements in the structure.

5. Conclusion

Resource-efficiency, recyclability and a low life-cycle impact are new criteria in building design and construction that require a detailed and data-rich evaluation [9,11]. A detailed analysis of the structural elements, not only of their individual materials but also of their connections and the compatibility of the fitted materials, is required to build truly sustainable structures. The RecyclingGraph approach presented in this paper can be used to translate detailed models of constructive designs into a numerical representation that can be processed by computational algorithms and design tools. This method can be utilized to evaluate designed and pre-designed structures and a catalogue of qualified design templates can be build up to support the BIM-based design development.

The presented RecyclingGraph approach must be developed further and an applicable design tool must be implemented. Research is also needed on the ability of disassembly for common connection principles and especially on the compatibility of material combinations.

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