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University of Southern Denmark

DANISH BUILDING RESEARCH INSTITUTE
AALBORG UNIVERSITY COPENHAGEN

Implementation of Circular Economy in the construction sector

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Industrial PhD

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Project partners

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UNIVERSITY OF SOUTHERN DENMARK

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A project born from the industries' motivation for circular economy

Resource supply/consumption and environmental impacts

- The construction industry is responsible for (Becqué et al., 2016):
  - **25%** of human induced CO_2 emission
  - **40%** of materials produced and consumed globally (by volume)
  - **40%** of the worlds waste generation (by volumne)
- Demand for construction has increased by **80%** from 1980 to 2008 (OECD, 2015).
- A great amount of materials ever extracted in human history are located in the built environment (Sanchez and Haas, 2018)
- It is estimated that the anthropogenic stock outweighs the natural resource stock (Oezdemir et al., 2017) **ie. future resources need to be extracted from our buildings (we need to rethink!)**

Politics and legislation:

- Circular Economy Advisory Board's recommendations for the government 2017
- The danish governments circular economy strategy 2018
- Danish Standardisation 2018
- EU waste directive 2018

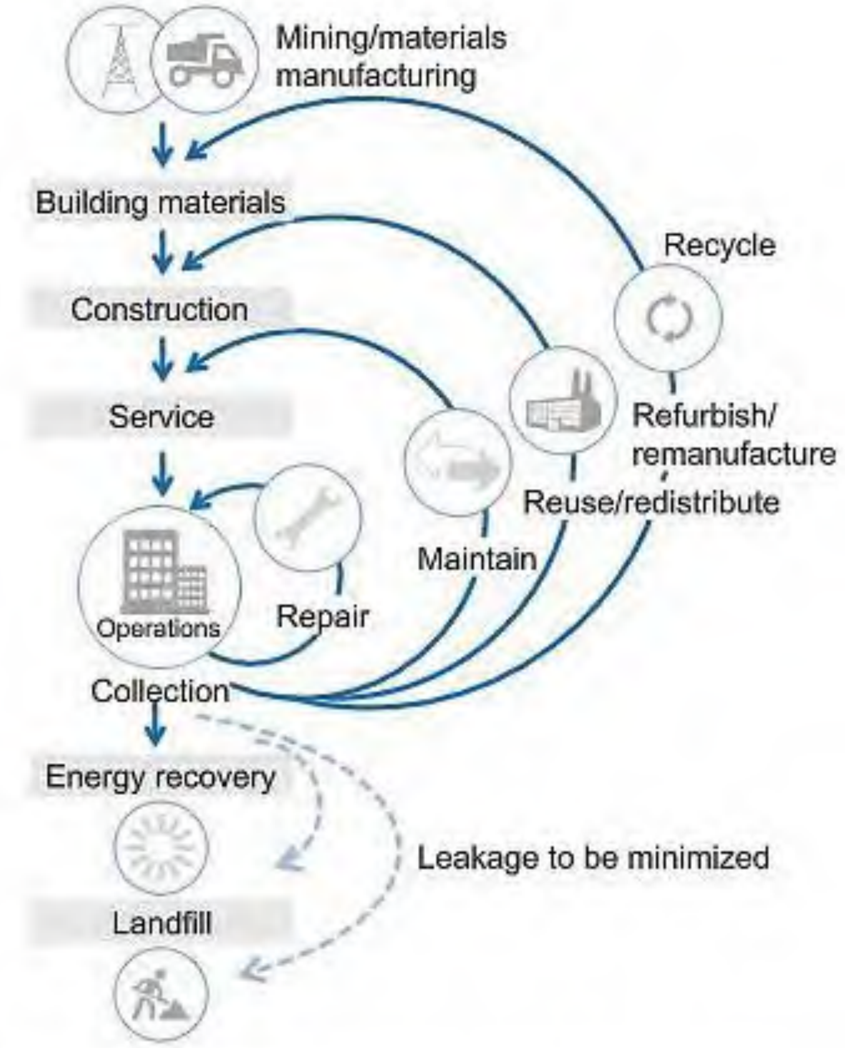
A need to prepare for the future!

The concpet of circular economy
in the buildings

“an industrial economy that is **restorative** and **regenerative** by **intention** and **design** and which aims to keep products, components and materials at their **highest utility** and **value** at all times” (Webster, 2015).

Circular economy within the built environment is about **managing the constant flow of resources within a regenerating capacity** thereby avoiding depletion and reducing burdens of the flows. Hence, design of buildings is about **which resources to use, where to extract them and how to use them.** In a circular economy, buildings will be **designed for whole life cycle** not simply end of use. (Rovers, 2018).

How to design for circular economy in buildings?



Source: Ellen MacArthur Foundation; World Economic Forum; The Boston Consulting Group

Where it all began

A business case

Life cycle assessment (LCA)

- EN 15978
- CML-baseline calculation method
- Ecoinvent 3.2 database

Construction

-860.000.000 DKK

Demolition

Selective d

Down-cycling

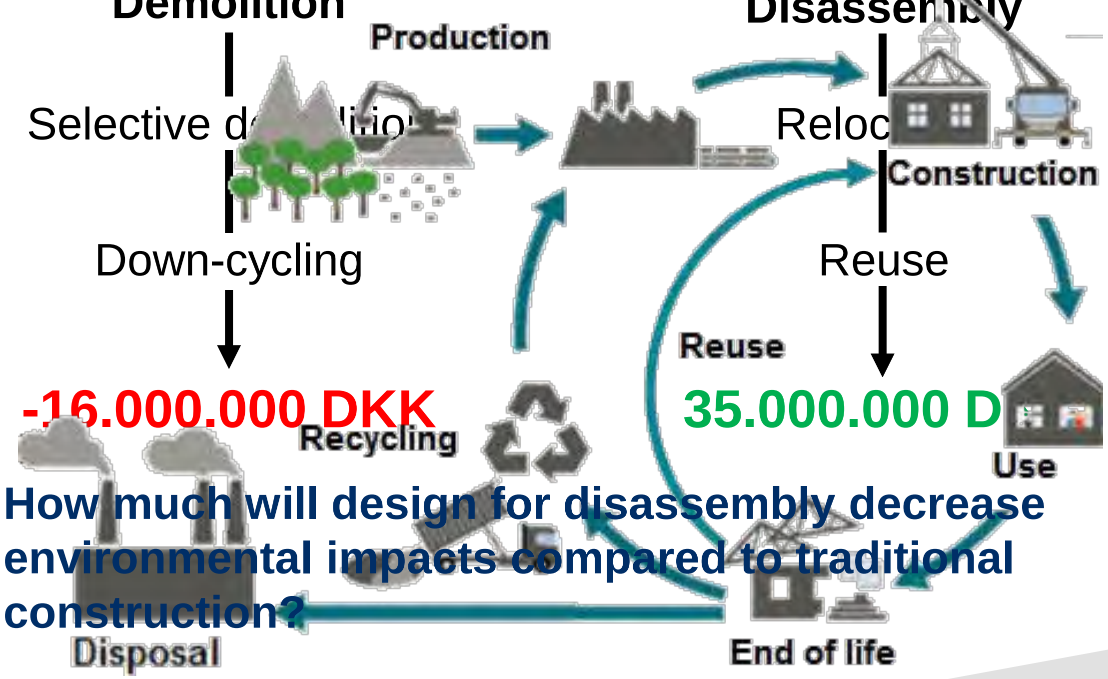
-16.000.000 DKK

Disassembly

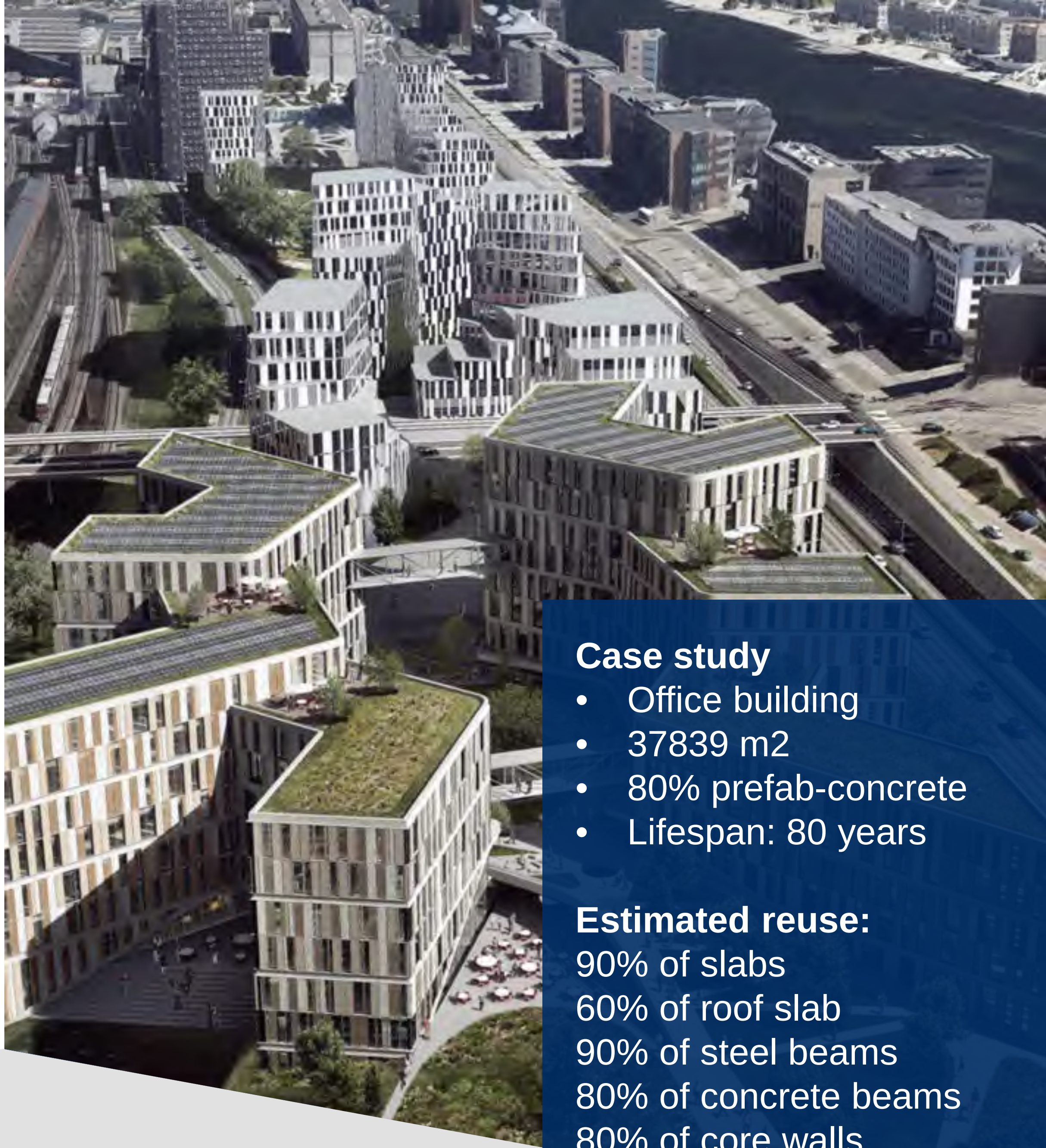
Reloc

Reuse

35.000.000 D



How much will design for disassembly decrease environmental impacts compared to traditional construction?



Case study

- Office building
- 37839 m2
- 80% prefab-concrete
- Lifespan: 80 years

Estimated reuse:

90% of slabs
60% of roof slab
90% of steel beams
80% of concrete beams
80% of core walls
90% of concrete columns

Building components

Reusable components	Use cycles	Environmental impacts					Resource use impacts		Toxicology impacts				Weighted impact savings [%]
		Impact saving [%]											
		GWP	ODP	POCP	AP	EP	ADPe	ADPf	FAETP	HTP	MAETP	TETP	
Floor slabs	2	45	46	45	45	46	46	46	46	43	44	45	45
	3	60	61	60	60	60	60	61	61	59	60	60	60
Core walls	2	36	32	27	30	28	11	32	13	20	18	7	23
	3	50	47	43	46	44	31	47	31	38	37	28	40
Roof slabs	2	31	32	34	33	33	43	32	43	39	38	51	37
	3	41	42	44	46	44	53	42	53	47	48	62	47
Columns	2	41	32	37	38	37	28	38	29	32	32	29	34
	3	57	54	55	55	55	48	56	49	51	51	49	53
Beams	2	25	28	34	31	34	42	31	41	39	40	43	35
	3	33	38	46	42	45	56	42	55	52	53	58	47

Legend
50-60
40-50
30-40
20-30
10-20
0-10
<0

Note: Weighted impact savings are calculated as the average impact savings of each reusable component compared to no reuse using equal weighting factors for each environmental impact category assessed, this includes: GWP, ODP, POCP, AP, EP, ADPe, ADPf, FAETP, MAETP, HTP and TETP.

(Eberhardt, Birgistdottir & Birkved 2018)

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The buildingsmaterial composistion is a determining factor

Building

		Environmental impacts										Resource use impacts				Toxicology impacts									
Building scenario	**Use cycles**	**Impact saving [%]**																						**Weighted impact savings [%]**	
		GWP		**ODP**		**POCP**		**AP**		**EP**		**ADPe**		**ADPf**		**FAETP**		**HTP**		**MAETP**		**TETP**			
		80	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**	**80**	**50**
DFD	2	15	18	8	12	7	9	7	10	8	11	0.3	0.6	10	13	7	10	5	10	6	9	17	22	8.2	11.3
	3	21	25	14	19	9	12	10	13	11	13	0.6	1	14	18	11	15	8	14	9	12	13	8	11.0	13.6

50-60
40-50
30-40
20-30
10-20
0-10
<0

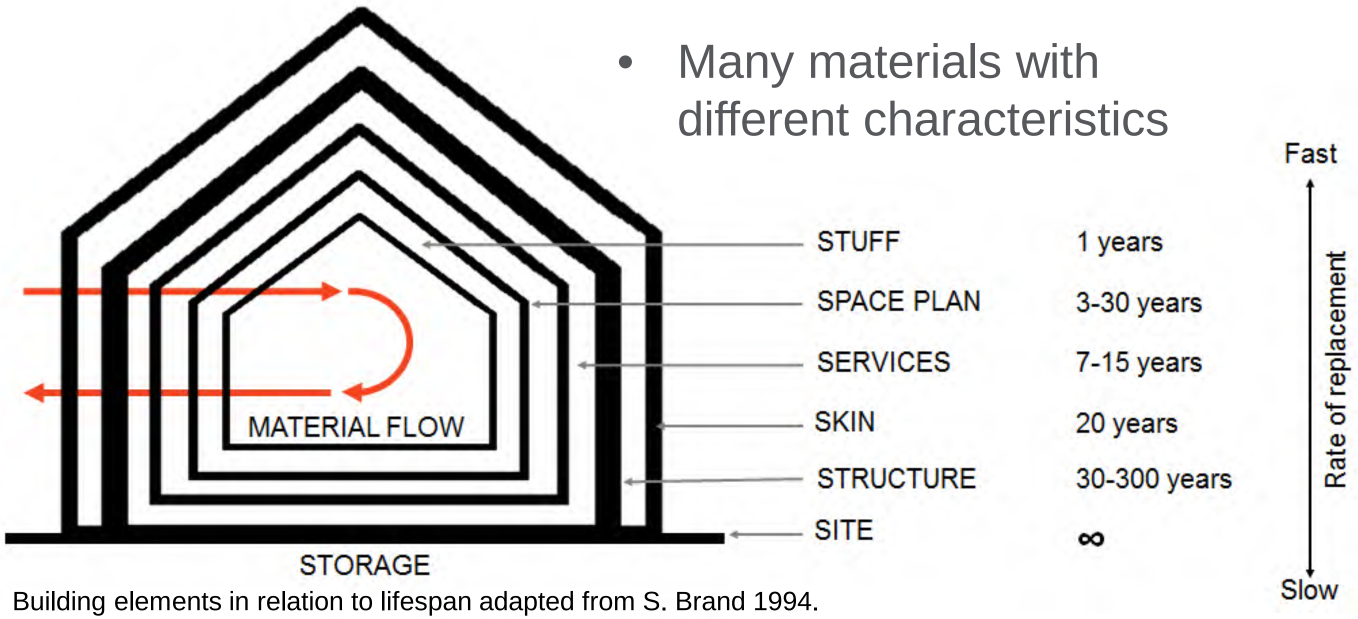
Abbreviations: DfD = design for disassembly; O1 = optimization scenario (concrete columns); O2 = optimization scenario 2 (steel columns); O3 = optimization scenario 3 (wooden columns); O4 = optimization scenario 4 (bubble decks).
Note: Energy consumption during operation is not included.
Note: Weighted impact savings are calculated as the average impact savings of each building scenario compared to no reuse of the reusable components using equal weighting factors for each environmental impact category assessed, this includes: GWP, ODP, POCP, AP, EP, ADPe, ADPf, FAETP, MAETP, HTP and TETP.

(Eberhardt, Birgistdottir & Birkved 2018)

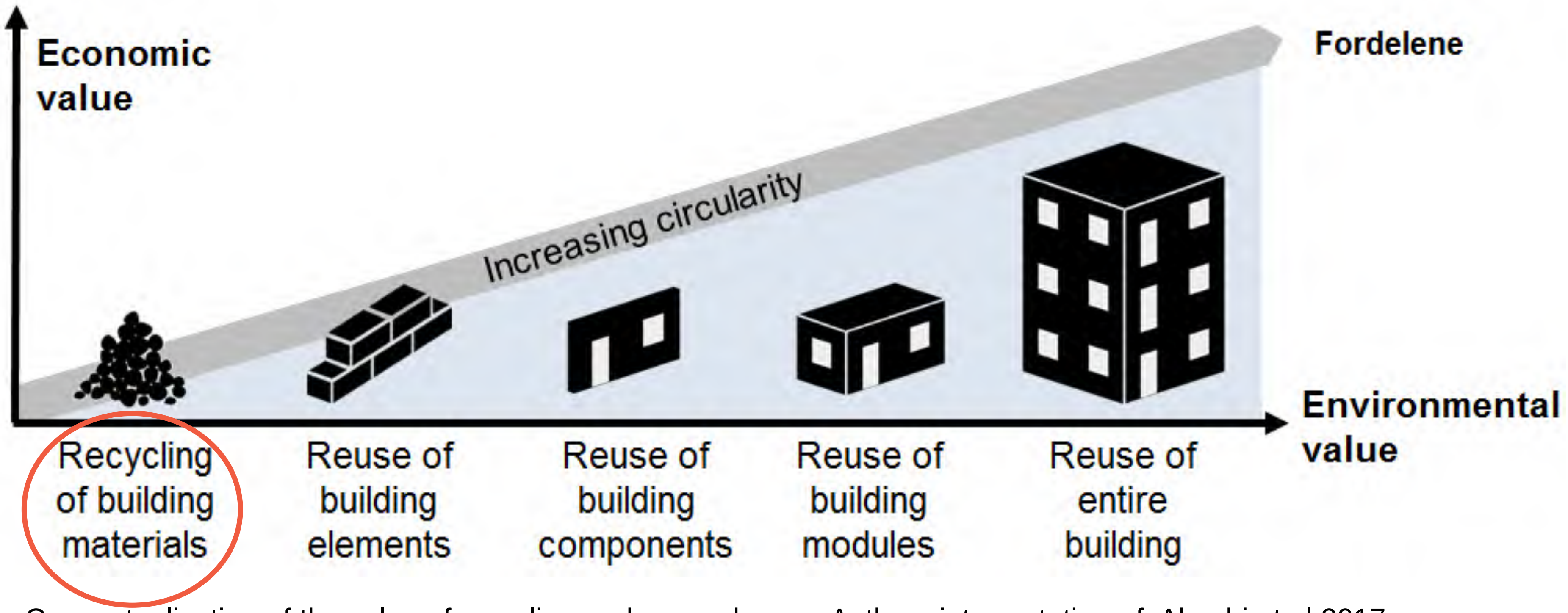
Concept challenges

- For which building components does this apply?
- When is economic and environmental value gained?

- Many materials with different characteristics



Building elements in relation to lifespan adapted from S. Brand 1994.



Conceptualization of the value of recycling and reuse degree. Authors interpretation of Akanbi et al 2017.

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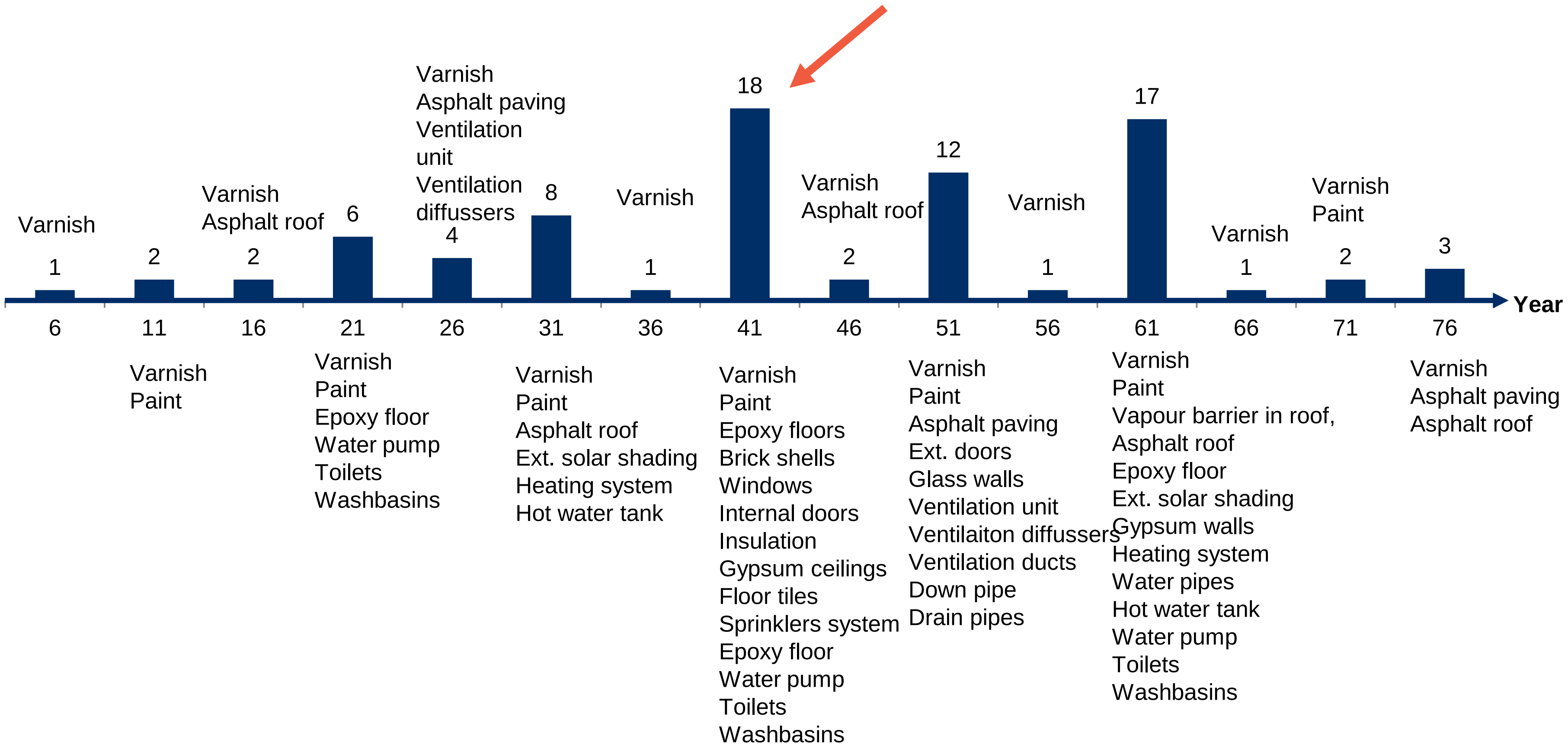
Concept challenges
The building metabolism



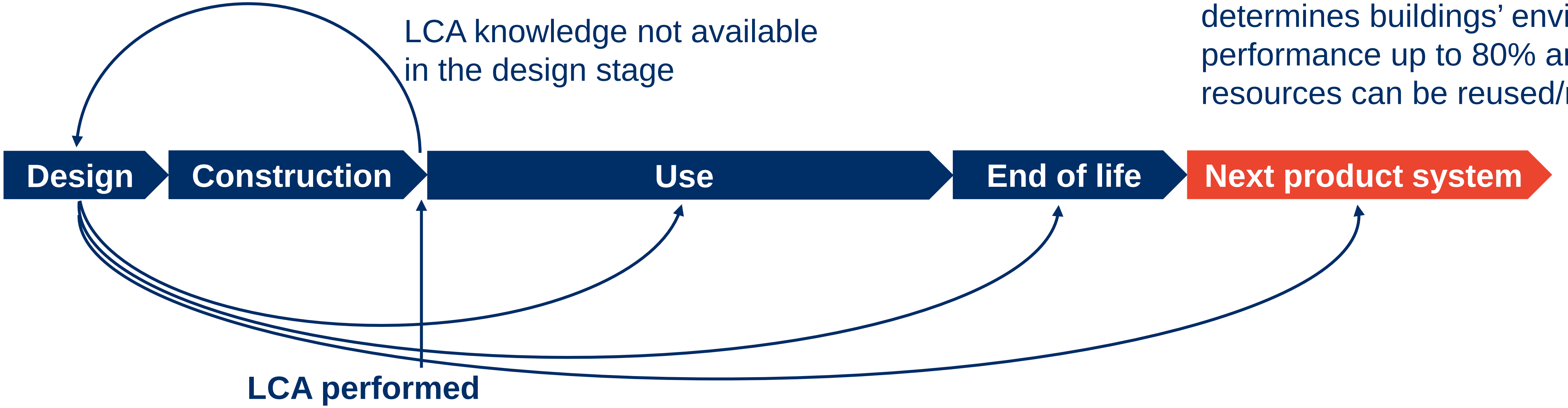
A potential for circular economy strategies throughout the building lifespan

Concept challenges

Limitations restricting the practical application of LCA to aid building design decisions:

- Time consuming
- Complex
- Requires an LCA expert
- Data intensive (data not available untill the end of construction)

Problem: Design decisions often determines buildings' environmental performance up to 80% and if resources can be reused/recycled



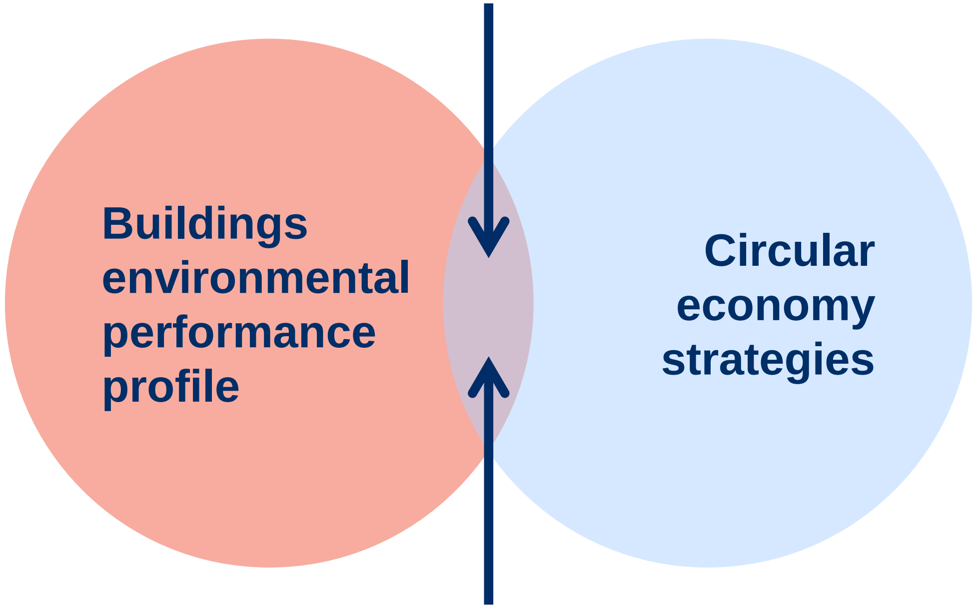
PhD project

The goal is to
develop a design tool that support the building designers select circular economy strategies

with the aim of
improving environmental performance of buildings

by studying
the link between circular economy strategies and the environmental performance of building typologies

Develop method for quantifying the environmental benefits of CE in buildings



New design strategies

Buildingtypologies' environmental performance profile

	Case study nr.	Author	Publication Year	Year of origin	Location	Building type	Material composition	Storeys	Concept (new-build/ refurbishment)	Floor area [m2]	FU	Service life [years]	Life cycle stage hotspots GWP	ODP	EP	POCP	AP	Embodied energy	Building component hotspots GWP	ODP	EP	POCP	AP	Embodied energy	Database	LCIA metod
Apartments	8	Paleari, M., Lavagna, M., Campioli, A.	2016		Italy	Apartment building (Zero energy building)	Masonry	2	New-build	4036	1 m2.yr	100	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Structure	Structure	Structure	Structure	Structure		Ecoinvent 2.2	EPD2008 method
	9	Atmaca, A.	2016	2014	Turkey	Apartment, Residential	Insitu reinforced concrete	5	New-build	1250	1 m2	50	A1-A3						Floors (concrete, steel)					Floors (concrete, steel)	ICE database	
	25G	Liljenström, C., Malmqvist, T. Et Al	2015	2008	Sweeden	Residential, apartment	prefab Concrete	5	new-build	11,003	1 m2	50	A1-A5						Structure (concrete)						IVL Miljödatabas Bygg)	
	9	Atmaca, A.	2016	2014	Turkey	Apartment, Residential	Insitu reinforced concrete	12	New-build	1200	2 m2	50	A1-A3						Floors (concrete, steel)					Floors (concrete, steel)	ICE database	
	12	Hrabovszky-Horváth, S., Szalay, Z.	2014	1975	Hungary	Residential, apartment	Prefab reinforced concrete	10	Refurbishment	6770	1 m2	80	A1-A3, B1-B5				A1-A3, B1-B5								Ecoinvent v 2.0	CML method
	15	Asdrubali, F., Baldassarri, C., Fthenakis, V.	2013	2008	Italy	Residential, multi-family (Apartment)	Reinforced concrete structure, bricks	4	New-build	1827	2 m2.yr	50	A1-A5, B1-B5						Envelope ext.						Ecoinvent	Eco-indicator 99, IPCC
	20	Blengini, G.A.	2008	1965	Italy	Residential building, block of flats (apartments)	Reinforced concrete,	10	New-build	6110	1 m2.yr	40	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Concrete	Concrete	Concrete	Concrete	Steel	Steel	Field measured data	SEMC and Eco indicator 99
	6	Zhang, X., Wang, F.	2017	2012	China, in cold region	Residential building (apartments)	Insitu concrete	17	new-build	17558	whole building	50	A1-A3					A1-A3	Concrete, steel							IPCC 2007
Single family houses	1	Balasbaneh, A.T., Marsono, A.K.B., Khaleghi, S.J.	2018		Malaysia	Single-family house	Timber structure (Hybrid concrete & timber)	1	New-build	155	Whole building	50	A1	A1			A1								Ecoinvent + MYLCID data	ReCiPe midpoint [H]
	1	Balasbaneh, A.T., Marsono, A.K.B., Khaleghi, S.J.	2018		Malaysia	Single-family house	Hybrid steel stud and timber	1	New-build	155	Whole building	50	A3	A3			A3								Ecoinvent + MYLCID data	ReCiPe midpoint [H]
	2	Colli, C., Bataille, A., Antczak, E., Buyle-Bodin, F.	2018	1939	France	Single-family house, semi-detached		1	Refurbishment	59	1 m2.yr	50	A1-A3	A1-A3		A1-A3	A1-A3		Structure	Structure		Structure	Structure		Ecoinvent v. 3.3	ILCD 2011 midpoint+
	18	Blengini, G.A., Di Carlo, T.	2010	2007	Italy	Single family house	Reinforced concrete frame, combined with masonry block walls.	2 + basement	New-build	250	1 m2.yr	70	A1-A3	A1-A3	A1-A3	A1-A3, B1-B5	A1-A3								Ecoinvent 2.0 and site measurements	IPPC 2007 methodology
	21	Citherlet, S., Defaux, T.	2005		Switzerland	Single family house	Concrete	3	New-build	266	m2.yr		A1-A3, B1-B5			A1-A3, B1-B5	A1-A3, B1-B5								Ökoinventare für Energiesysteme (ESU)	CML
	24G	Rasmussen, F.N., Birgisdóttir, H.	2015		Denmark	Single family house	Concrete	1	new-build	149	1 m2.yr	120	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Ground-dek, roof	Roof	Roof. Windows	Roof	Roof, windows		ESU-CO- og Ökobau-databaserne	
	17	Ortiz-Rodriguez, O., Castells, F., Sonnemann, G.	2010		Colombia	Single family house, dewling, semi-detached	brick, concrete and steel	2	New-build	140	2 m2	50	A1-A5, B1-B5	A1-A5, B1-B5			A1-A5, B1-B5		Concrete, Steel						Ecoinvent v 2.2	CML 2 method
	16	Cuéller-Franca, R., M., Azapagic, A.	2012		UK	Single family house, semi-detached	Traditional build, brick and block	2	New-build	90	Whole building	50	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Materials with bricks	Bricks	Bricks	Bricks	Bricks		Ecoinvent	CML 2001 method
	10	Buyle, M., Audenaert, A., Braet, J., Debacker, W.	2015		Flemish/Belgium	Connected dwellings, single family house	Massive structure, masonry brick walls	2	New-build	117	Whole building	60						A1-A3							Ecoinvent 3.1	ReCiPe Endpoint [H]
	13	McGrath, T., Nanukuttan, S., Owens, K., Basheer, M., Keig, P.	2013		UK	Single family house, mid-terrace Victorian house, semi-detached	Brick solid wall	3	new-build	144	1 m2	50	A1-A3						Concrete precast elements						Ecoinvent	ReCiPe Midpoint and Endpoint
	16	Cuéller-Franca, R., M., Azapagic, A.	2012		UK	Single family house, detached	Traditional build, brick and block	2	New-build	130	Whole building	50	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Materials with bricks	Bricks	Bricks	Bricks	Bricks		Ecoinvent	CML 2001 method
	16	Cuéller-Franca, R., M., Azapagic, A.	2012		UK	Single family house, terraced	Traditional build, brick and block	2	New-build	60	Whole building	50	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Materials with bricks	Bricks	Bricks	Bricks	Bricks		Ecoinvent	CML 2001 method
	17	Ortiz-Rodriguez, O., Castells, F., Sonnemann, G.	2010		Spain	Single family house, dewling	brick, concrete and steel	2	New-build	160	1 m2	50	A1-A3, B1-B5	A1-A3, B1-B5			A1-A3, B1-B5		Concrete						Ecoinvent v 2.1	CML 2 method
	15	Asdrubali, F., Baldassarri, C., Fthenakis, V.	2013	2002	Italy	Single family house, detached	Reinforced concrete structure, bricks	3	New-build	443	1 m2.yr	50	A1-A5, B1-B5						Envelope ext., structural elements						Ecoinvent	Eco-indicator 99, IPCC 2007
Office	3	Lamperti Tomaghi, M., Loli, A., Negro, P.	2018		Italy	Office building	Concrete structure	3	New-build	790	Whole building	100	A1-A3						Structure						Database from SimaPro	IPCC 2007
	27G	Junnila, S.	2004	1998-2001	Finland	Office Building	Beam-column system, prefab concrete	4	New-build	17,300	1 m2	50	A1-A3		A1-A3, B1-B5	B1-B5	A1-A3, B1-B5		Structural frame		Structural frame, Ext. envelope	HVAC services, roof elements, Surfaces (int)	Surfaces (int), Structural frame, external envelope		SimaPro Database	Eco-indicator 95
	23G	Birgisdóttir, H., Madsen, S.S.	2017	2015	Danmark	Office building	Sandwich construction, concrete and curtain walls	4 + basement	new-build	11,500	1 m2.yr	80	A1-A3					B4	Slabs, windows, ext. Envelope						Ökobau database	DK-GBC LCA
	23G	Birgisdóttir, H., Madsen, S.S.	2017	2015	Danmark	Office building	Brick facade, reinforced concrete	6 + basement	New-build	6,200	1m2.yr	80	A1-A3					A1-A3	Slabs, inner walls						Ökobau database	DK-GBC LCA
	4	Najjar, M., Figueiredo, K., Palumbo, M., Haddad, A.	2017		Brazil	Office building	Reinforced concrete floors, masonry brick walls	4	New-build (hypothetical)	2730	Whole building	50	A1-A3	A1-A3	A1-A3		A1-A3		Curtain wall mullions, walls	Floors	Walls		Walls	Walls, Curtain wall mullions	GABI database	Tally application in Revit
	4	Najjar, M., Figueiredo, K., Palumbo, M., Haddad, A.	2017		Brazil	Office building	Reinforced concrete floors, masonry brick walls	4	New-build (hypothetical)	2730	Whole building	50	A1-A3	A1-A3	A1-A3		A1-A3		Walls	Floors	Walls		Floors	Walls	GABI database	Tally application in Revit
Multi storey offices	15	Asdrubali, F., Baldassarri, C., Fthenakis, V.	2013	2009	Italy	Multy-story office	Reinforced concrete structure, bricks	5	New-build	3353	3 m2.yr		A1-A5, B1-B5						Envelope ext.						Ecoinvent	Eco-indicator 99, IPCC
	27G	Junnila, S.	2004	1998-2001	Finland	Office building, 3 towers	Insitu concrete	5	New-build	15,600	2 m2	50	A1-A3		A1-A3, B1-B5	A1-A3, B1-B5	A1-A3, B1-B5		Structural frame		Structural frame, Extern... envelo...	External envelope, structural ...	Structural frame, ...	[illegible]	SimaPro ...	Eco-indicator 95
	27G	Junnila, S.	2004	1998-2001	Finland	Office building	Prefab reinforced concrete	9	New-build	24,000	1 m2	50	A1-A3		A1-A3, B1-B5	B1-B5	A1-A3, B1-B5		Structural frame		Structu... fram...	[illegible]	[illegible]	[illegible]	[illegible]	...-indicator 95
	7	Azzouz, A., Borchers, M., Moreira, J., Mavrogianni, A.	2016		UK	Office building	RC, structural frame and flat slab construction, brick facade	11	New-build	15590	Whole building	100	A1-A3					A1-A3	Floors/slabs		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	...MPACT
	19	Kofoworola, O.F., Gheewala, S.H.	2008		Thailand	Commercial office building	Concrete, brick & curtain wall combination	38	New-build	60,000	Whole building	50	A1-A3			A1-A3	A1-A3		Cement, concrete		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	24G	Rasmussen, F.N., Birgisdóttir, H.	2015		Denmark	Office building (3283 m2)	reinforced concrete, wood envelope		new-build	3283	1 m2.yr	80	A1-A3	A1-A3	A1-A3	A1-A3	A1-A3		Slabs	Slabs	Slabs windo...	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Schools	11	Ajayi, S.O., Oyedele, L.O., Ceranic, B., Gallanagh, M., Kadiri, K.O.	2015		Canada	Primary School building	Brick/block building	2	New-build	2100	Whole building	30	A1-A3								[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	...na impact ...mator (IE)
	14	Zabalza, I., Valero, A., Aranda, A., Llera, E.	2013	2009	Spain	University building	Reinforced concrete	2	New-build	1743	Whole building	50	A1-A3						Concrete, cement		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	...PC 2007 ...thodology
	26G	Wang, E., Shen, Z., Berryman, C.	2011		U.S.	University campus	Steel frame	3	New-build	3190	whole building	50	A1-A3					A1-A3	Steel		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	22	Scheuer, C., Keoleian, G.A., Reppe, P.	2003		U.S.	University building,	Reinforced concrete, bricks, Steel	6	new-build	7300	Whole building	75	A1-A3	A1-A3	A1-A3		A1-A3	A1-A3						Steel, cement in concrete	DEAM(TM) database	
Other	5	Hu, M.	2017	1865	U.S.	Opera house		4	Existing	2137	Whole building	75												Walls	IE4B, Athena	EPA TRACI methodology

- Residential
- Office
- School
- Other

Systematic literature review

Registration of:

- Building type
- Location
- Year of origion
- Number of storeys
- Material composition
- Floor area
- Functional unit
- Service life
- Environmental hotspot:
  - Life cycle stage
  - Building component/material

Preliminary findings:

- Concrete buildings
- Production stage

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School

Hospital

Office

Residential

Circular economy strategies

Systematic litterature review

- Different ways of achieving CE: How is CE being used in building design?
- Ranked according to the strategies most used
- We have primarily focused on design for disassembly
- The strategies are connected
- Studies suggest to create new design strategies through a combination of several circular economy strategies to reduce environmental impacts and create value for the construction sector
- An example: Circle House (x)

1	Design for assembly/disassembly	X
2	Design for material selection/substitution	X
3	Design for adaptability and flexibility	X
4	Design for product-service-systems	X
5	Design in modularity	X
6	Design for prefabrication	X
7	Design for standardization	X
8	Design for secondary materials	X
9	Design for optimized shapes/dimensions	
10	Design for material passport	X
11	Design for material optimisation	
12	Design for accessibility	X
13	Design for durability	X
14	Design using BIM	
15	Design in layers	
16	Design for material storage	
17	Design reusing existing building/components/materials	
18	Design for symbiosis	
19	Design out secondary finishes	X
20	Design for use	

2020 Circle House

60 social housing residents, 90% of the materials can be reused or recycled without loss of value

Realisation: Collaboration between client, architect, municipality, researchers, manufacturers, industry partners, consultants etc.

Location: Lisbjerg, Denmark

Client: Lejerbo

Funding: DK EPA (6.9 mio)
Realdania (3 mio)

Analysis: Construction techniques, value chains, business odels, business cases, legislation

Tender: 2018

Construction: 2019

Finish: 2020

1	Design for assembly/disassembly	X
2	Design for material selection/substitution	X
3	Design for adaptability and flexibility	X
4	Design for product-service-systems	X
5	Design in modularity	X
6	Design for prefabrication	X
7	Design for standardization	X
8	Design for secondary materials	X
9	Design for optimized shapes/dimensions	
10	Design for material passport	X
11	Design for material optimisation	
12	Design for accessibility	X
13	Design for durability	X
14	Design using BIM	
15	Design in layers	
16	Design for material storage	
17	Design reusing existing building/components/materials	
18	Design for symbiosis	
19	Design out secondary finishes	X
20	Design for use	

Next step: creating new meaningful design strategies specific for the construction sector!

Thank you for the attention!

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