Decision Support System

for a circular integrated floor-system design in Office buildings (Netherlands)

MSc. Building Technology Graduation Thesis

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abt

Context

In the Netherlands…….

Increase in **demolitions** of Office buildings

Rapid **change in user demands**

Construction industry contributes to

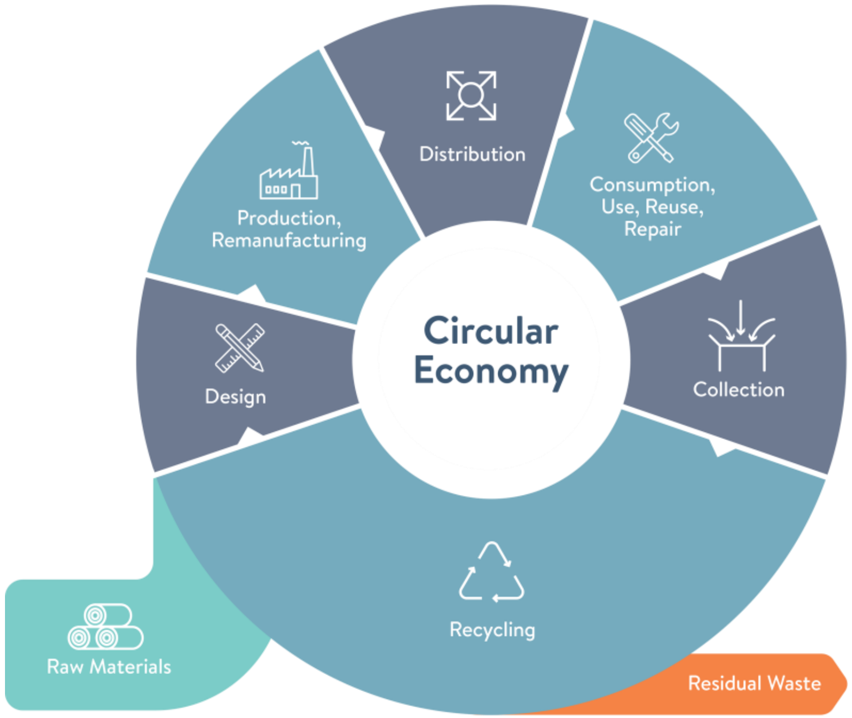
50% of **raw materials consumption**

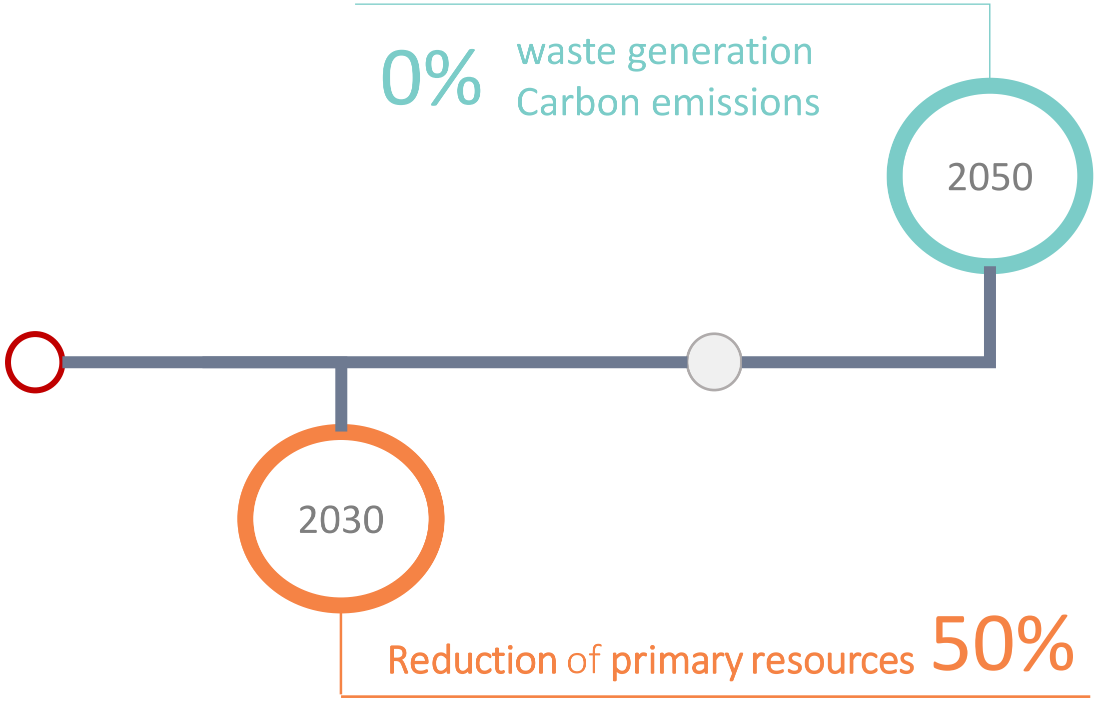
40% of **total waste generated**

(CBS; Remøy, 2010; Transitieteam Bouw, 2018)

Context

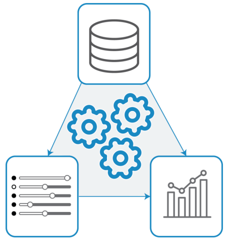
In the Netherlands transition…….



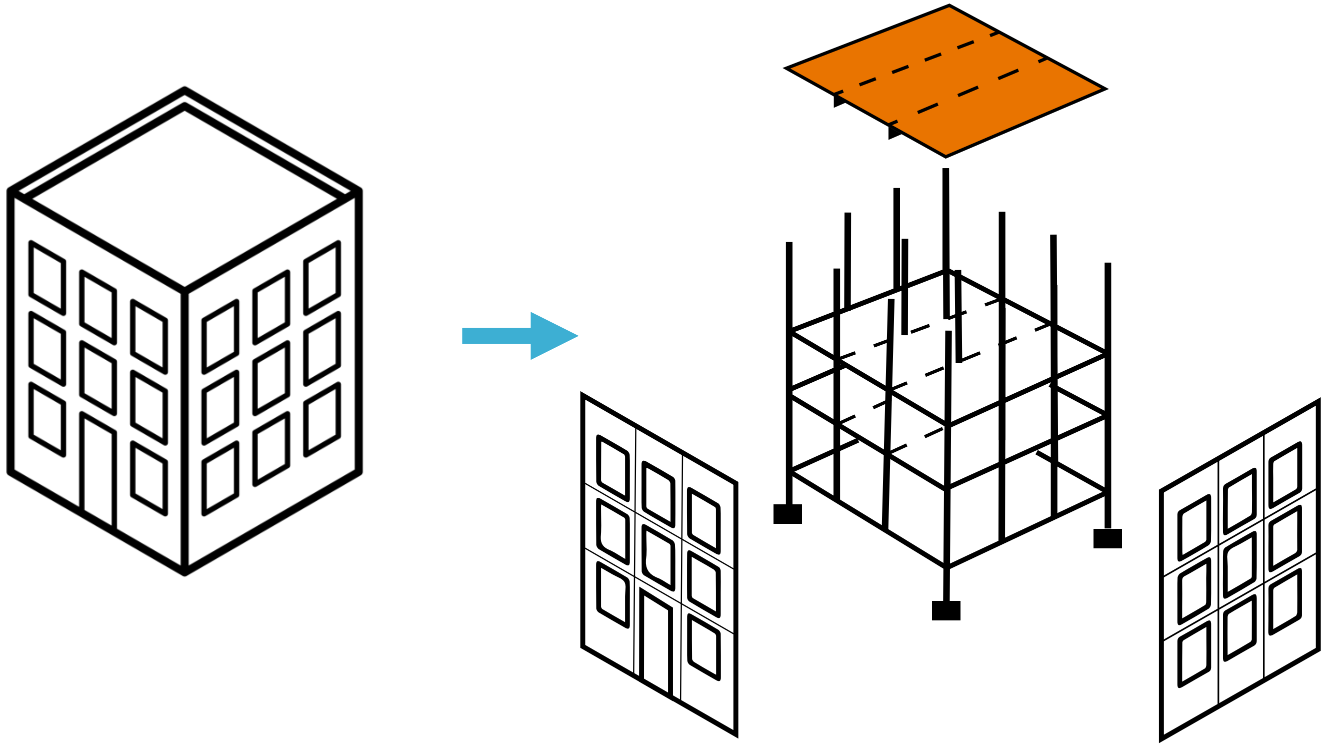


(Government of the Netherlands, 2016)

Problem



Floor-system



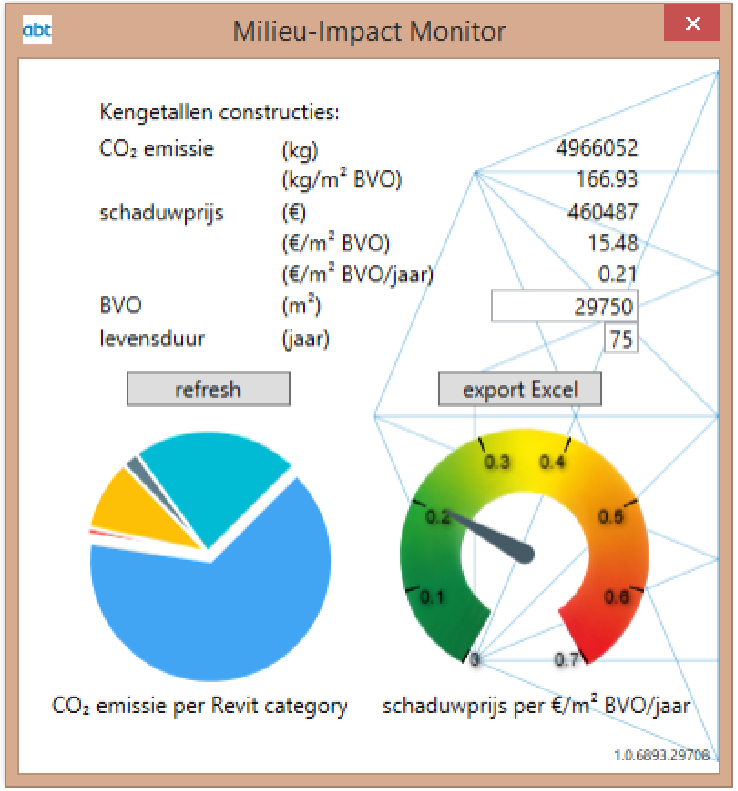
> 50% of structural skeleton

(Hegger, 2006; Van Haalen, 2018)

Problem

Floor-system

Floors	3222188	64.88 %
Structural Columns	45678	0.92 %
Structural Foundations	472033	9.51 %
Structural Framing	108740	2.19 %
Walls	1117412	22.50 %



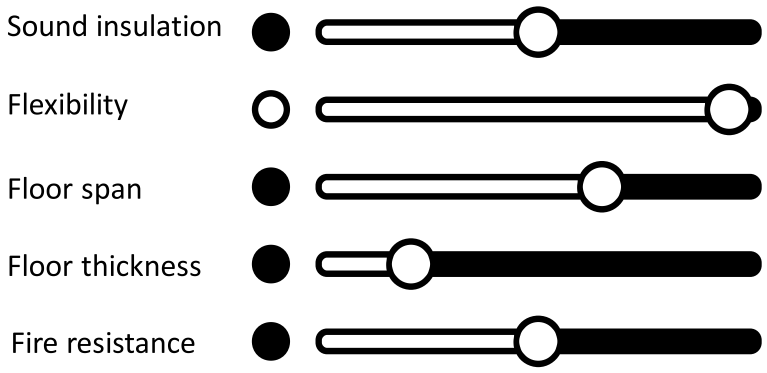
> 50% of carbon emissions

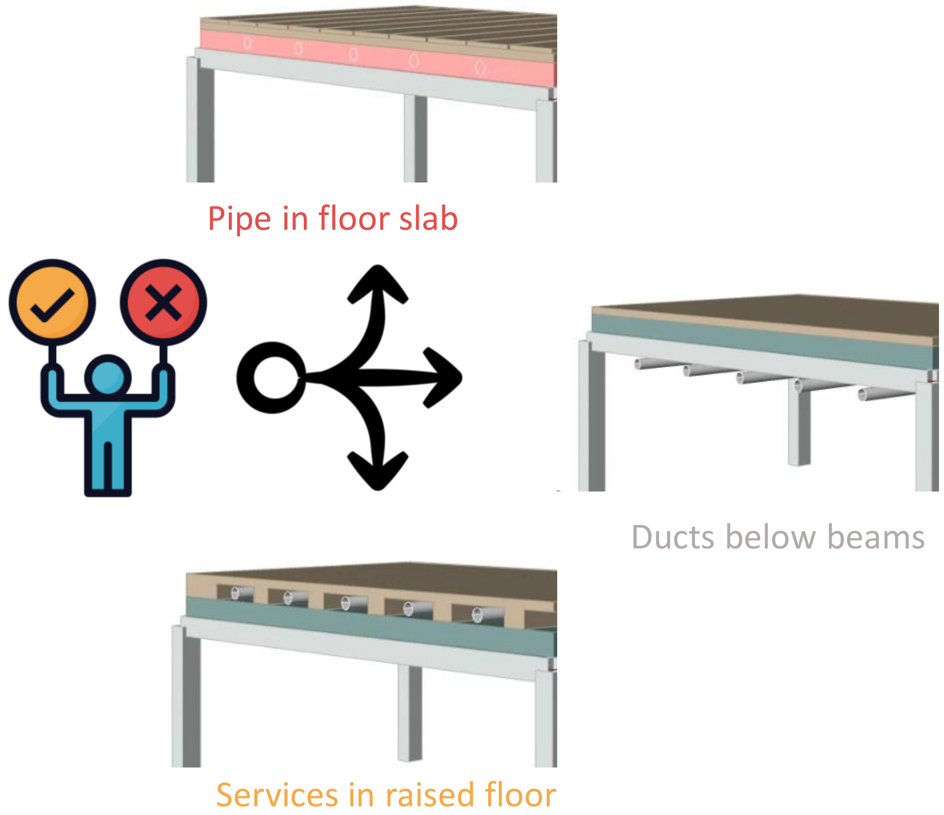
(Van Haalen, 2018)

Problem

Integration in a Floor-system

Design Criteria

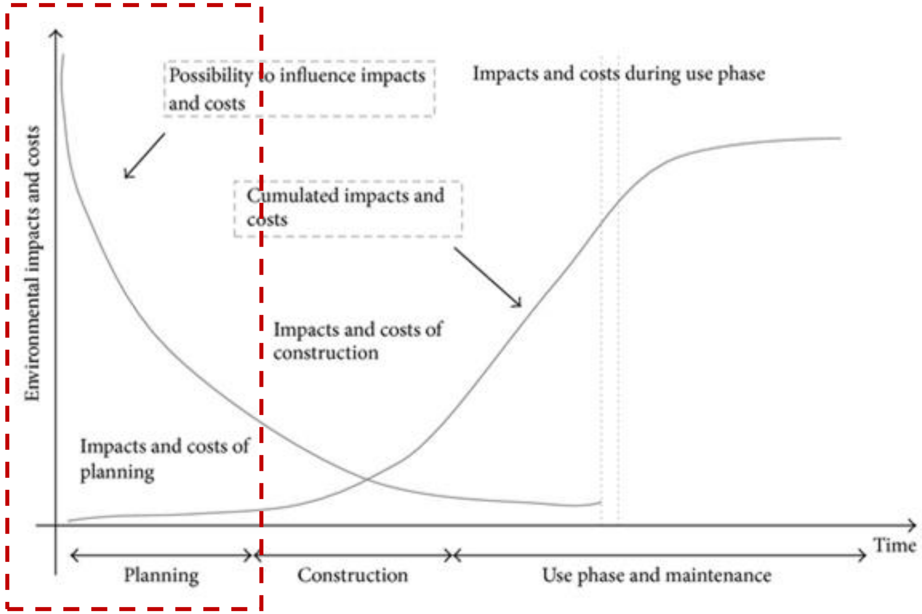


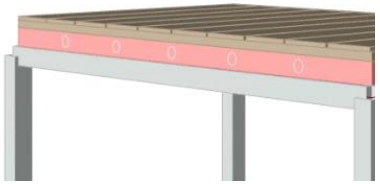


(ISSO 80;SBR 2005; Kennisbank; Cie,2016)

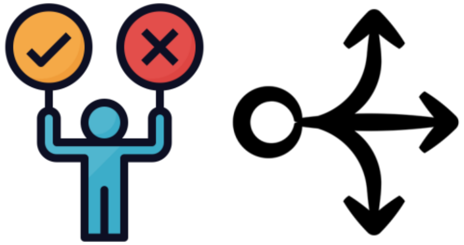
Problem

Integration in a Floor-system





Pipe in floor slab



Ducts below beams

Services in raised floor

(Bragança et al., 2014; ISSO 80;SBR 2005; Kennisbank; Cie,2016)

Hypothesis

Integration in a Floor-system in early or preliminary stages of design

Design Criteria

Sound insulation

Flexibility

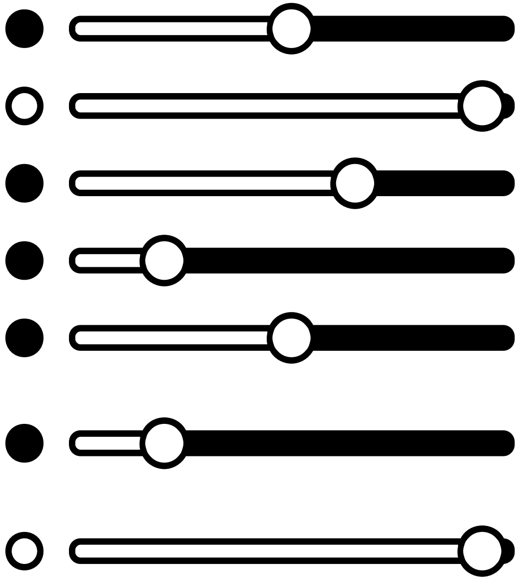
Floor span

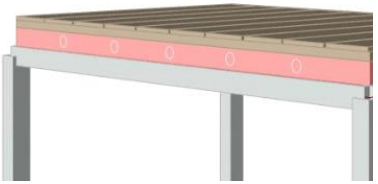
Floor thickness

Fire resistance

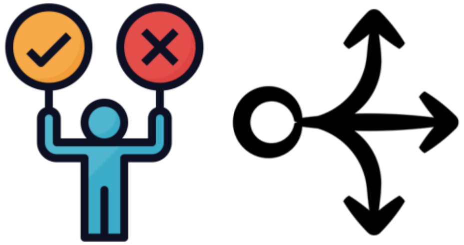
Environmental impact

Material Circularity





Pipe in floor slab

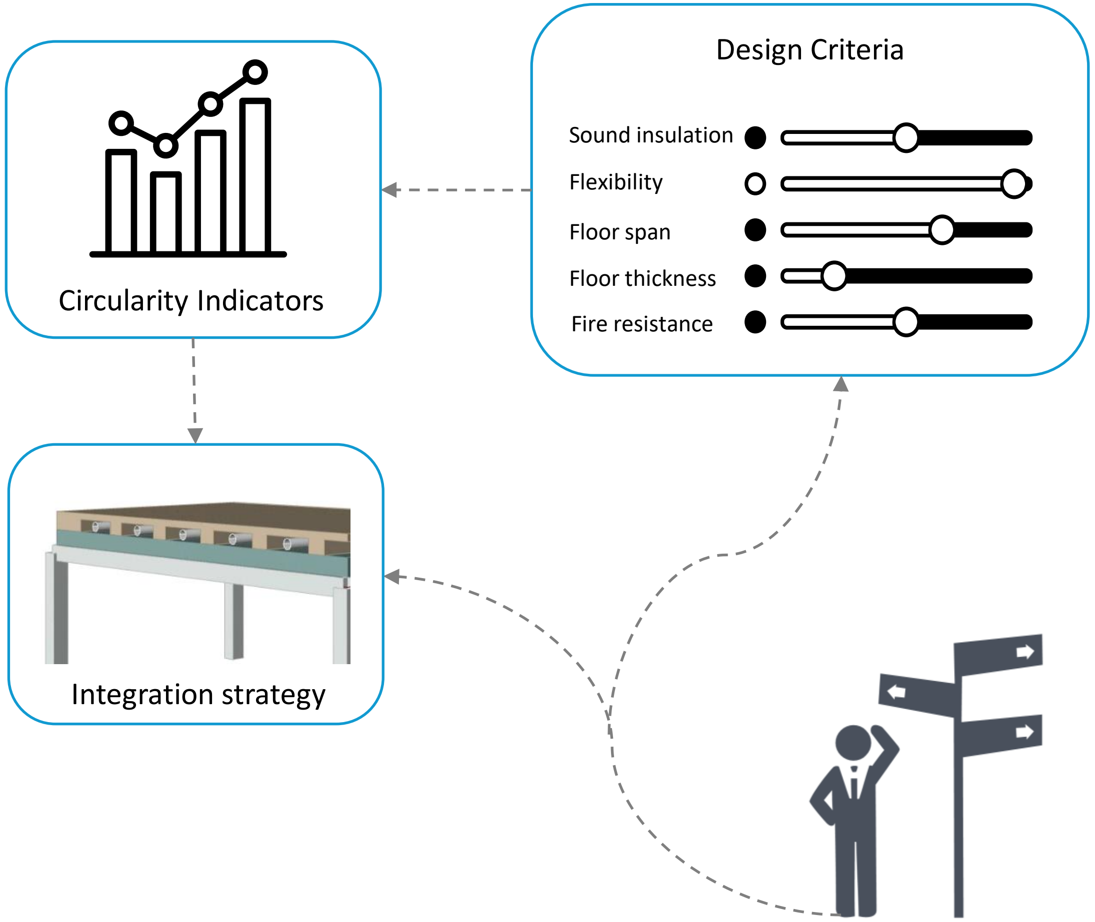


Ducts below beams

Services in raised floor

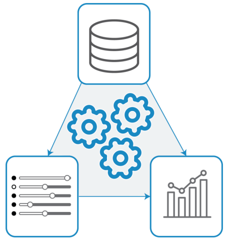
Research Objective

Decision Support System (DSS)



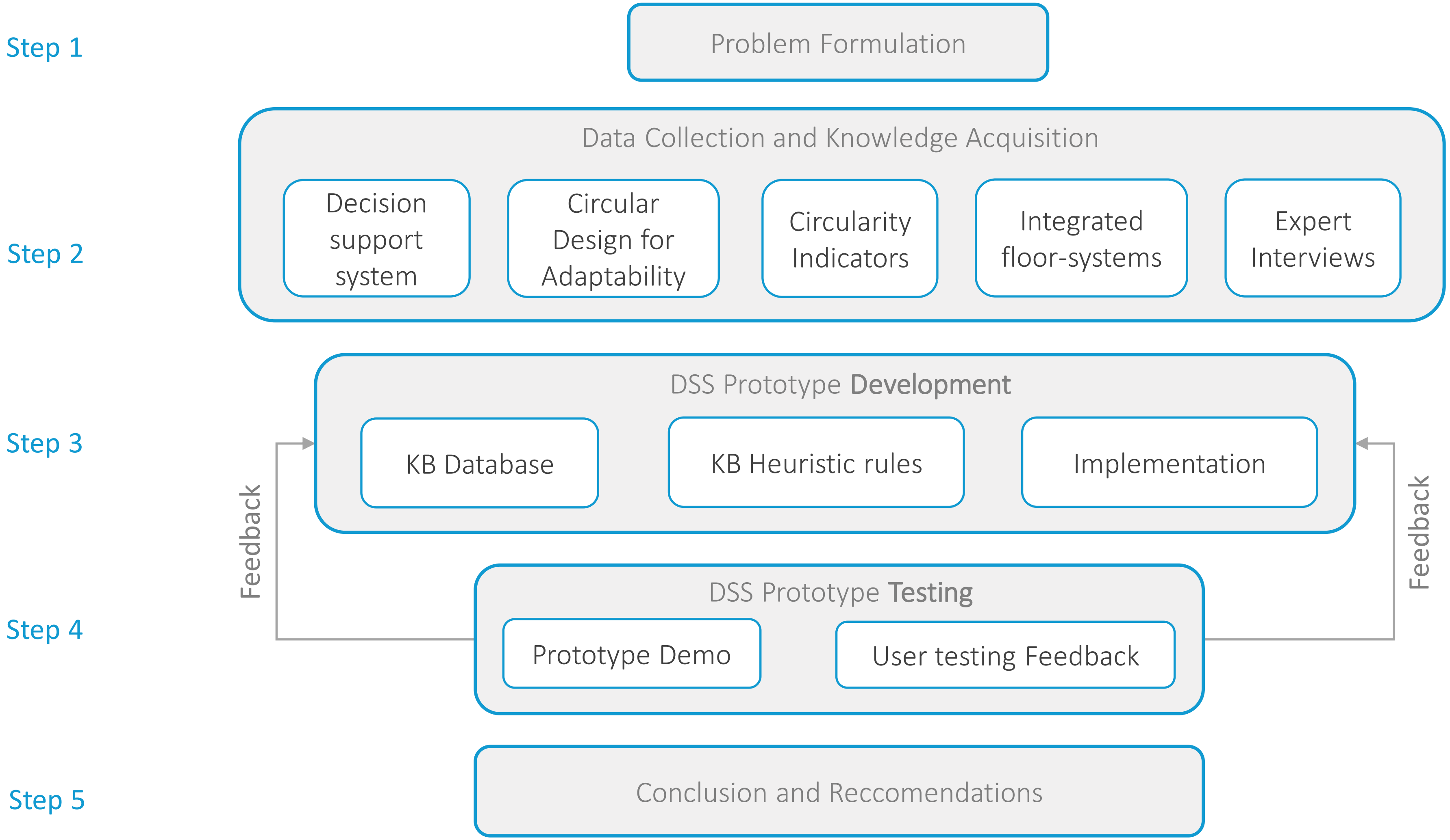
In early or preliminary stages of design

Research Question



How can a **decision support system** assist the stakeholders involved in the **preliminary design phase** of an **integrated floor-system**, to compare design options based on **technical performance** and **degree of circularity** for making a suitable design choice to **facilitate adaptability in office buildings** (Netherlands) ?

Methodology



Step 2 | Data Collection and Knowledge Acquisition

1. Decision support system
2. Circular Design for Adaptability
3. Circularity Indicators
4. Integrated floor-systems
5. Expert Interviews

Decision Support System (DSS)

Definition

: DSS is a **computer-based system** that supports the **decision makers** (DMs) in the process towards **framing** and **exploring** the **implications of their judgements**, and therefore **making informed decision** based on understanding

(French et al., 2010)

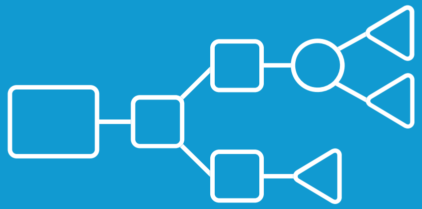
Decision Support System (DSS)

Classification

Data-driven

+

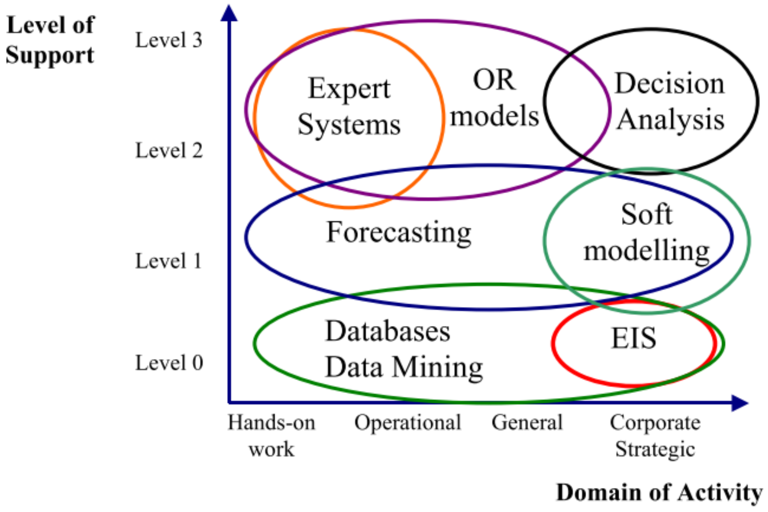
Model-driven



(French et al., 2010)

Decision Support System (DSS)

Classification

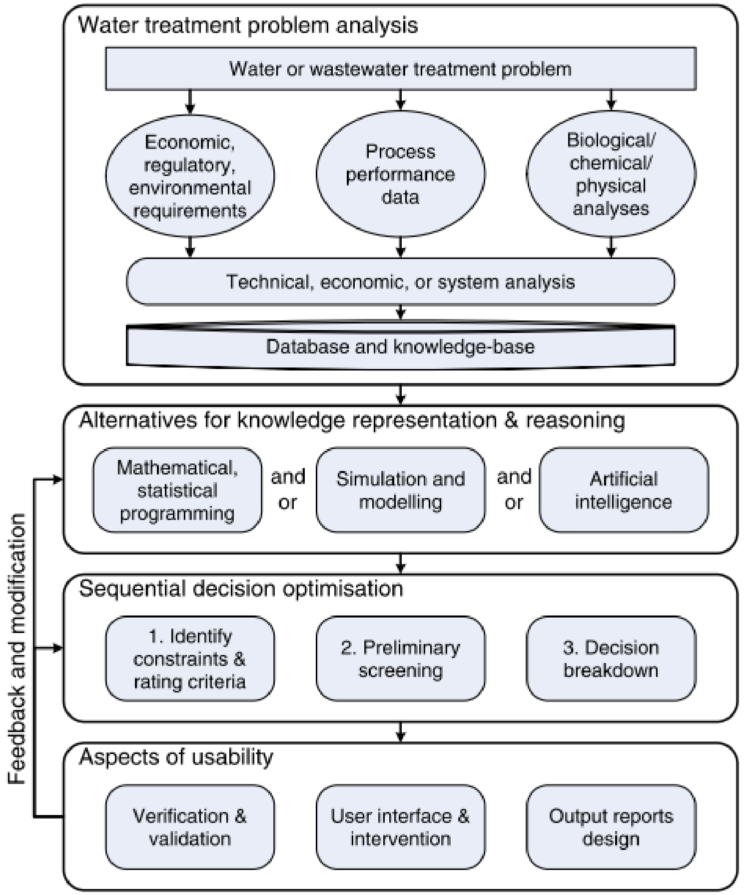


Level 3	Evaluation and ranking of strategies alternatives by balancing their benefits/drawbacks
Level 2	Simulation and analysis of the potential consequences of the strategies; feasibility check and insight into benefits/drawbacks
Level 1	Analysis of the data towards forecasting the performance through one or more decision models
Level 0	Only providing the information as is to the DMs with minimal analysis of the data

(French et al., 2010)

Decision Support System (DSS)

Typical development process



(Poch et al., 2004)

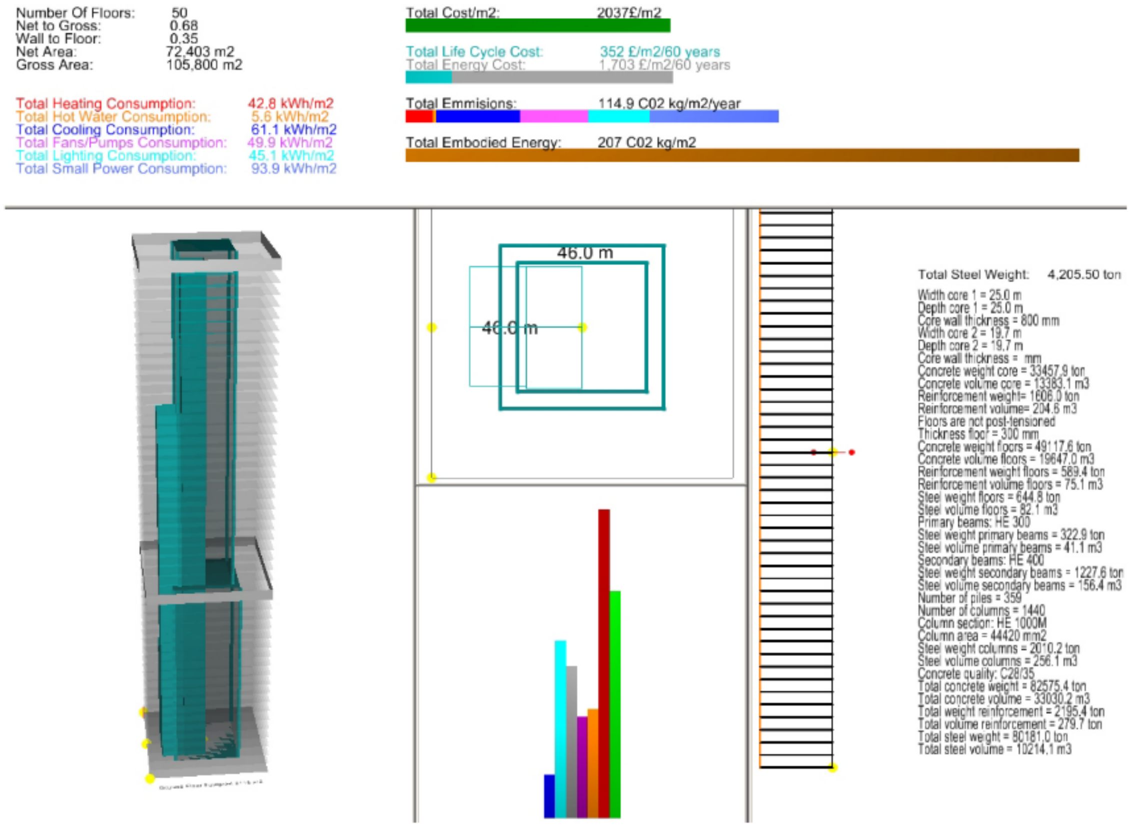
Decision Support System (DSS)

Sate-of-the-Art examples in AEC

Feature Type: TallBuilding_Cost

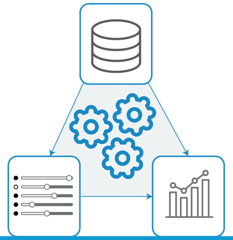
Update Method: FromMEAndStructure

Property	Expression
MEP: TallBuilding_CoreME	MechanicalSystem
StructuralPerformanceFeature:..	StructuralSystem
Energy: TallBuilding_Energy	EnergyCalculations
FloorPlateAreas:..	FloorPlateInfo
NetToGross: TallBuilding_NetToGross	NetToGross
SurfaceArea: double	bsplineSurface02.Area (14035.888)
Piles_Depth: double	StructuralSystem.PileLength (40)
ProppedFloors: bool	PrimaryInputs.Structure_PropFloors (false)
BasementSlabConcrete_m3: double	3
BasementSlabReinf_m3: double	3
FrameType: FrameTypeOption	PrimaryInputs.Structure_TypeOf_Frame..
CoreType: StructureTypeOption	PrimaryInputs.Structure_TypeOf_CoreStructure..
CostOfEnergyScaled: bool	PrimaryInputs.Energy_CostScaled (false)
CostOfElectricity_sterlingPerkWh:..	PrimaryInputs.Energy_CostOfElectricity_sterlingPe..
CostOfGas_sterlingPerkWh: double	PrimaryInputs.Energy_CostOfGas_sterlingPerkWh..
Substructure_SterlingPerM2: double	78.300
Superstructure_SterlingPerM2: double	323.023
Facade_SterlingPerM2: double	276.664
Lifts_SterlingPerM2: double	185
InternalFinishes_SterlingPerM2: double	198.000
MEP_SterlingPerM2: double	562.640
OnCosts_SterlingPerM2: double	413.278
TotalCost: double	215504461.468
TotalEneryCost: double	180197029.932
TotalEneryCost_SterlingPerM2: double	1703.186
TotalSteelWeight: double	4205.5
Success: bool	true

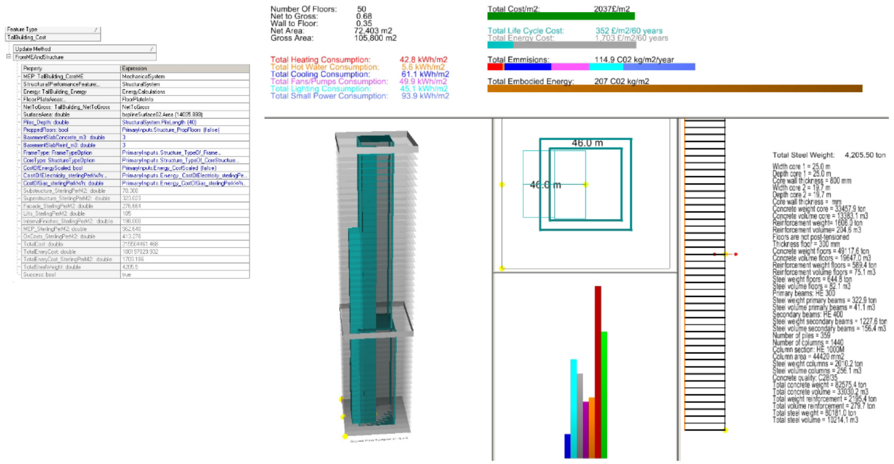


(Coenders, 2011)

Decision Support System (DSS)



Dashboard Based Design tool (DSS)



Open to many design typologies

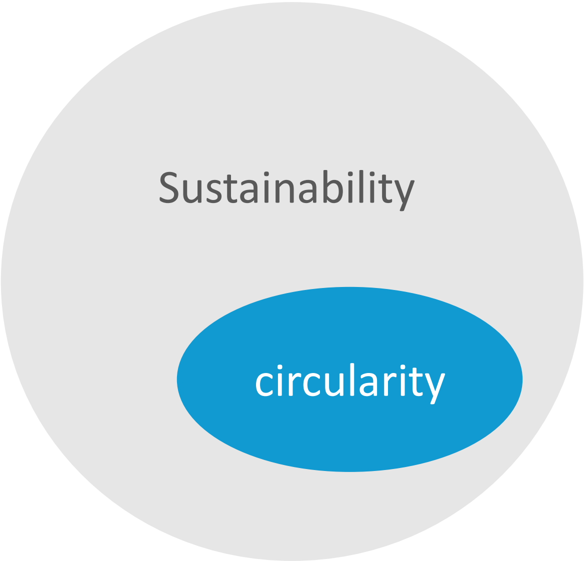
Insightful

Informative

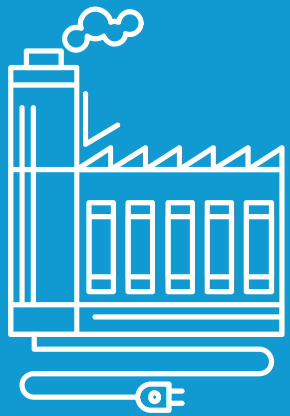
Interactive

Provides feedback

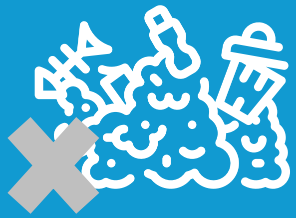
Circular Design for Adaptability



Resource efficiency



Reduce energy consumption



Zero waste generation

(Geissdoerfer et al. 2017, EMF, 2018)

Circular Design for Adaptability

Retain highest value of the material/product

Keep material in use

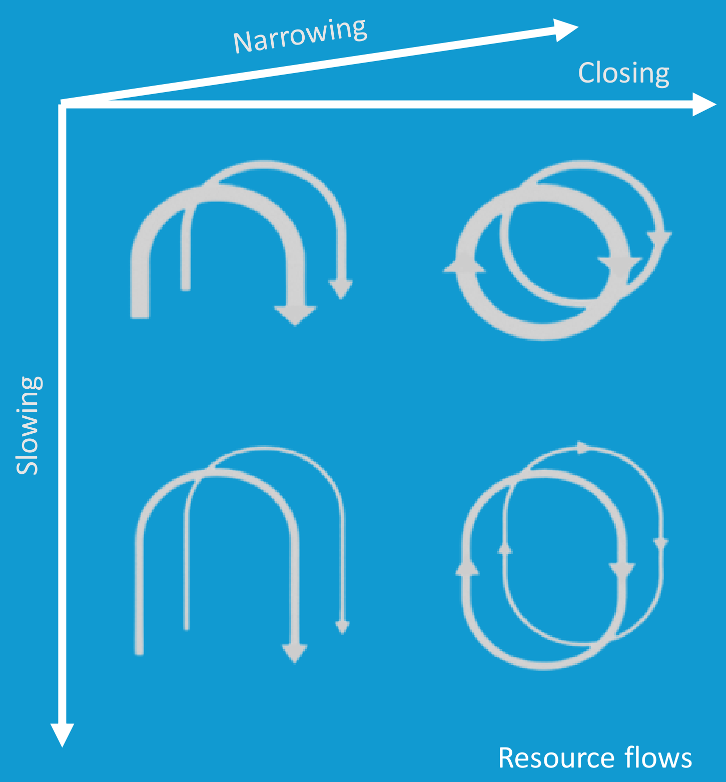
Regenerate natural systems

Design out of waste

(EMF, 2018)

Circular Design for Adaptability

Retain highest value of the material/product



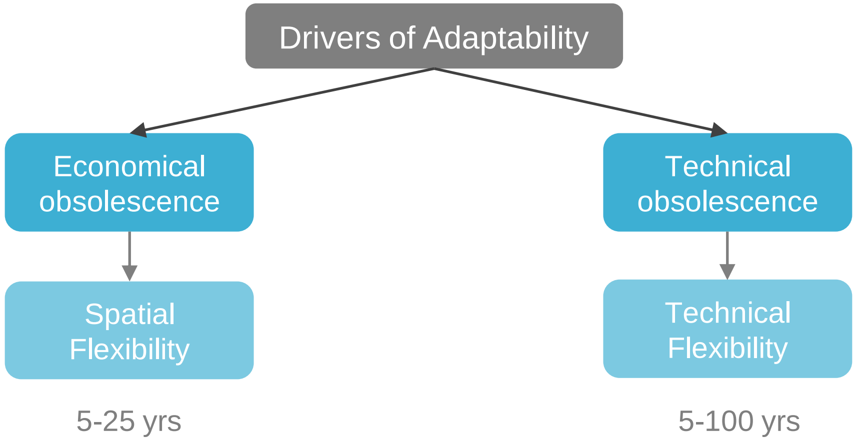
(Geissdoerfer et al., 2017; Bocken et al., 2016)

Circular Design for Adaptability

	Design for X
Circularity Class A	Longitivity; Upgradability; Adaptability
Circularity Class B	Maintenance; Leasing
Circularity Class C	Refurbish; Remanufacture
Circularity Class D	Recycle; Re or Disassembly;

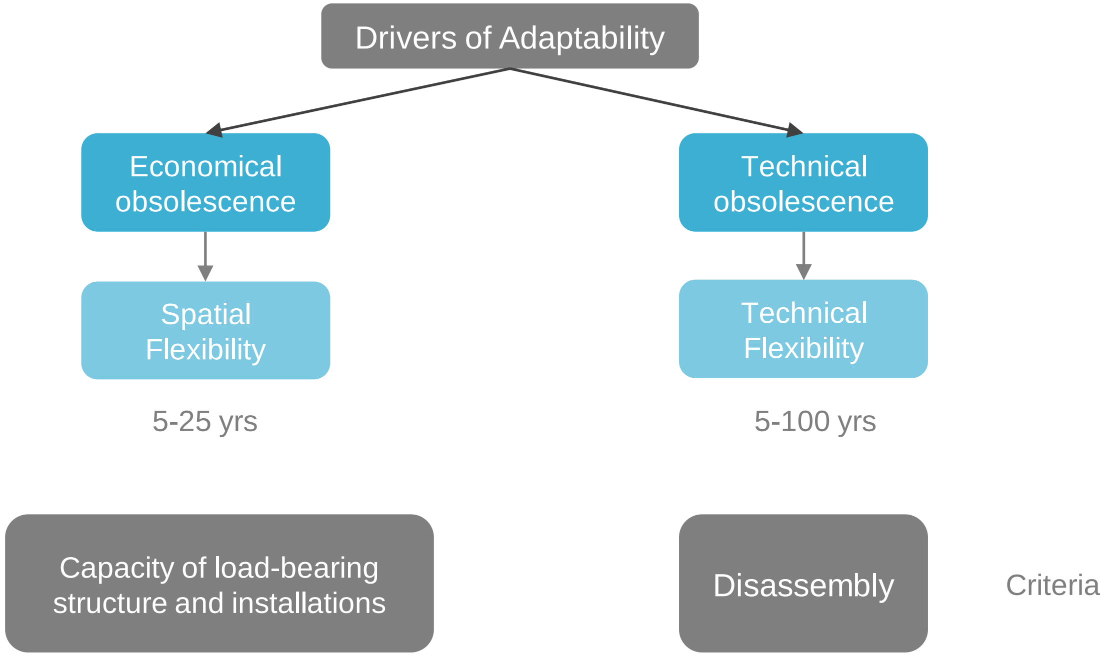
(Saidani et al., 2017; Bocken et al. (2016))

Circular Design for Adaptability



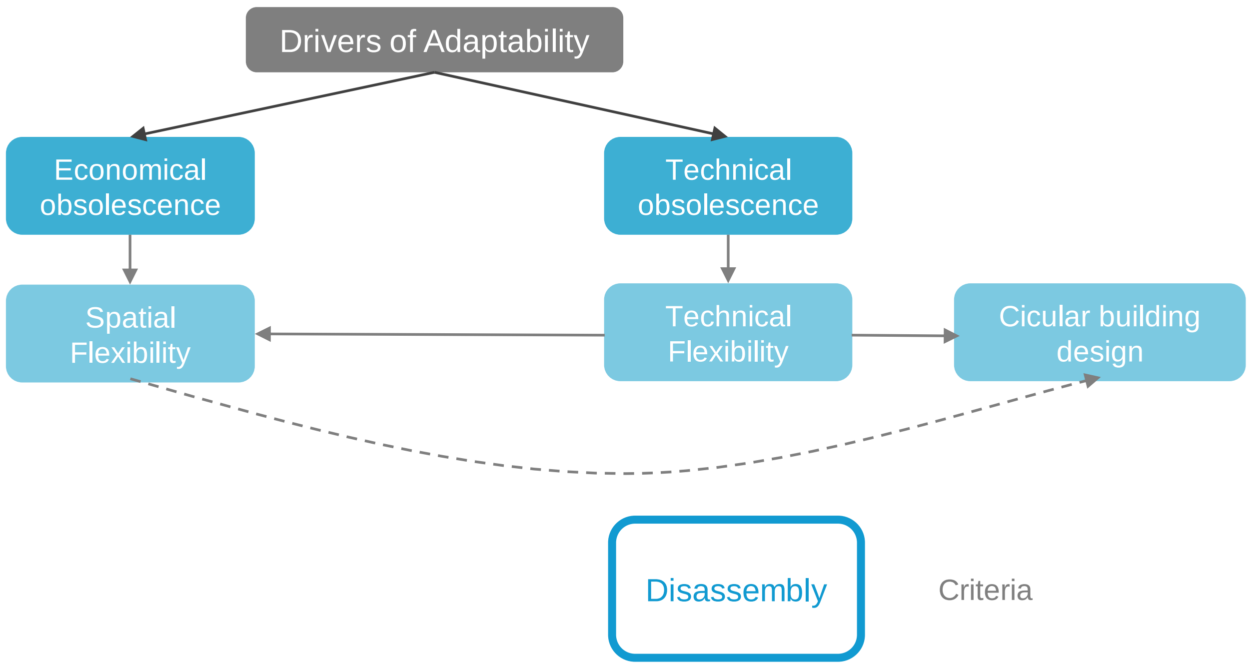
(Durmisevic, 2006)

Circular Design for Adaptability



(Durmisevic, 2006)

Circular Design for Adaptability

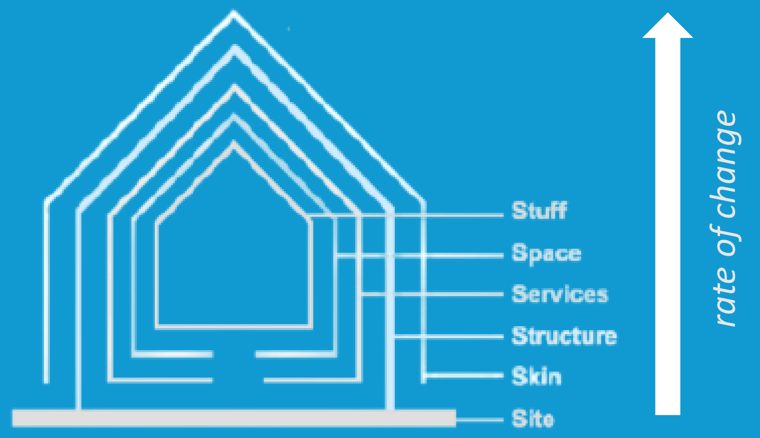


(Durmisevic, 2006)

Circular Design for Adaptability

Disassembly

Systems thinking approach



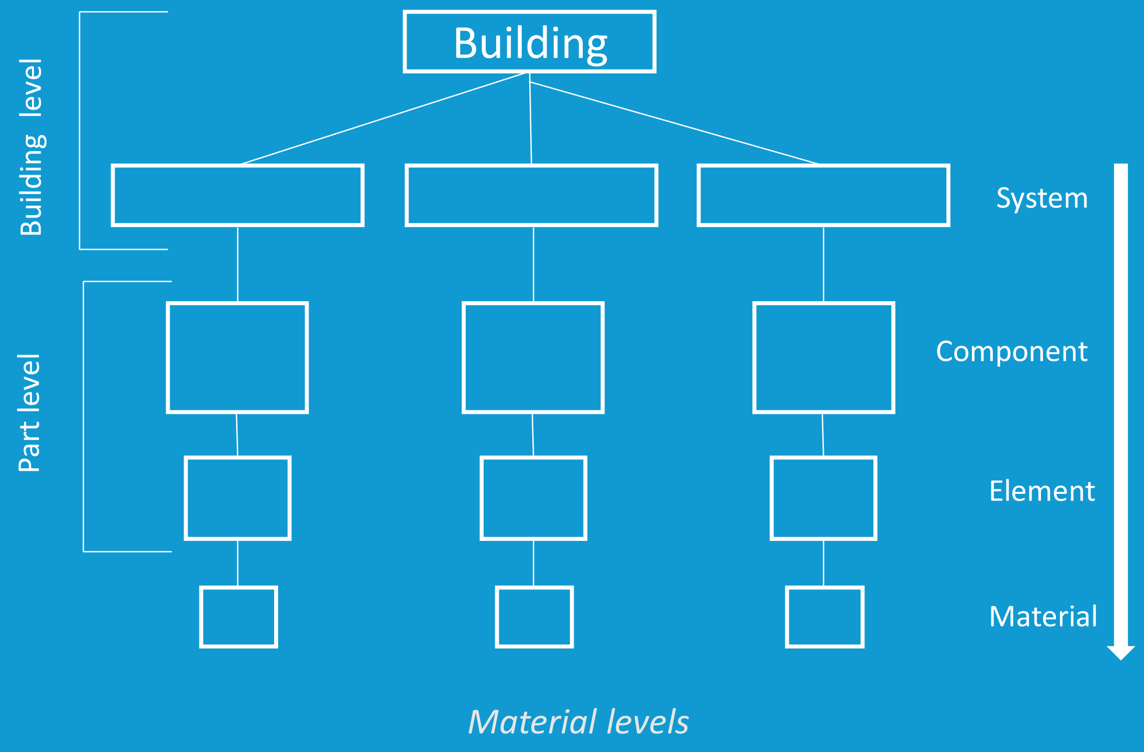
Building layers

(Brand, 1994)

Circular Design for Adaptability

Disassembly

Systems thinking approach



(Dumisevic, 2006)

Circular Design for Adaptability

Resource efficiency

Disassembly

Regeneration of natural systems

Retaining value of the product

Circularity Indicators

Material balance

Flexibility

Environmental impact

Service life planning

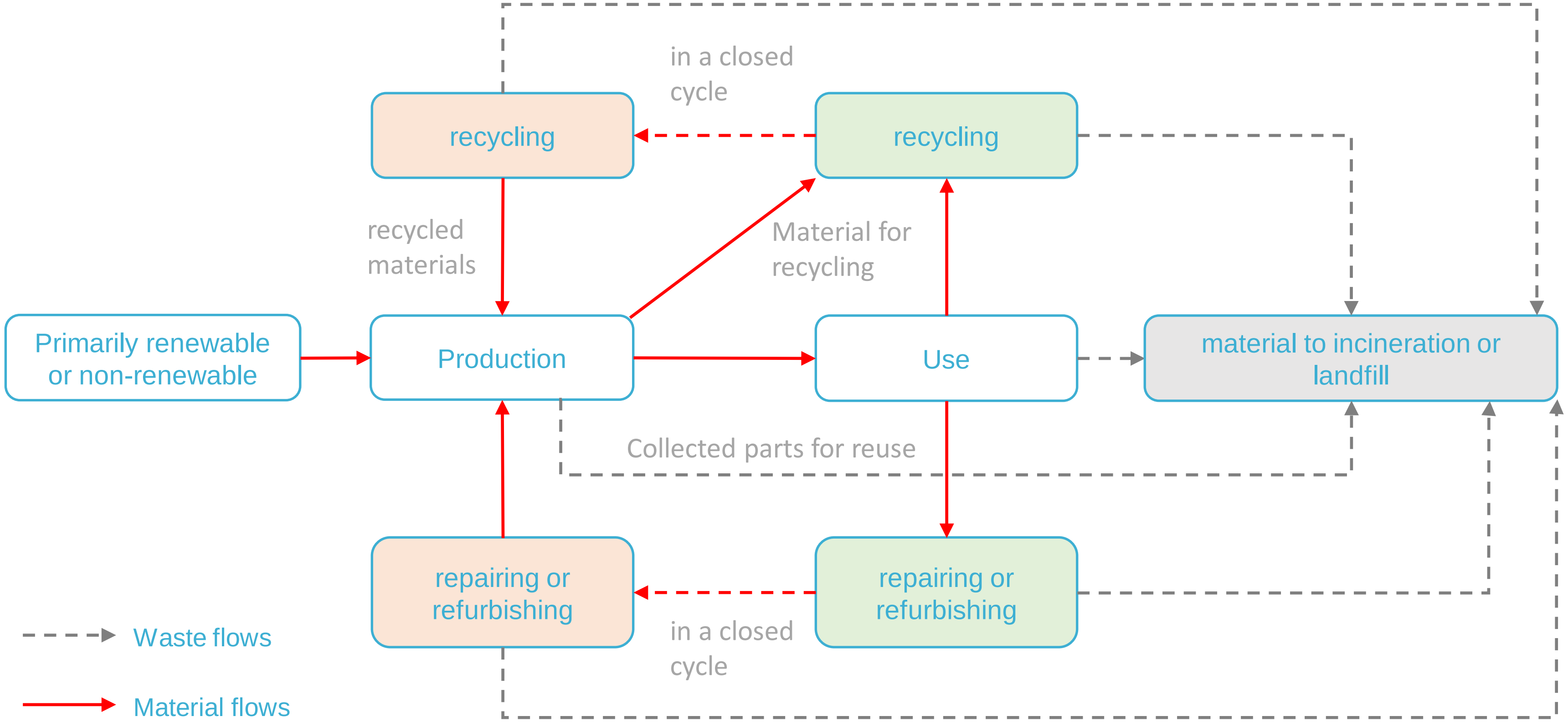
Circularity Indicators

At product level

Amount of virgin material used (%)

Amount of material available for next cycle (%)

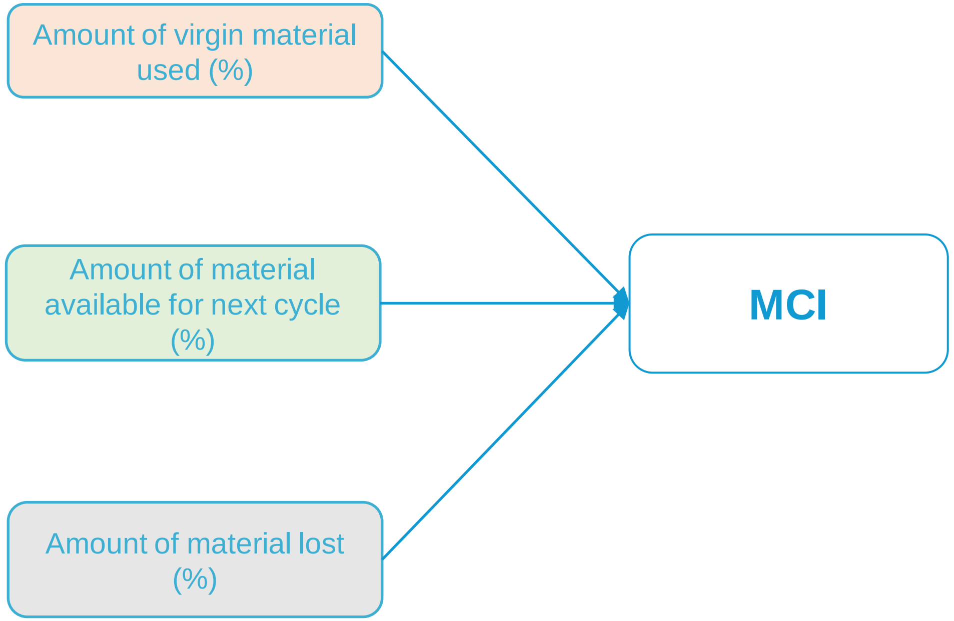
Amount of material lost (%)

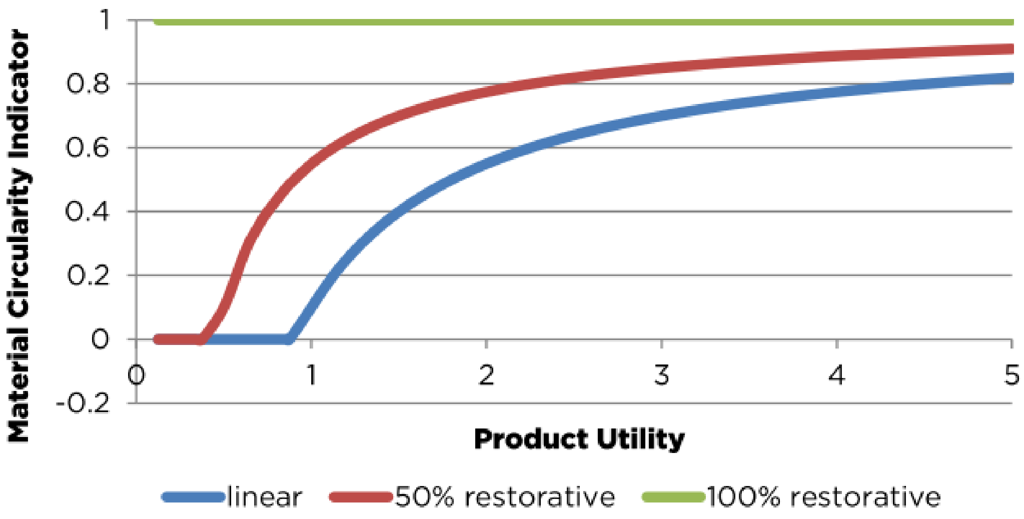


(Measuring Circularity, 2020)

Circularity Indicators

At product level





(EMF. 2018)

Circularity Indicators

At product level

Functional decomposition

Physical decomposition

Functional Separation	
1.0	Separation of functions
0.6	Integration of functions with same life cycle into one element
0.1	Integration of functions with different life cycle into one element
Functional dependence	
1.0	Separation of functions
0.8	Planned interpenetrating for different solutions (overcapacity)
0.4	Planned interpenetrating for one solution
0.2	Unplanned interpenetrating
0.1	Total dependence

(Dumisevic, 2006)

Circularity Indicators

At product level

Functional decomposition

Physical decomposition

Type of connection	
1.0	Accessory external connection or connection system
0.8	Direct connection with additional fixing devices
0.6	Direct integral connection with inserts (pin)
0.5	Direct integral connection
0.4	Accessory internal connection
0.2	Filled soft chemical connections
0.1	Filled hard chemical connection
0.1	Direct chemical connection
Accessibility	
1.0	Accessible
0.8	Accessible with additional operation which causes no damage
0.6	Accessible with additional operation/causes reparable damage
0.4	Accessible with additional operation/causes partly reparable damage
0.1	Not accessible – total damage of bought elements

(Dumisevic, 2006)

Circularity Indicators

At product level

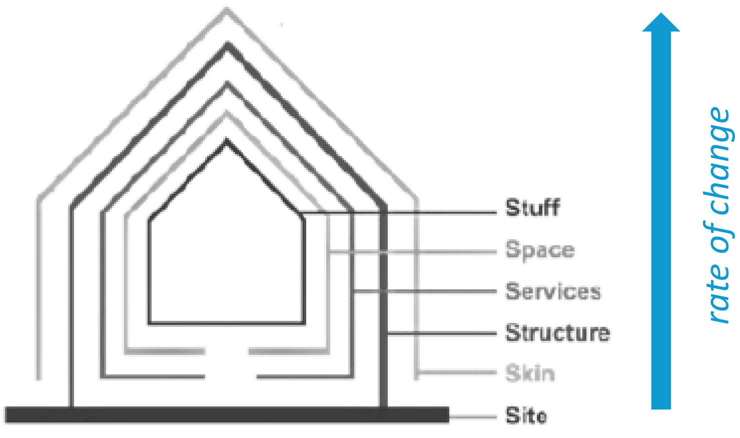
MPG per functional unit

Impact category	Unit	Weighting of results
Climate change – total	kg CO2-eq.	Single-score indicator
Climate change – fossil	kg CO2-eq.	
Climate change – biogenic	kg CO2-eq.	
Climate change – land use and change to land use	kg CO2-eq.	
Ozone layer depletion	kg CFC11-eq.	
Acidification	mol H+-eq.	
Freshwater eutrophication	kg PO4-eq.	
Seawater eutrophication	kg N-eq.	
Land eutrophication	mol N-eq.	
Photochemical ozone formation	kg NMVOC-eq.	
Depletion of abiotic raw materials, minerals, and metals	kg Sb-eq.	
Depletion of abiotic raw materials Fossil fuels	MJ, net cal. val.	
Water use	m3 world eq.	
Fine particulate emissions	Illness incidence	
Ionizing radiation	kBq U235-eq.	
Ecotoxicity (freshwater)	CTUe	
Human toxicity, carcinogenic	CTUh	
Human toxicity, non-carcinogenic	CTUh	
Land-use related impact/soil quality	Dimensionless	

(Measuring Circularity, 2020;Stichting Nationale Milieudatabase, 2020)

Circularity Indicators

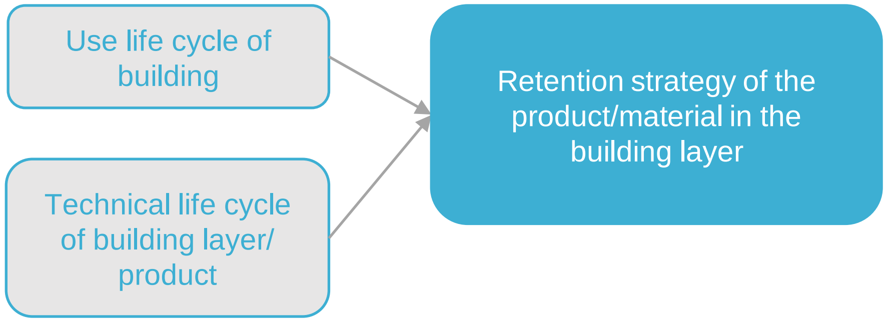
At product level



Building layers

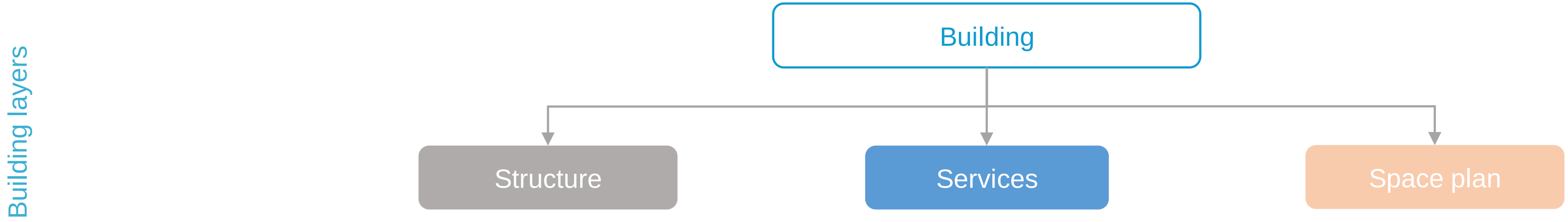
Scenario

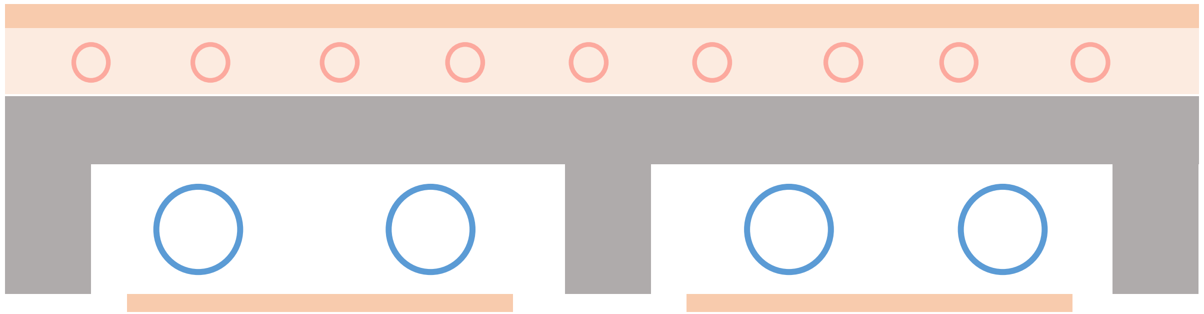
ULC<TLC = Reuse;
ULC=TLC = Repurpose/recycle;
ULC>TLC = Maintain



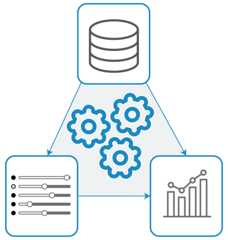
(Dumisevic, 2006)

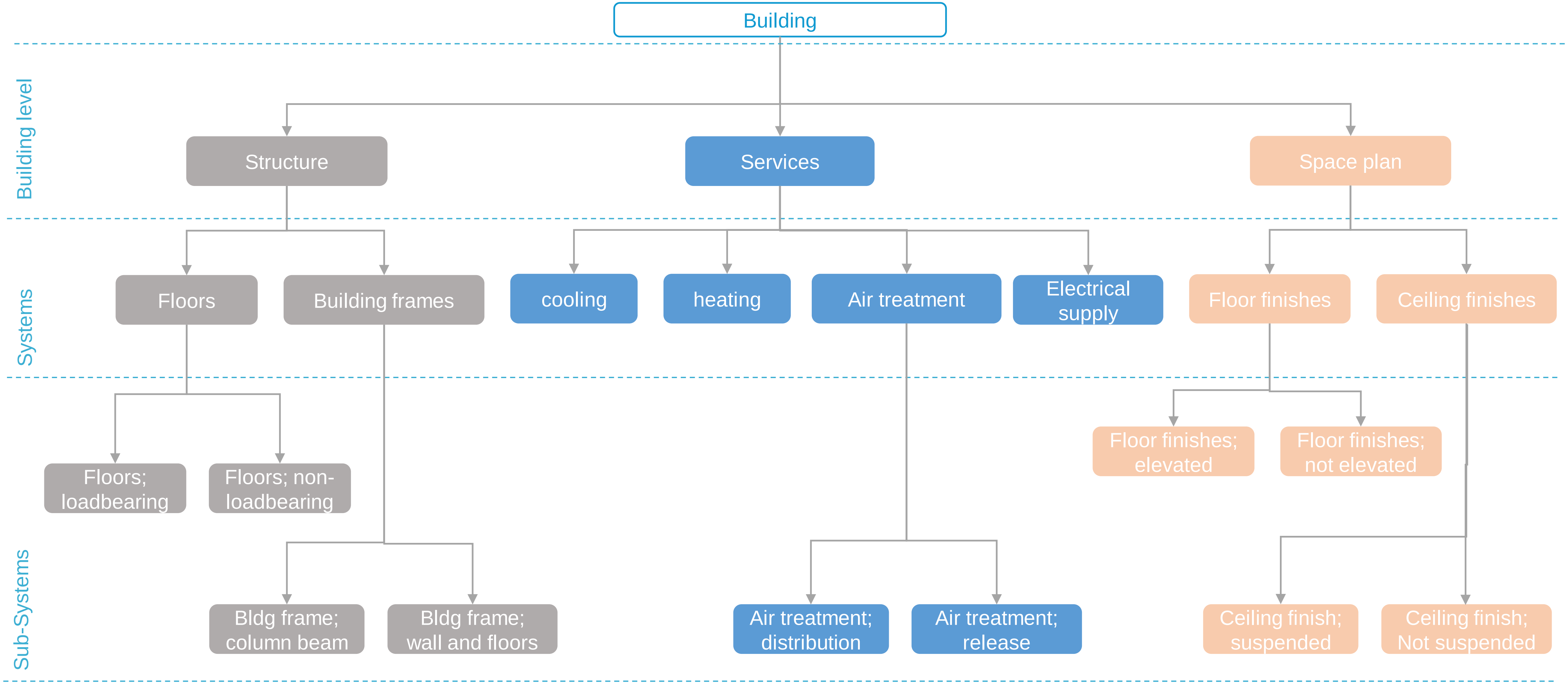
Integrated floor system





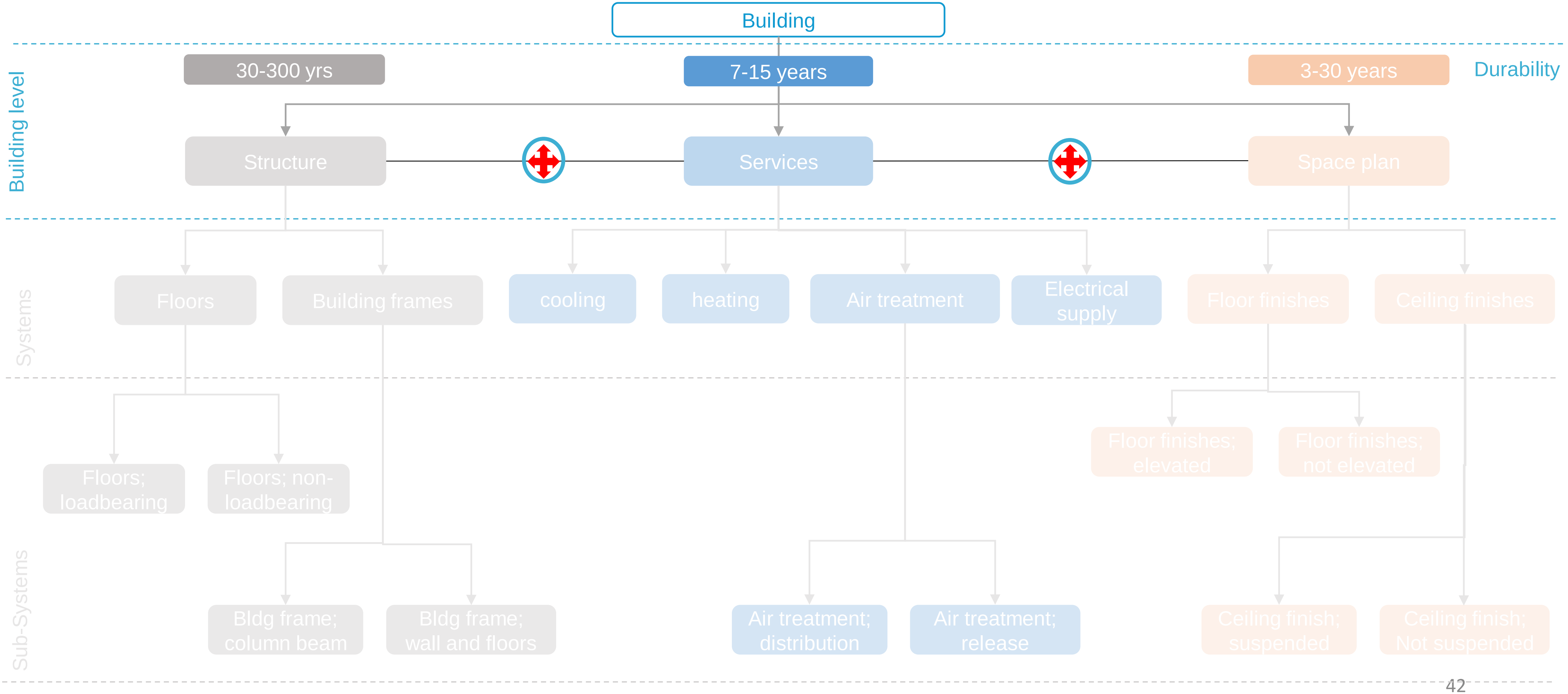
Integrated floor system





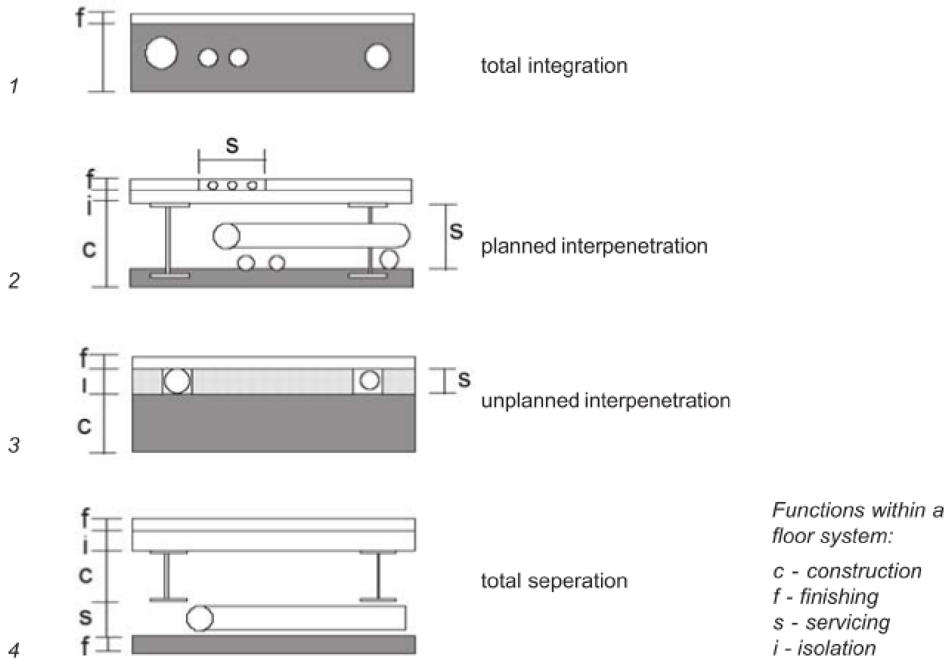
(NL SfB, Bimloket 2021)

Integrated floor system



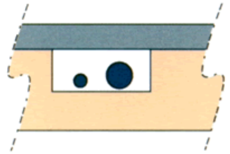
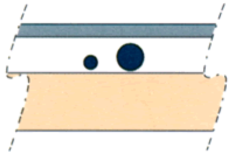
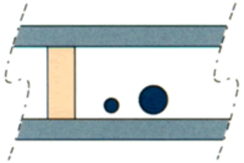
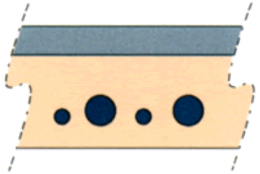
Integrated floor system

Functional dependency



(Dumisevic, 2006)

Integrated floor system

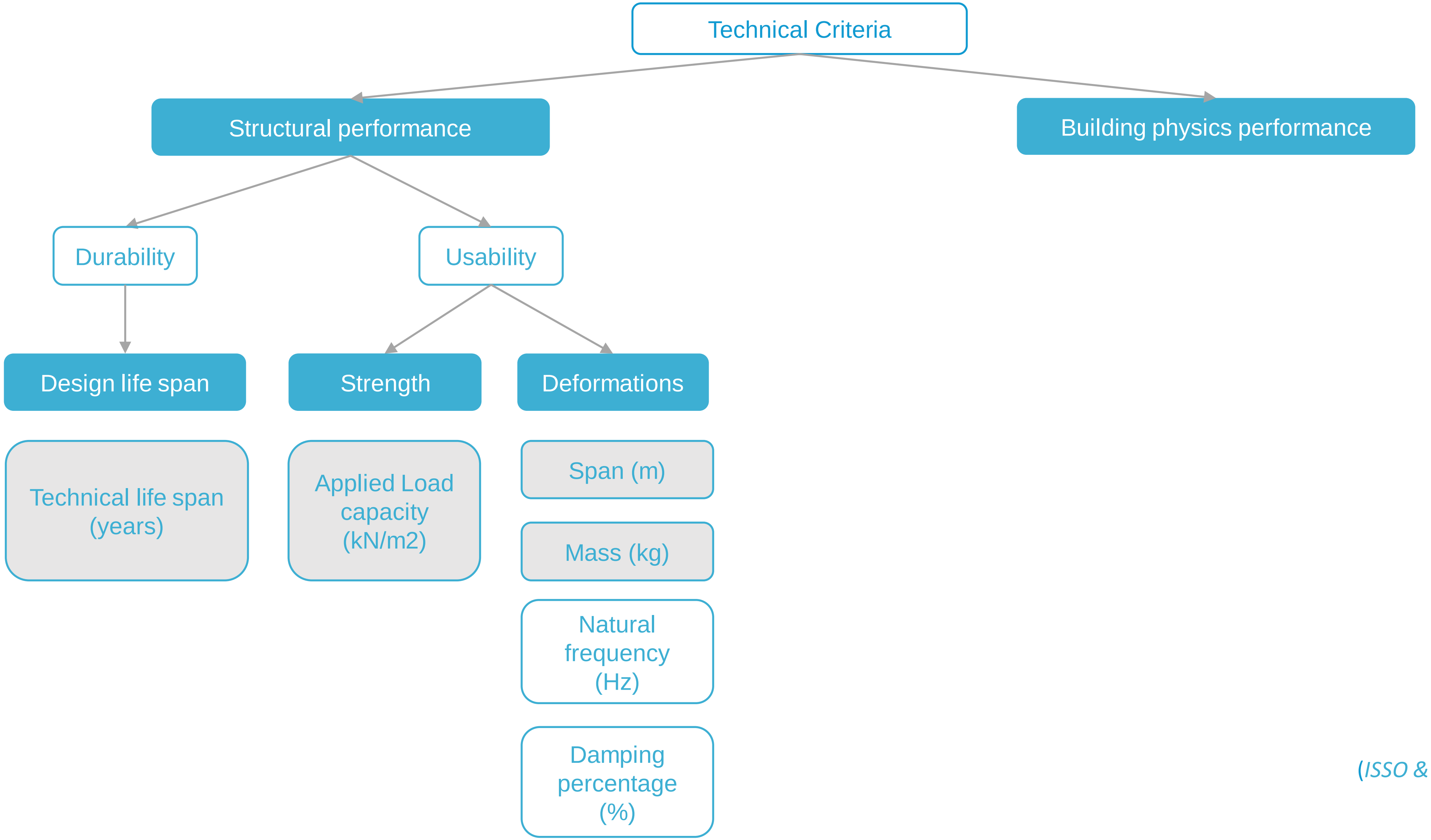
Integration typologies	Integration strategy	Flexibility dependent on space layer (screed)
 Gutter model	In the slab	yes
 Built-in or raised floor model	In the raised floor	yes
 Hollow floor model	In-between the beam	yes
 Capacity model	In the slab	no

Criteria for selection

- Flexibility (use and process)
- Concrete core activation
- Floor height
- Low weight
- Prefabrication (fast construction)

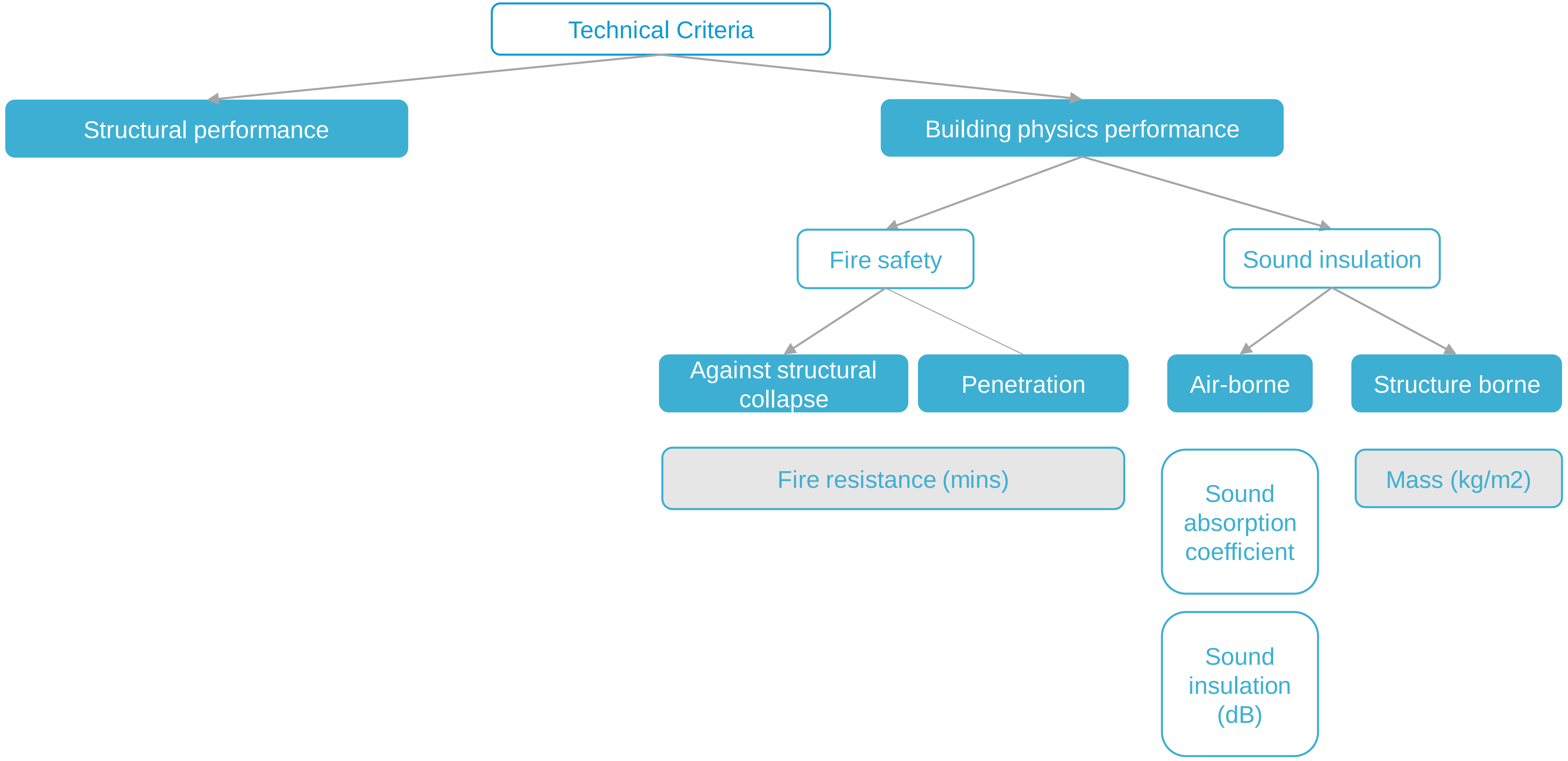
(*SBR publication 2005*)

Integrated floor system



(*ISSO & SBR publications, Cie, 2016*)

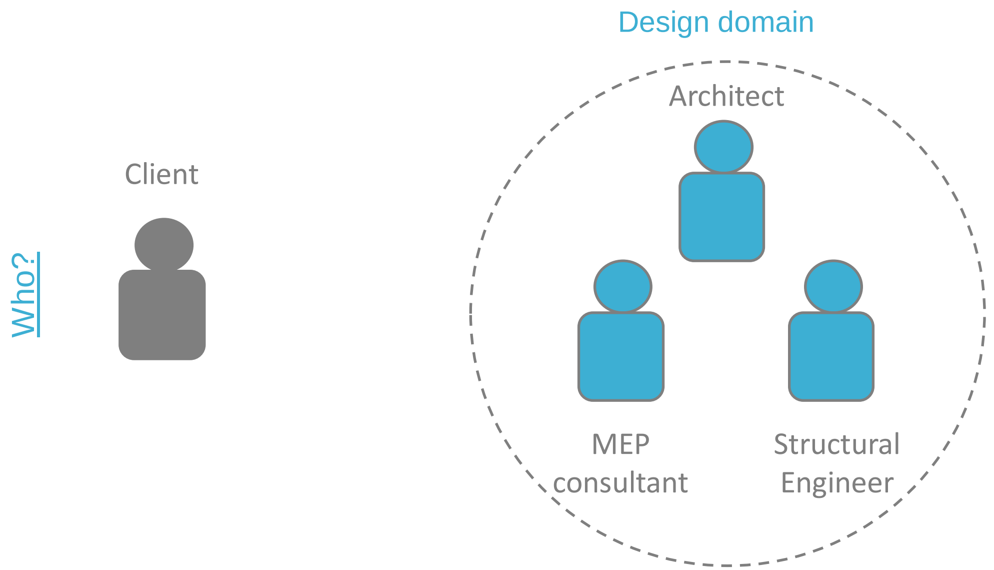
Integrated floor system



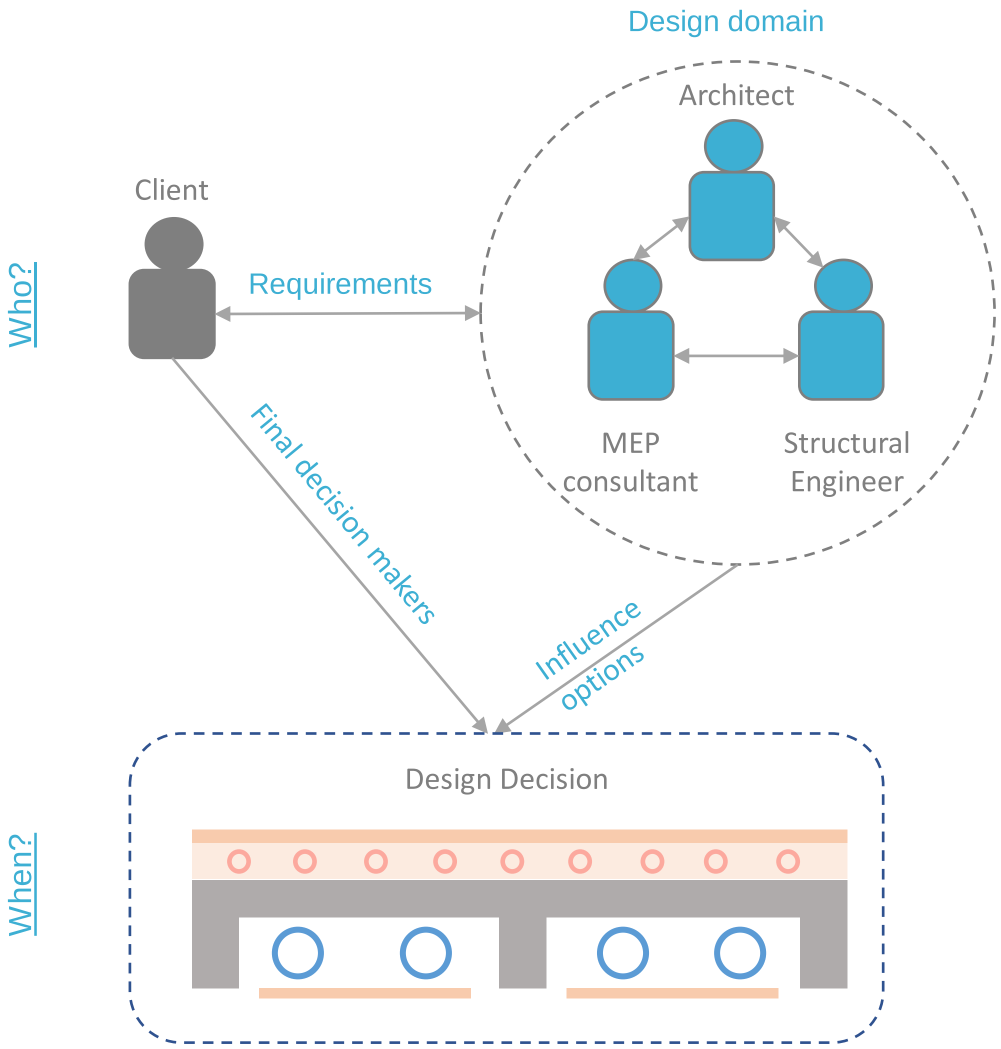
(*ISSO & SBR publications, Cie, 2016*)

Insights from experts

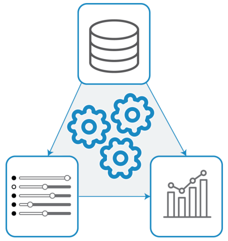
A total of 10 participants were interviewed



Insights from experts



Preliminary design phase



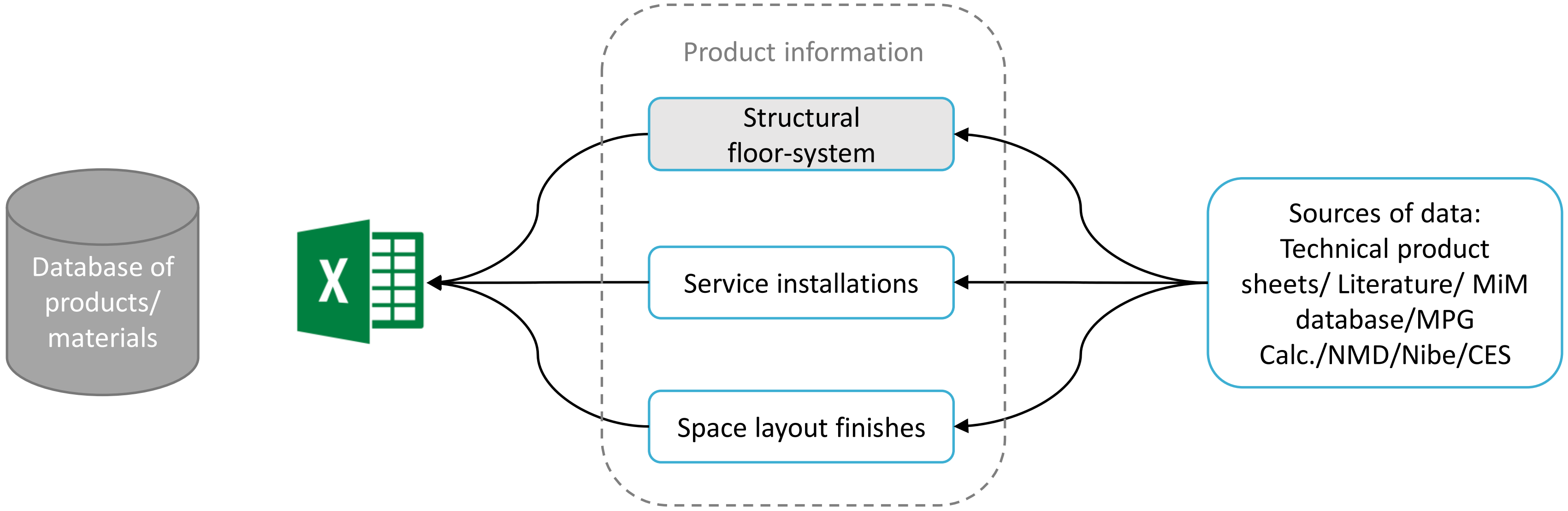
What?

Challenge	To integrate or not?
Main Criteria	Flexibility
To reduce environmental impact	Materialization
Most used circular strategy	Design for maintenance
Expectations for Decision support system	Multiple options
	Interactivity
	informative
	Reduce time & effort
	Flexible and transparent

Step 3 | DSS Prototype Development

1. KB Database
2. KB Heuristic Model
3. Implementation

KB Database Structure



KB Database Structure

Total alternatives = 10 x structural floor-system

Technical indicators

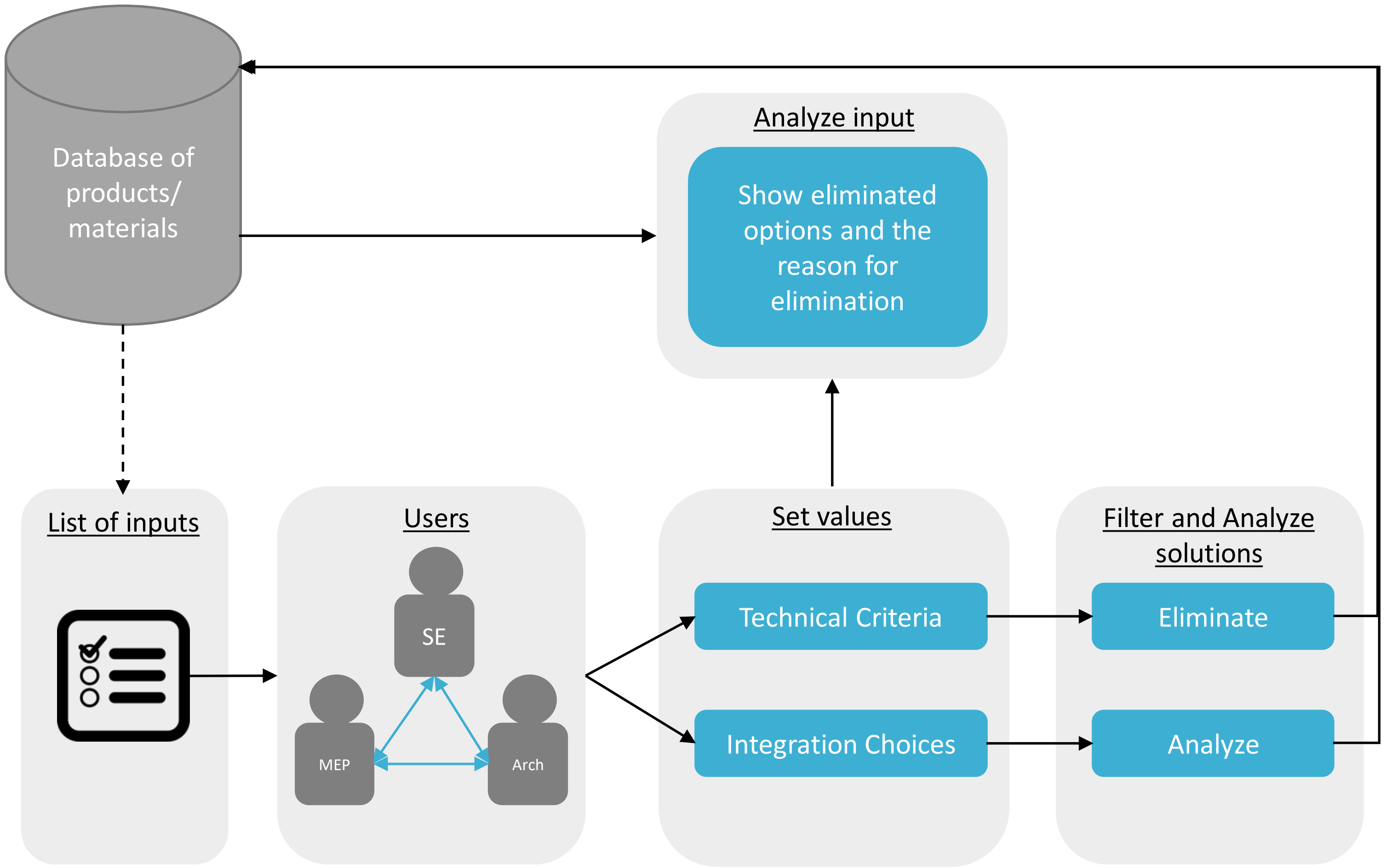
Family	MPG calc. Ref. Code	Product name	Material	Slab Thickness (mm)	Width (m)	Length (m)	Mass (kg/m2)	Total applied Load (kN/m2)	Span range (m)	Fire resistance (mins)	Active heating/pipe integration	Technical life span (yrs) (industry avg)
Structural floor	23.01.046	VBI Hollow core floor 150	Concrete C12/15	150	1.2	7.2	268	2.5	7.2	60	0	100
	23.01.018	VBI Hollow core floor 200	Concrete C44/55	200	1.2	7.2	308	7	7.2	90	0	100
	nibe	VBI Climatefloor 200	Concrete C45/55	200	1.2	7.2	384	4	7.2	90	1	75
	nibe	VBI Climatefloor 260	Concrete C45/55	260	1.2	7.2	510	5	9.5	120	1	75
	28.02.025	CLT Rib panel (open type)	Timber	320	2.5	7.2	150	5	7.2	60	0	75
	47.04.012	Comflor 225 (1.25mm thk) propped	Composite C35/45	295	0.6	7.2	331.4	5	8	60	1	75
	47.04.013	Comflor 225 (1.25mm thk) propped	Composite C35/45	305	0.6	7.2	361	5	7.9	90	1	75
	47.04.014	Comflor 225 (1.25mm thk) propped	Composite C35/45	315	0.6	7.2	385	5	7.73	120	1	75
	28.02.025	LVL rib panel (Semi-open type)	Timber	480	2.5	7.2	245	6	7.2	60	0	75
	28.02.025	LVL rib panel (Semi-open type)	Timber	330	2.5	7.2	168.3	3	7.2	60	0	75

KB Database Structure

Total alternatives = 10 x structural floor-system

			Circularity indicators											
Family	MPG calc. Ref. Code	Product name	MPG per unit m2	Amount of Virgin Material used	Material available for next cycle	Amount of material lost	Pipes Integration type	Dependency on screed	Functional Separation	Functional Dependence	Accessibility	Connection type	Renewable source of material?	MCI
Structural floor	23.01.047	VBI Hollow core floor 260	3.9	86.14	98.95	1.05	x	0	0.0	0.0	0.0	0.0	0	0.71
	23.01.018	VBI Hollow core floor 200	3	86.23	98.96	1.04	x	0	0.0	0.0	0.0	0.0	0	0.71
	nibe	VBI Climatefloor 200	7.32	86.14	98.95	1.05	Gutter	1	0.1	0.4	0.0	0.0	0	0.61
	nibe	VBI Climatefloor 260	8.44	86.12	98.95	1.05	Gutter	1	0.1	0.4	0.0	0.0	0	0.61
	28.02.025	CLT Rib panel (open type) (320)	4.24	90.92	15.30	84.70	x	0	0.0	0.0	0.0	0.0	1	0.96
	47.04.012	Comflor 225 (295)	9.5	84.75	98.75	1.25	Capacity	0	0.1	0.8	0.1	0.1	0	0.61
	47.04.013	Comflor 225 (305)	9.8	84.75	98.75	1.25	Capacity	0	0.1	0.8	0.1	0.1	0	0.61
	47.04.014	Comflor 225 (315)	10.35	84.75	98.75	1.25	Capacity	0	0.1	0.8	0.1	0.1	0	0.61
	28.02.025	LVL rib panel (Semi-open type) (480)	6.36	99.12	15.77	84.23	x	0	0.0	0.0	0.0	0.0	1	0.92
	28.02.025	LVL rib panel (Semi-open type) (330)	4.3725	99.12	15.77	84.23	x	0	0.0	0.0	0.0	0.0	1	0.92

KB Heuristic logic Model

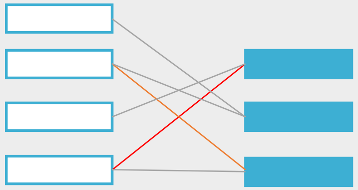


Implementation

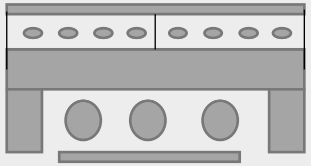
Dashboard visualization

Set inputs

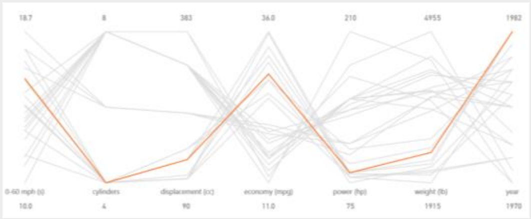
Live feedback (influence on choice)



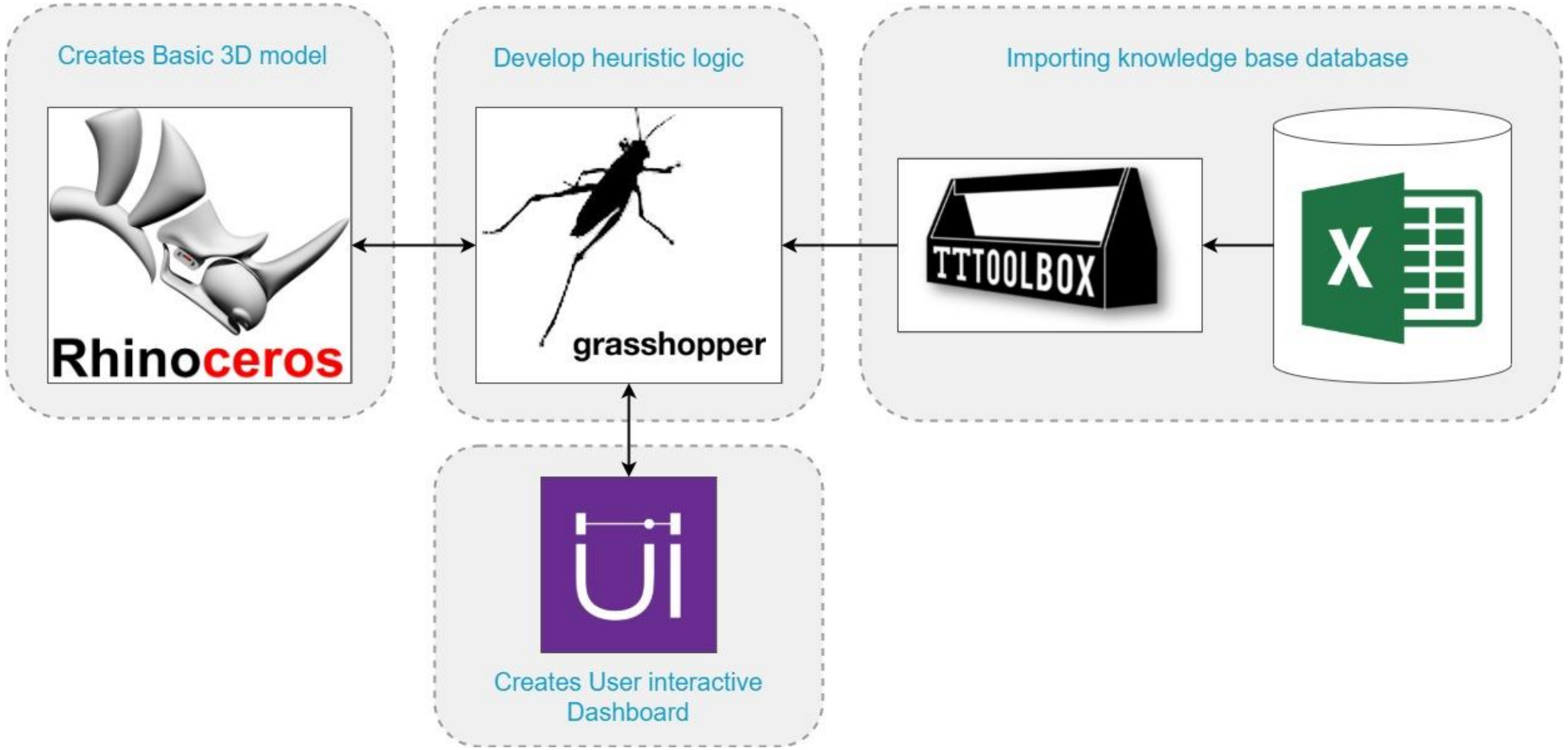
3-D basic configuration



Solutions for comparison



Implementation

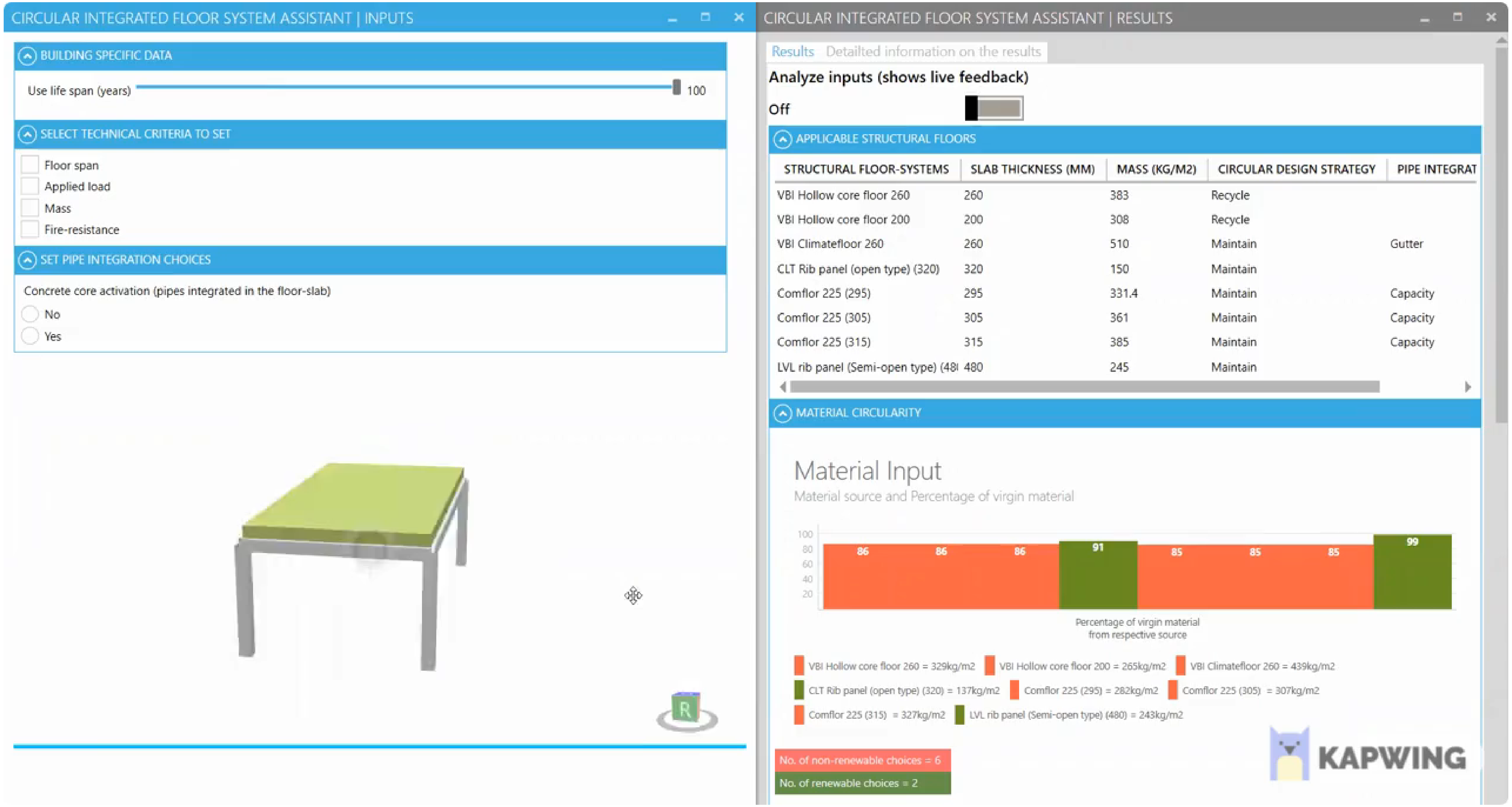


Step 4 | DSS Prototype & Testing

1. Prototype Demo

2. User Testing Feedback

Prototype Demo



User Feedback

Compliments

- dashboard based design tool offers a very user-friendly and interactive experience
- It supports the preliminary design stages of a project by giving quick insights into the possible alternatives for a given design case
- the users recognized that by scaling up this approach, with a bigger database of knowledge, it could provide much deeper insights and could be a valuable for industry wide application in the future

User Feedback

Possible improvements

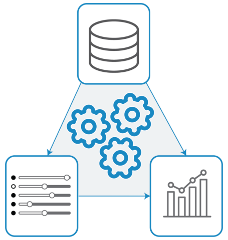
- The addition of a table that could show the solutions that have been eliminated will be valuable
- Addition of technical criteria for space layer, that consists of mass requirements to be set for screed and ceiling to determine overall mass of the system and the addition of sound insulation properties per product for better acoustic performance insights.
- Addition of the impact on the overall floor-to-floor height due to integration strategy is another recommendation by the user
- the users suggested it could be valuable to conclude the results by aggregating all indicators and ranking them for better informed decision making

Step 5 | Conclusion

1. Answering research question

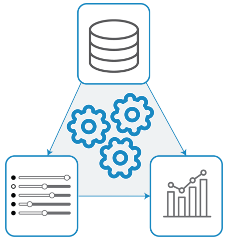
2. Recommendations

Conclusion



How can a decision support system assist the stakeholders involved in the preliminary design phase of an integrated floor-system, to compare design options based on technical performance and degree of circularity for making a suitable design choice to facilitate adaptability in office buildings (Netherlands) ?

Conclusion



How can a **decision support system** assist the stakeholders involved in the **preliminary design phase** of an **integrated floor-system**, to compare design options based on **technical performance** and **degree of circularity** for making a suitable design choice to **facilitate adaptability in office buildings** (Netherlands) ?

A Decision Support System development based on a Dashboard based design tool can help the Decision makers in early design stages

- By providing an interactive, informative platform that is open to compare multiple design typologies
- By sharing quick insights into impacts of design decision on Circularity related indicators especially flexibility facilitating adaptable office buildings
- By sharing live feedback on the design decisions and educating them on which design crietria has led to the display of applicable options
- The bigger the database, more the insights that can be inferred

Recommendations

- The developed DSS is only as good as the knowledge gathered and data collected, therefore it is very important to be critical of the problem formulation and categorizing/filtering the relevant data and knowledge model

- Aggregation of all the different circularity indicators into one scoring system that can rank all the floor-systems can be valuable to better advice the decision makers

- Making the DSS reversible in terms of the input and output criteria and indicators can allow more freedom and flexibility for the decision makers

Questions?

‘The significance of seeking a scientific basis for design does not lie in the likelihood of reducing design to one or another of the sciences… Rather it lies in a concern to connect and integrate useful knowledge from the arts and sciences alike.’

- Richard Buchanan, ”The wicked Problems in Design Thinking”, in Margolin and Buchanan, eds., The idea of Design, 1995.