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

Building Design 3:
Digitalisation in the Design Process

Sustainable Built Environment Conference 2019 (SBE19 Graz)

Date and time: 12/Sep/2019, 4:15pm - 5:45pm
Location: HS VI, Technical University Graz

Dr. Dirk Schwede (PhD USyd AUS)
Institute for Building Energetics,
Thermotechnology and Energy Storage (IGTE)
University of Stuttgart, Pfaffenwaldring 35
70569 Stuttgart, Germany

dirk.schwede@igte.uni-stuttgart.de

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz

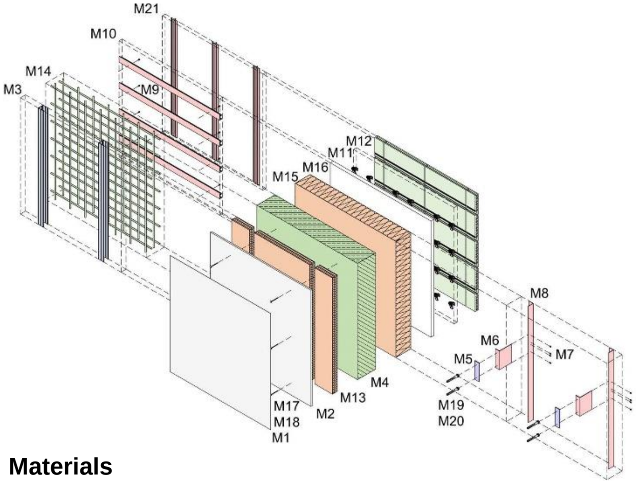
- in future, resource efficiency of buildings will be required as a necessary quality of building designs, like energy-efficient building today.
- up to now there are still no applicable tools and assessment methods that enables engineers and architects to systematically translate these objectives into constructible designs.
- 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.**

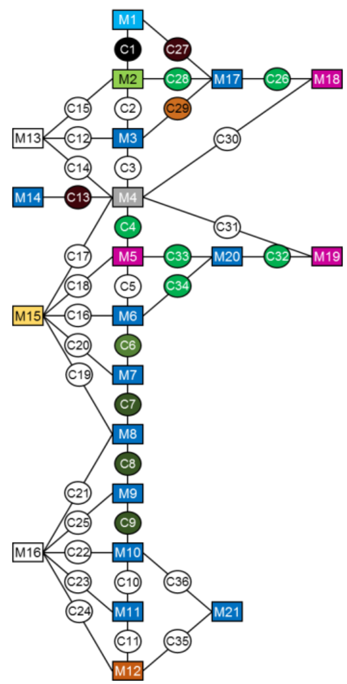
Method for analysing the recyclability of building structures

Schwede, D.; Störl, E.: Methode zur Analyse der Rezyklierbarkeit von Baukonstruktionen. in: Bautechnik, 2017, H. 1

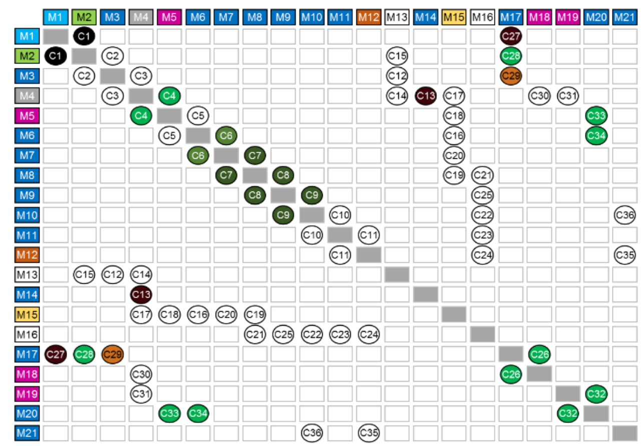
Concrete wall with suspended brick facade



RecyclingGraph



ConnectionMatrix

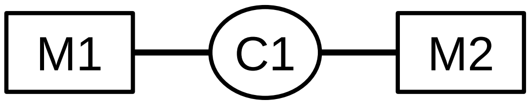


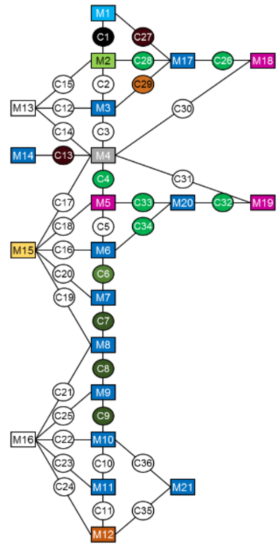
Materials

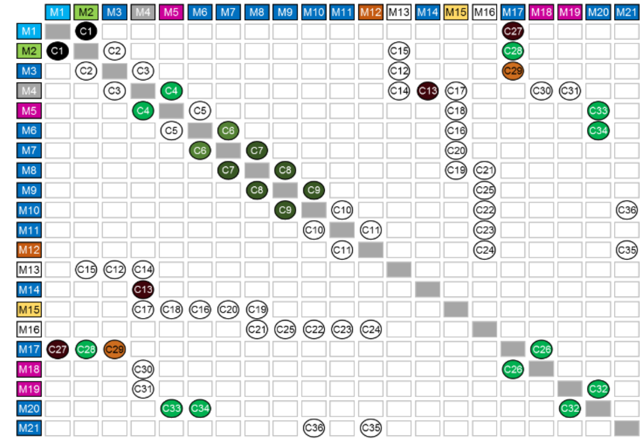
M1 Innenfarbe Dispersionsfarbe
M2 Gipskartonplatte, 12 mm
M3 Metallständerprofil, Stahl, 50 mm x 50 mm
M4 Beton, 180 mm
M5 Thermisches Trennelement, PVC hart, 5 mm
M6 Wandhalter Alu, 120 mm x 160 mm
M7 Niete, Stahl
M8 vertikales Grundprofil Alu, 50 mm x 50 mm
M9 Niete, Stahl
M10 Tragprofil Alu, 20 mm x 50 mm
M11 Klipshalter Alu, 20 mm x 50 mm
M12 Ziegelplatten, 390 mm x 190 mm
M13 Luftschicht, 50 mm
M14 Baustahlmatten
M15 Dämmung Steinwolle, 150 mm
M16 Luftschicht, 30 mm
M17 Schraube, Stahl
M18 Dübel, Kunststoff
M19 Dübel, Kunststoff
M20 Schraube, Stahl
M21 Fugenprofil Alu, 30 mm x 60

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz



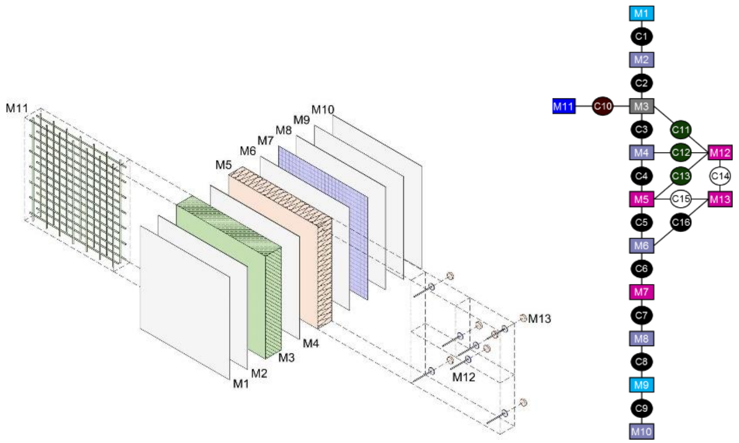




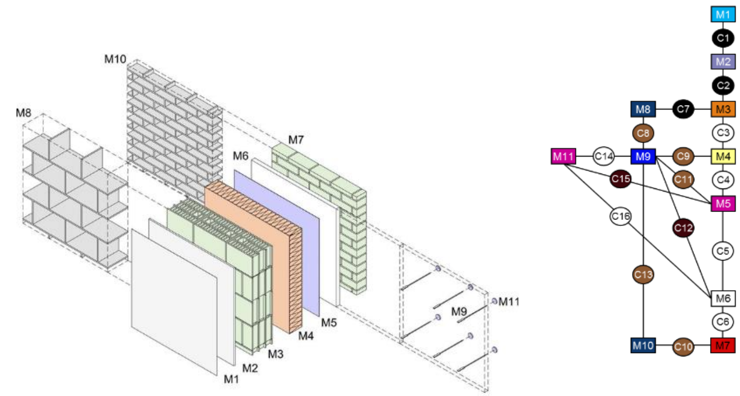
material elements parameters (examples)	connection elements parameters (examples)
▪ Mass of material	▪ Ability to be disassembled
▪ Environmental impact for LCA	▪ Compatibility of elements for processing
▪ Resource demand for LCA	▪ Worktime for disassembly
▪ Durability of material	▪ Required tools for disassembly
▪ Classification of hazards for health	
▪ Classification of hazards for environment	
▪ Economic value/burden after recycling	
▪ Specification of applicable ways of processing	

Detailed analysis of resource use and the environmental impact in exterior wall structures

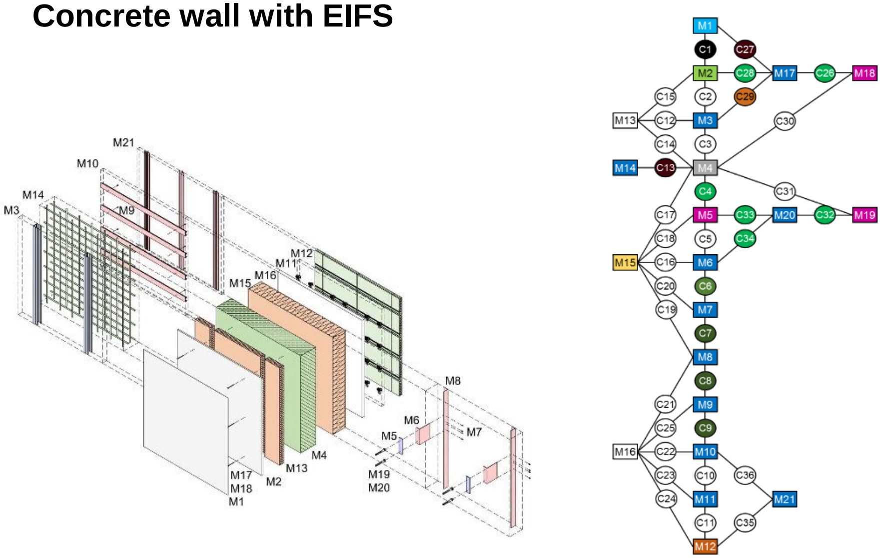
Schwede, D.; Störl, E.: Detaillierte Analyse des Ressourceneinsatzes und der Umweltwirkung in Außenwandaufbauten (Bautechnik 95 (2018))



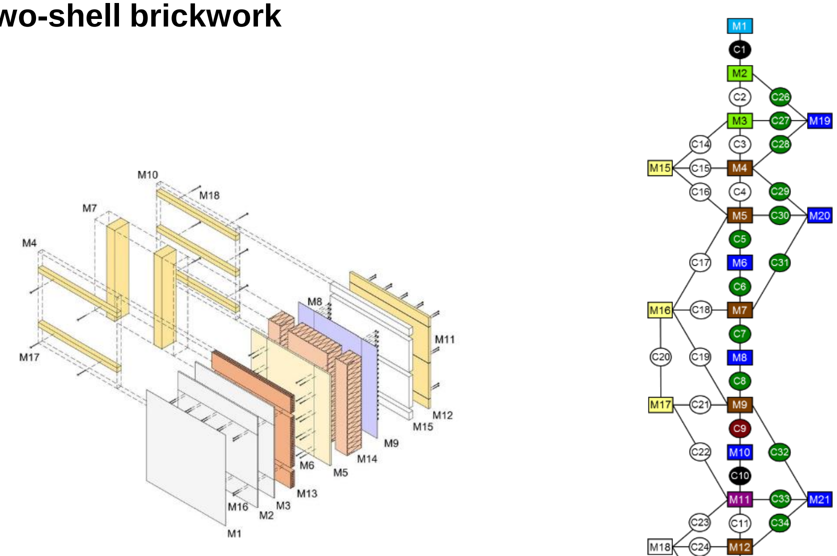
Concrete wall with EIFS



two-shell brickwork



Concrete wall with suspended brick facade



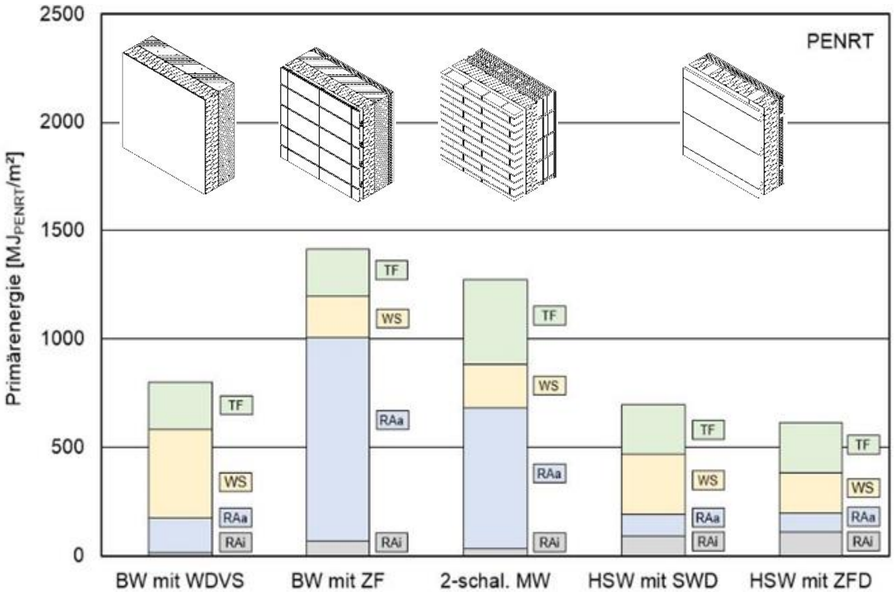
Wooden stand wall with stone wool insulation

alternative for LCA: wooden stand wall with cellulose insulation

Detailed analysis of resource use and the environmental impact in exterior wall structures

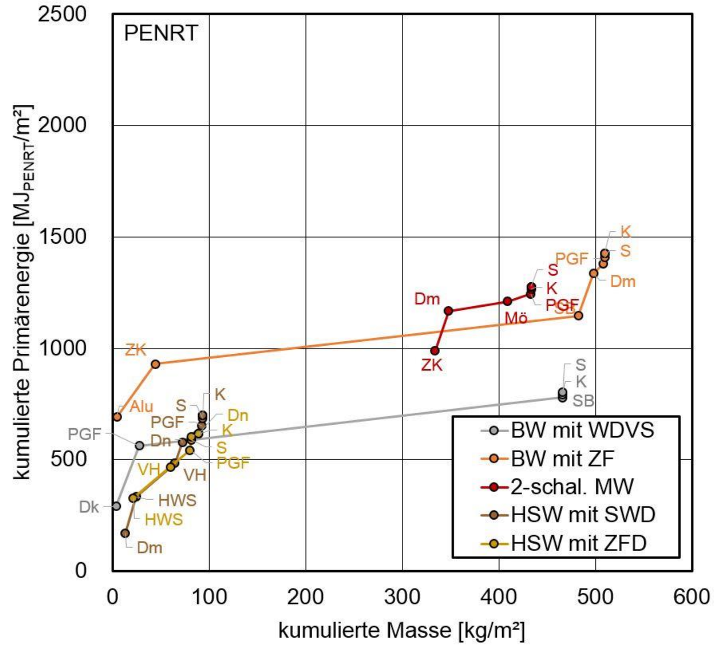
Schwede, D.; Störl, E.: Detaillierte Analyse des Ressourceneinsatzes und der Umweltwirkung in Außenwandaufbauten (Bautechnik 95 (2018))

non-renewable primary energy content (PENRT) summarized in function groups



Comparison of resource use for five modeled wall structures

non-renewable primary energy content (PENRT) summarized in material groups



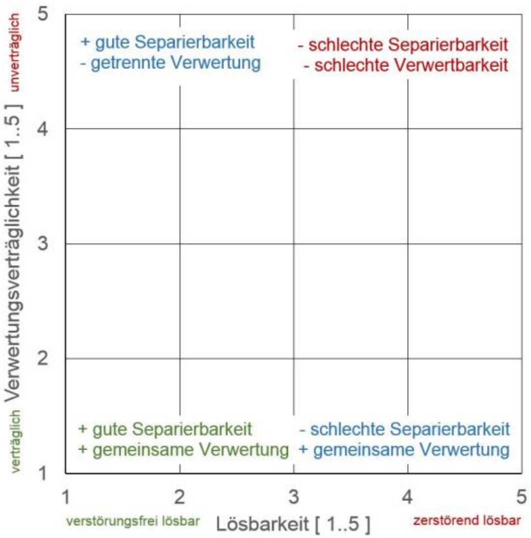
Cumulative environmental impact of material groups plotted above the cumulative mass for five outer wall structures (ordered by the contribution to the cumulative use of resources)

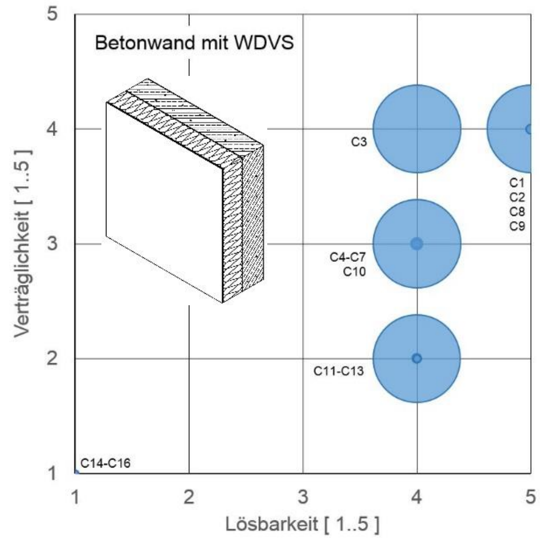
RAi	room closure, inside
RAa	room closure, outside
WS	thermal insulation
TF	structural elements

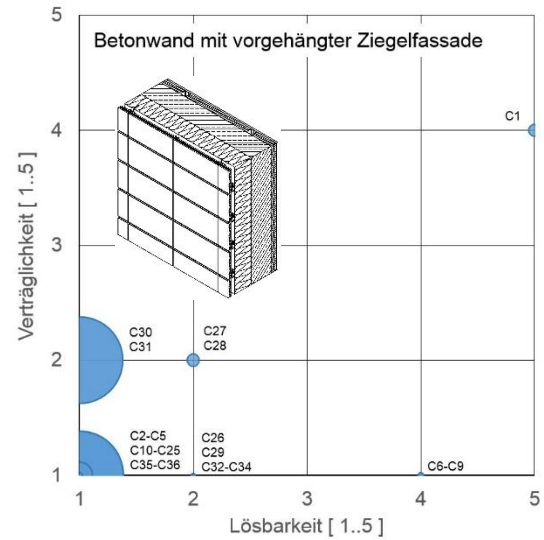
Alu	Aluprofile
Dk	Insulation, EPS
Dm	Insulation, mineral
Dn	Insulation, of course
HWS	Wood-based materials (without insulation)
K	Plastics
LS	Air layers
Mö	Mortar (wallwork)
PGF	Plasters, plasterboard, paints
S	Steel (fixing, substructures)
SB	Reinforced concrete
VH	Wood
ZK	Bricks, clinker

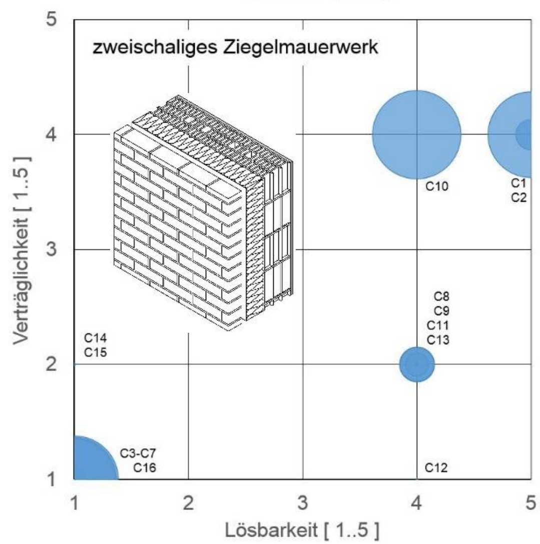
Methode zur Analyse der Rezyklierbarkeit von Baukonstruktionen

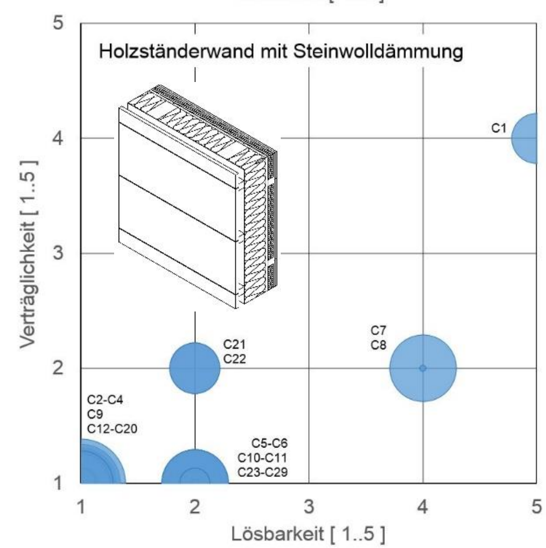
nach: Schwede, D.; Störl, E.: Methode zur Analyse der Rezyklierbarkeit von Baukonstruktionen. in: Bautechnik, 2017, H. 1









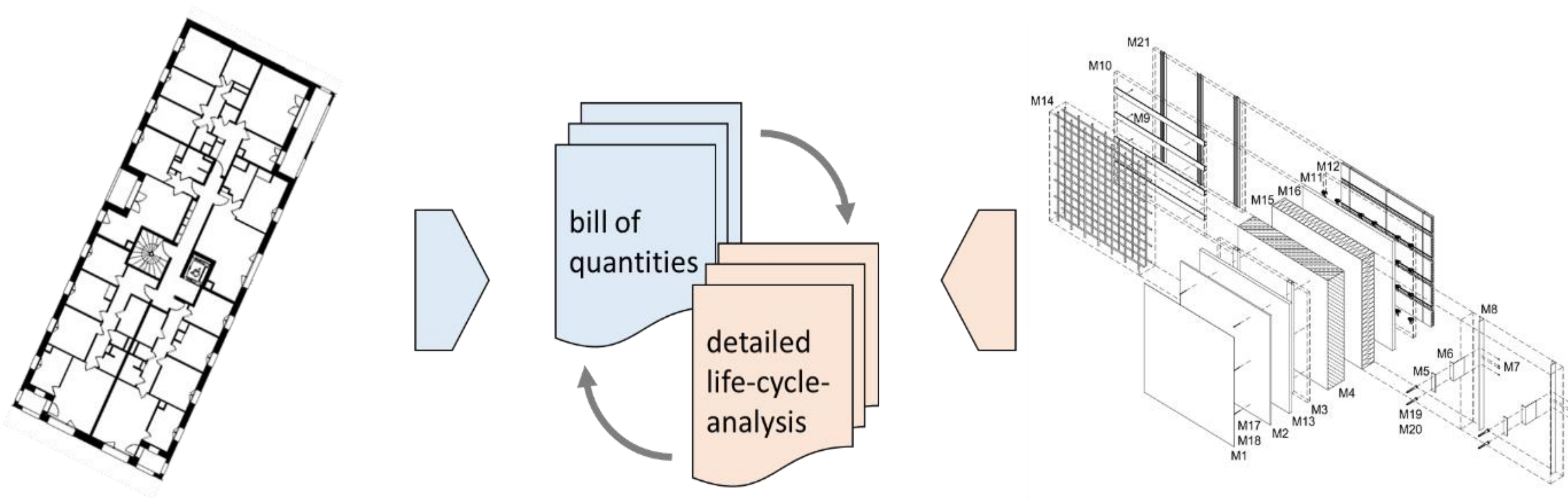


Classification of the recyclability of the design and the material according to the dismemberability and utilization compatibility of the material pairings

The size of the points stands for the material mass

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz



project BIM model
limited level of geometry (LoG)
limited level of information (LoI)

detailed analysis of recyclability and life-cycle-impact

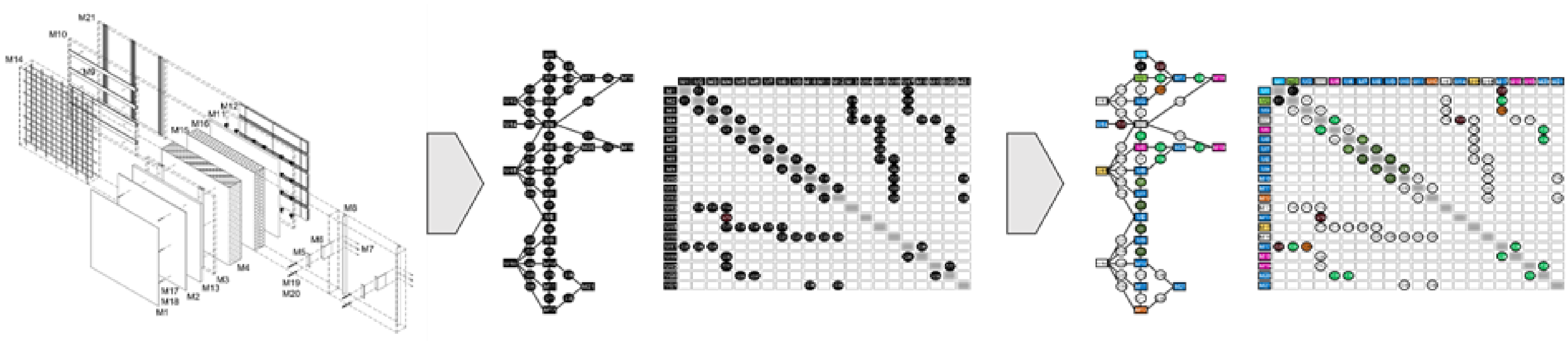
object BIM models
high level of geometry (LoG)
high level of information (LoI)

aggregation of detailed analysis results on building level

as an object-oriented approach BIM allows nested representations with adapted levels of detail.

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz



A. geometric and volumetric BIM model

B. simple recycling graph and connection matrix

C. qualified recycling graph and connection matrix

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.

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz

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

assessment rules for the assessment of disassembly and processing of material elements

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	#	Σ	Ø
M1		5												1	5	5,0
M2	5		5											2	10	5,0
M3		5		4							4	4		4	17	4,3
M4			4		4							4		3	12	4,0
M5				4		4						4	1	4	13	3,3
M6					4		4						4	3	12	4,0
M7						4		4						2	8	4,0
M8							4		5					2	9	4,5
M9								5		5				2	10	5,0
M10									5					1	5	5,0
M11			4											1	4	4,0
M12			4	4	4								1	4	13	3,3
M13					1	4						1		3	6	2,0

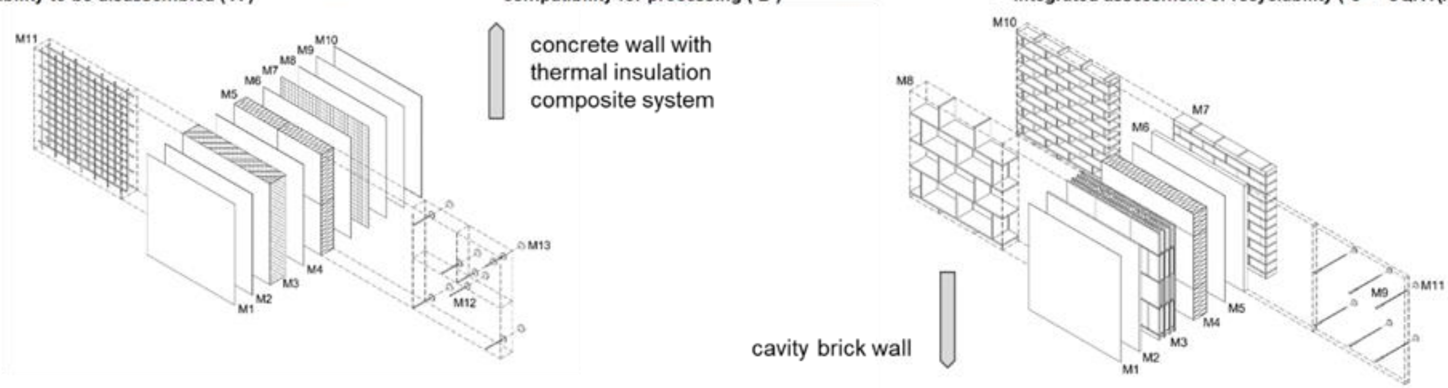
ability to be disassembled (A)

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	#	Σ	Ø
M1		4												1	4	4,0
M2	4		4											2	8	4,0
M3		4		4							3	2		4	13	3,3
M4			4		3							2		3	9	3,0
M5				3		3						2	1	4	9	2,3
M6					3		3						5	3	11	3,7
M7						3		3						2	6	3,0
M8							3		4					2	7	3,5
M9								4		4				2	8	4,0
M10									4					1	4	4,0
M11			3											1	3	3,0
M12			2	2	2								1	4	7	1,8
M13					1	5						1		3	7	2,3

compatibility for processing (B)

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	#	Σ	Ø
M1		4,5												1	4,5	4,5
M2	4,5		4,5											2	8,9	4,5
M3		4,5		4							3,5	2,8		4	14,8	3,7
M4			4		3,5							2,8		3	10,3	3,4
M5				3,5		3,5						2,8	1	4	10,8	2,7
M6					3,5		3,5						4,5	3	11,4	3,8
M7						3,5		3,5						2	6,9	3,5
M8							3,5		4,5					2	7,9	4,0
M9								4,5		4,5				2	8,9	4,5
M10									4,5					1	4,5	4,5
M11			3,5											1	3,5	3,5
M12			2,8	2,8	2,8								1	4	9,5	2,4
M13					1	4,5						1		3	6,5	2,2

integrated assessment of recyclability (C = SQRT(AxB))



	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	#	Σ	Ø
M1		5										1	5	5,0
M2	5		5									2	10	5,0
M3		5		1				4				3	10	3,3
M4			1		1				4			3	6	2,0
M5				1		1			4		1	4	7	1,8
M6					1		1		4		1	4	7	1,8
M7						1				4		2	5	2,5
M8			4						4			2	8	4,0
M9				4	4	4		4		4	1	6	21	3,5
M10							4		4			2	8	4,0
M11					1	1			1			3	3	1,0

ability to be disassembled (A)

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	#	Σ	Ø
M1		4										1	4	4,0
M2	4		4									2	8	4,0
M3		4		1				4				3	9	3,0
M4			1		1				2			3	4	1,3
M5				1		1			2		2	4	6	1,5
M6					1		1		1		1	4	4	1,0
M7						1				4		2	5	2,5
M8			4						2			2	6	3,0
M9				2	2	1		2		2	2	6	11	1,8
M10							4		2			2	6	3,0
M11					2	1			2			3	5	1,7

compatibility for processing (B)

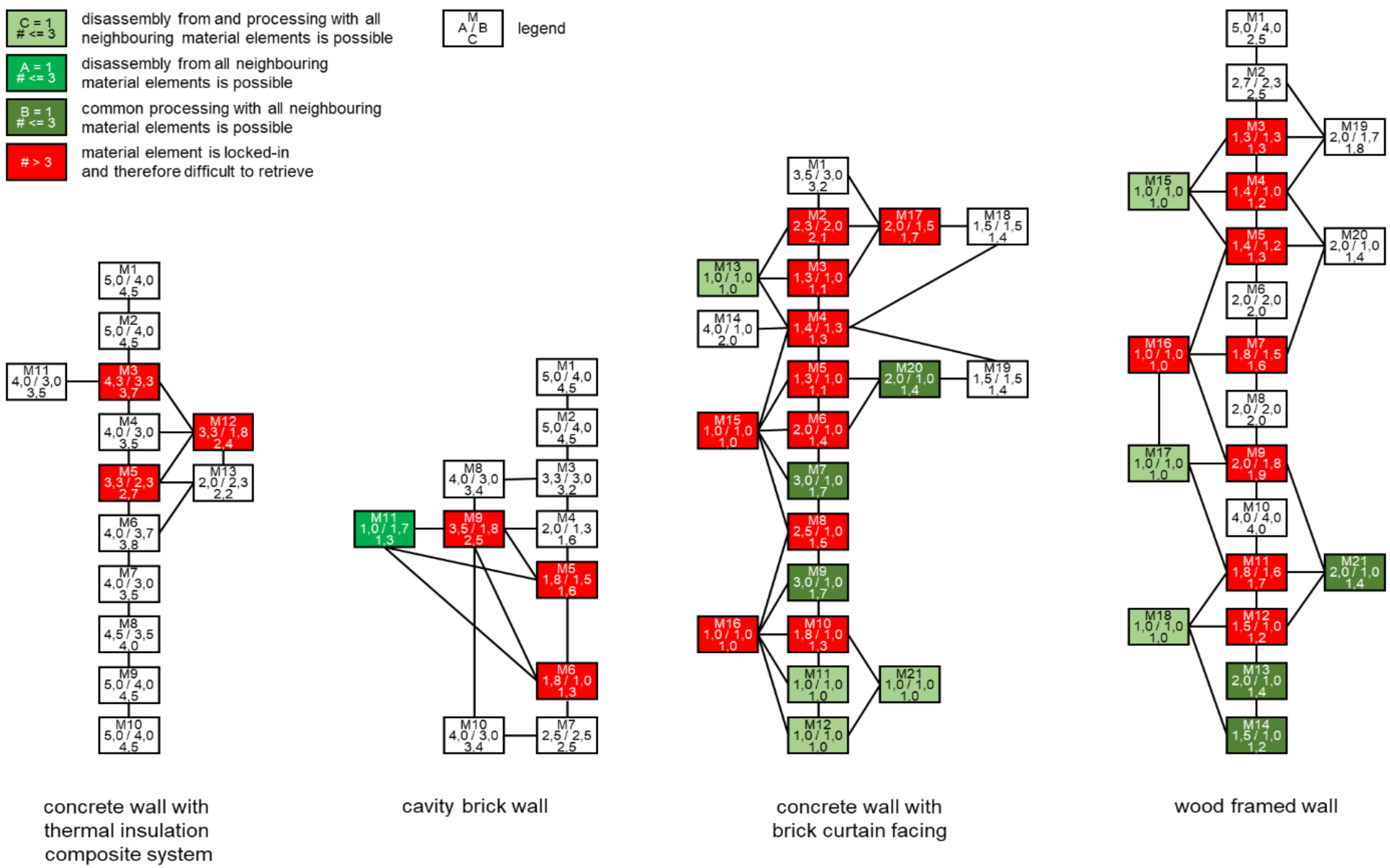
	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	#	Σ	Ø
M1		4,5										1	4,5	4,5
M2	4,5		4,5									2	8,9	4,5
M3		4,5		1				4				3	9,5	3,2
M4			1		1				2,8			3	4,8	1,6
M5				1		1			2,8		1,4	4	6,2	1,6
M6					1		1		2		1	4	5,0	1,3
M7						1				4		2	5,0	2,5
M8			4						2,8			2	6,8	3,4
M9				2,8	2,8	2		2,8		2,8	1,4	6	14,7	2,5
M10							4		2,8			2	6,8	3,4
M11					1,4	1			1,4			3	3,8	1,3

integrated assessment of recyclability (C = SQRT(AxB))

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)).

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz



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

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

nach: Schwede, D.: Application of RecyclingGraphs for the Optimisation of the Recyclability in Building Information Modelling. SBE19, TU Graz

→ 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.**

Thank you!

Dr. Dirk Schwede (PhD Usyd AUS)

e-mail dirk.schwede@igte.uni-stuttgart.de
phone +49 (0) 711 685-62090
www. igte.uni-stuttgart.de

University of Stuttgart
Institute for Building Energetics,
Thermotechnology and Energy Storage (IGTE)
Pfaffenwaldring 35
70569 Stuttgart
Deutschland