Digital Solutions for a Circular Façade Economy

A conceptual framework for a Façade's Product Passport to facilitate decision making at the End of Service (EoS) of a Building Façade.

Abhishek Holla | 5109906

Mentor Team

Dr.Michela Turrin

Phd. Juan Azcarate

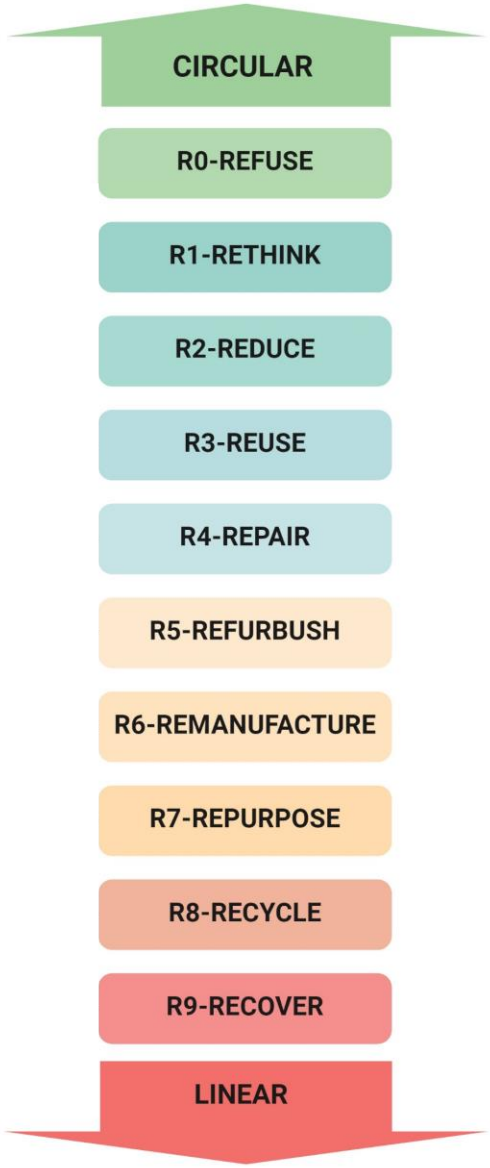
External Supervisor: Monique Fledderman

Internal Advisor: Prof.dr.Ir.Peter van Oosterom

Government of the Netherlands

100% circular by **2050**

9R FRAMEWORK



Soource:: 9R Framework Potting et al. (2017); Figures : Delolite, 2017

CURRENT(2017) STATUS

86% Recycled
95% Recovered

CIRCULAR

R0-REFUSE

R1-RETHINK

R2-REDUCE

R3-REUSE

R4-REPAIR

R5-REFURBUSH

R6-REMANUFACTURE

R7-REPURPOSE

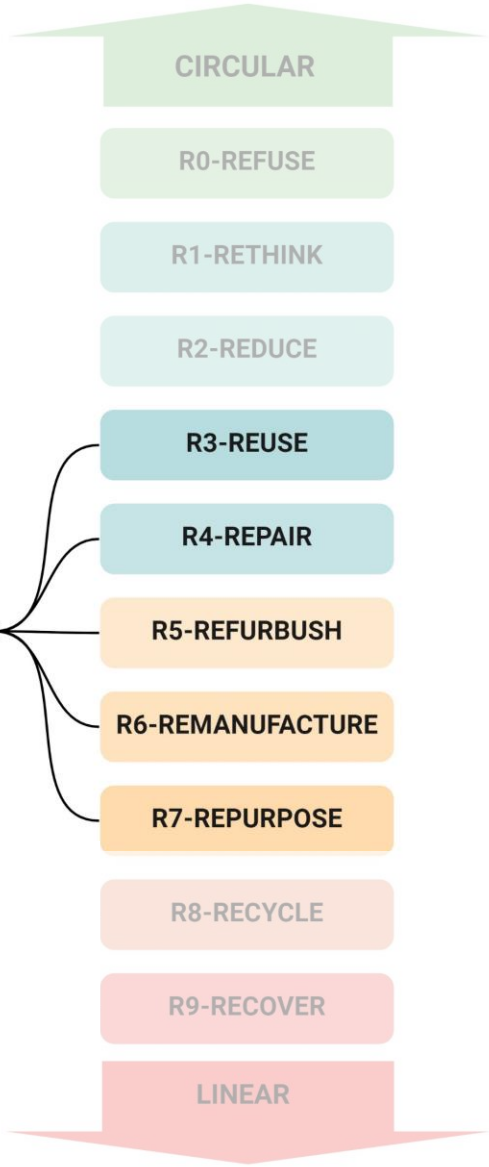
R8-RECYCLE

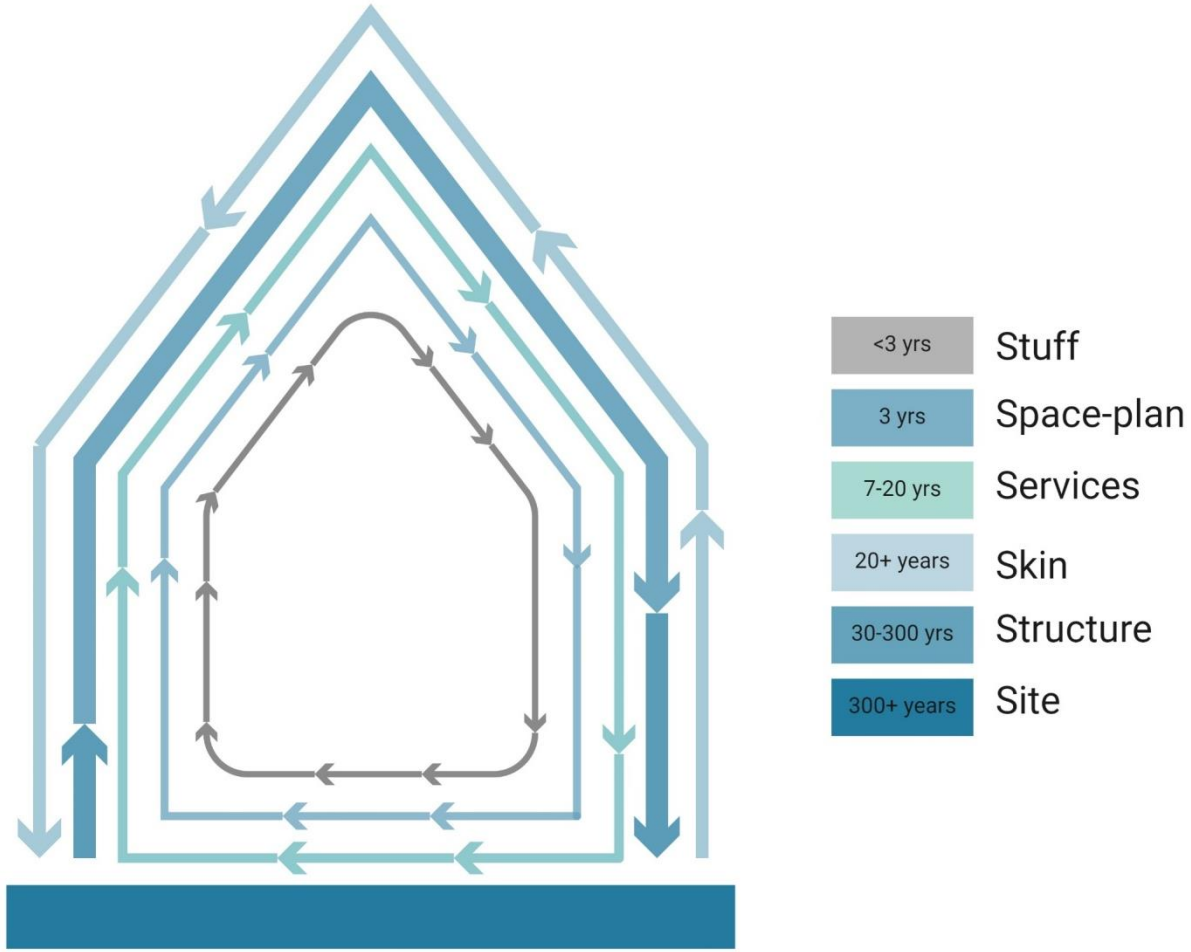
R9-RECOVER

LINEAR

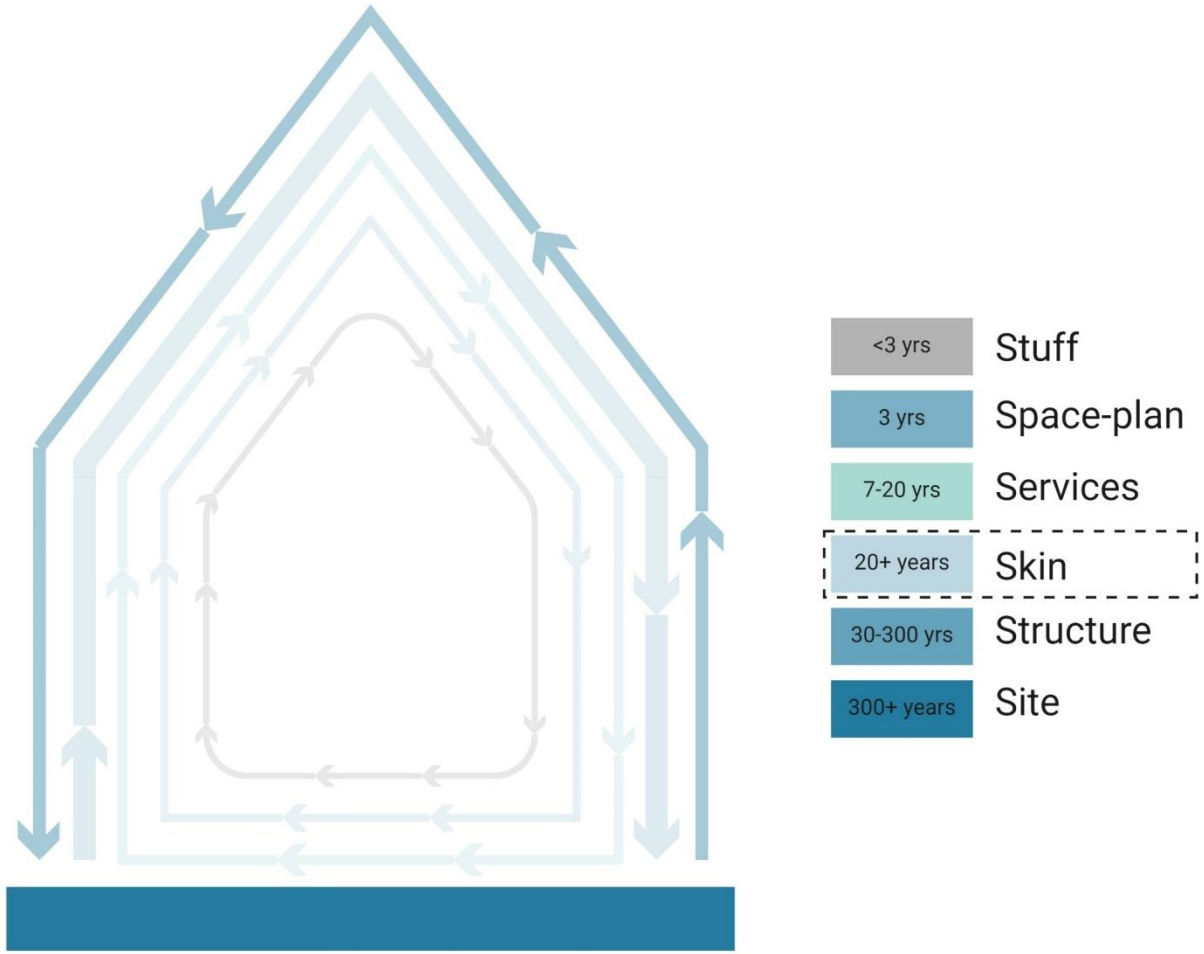
Soource:: 9R Framework Potting et al. (2017); Figures : Delolite, 2017

STATUS OF HIGHER RE-LIFE VALUES





Soource:: Brand(1994)

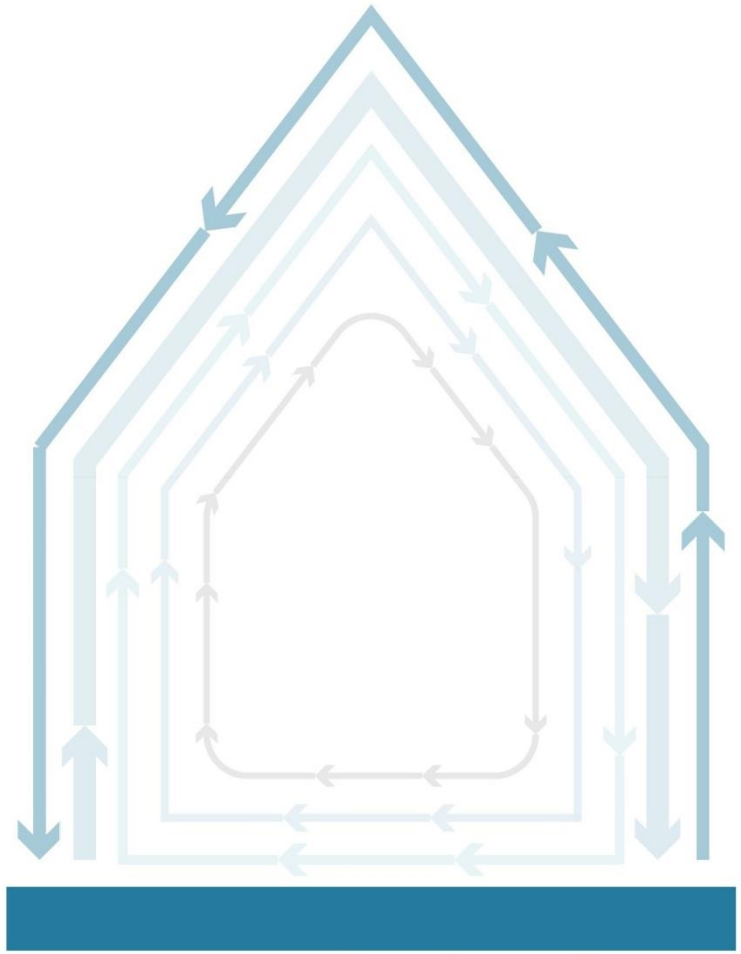

<3 yrs
Stuff
3 yrs
Space-plan
7-20 yrs
Services
20+ years
Skin
30-300 yrs
Structure
300+ years
Site

Protection from rain & snow

Natural light, Protection against UV

Push & Pull from wind loads

Noise

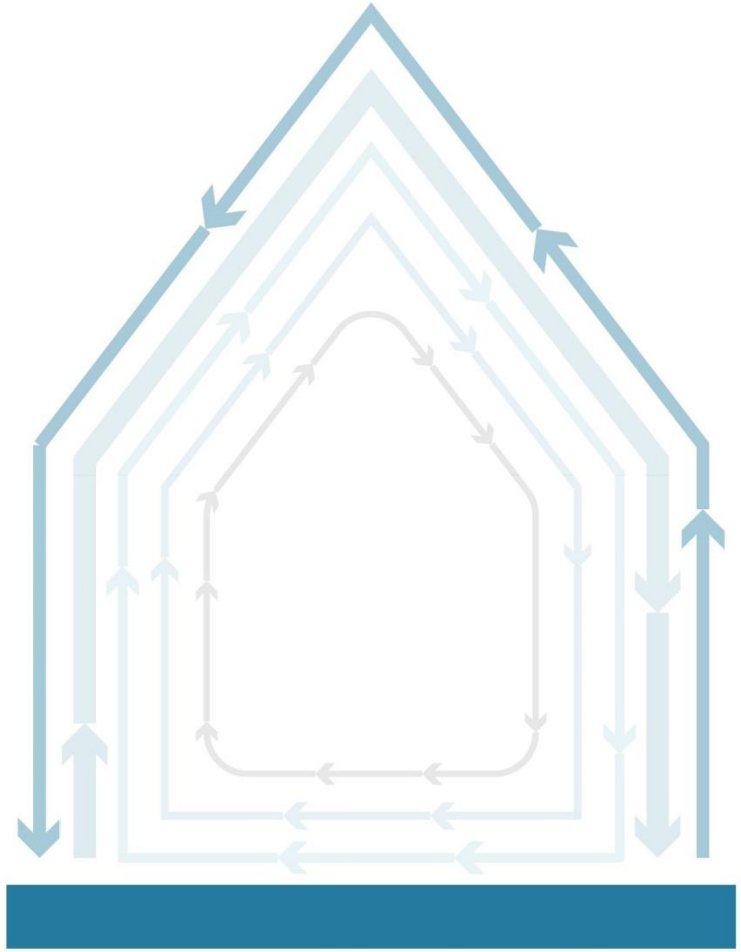


Protection from rain & snow

Natural light, Protection against UV

Push & Pull from wind loads

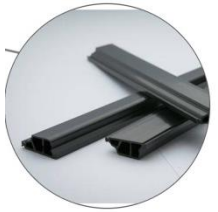
Noise



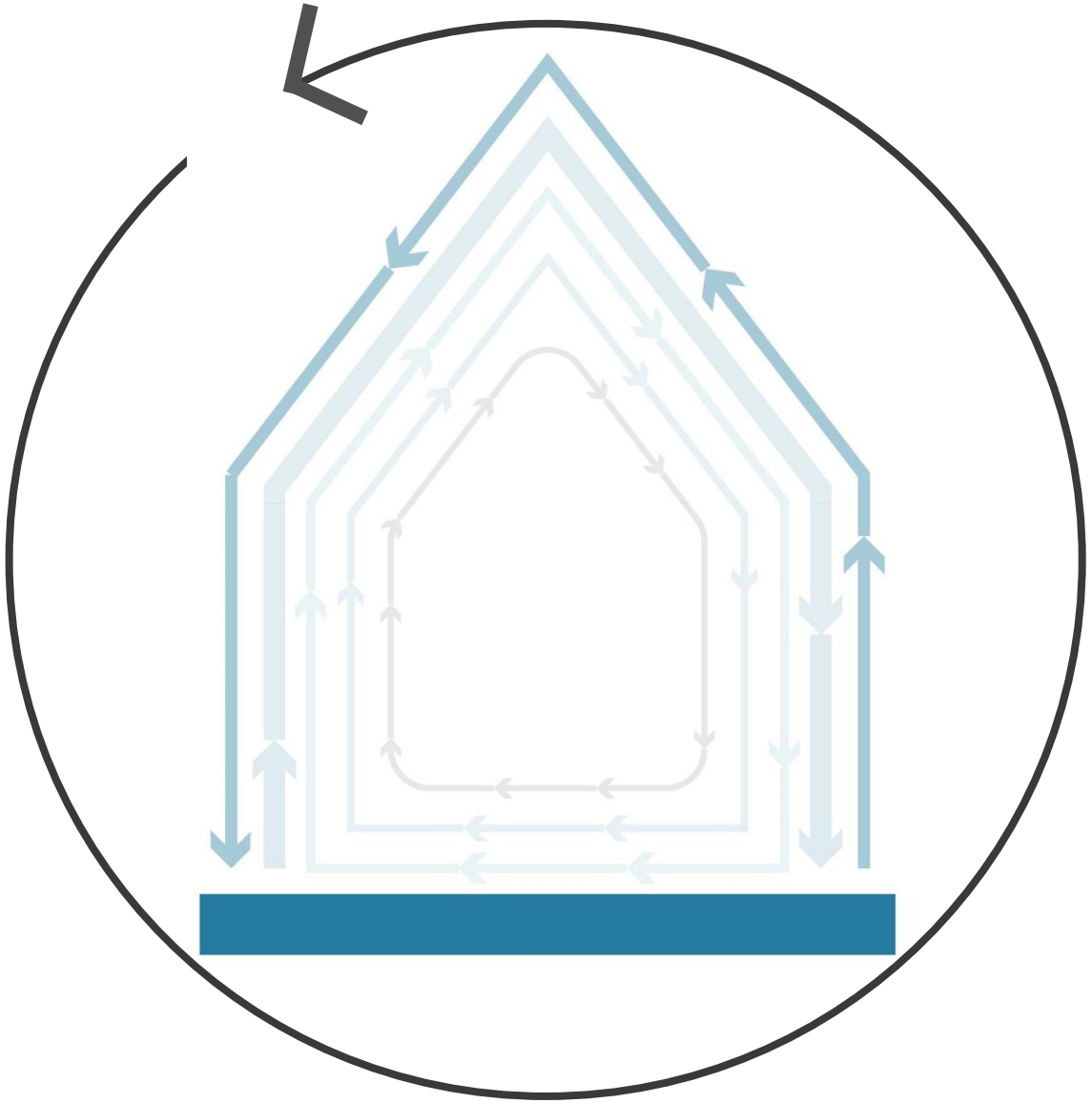
Aluminum

Glass

Rock wool



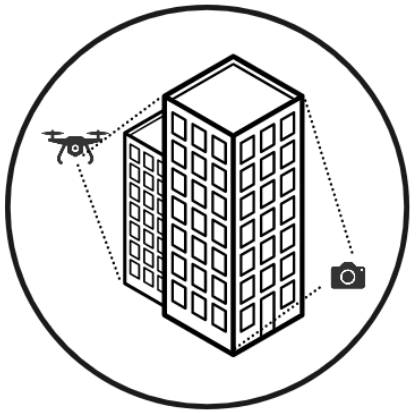
EPDM



TU Delft + VMRG KEURMERK

Façade Identification

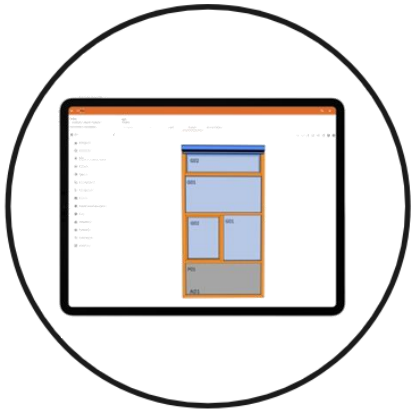
Extended Producer Responsibility



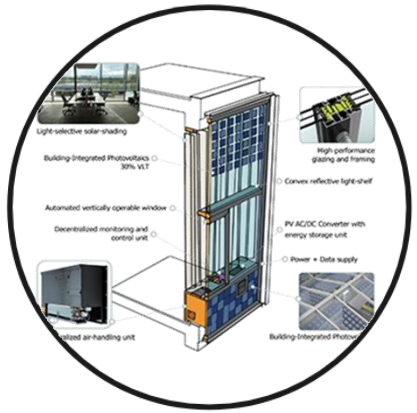
Automated Condition assessment

Soource:: 9R Framework Potting et al. (2017); Figures : Delolite, 2017

TU Delft + VMRG KEURMERK

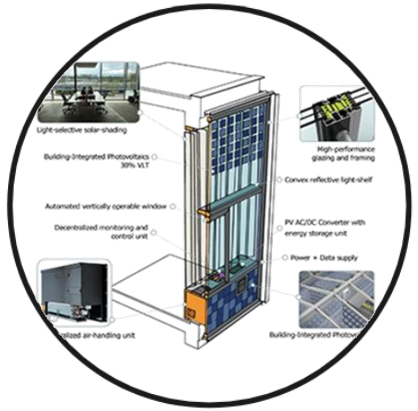


Cirlinq



Façade Leasing Project

FaSA



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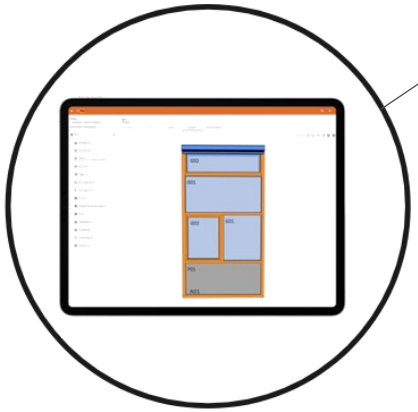

CIRCULAR

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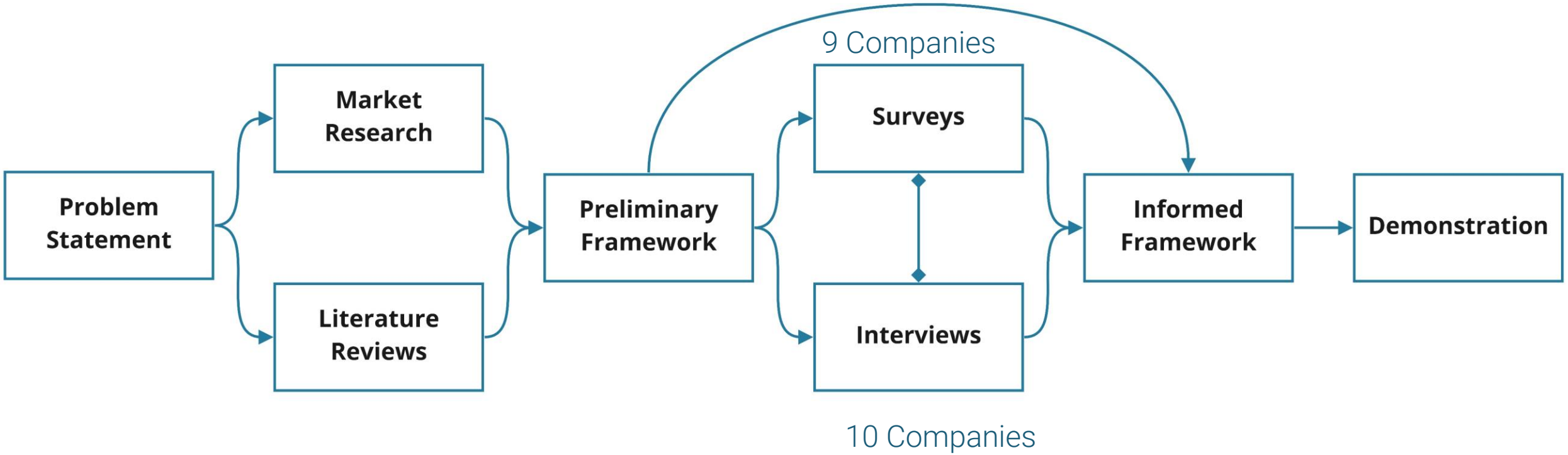
LINEAR

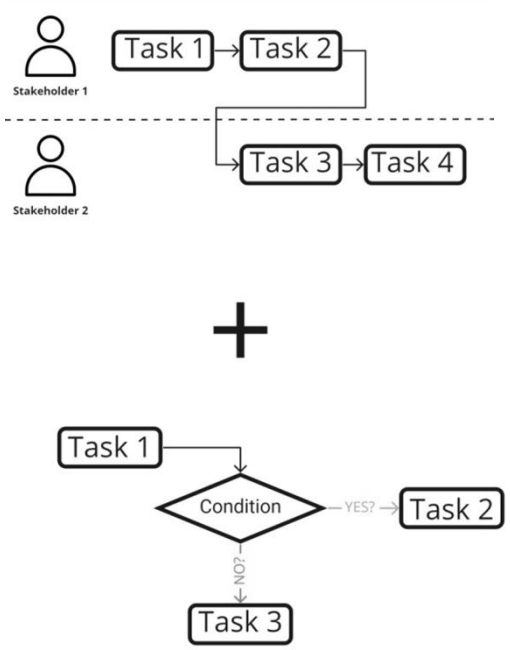
How can a conceptual framework be developed to collect, organize and store the information exchanged in the circular lifecycle of a Unitized metal façade to enable decision making at its End of service (EoS)?

RESEARCH METHODOLOGY

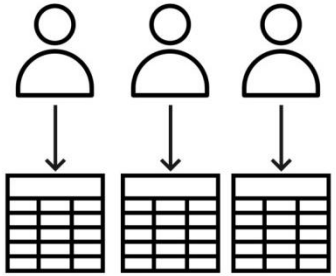


RESEARCH OUTPUTS

Information Infrastructure

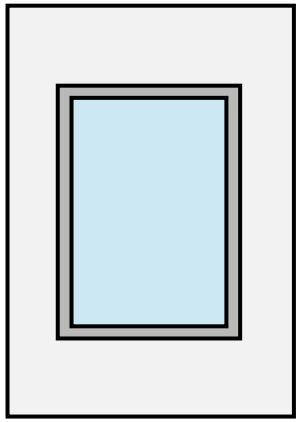


Decision trees and Process maps

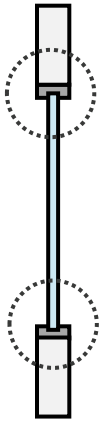


Data templates per stakeholder

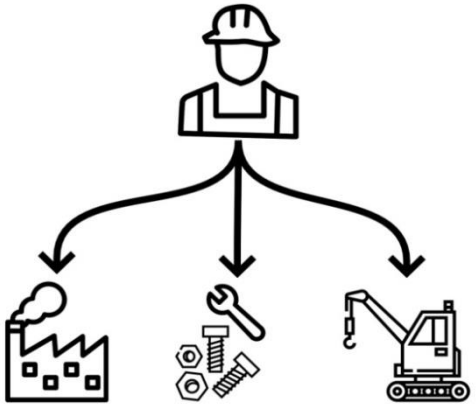
INCLUSIONS/EXCLUSIONS



Unitized Metal Facades



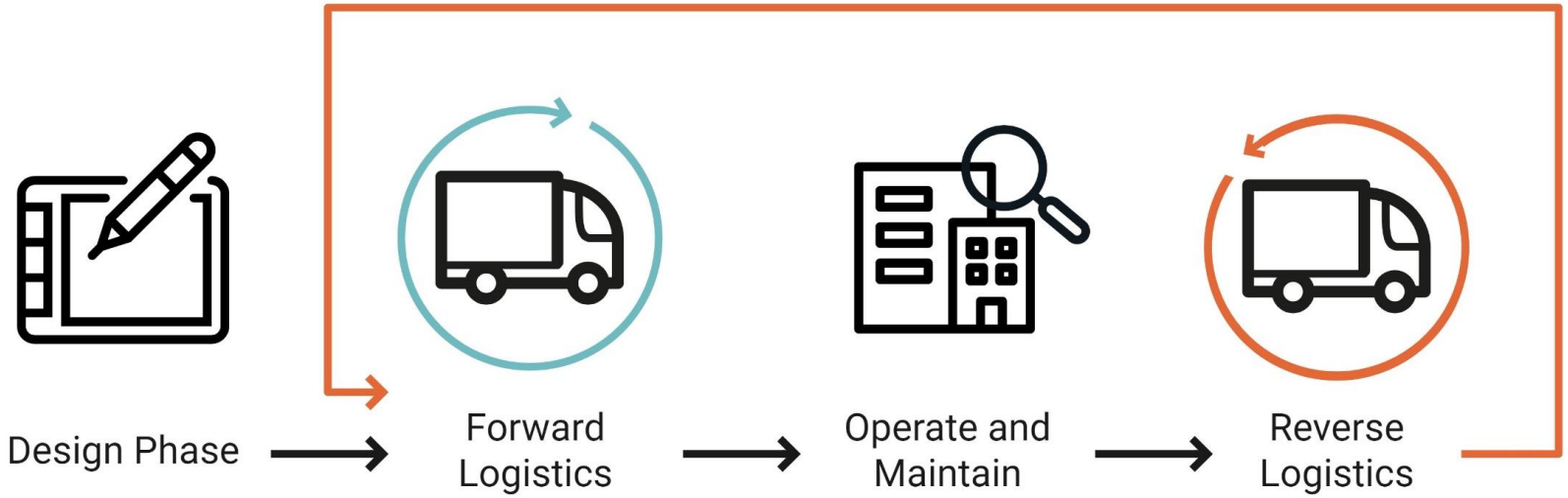
Only Frames are considered

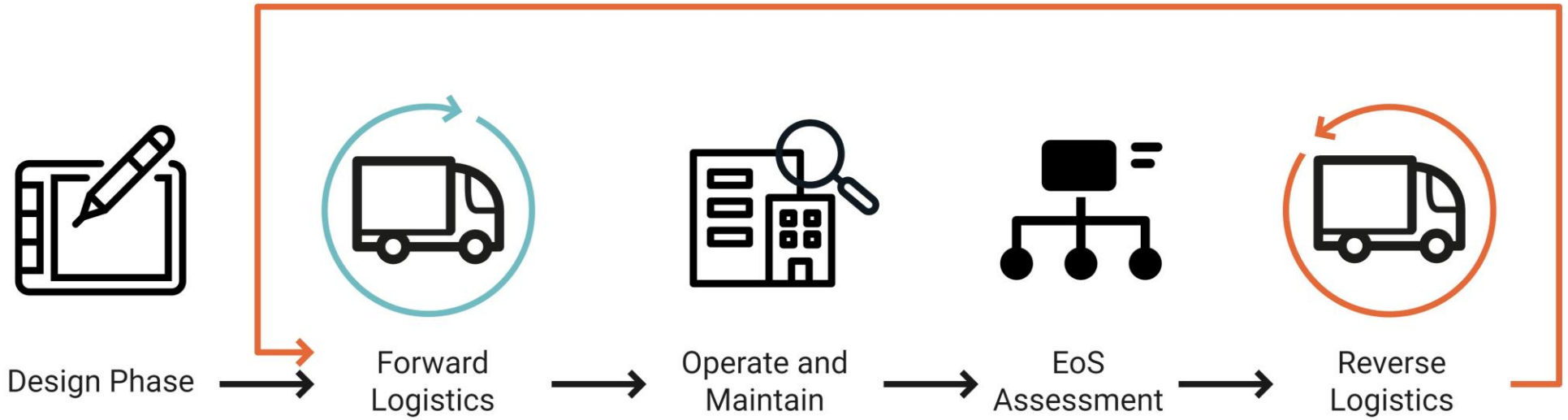


Addressed to direct stakeholders

Excludes Economic criteria

How can a conceptual framework be developed to collect, organize and store the **information exchanged in the circular lifecycle of a Unitized metal façade** to enable decision making at its End of service (EoS)?


Design Phase
Forward Logistics
Operate and Maintain
Reverse Logistics


Design Phase
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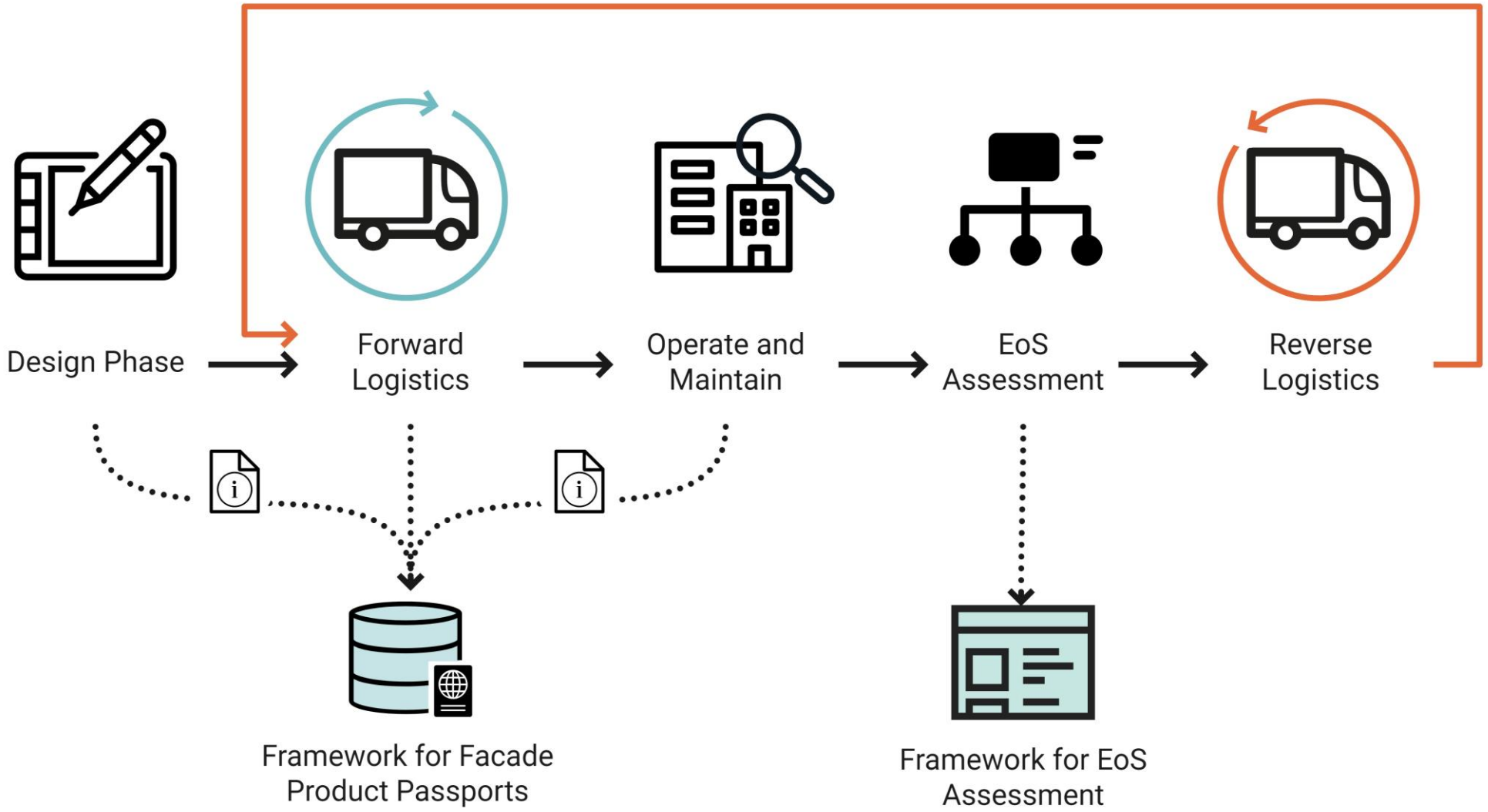
EoS Assessment
Reverse Logistics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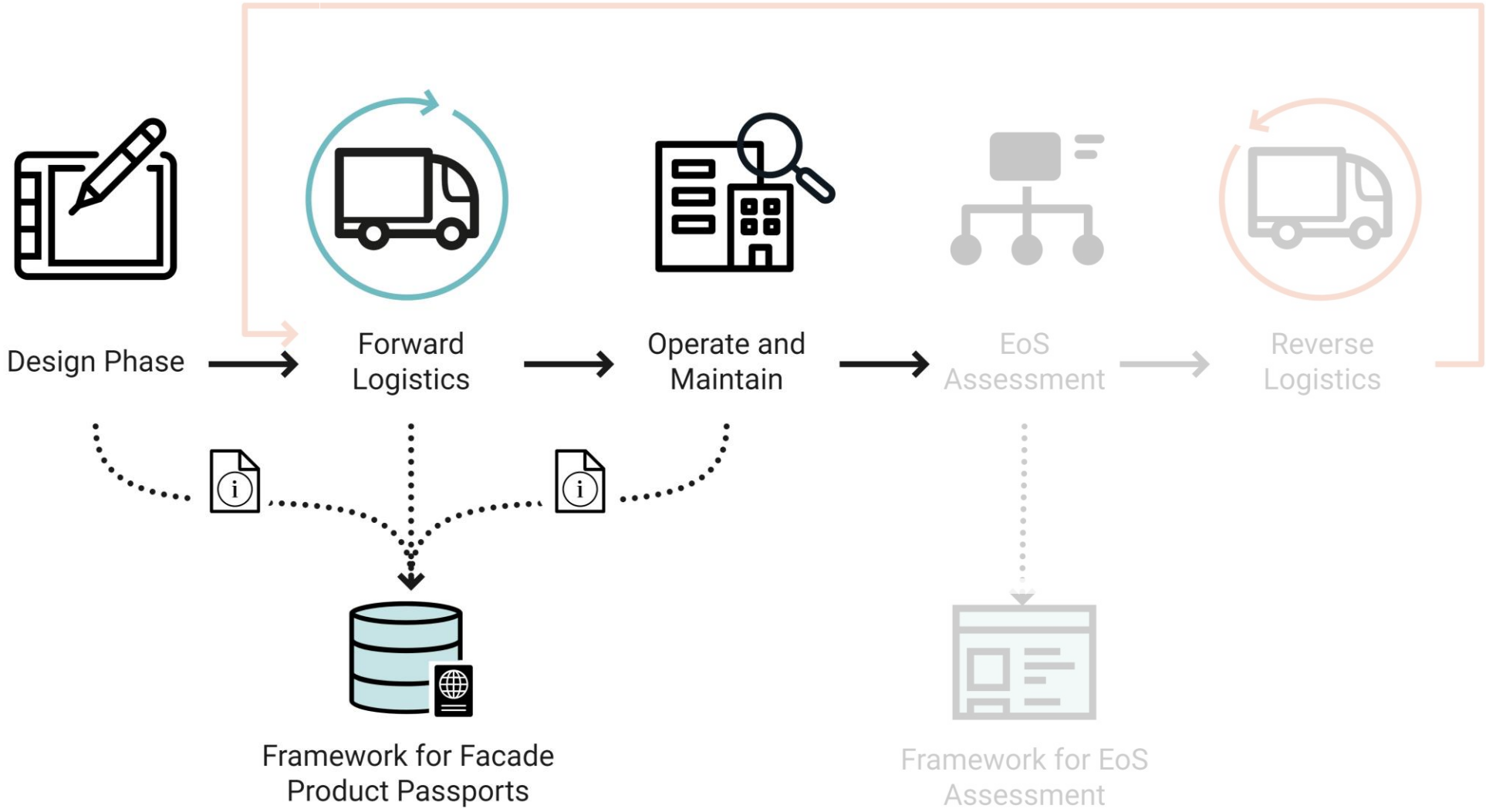
Framework for Facade Product Passports
Framework for EoS Assessment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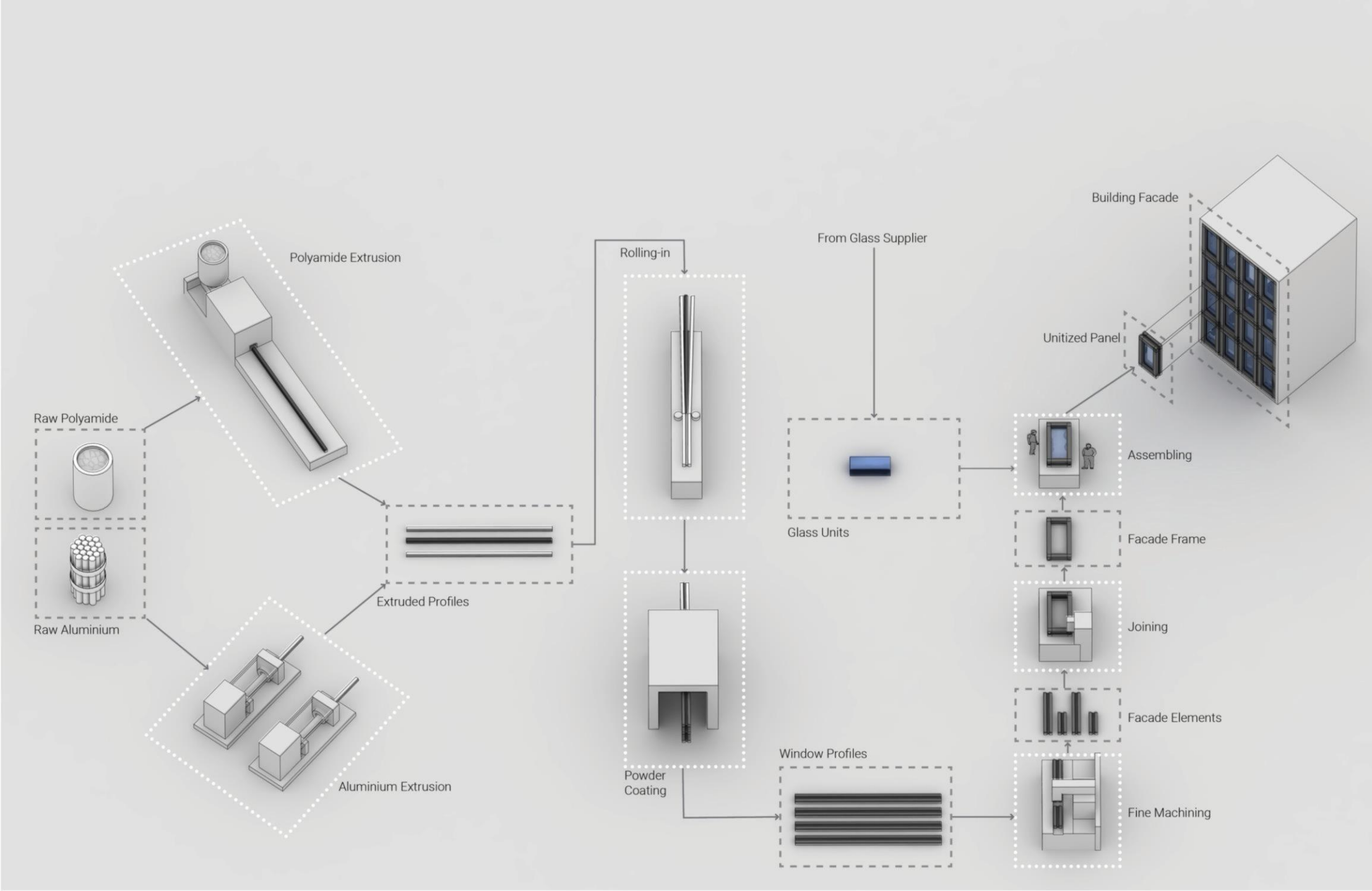
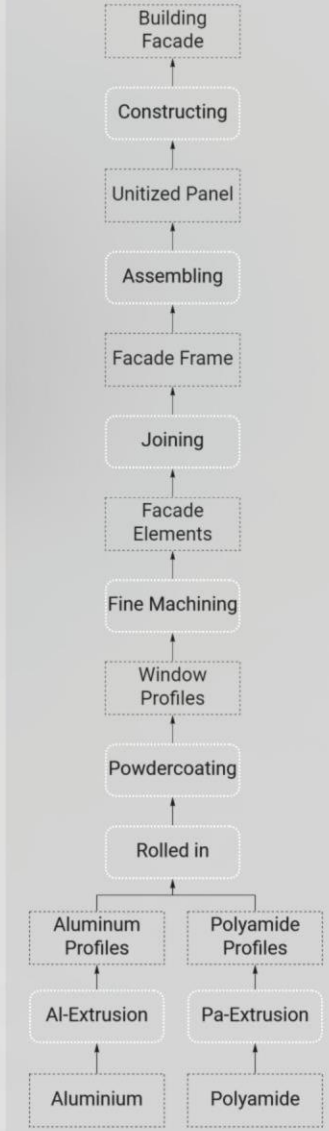
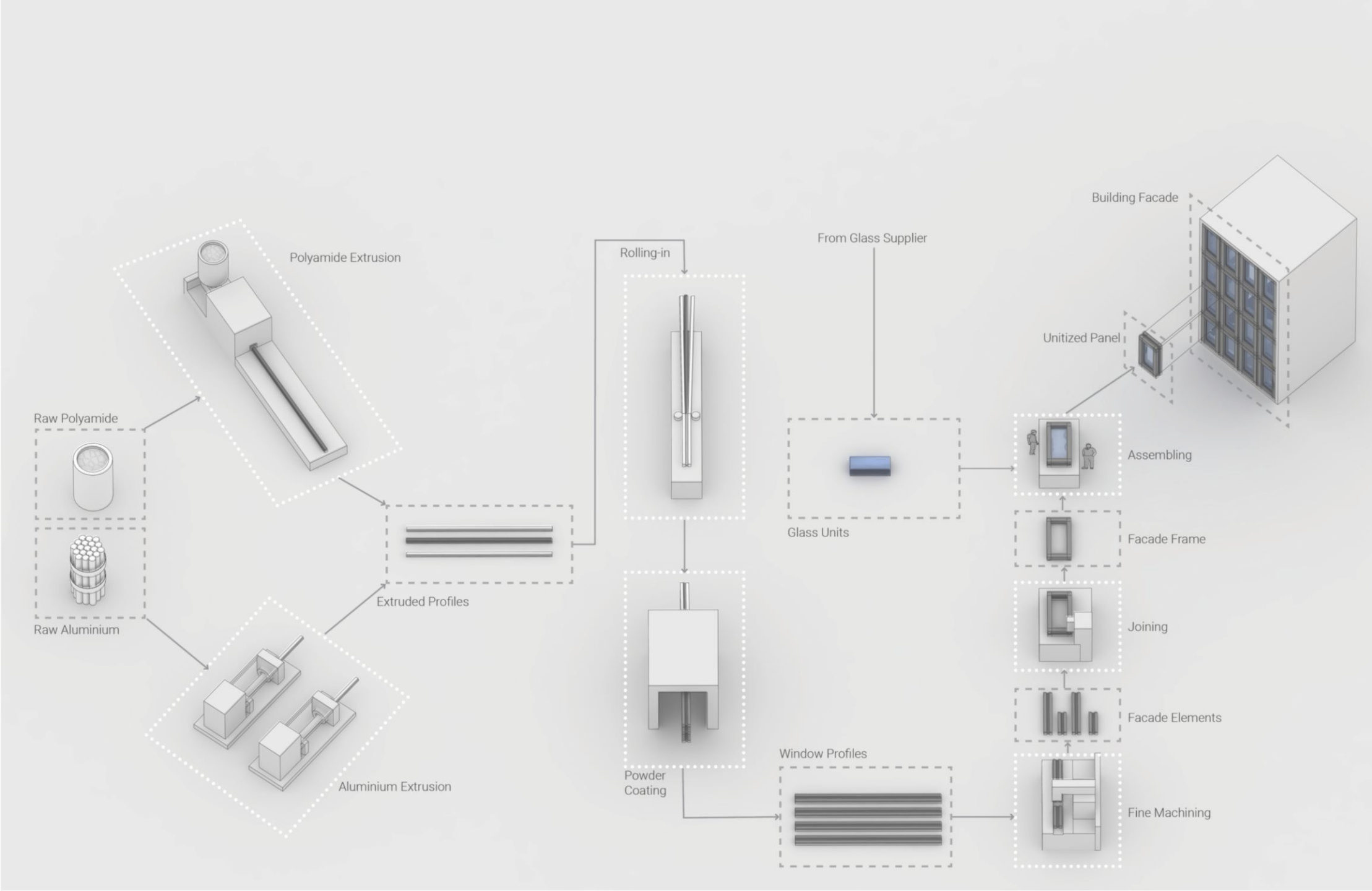


Lifecycle Stages





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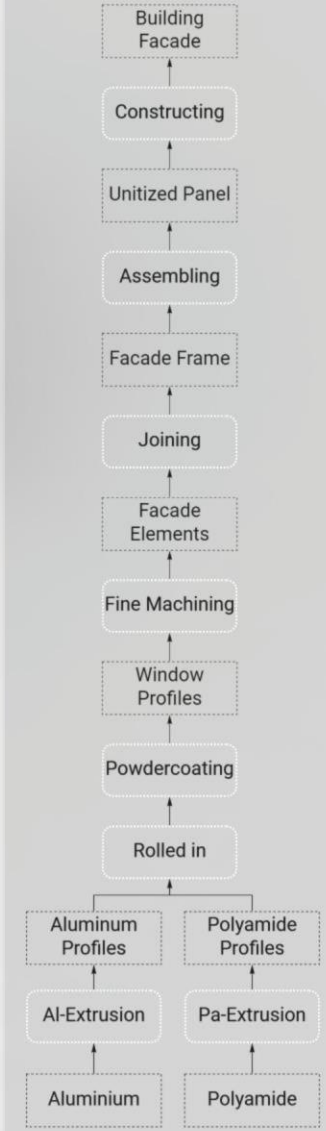

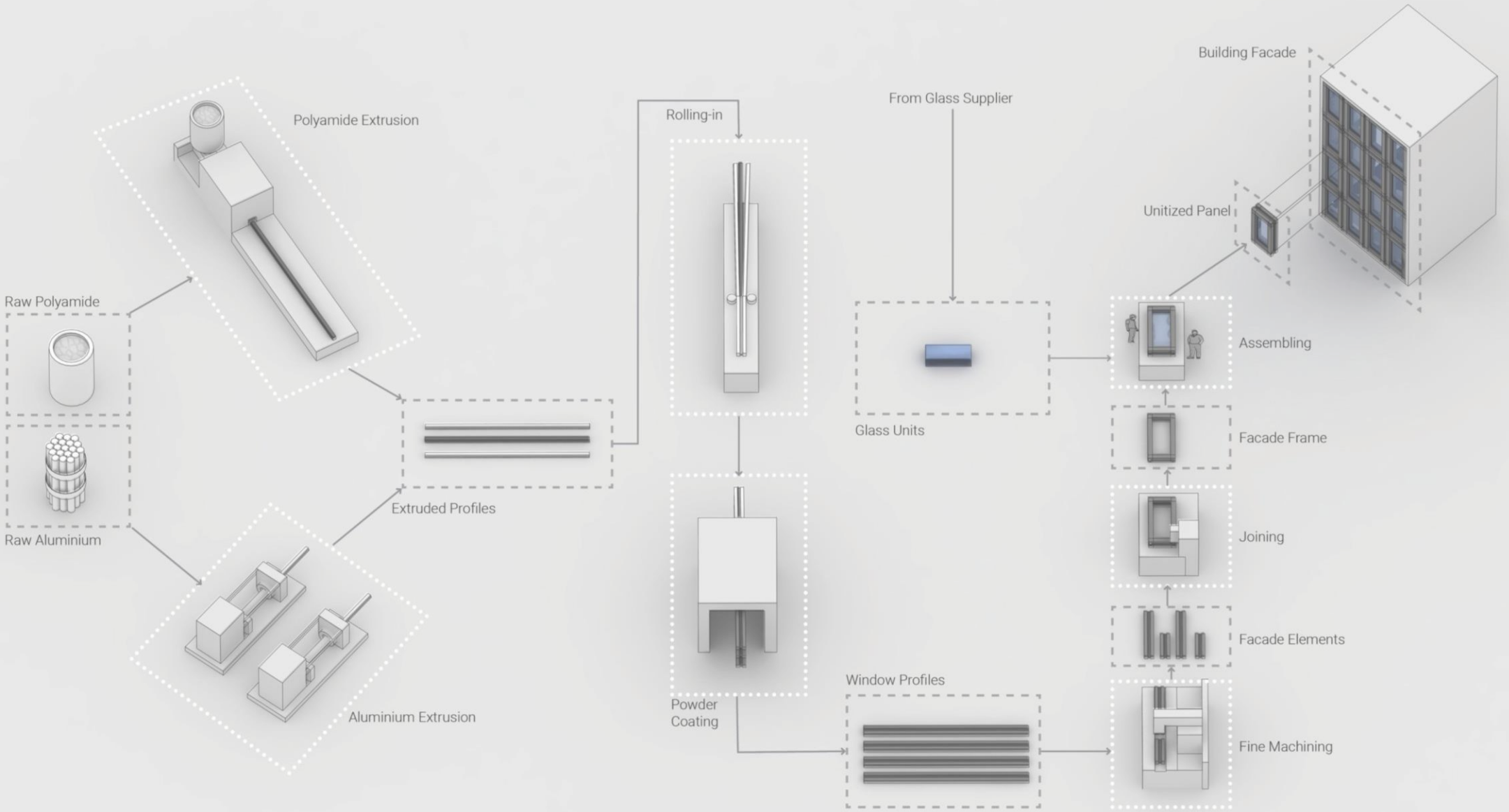

Product Levels

- Building Part
- Process
- Component
- Process
- Sub-Component
- Process
- Elements
- Process
- Products
- Process
- Process
- Material
- Processess
- Raw Material

Raw Material Manufacturers

System Manufacturers

System Suppliers

Facade Builders

Façade Maintanance

Polyamide Extrusion

Raw Polyamide

Raw Aluminium

Extruded Profiles

Aluminium Extrusion

Rolling-in

Powder Coating

From Glass Supplier

Glass Units

Window Profiles

Building Facade

Unitized Panel

Building Facade

Assembling

Facade Frame

Joining

Facade Elements

Fine Machining

Product Levels

- Building Part
- Process
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- Process
- Sub-Component
- Process
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- Process
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- Process
- Process
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Raw Material Manufacturers

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Window Profiles

Building Facade

Unitized Panel

Building Facade

Assembling

Facade Frame

Joining

Facade Elements

Fine Machining

Information Levels

L6_Building Part

Process

L5_Comp

Process

L4_Sub Comp

Process

L3_Elements

Process

L2_Products

Process

L1_Material

Process

L0_Raw Material

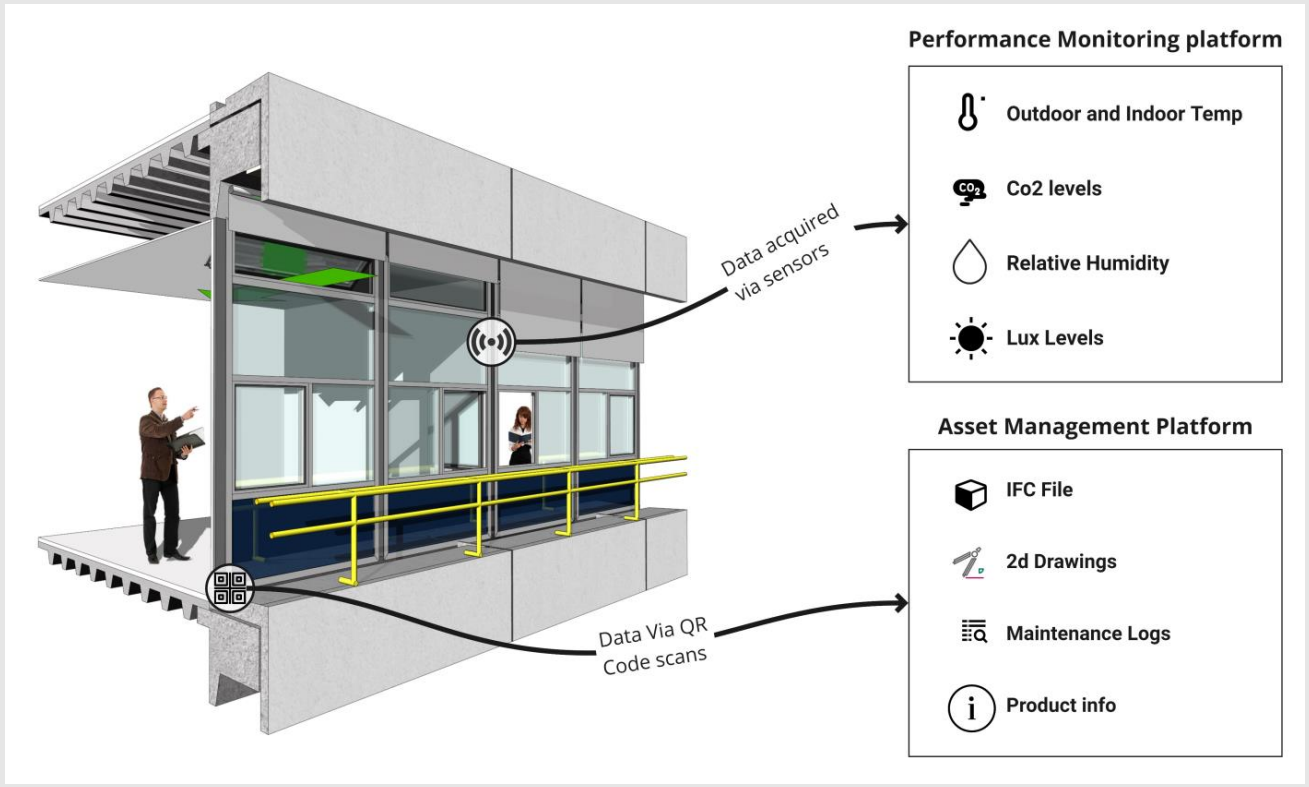
Raw Material Manufacturers

System Manufacturers

System Suppliers

Facade Builders

Façade Maintanance



Performance Monitoring platform

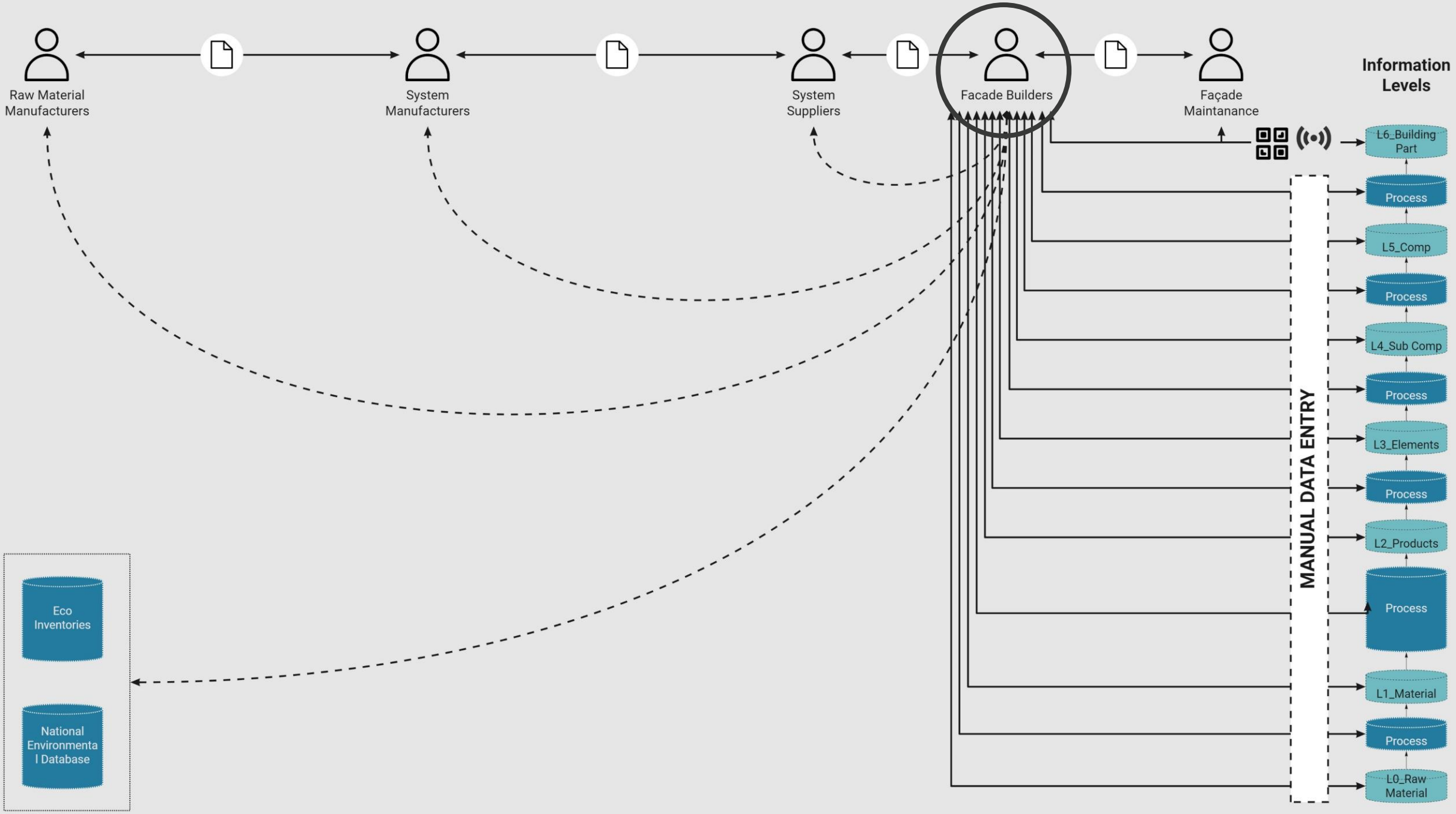
- Outdoor and Indoor Temp
- Co2 levels
- Relative Humidity
- Lux Levels

Asset Management Platform

- IFC File
- 2d Drawings
- Maintenance Logs
- Product info

Information Levels

- L6_Building Part
- Process
- L5_Comp
- Process
- L4_Sub Comp
- Process
- L3_Elements
- Process
- L2_Products
- Process
- L1_Material
- Process
- L0_Raw Material


Raw Material Manufacturers
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System Suppliers
Facade Builders
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Information Levels
L6_Building Part
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L4_Sub Comp
Process
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Process
L2_Products
Process
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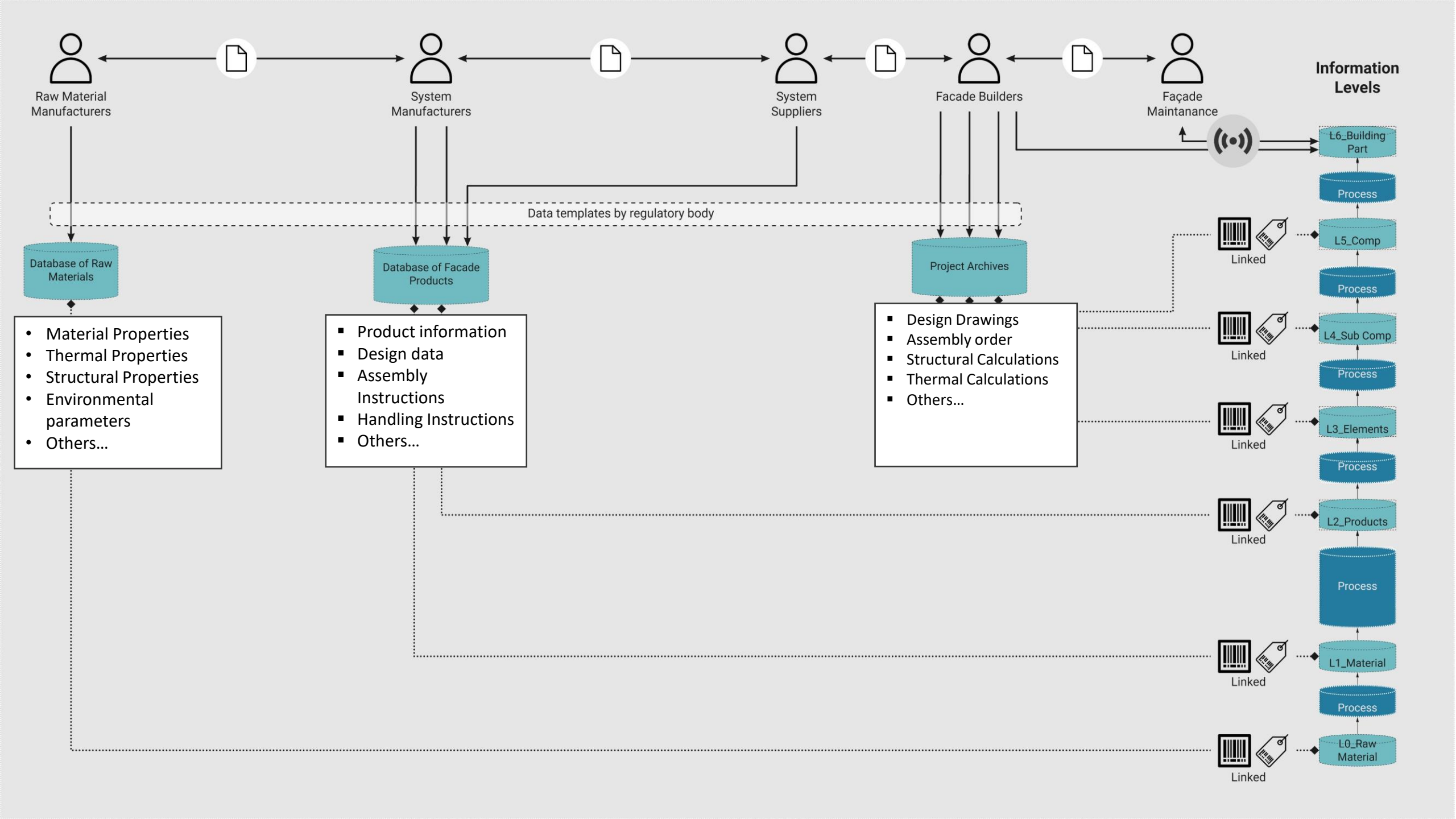
Process
L0_Raw Material
MANUAL DATA ENTRY
Eco Inventories
National Environmental Database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L4_Sub Comp
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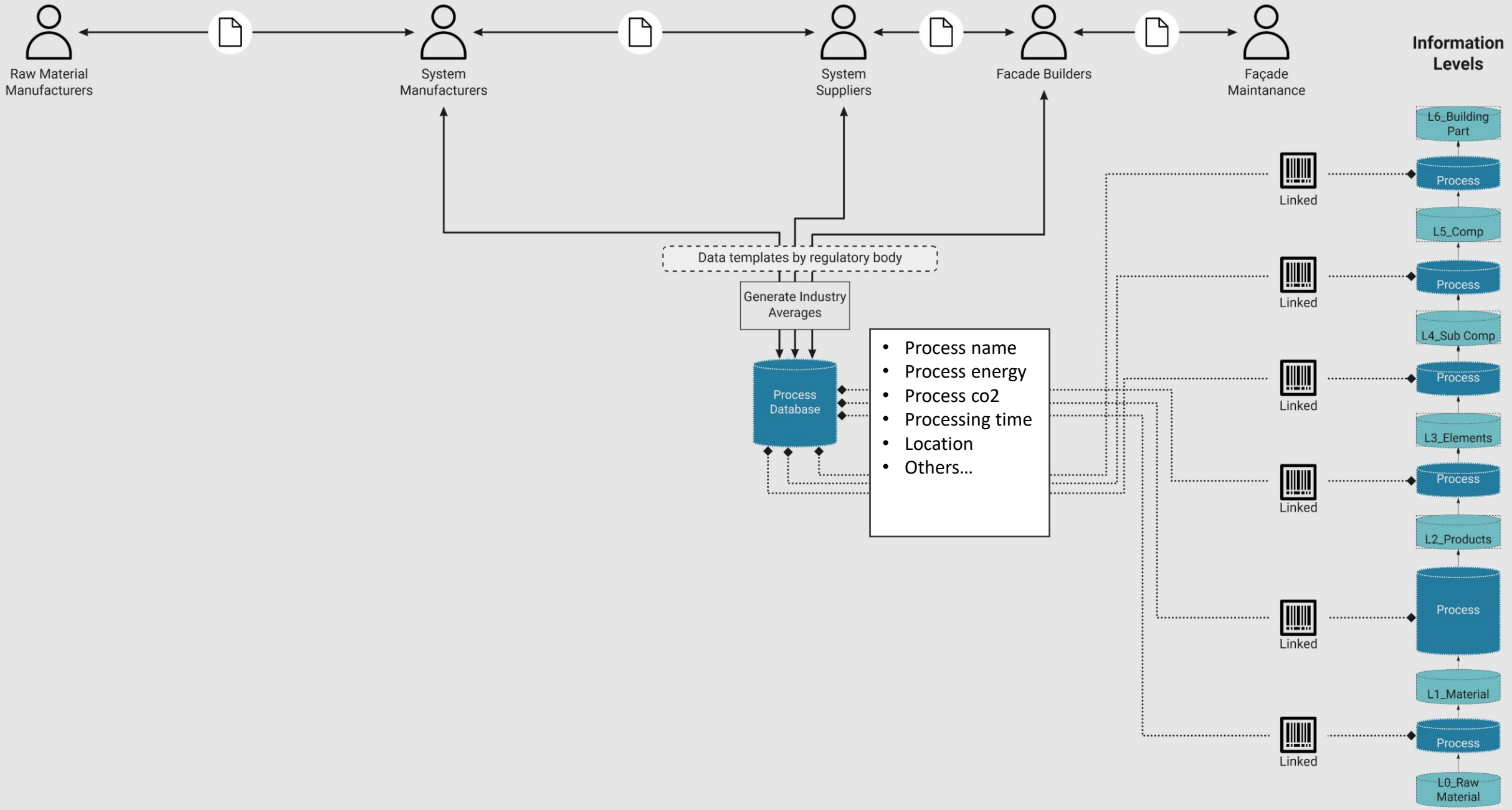
L3_Elements
Process
L2_Products
Process
L1_Material
Process
L0_Raw Material
Data templates by regulatory body
Database of Raw Materials
Database of Facade Products
Project Archives
Linked
Linked
Linked
Linked
Linked
• Material Properties
• Thermal Properties
• Structural Properties
• Environmental parameters
• Others…
▪ Product information
▪ Design data
▪ Assembly Instructions
▪ Handling Instructions
▪ Others…
▪ Design Drawings
▪ Assembly order
▪ Structural Calculations
▪ Thermal Calculations
▪ Others…


Raw Material Manufacturers
System Manufacturers
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Facade Builders
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Data templates by regulatory body
Generate Industry Averages
Process Database
Process name
Process energy
Process co2
Processing time
Location
Others…
Linked
Linked
Linked
Linked
Linked
Information Levels
L6_Building Part
Process
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Process
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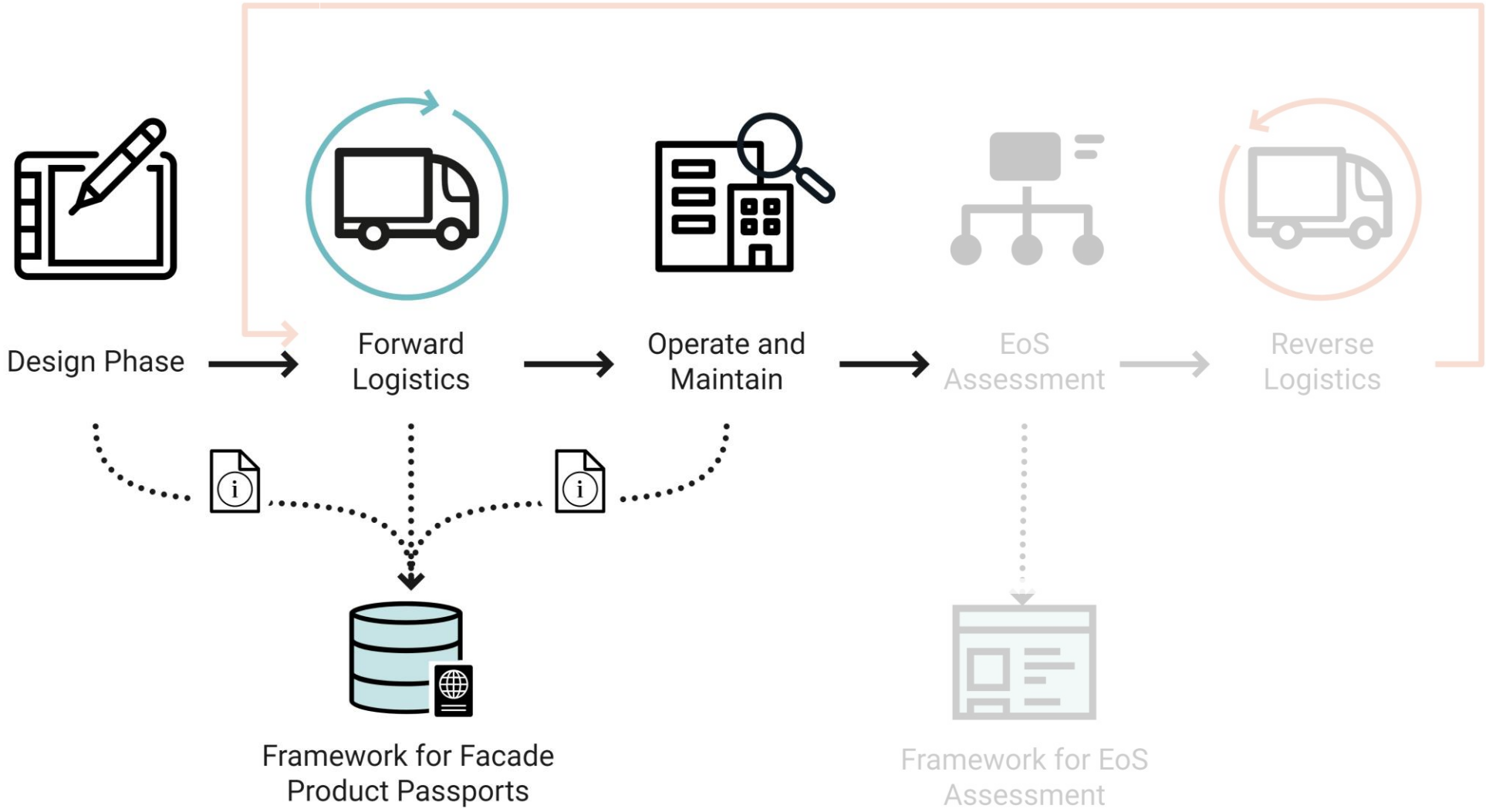
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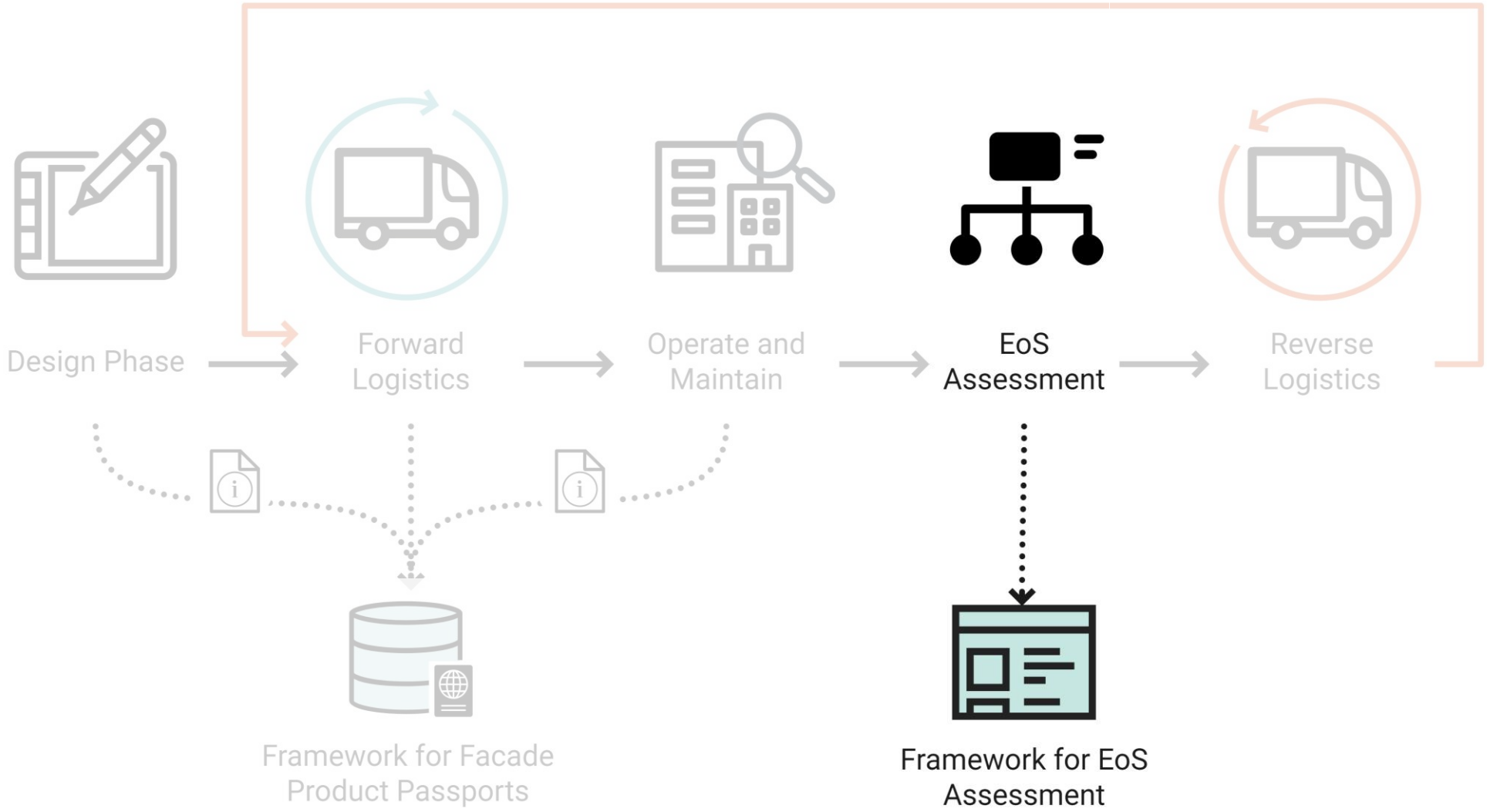
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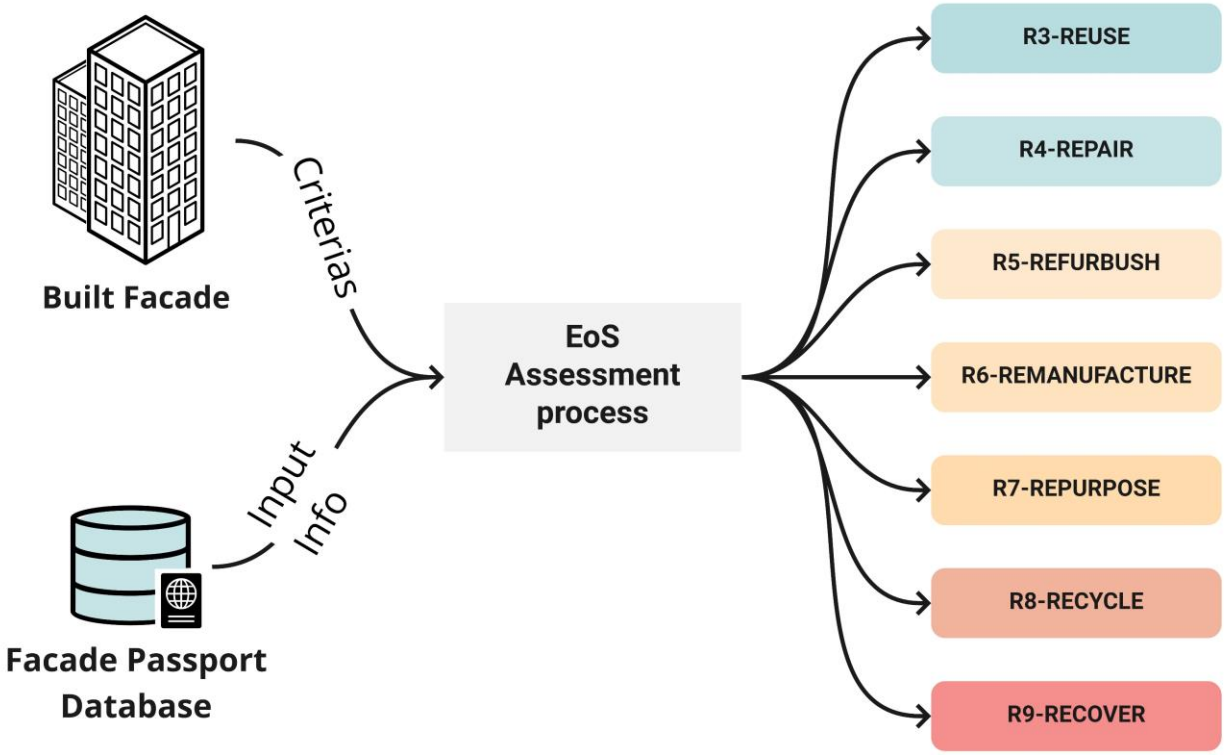
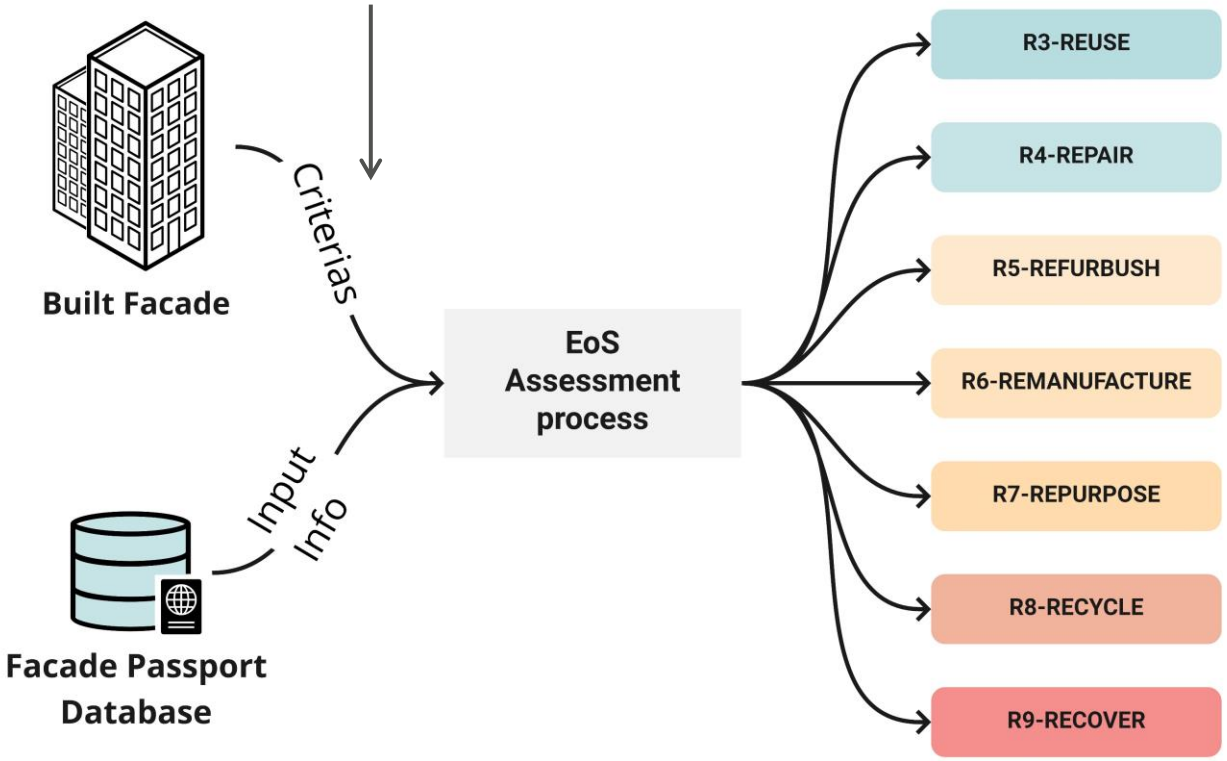
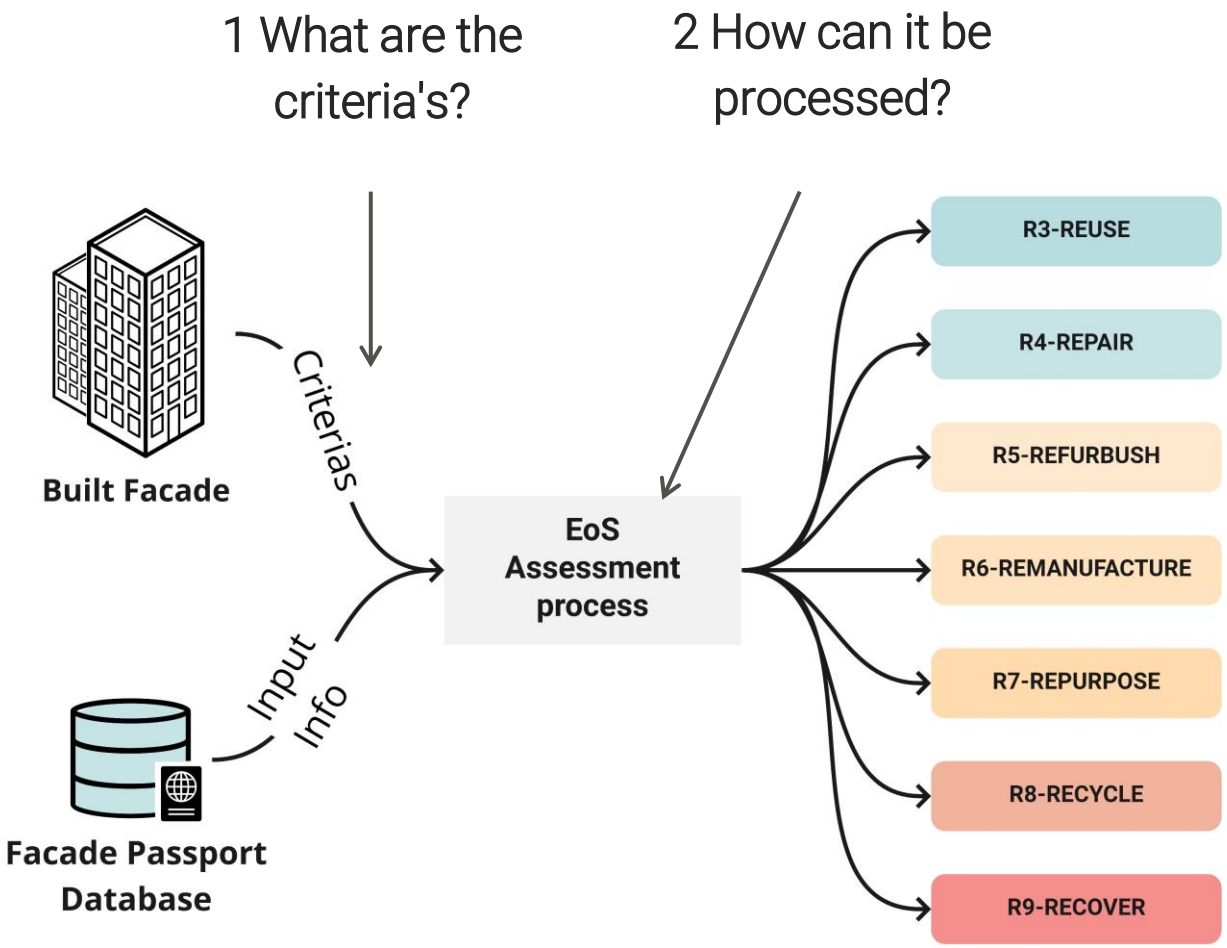

Built Facade
Criterias
Input Info
Facade Passport Database
EoS Assessment process
R3-REUSE
R4-REPAIR
R5-REFURBUSH
R6-REMANUFACTURE
R7-REPURPOSE
R8-RECYCLE
R9-RECOVER

1 What are the criteria's?




1 What are the criteria's?
2 How can it be processed?
Built Facade
Criterias
Input Info
Facade Passport Database
EoS Assessment process
R3-REUSE
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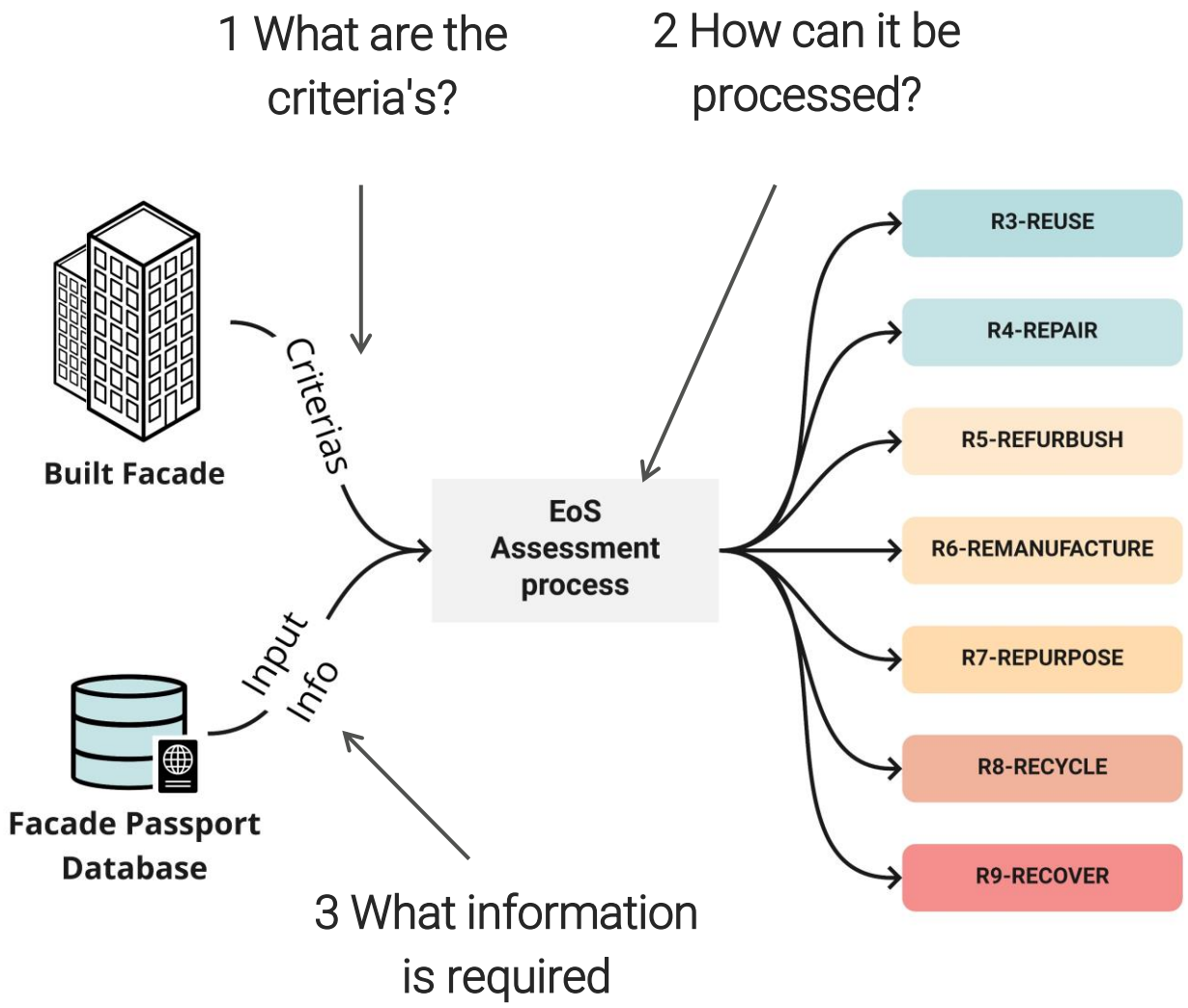
1 What are the criteria's?
2 How can it be processed?
Built Facade
Criterias
Input Info
EoS Assessment process
Facade Passport Database
3 What information is required
R3-REUSE
R4-REPAIR
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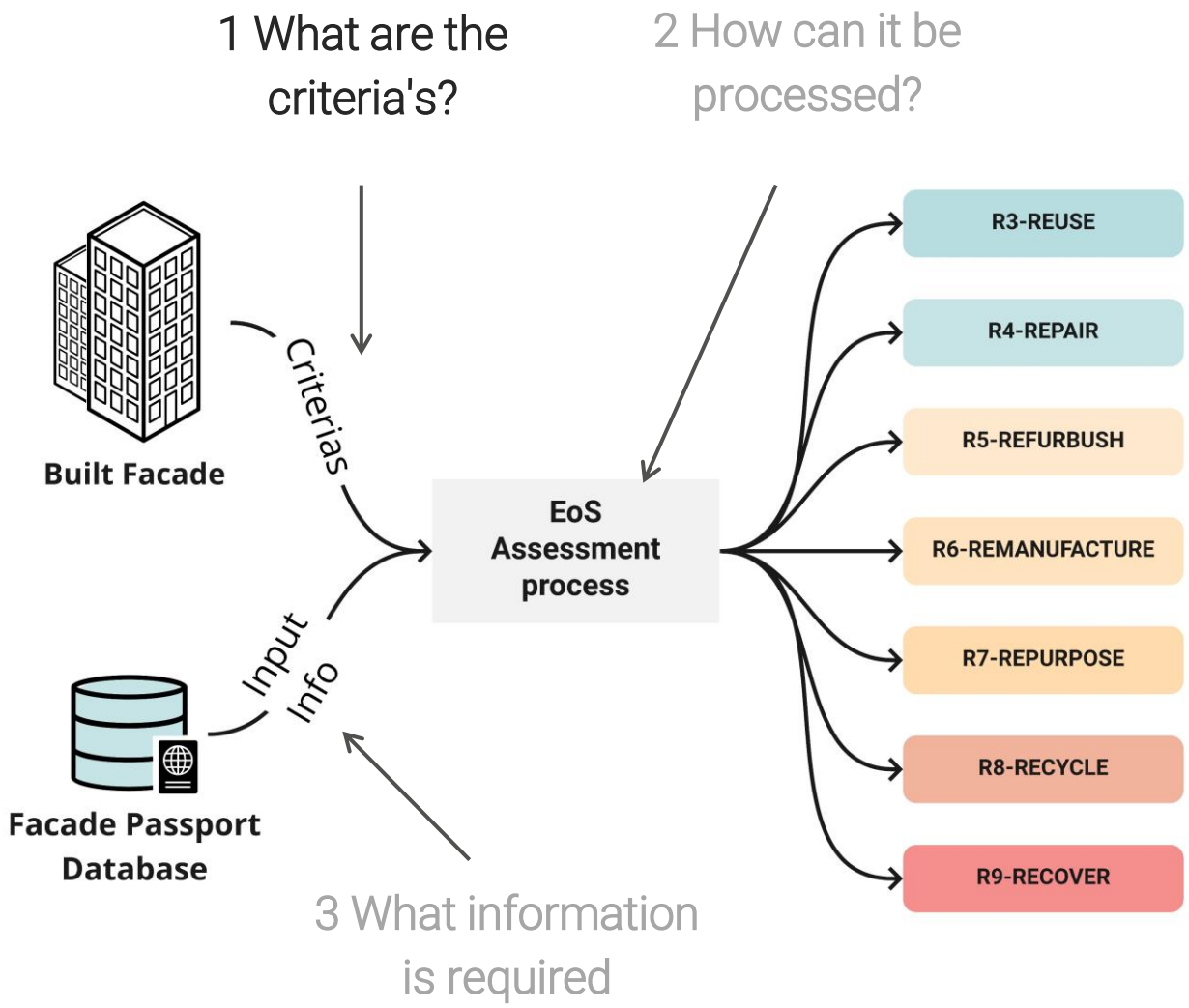
R6-REMANUFACTURE
R7-REPURPOSE
R8-RECYCLE
R9-RECOVER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R3-REUSE
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R7-REPURPOSE
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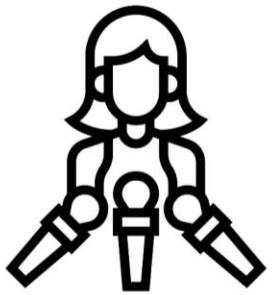
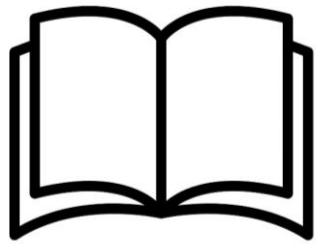
R9-RECOVER
3 What information is required



Interviews

Reusability Criteria

Common Defects



Literature

Morphological Matrix

DfD

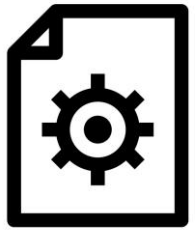
Detachability Index

NEN 2767

Design Criteria for circular facades

Assessment of facades

Residual Value	Connection Type	Areas	Modular Sizing	Flexibility	Connection Points
Recyclability	Component Access	Typology	Grid Geometry	Horizontal Grid Span	Facade Position
Façade Performances	Connection Access	Toxicity	Tolerances	Grid Size	Vertical Grid Span
Defects	Disassembly Direction	Structural System	Quantities	Grid Modularity	Crossection Geometry



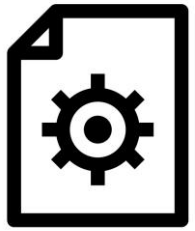
Automated

Conditional Values	Conditional Criterias	Descriptive Values	Descriptive Criterias

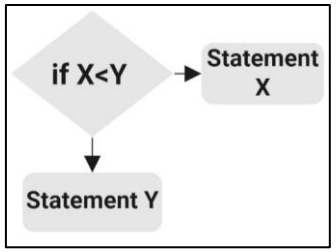
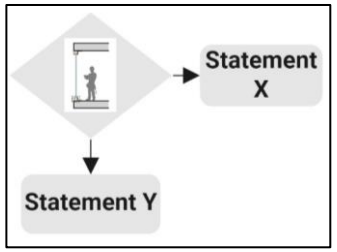
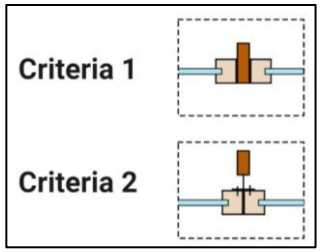
Objective Criterias → increasing level of subjectivity → Subjective Criterias

Residual Value	Connection Type	Areas	Modular Sizing	Flexibility	Connection Points
Recyclability	Component Access	Typology	Grid Geometry	Horizontal Grid Span	Facade Position
Façade Performances	Connection Access	Toxicity	Tolerances	Grid Size	Vertical Grid Span
Defects	Disassembly Direction	Structural System	Quantities	Grid Modularity	Crossection Geometry

Manual



Automated

Conditional Values	Conditional Criterias	Descriptive Values	Descriptive Criterias
		Criteria 1 = X Criteria 2 = Y Criteria 3 = Z	

Objective Criterias → increasing level of subjectivity → Subjective Criterias

Residual Value	Connection Type	Areas	Modular Sizing	Flexibility	Connection Points
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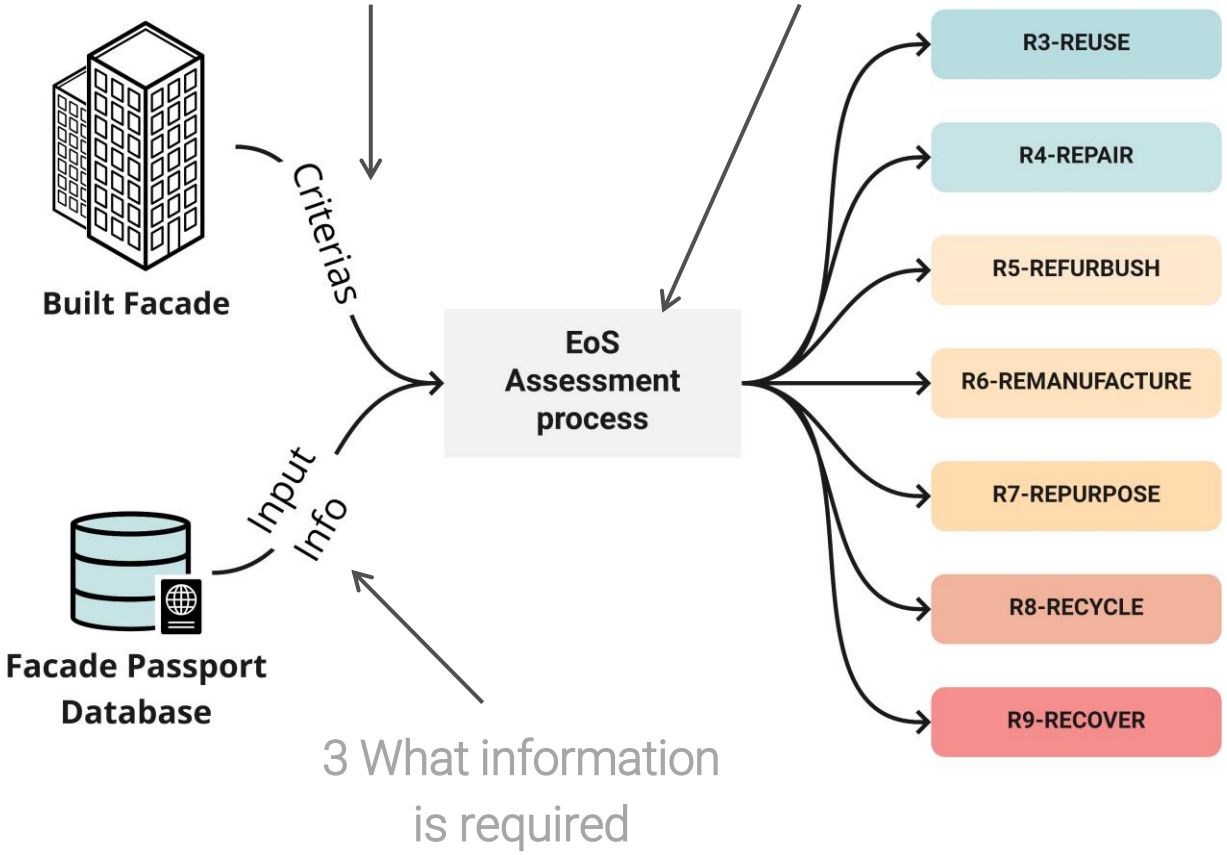
Defects	Disassembly Direction	Structural System	Quantities	Grid Modularity	Crossection Geometry

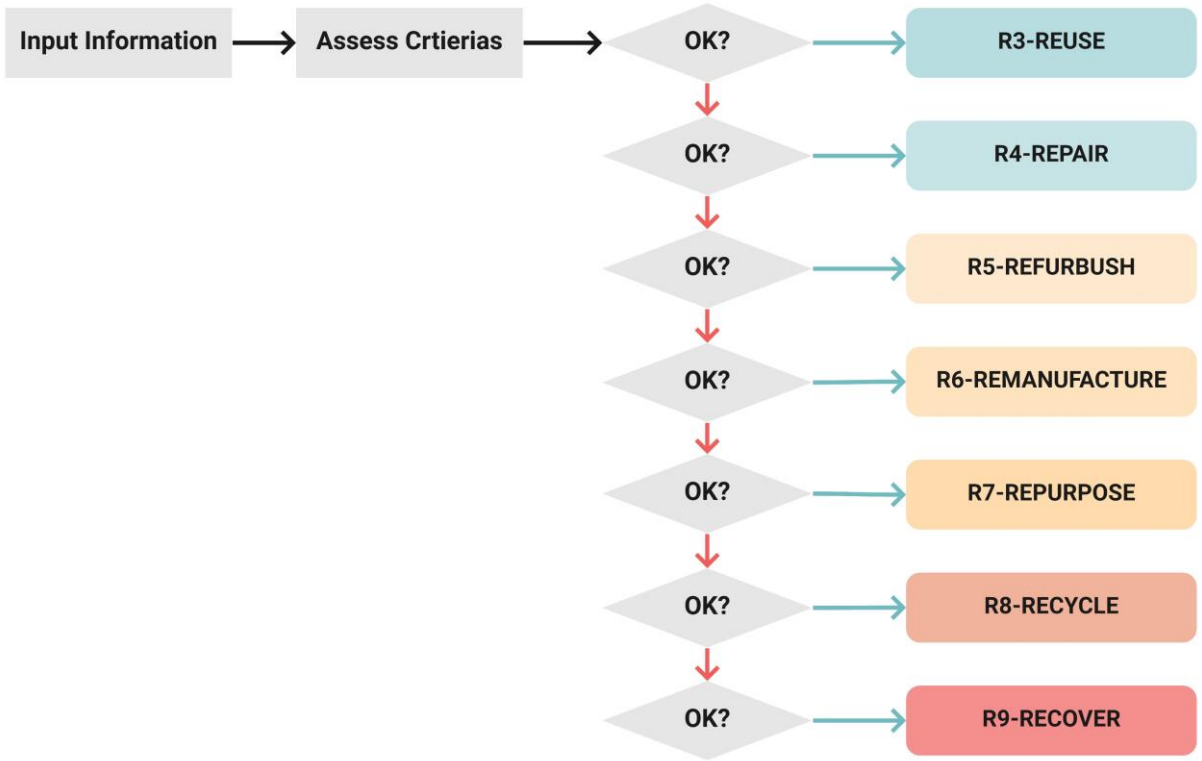
Manual

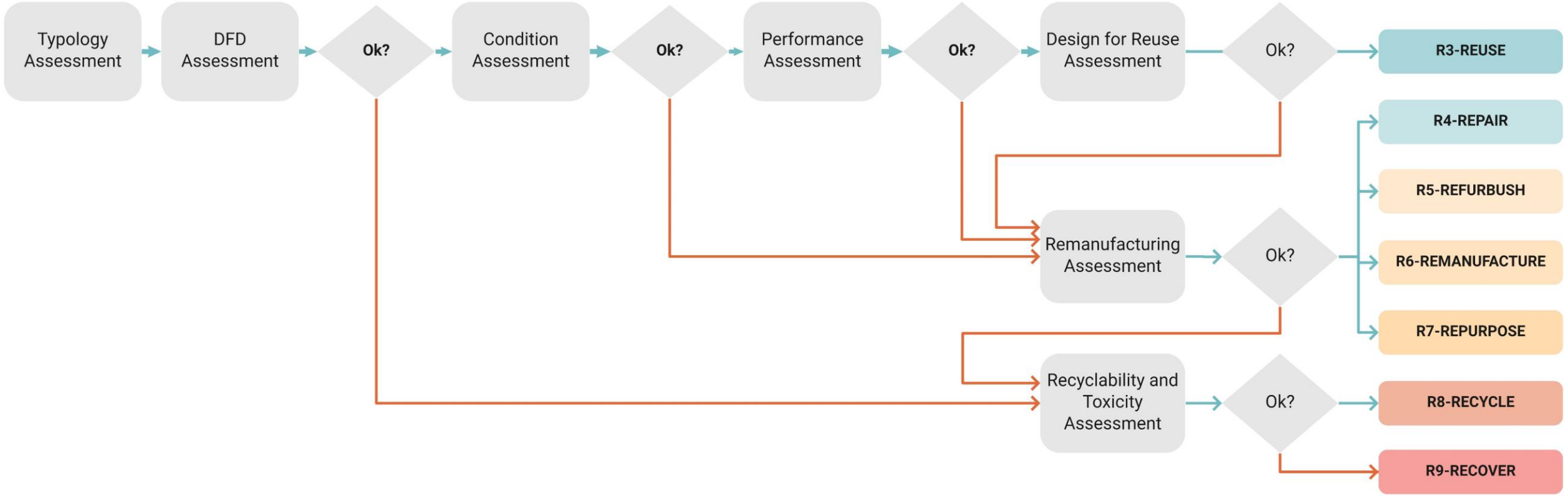
1 What are the criteria's?

2 How can it be processed?



3 What information is required


Input Information
Assess Crtierias
OK?
R3-REUSE
OK?
R4-REPAIR
OK?
R5-REFURBUSH
OK?
R6-REMANUFACTURE
OK?
R7-REPURPOSE
OK?
R8-RECYCLE
OK?
R9-RECOVER


Typology Assessment
DFD Assessment
Ok?
Condition Assessment
Ok?
Performance Assessment
Ok?
Design for Reuse Assessment
Ok?
R3-REUSE
R4-REPAIR
R5-REFURBUSH
Remanufacturing Assessment
Ok?
R6-REMANUFACTURE
R7-REPURPOSE
Recyclability and Toxicity Assessment
Ok?
R8-RECYCLE
R9-RECOVER

Typology Assessment

DFD Assessment

Condition Assessment

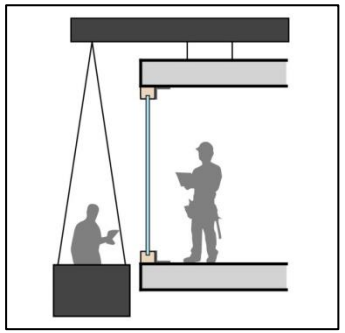
Performance Assessment

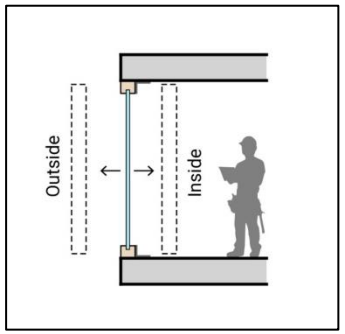
Design for Reuse Assessment

Remanufacturing Assessment

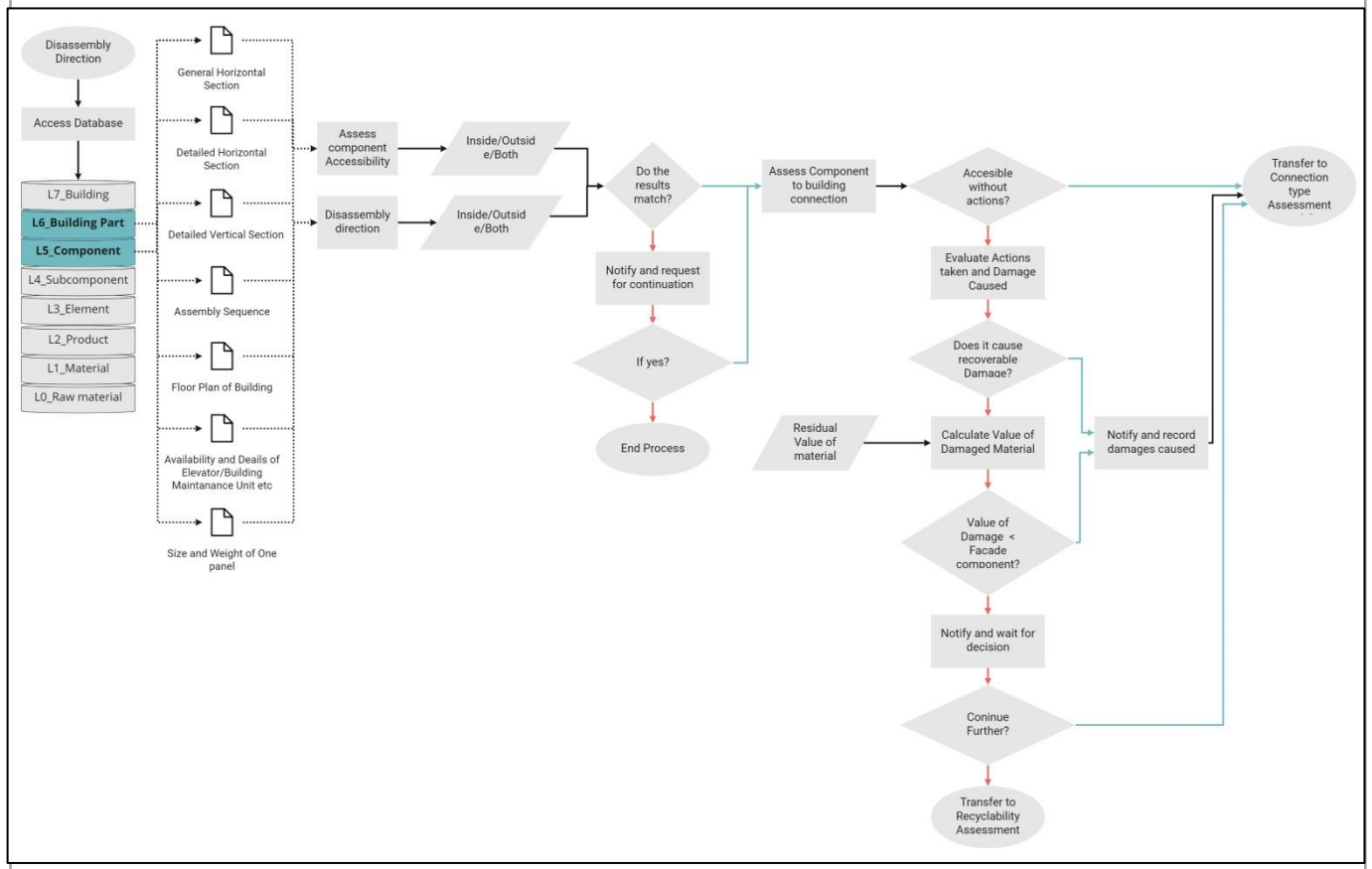
Recyclability and Toxicity Assessment

Criterias

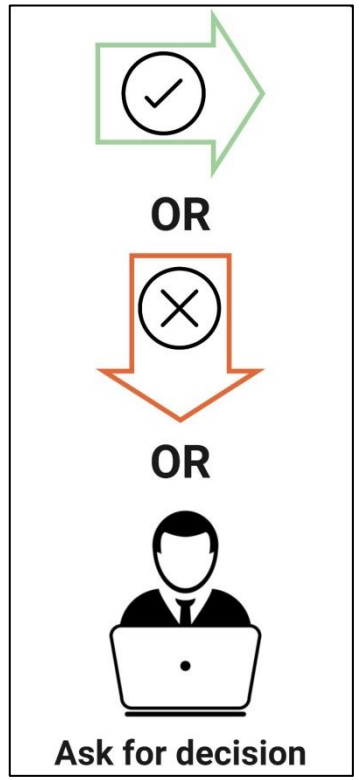




Process



Results

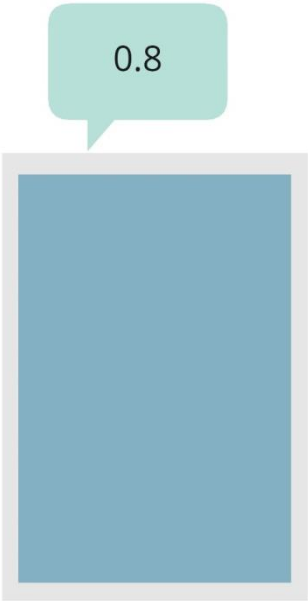


Criterias

- SURFACE DEFECTS
- STRUCTURAL DEFECTS
- PERFORMATIVE DEFECTS

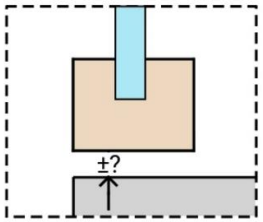
Process

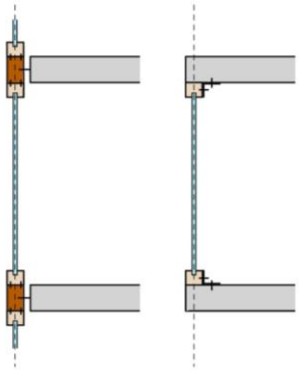
Results



Typology Assessment | DFD Assessment | Condition Assessment | Performance Assessment | **Design for Reuse Assessment** | **Remanufacturing Assessment** | Recyclability and Toxicity Assessment

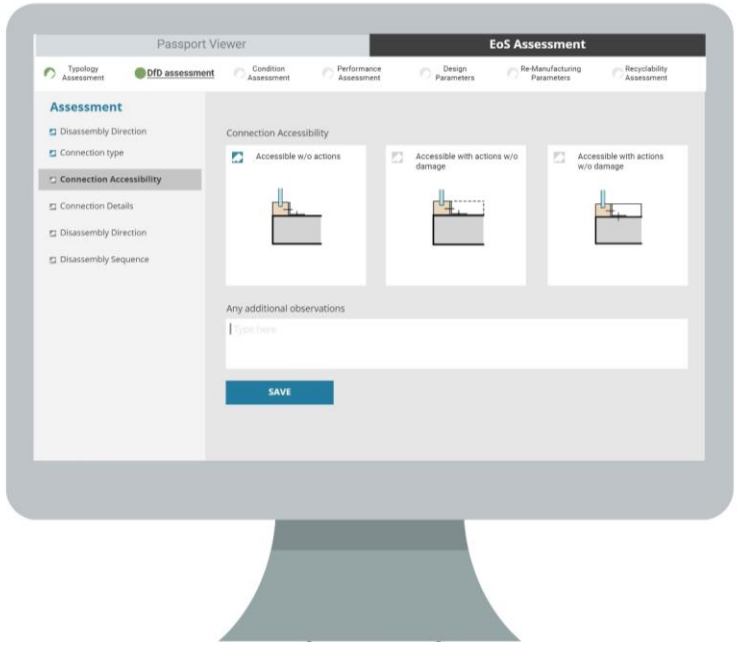
Criterias



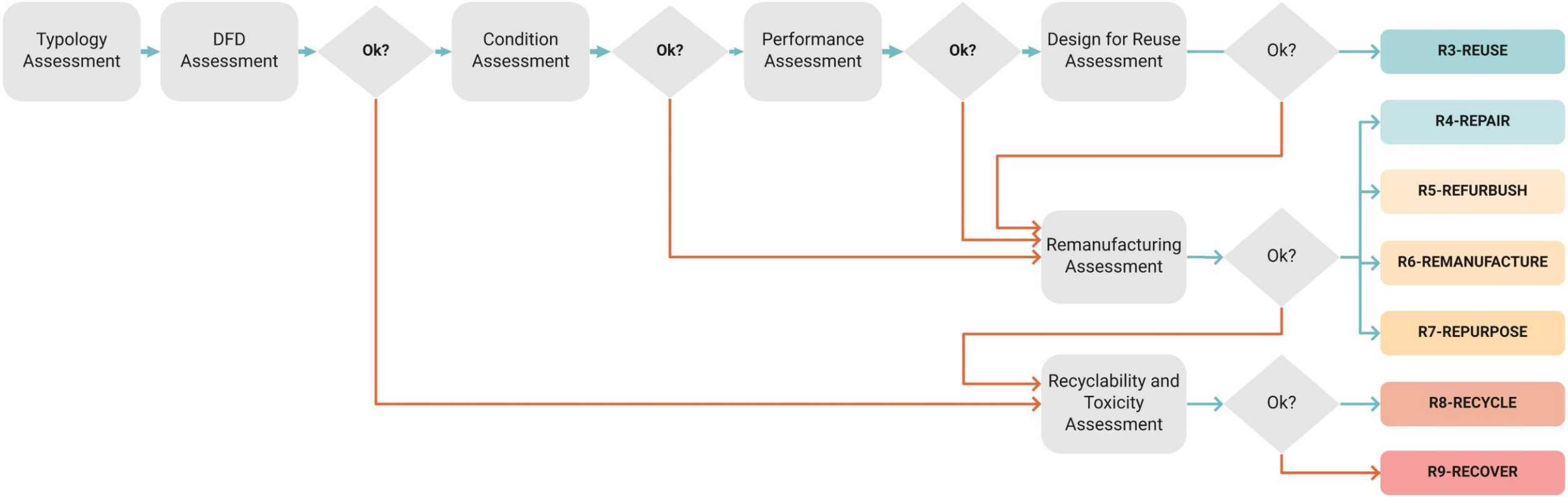


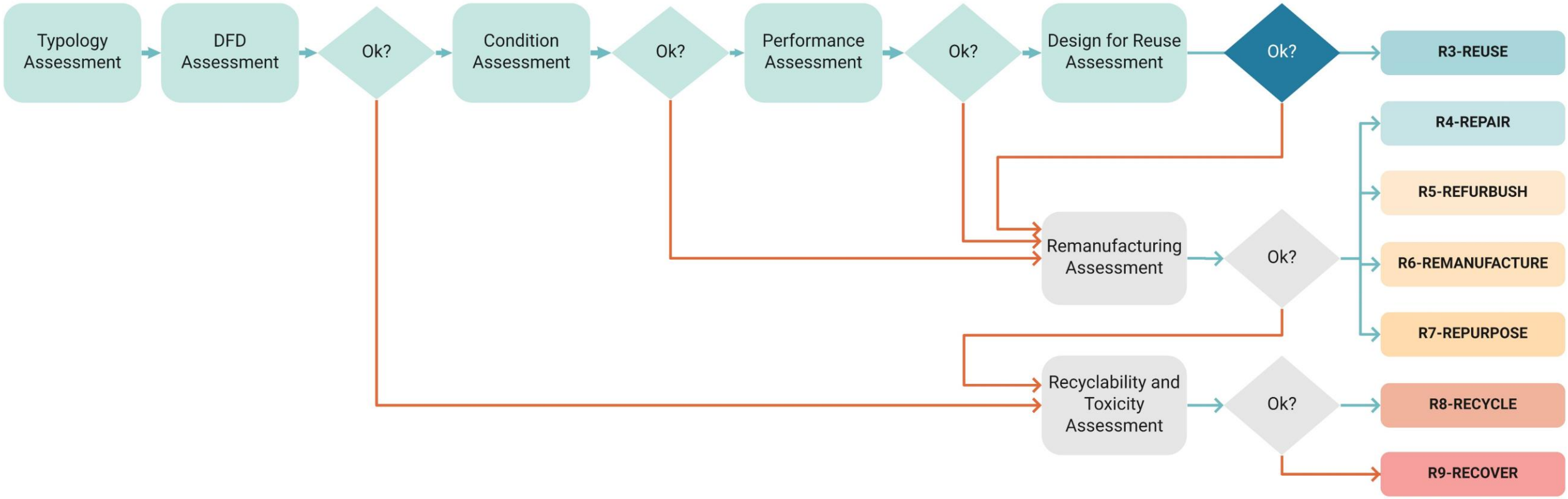
Process

Display Criteria and relevant Information



Results


Typology Assessment
DFD Assessment
Ok?
Condition Assessment
Ok?
Performance Assessment
Ok?
Design for Reuse Assessment
Ok?
R3-REUSE
R4-REPAIR
R5-REFURBUSH
Remanufacturing Assessment
Ok?
R6-REMANUFACTURE
R7-REPURPOSE
Recyclability and Toxicity Assessment
Ok?
R8-RECYCLE
R9-RECOVER


Typology Assessment
DFD Assessment
Ok?
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Ok?
Performance Assessment
Ok?
Design for Reuse Assessment
Ok?
R3-REUSE
R4-REPAIR
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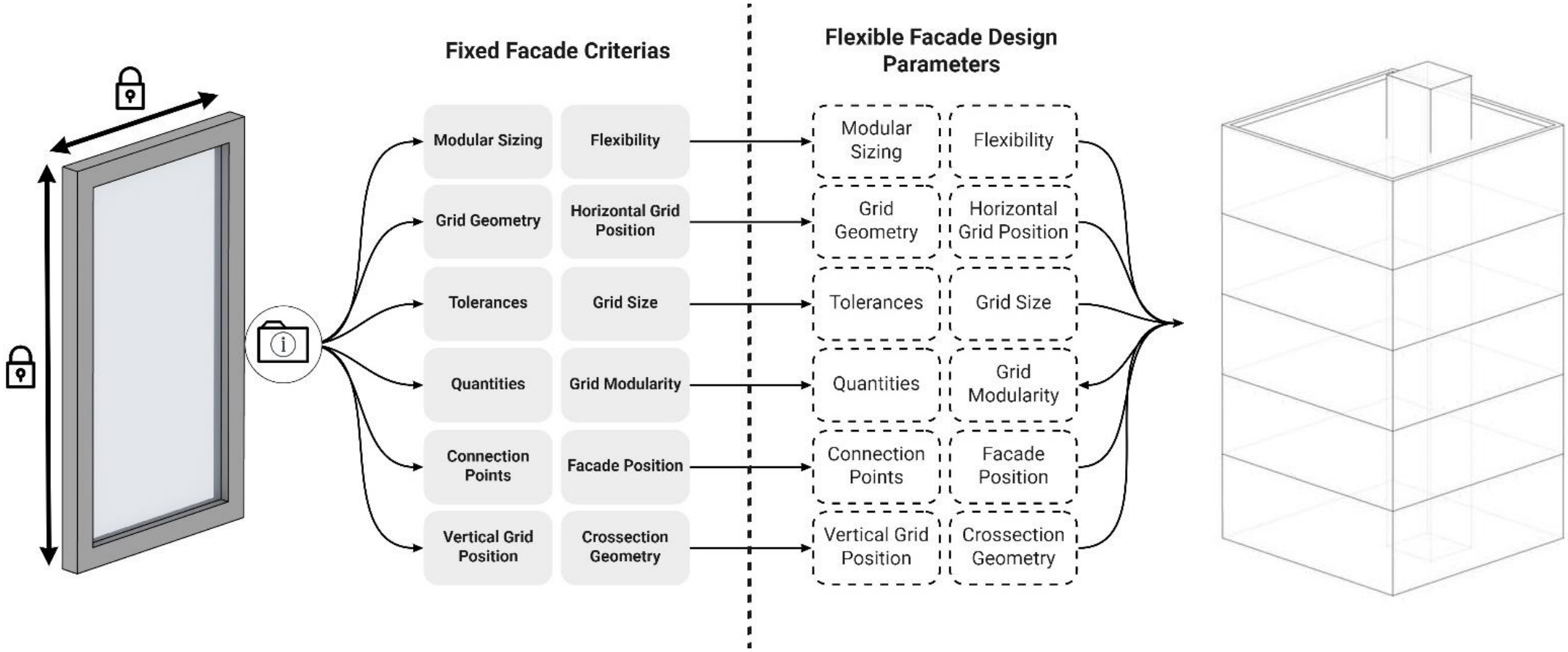
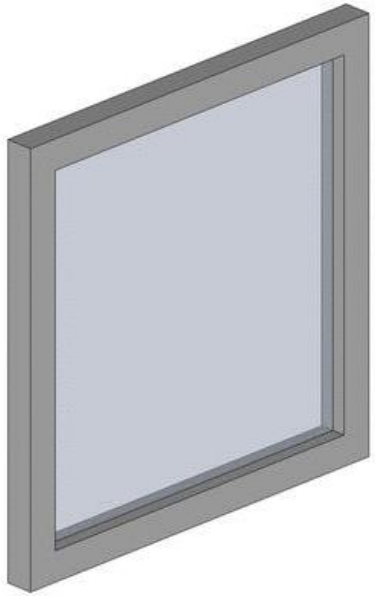
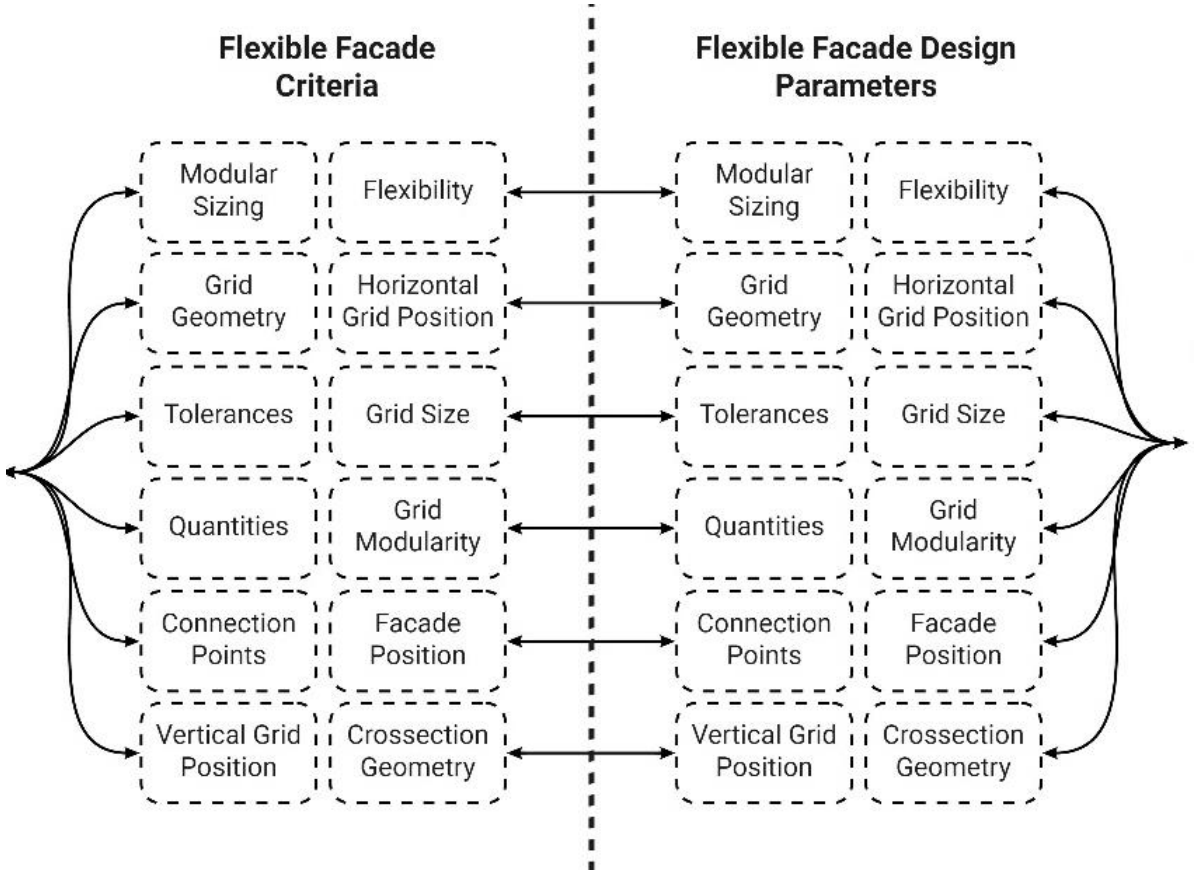
Remanufacturing Assessment
Ok?
R6-REMANUFACTURE
R7-REPURPOSE
Recyclability and Toxicity Assessment
Ok?
R8-RECYCLE
R9-RECOVER

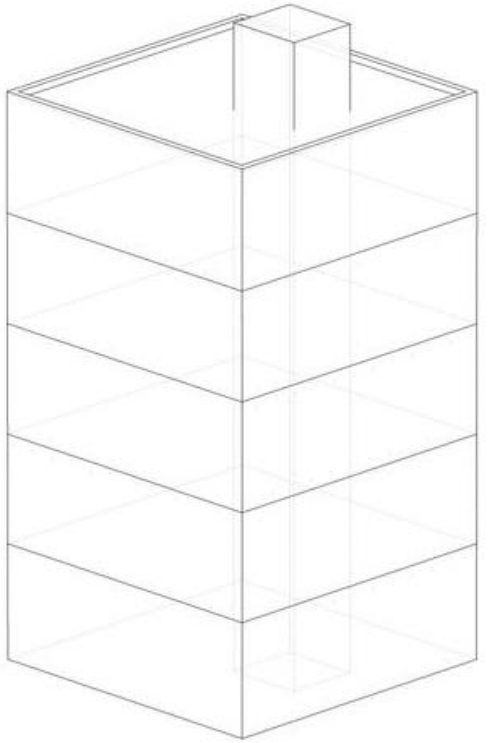
Building Matched to the Facade



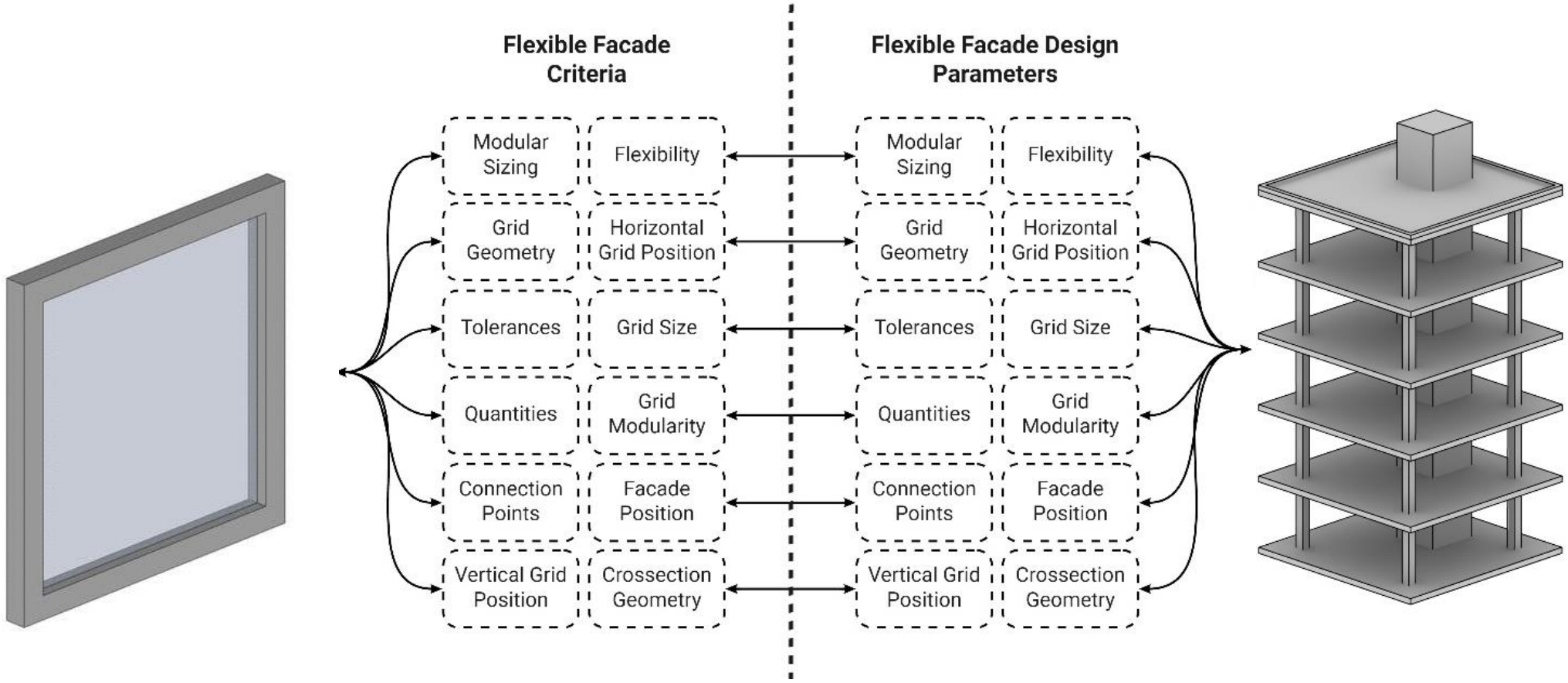
Two way Matching

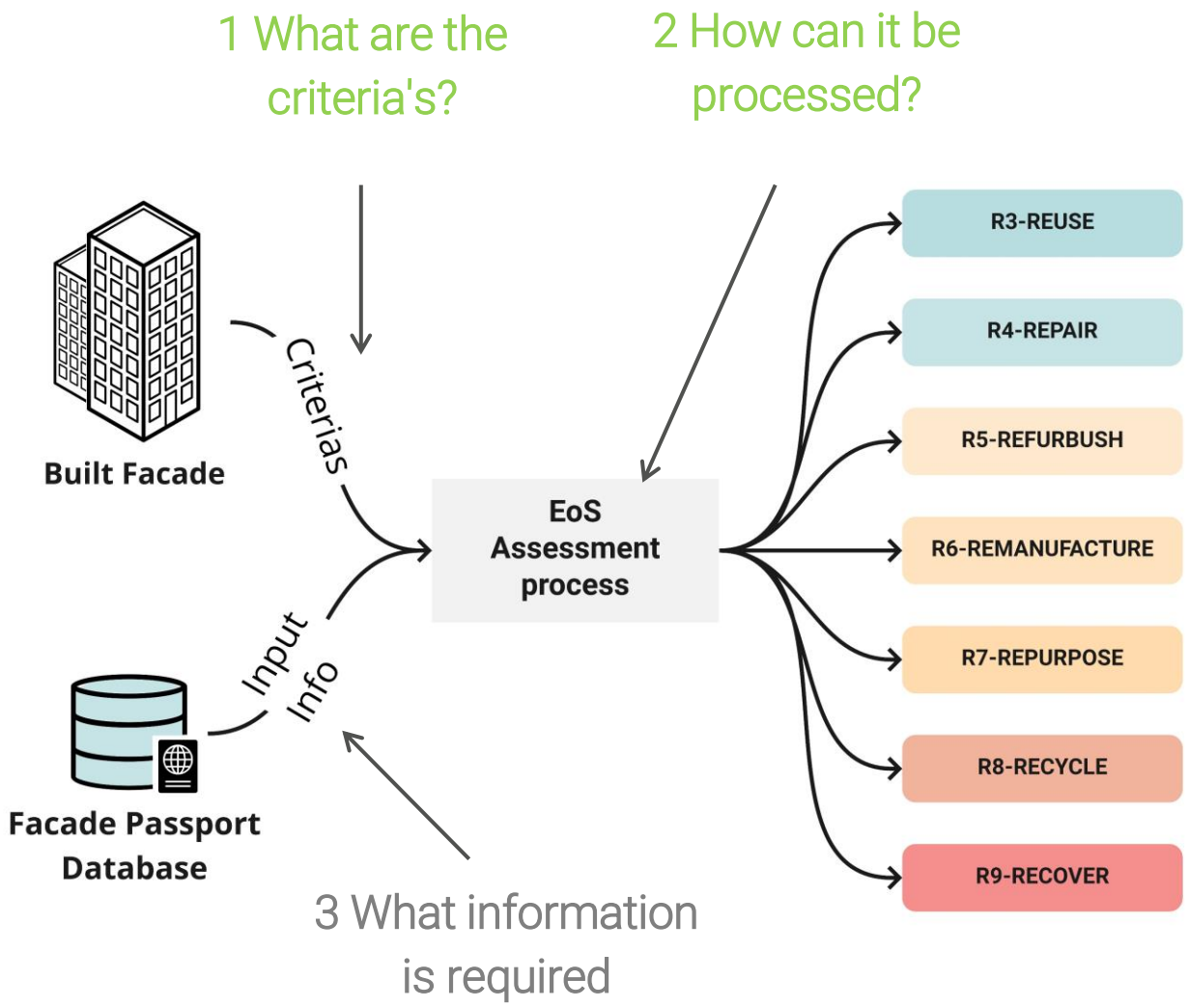


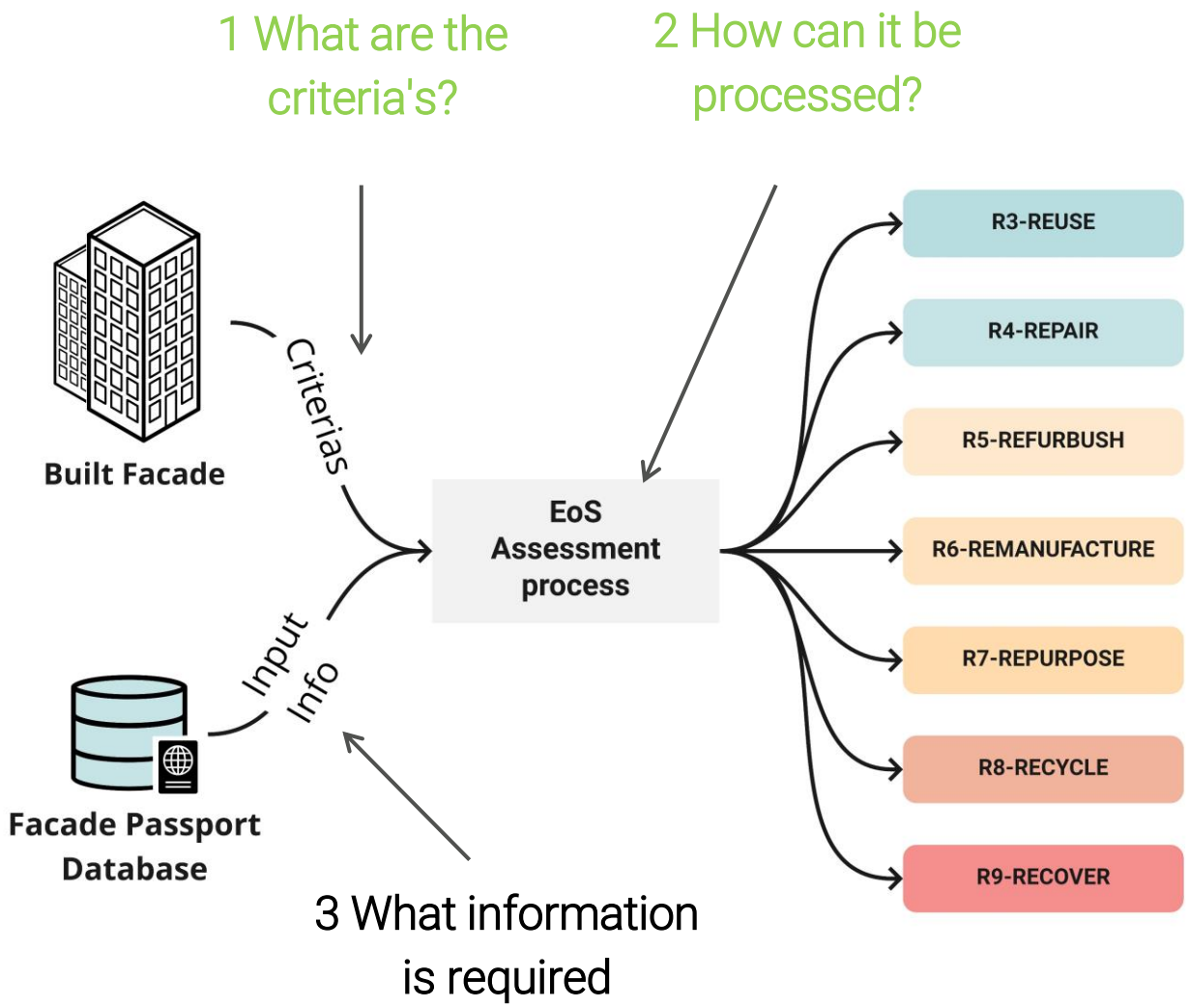




Façade Matched to building




1 What are the criteria's?
2 How can it be processed?
Built Facade
Criterias
Input Info
Facade Passport Database
EoS Assessment process
R3-REUSE
R4-REPAIR
R5-REFURBUSH
R6-REMANUFACTURE
R7-REPURPOSE
R8-RECYCLE
R9-RECOVER
3 What information is required


1 What are the criteria's?
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Built Facade
Criterias
Input Info
Facade Passport Database
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R3-REUSE
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R5-REFURBUSH
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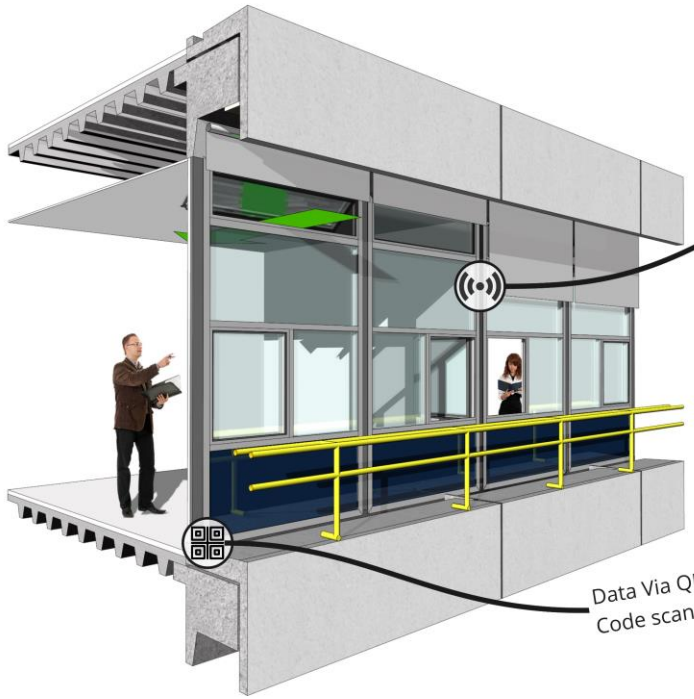
R7-REPURPOSE
R8-RECYCLE
R9-RECOVER
3 What information is required

Demonstrations

Source: Section: Alkondor; Photographs: TU Delft

Google

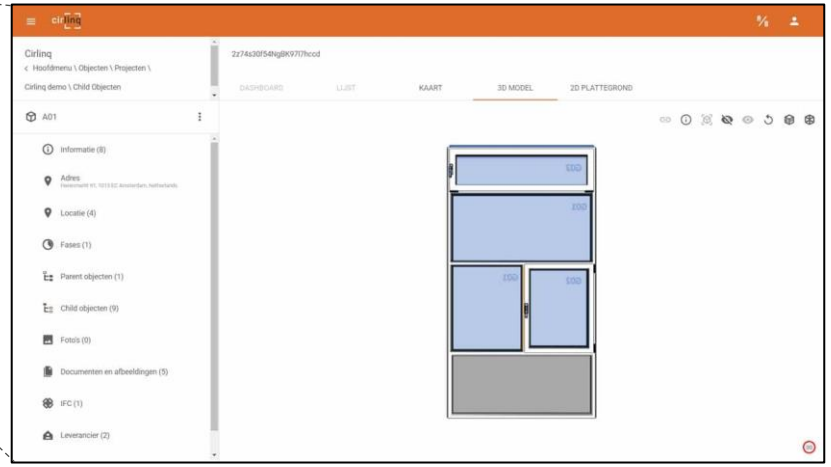


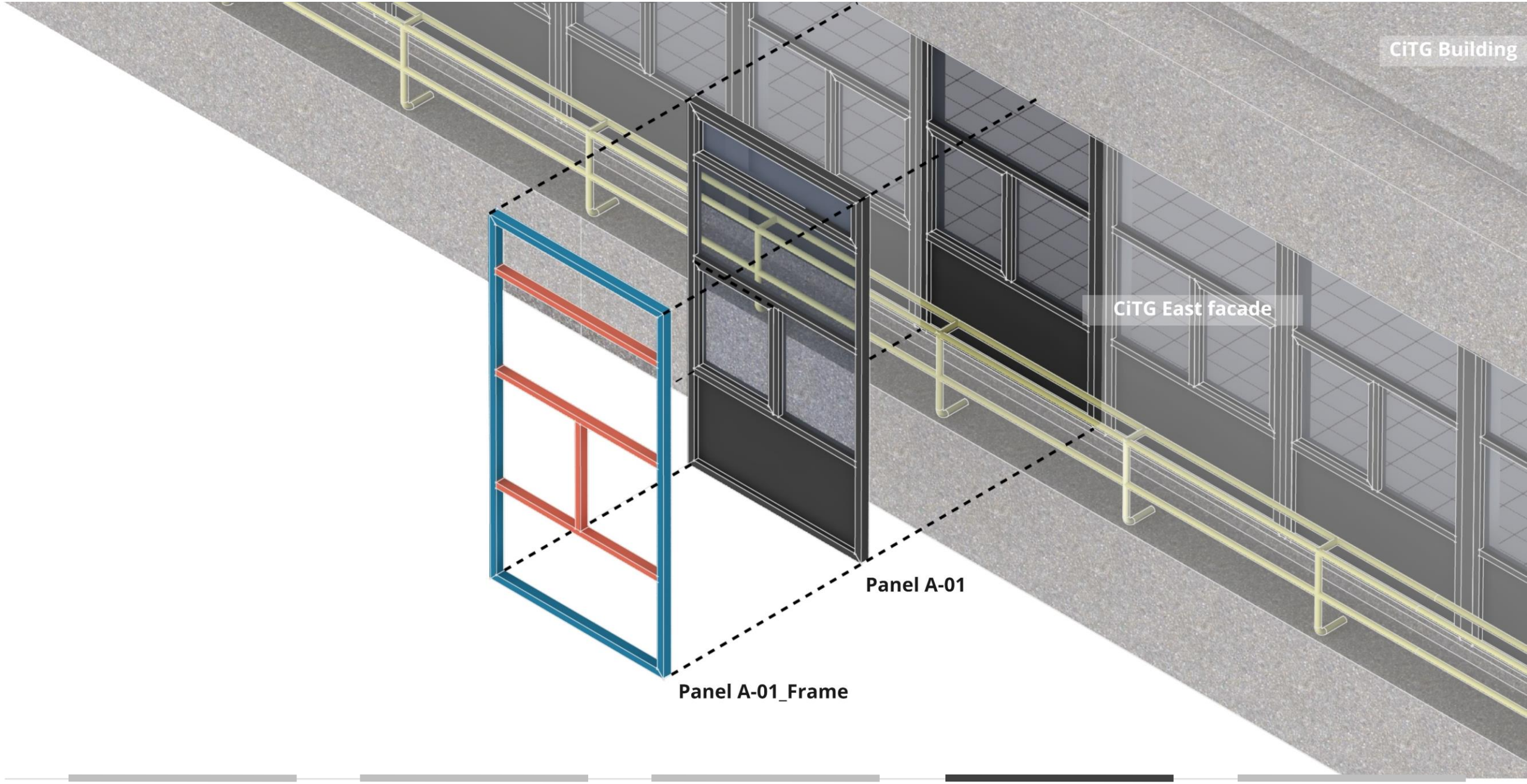
Performance Monitoring platform

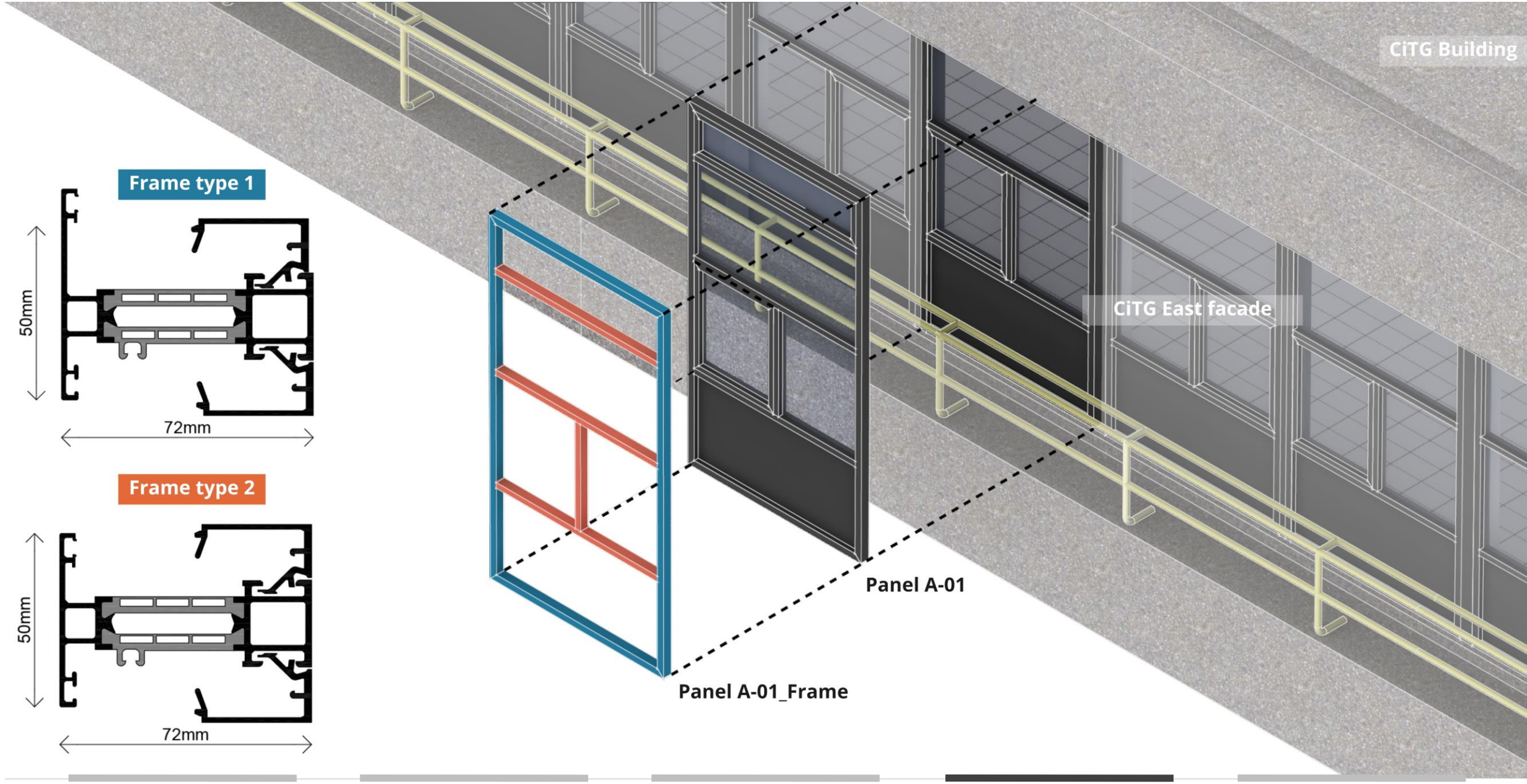
- Outdoor and Indoor Temp
- Co2 levels
- Relative Humidity
- Lux Levels

Asset Management Platform

- IFC File
- 2d Drawings
- Maintenance Logs
- Product info

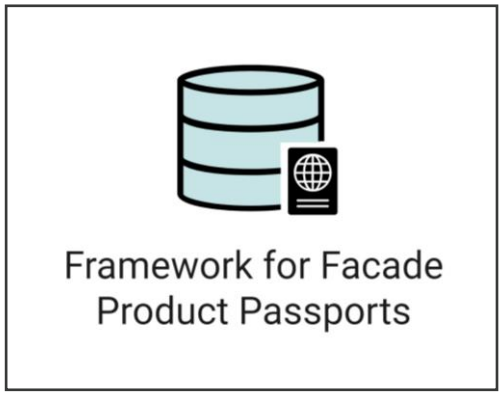


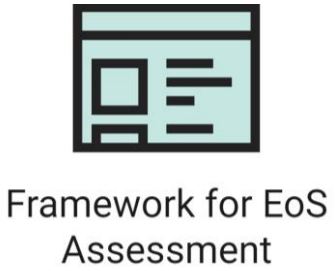

CiTG Building
CiTG East facade
Panel A-01
Panel A-01_Frame



Frame type 1

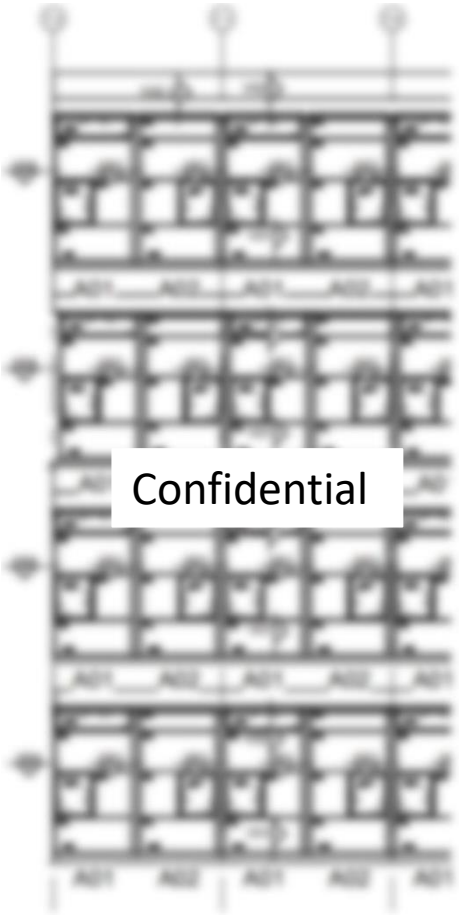
Frame type 2


Framework for Facade
Product Passports


Framework for EoS
Assessment

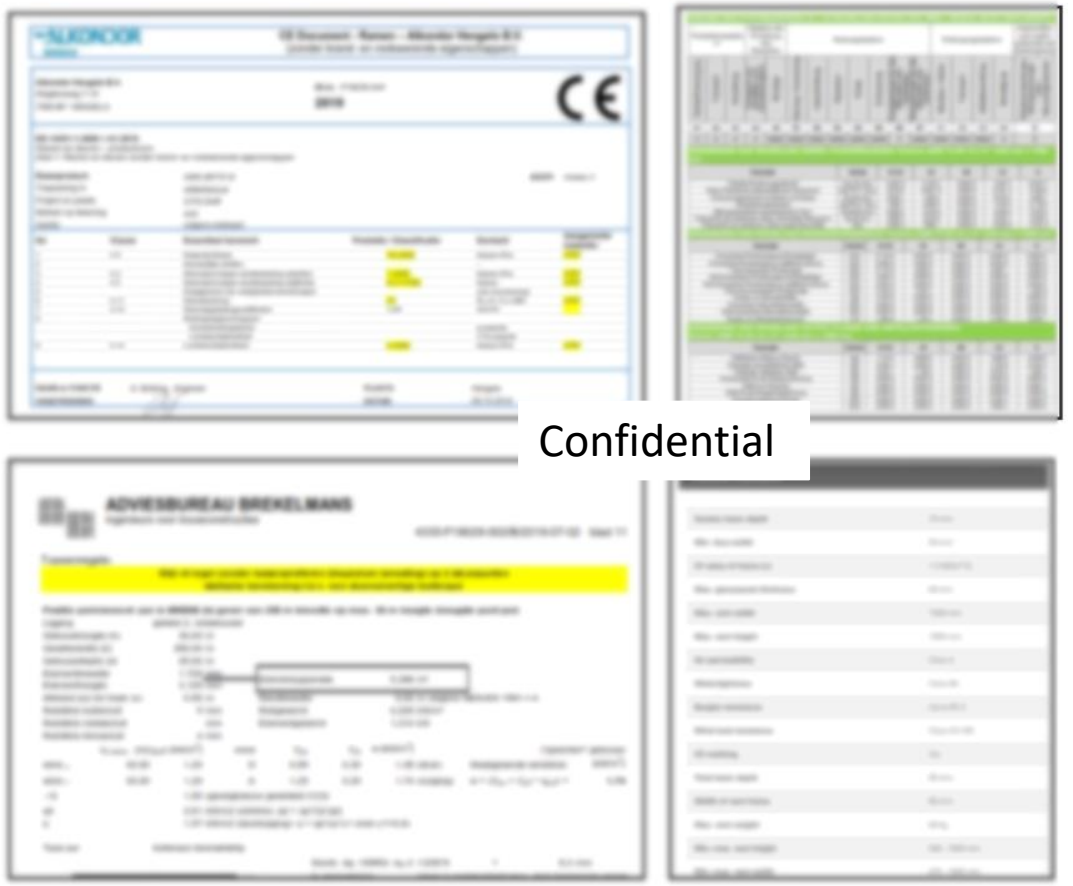
DOCUMENTS RECEIVED

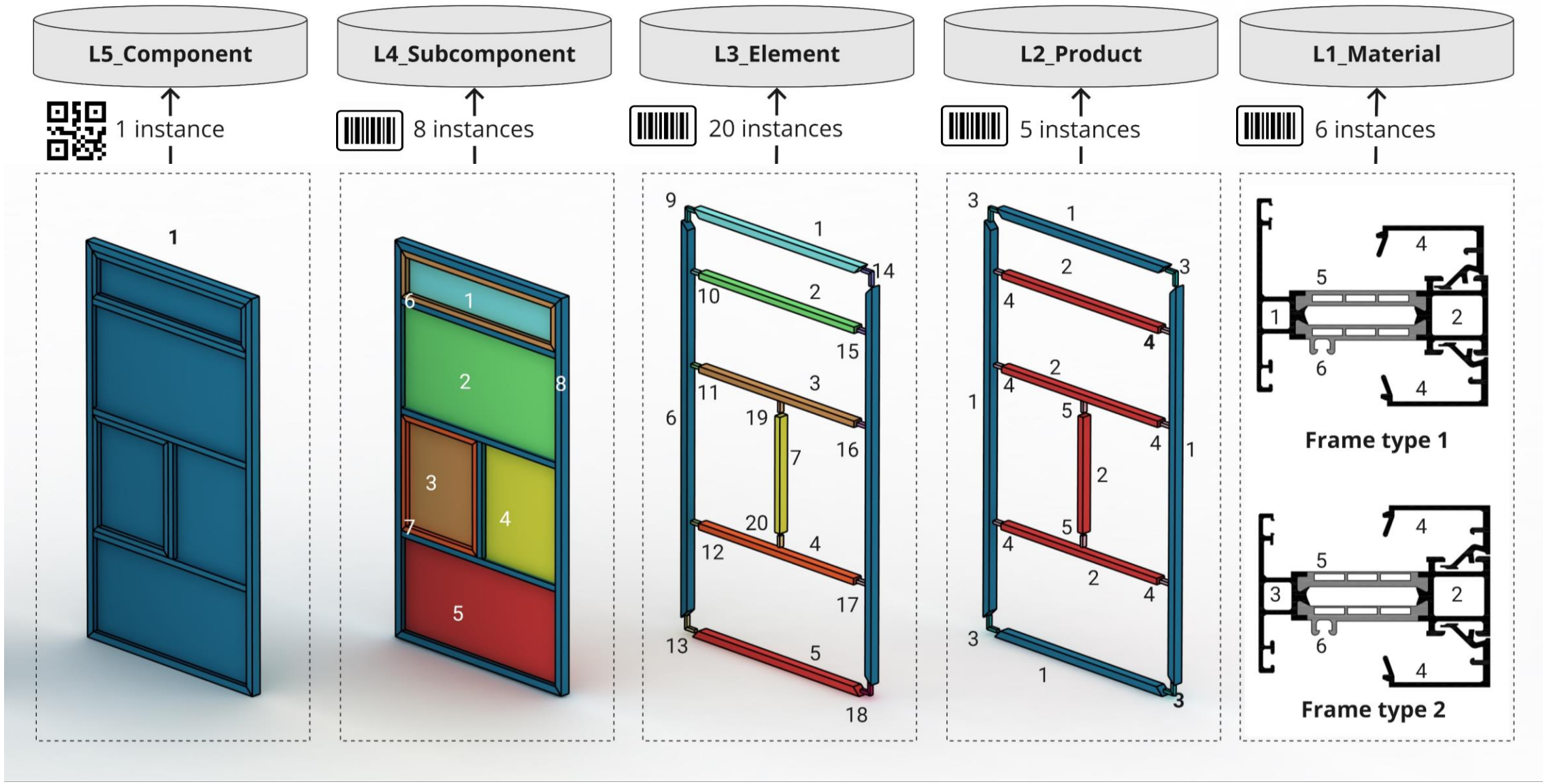
Drawings

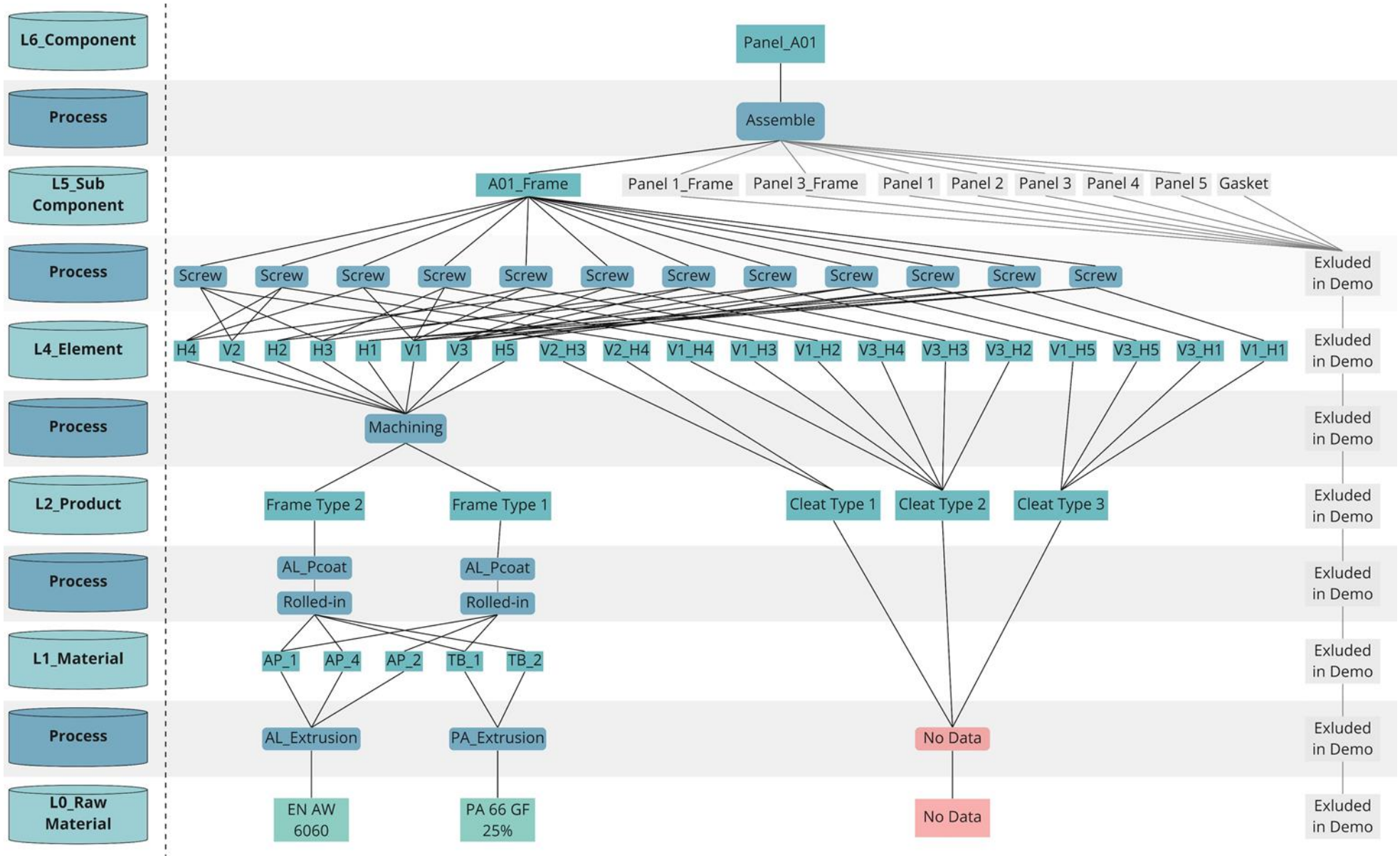


Photographs

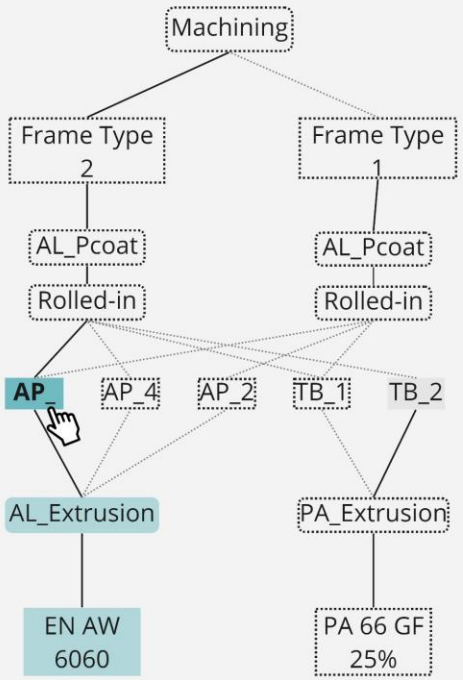
Certificates




L5_Component
L4_Subcomponent
L3_Element
L2_Product
L1_Material
1 instance
8 instances
20 instances
5 instances
6 instances
Frame type 1
Frame type 2

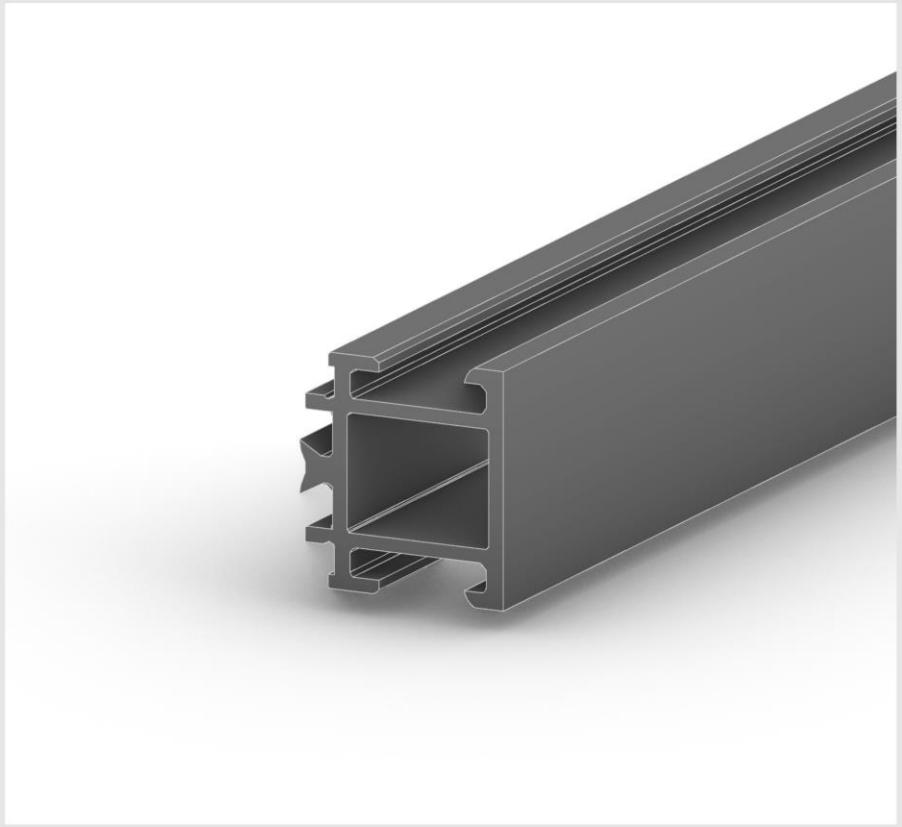

L6_Component
Process
L5_Sub Component
Process
L4_Element
Process
L2_Product
Process
L1_Material
Process
L0_Raw Material
Panel_A01
Assemble
A01_Frame
Panel 1_Frame
Panel 3_Frame
Panel 1
Panel 2
Panel 3
Panel 4
Panel 5
Gasket
Screw
H4
V2
H2
H3
H1
V1
V3
H5
V2_H3
V2_H4
V1_H4
V1_H3
V1_H2
V3_H4
V3_H3
V3_H2
V1_H5
V3_H5
V3_H1
V1_H1
Machining
Frame Type 2
Frame Type 1
Cleat Type 1
Cleat Type 2
Cleat Type 3
AL_Pcoat
Rolled-in
AP_1
AP_4
AP_2
TB_1
TB_2
AL_Extrusion
PA_Extrusion
No Data
EN AW 6060
PA 66 GF 25%
Exluded in Demo

Instance Tree View



Displaying details of Material : **AP_1**

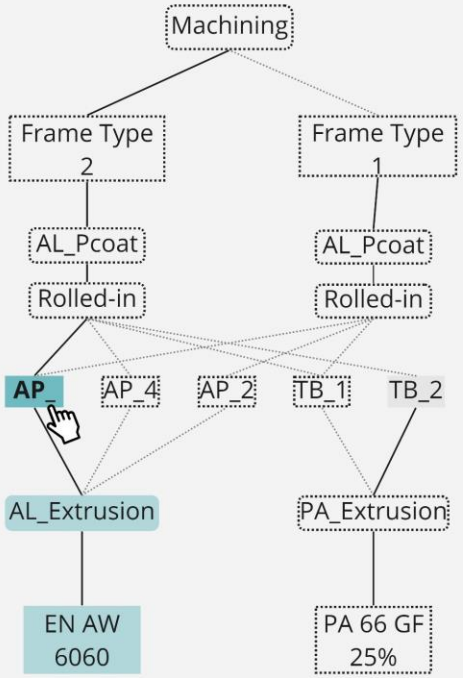
Material View



Properties

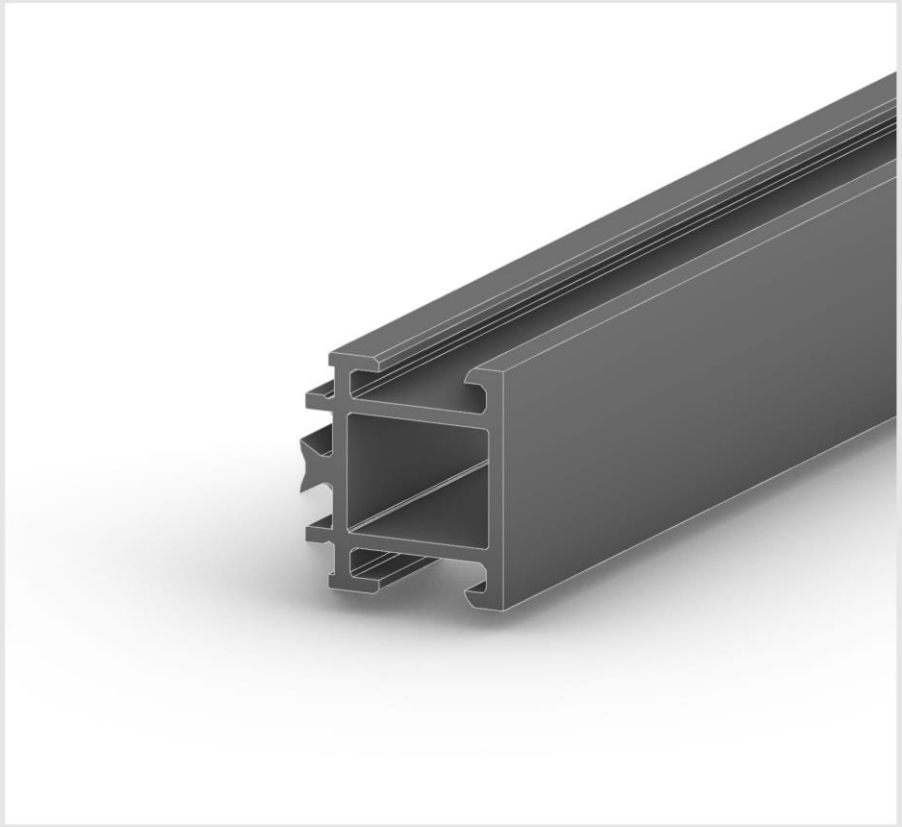
IDs	Instance ID	AP_1
	Common Name	Aluminium Profile
Manufacturers Data	Manufacturer Name	Company XYZ
	Manufacturer Location	<Location>
	Year of Dataset	DD/MM/YY
	Cost	<insert cost>
	Process 1	AL_Extrusion
Physical Properties	Crossection Area	0.011m2
	Manufactured Lengths	6000 mm
	Width	25 mm
	Height	22 mm
	Wall Thickness	1.1 mm
	Weight	178.2kg
Design Data	Crossection Drawing	Link to 2d Drawing
	Crossection 3d	Link to 3d Model

Instance Tree View



Displaying details of Material : **AP_1**

Material View



Properties

IDs	Instance ID	AP_1
	Common Name	Aluminium Profile
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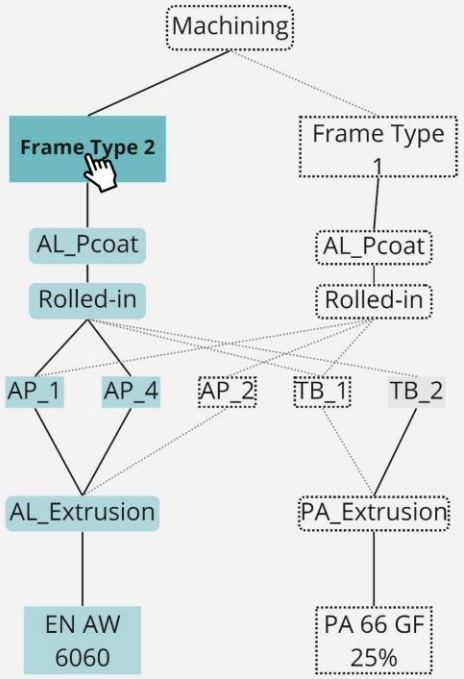
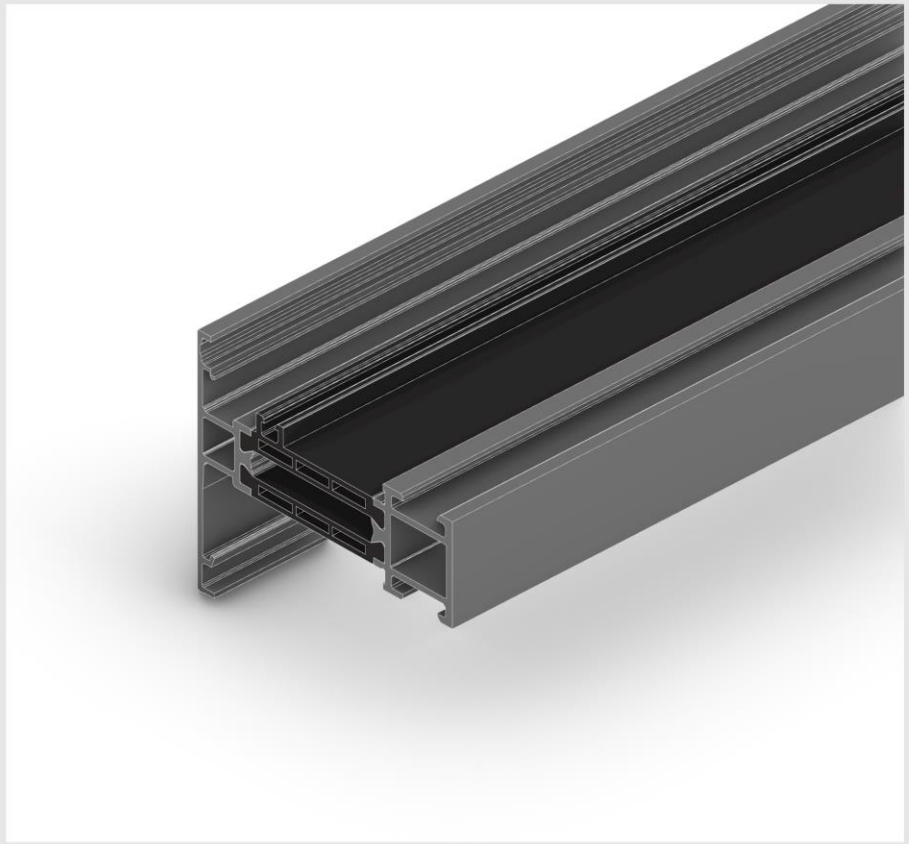
	Crossection 3d	Link to 3d Model

Instance Tree View



Displaying details of Product : **Frame Type_1**

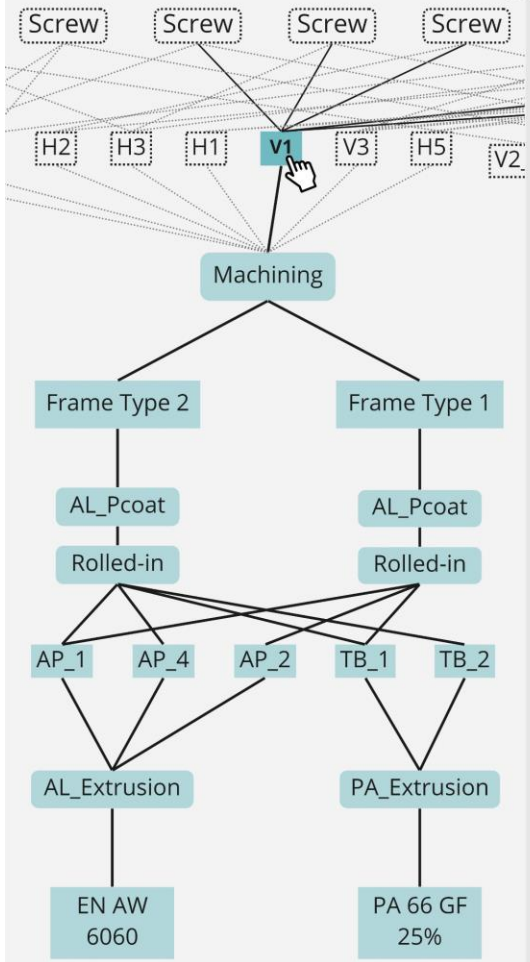
Product View



Properties

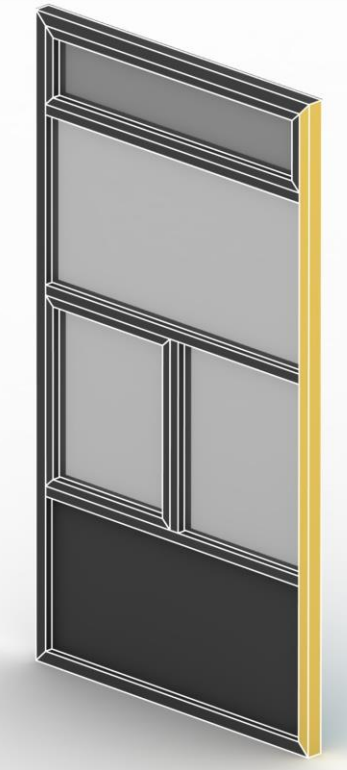
IDs	Instance ID	Frame Type_1
	Common Name	Window Frame
Manufacturers Data	Manufacturer Name	"Company Name"
	Manufacturer Location	"Location"
	Year of Dataset	"Insert date"
	Cost	"Insert date"
	Process 1	AL_Extrusion
Physical Properties	Crossection Area	0.04m2
	Manufactured Lengths	6000 mm
	Width	60 mm
	Height	50 mm
	Wall Thickness	1.1 mm
	Weight	648 kg
Design Data	Crossection Drawing	Link to 2d Drawing
	Crossection 3d	Link to 3d Model

Instance Tree View



Displaying details of Element : **V_1**

Element View

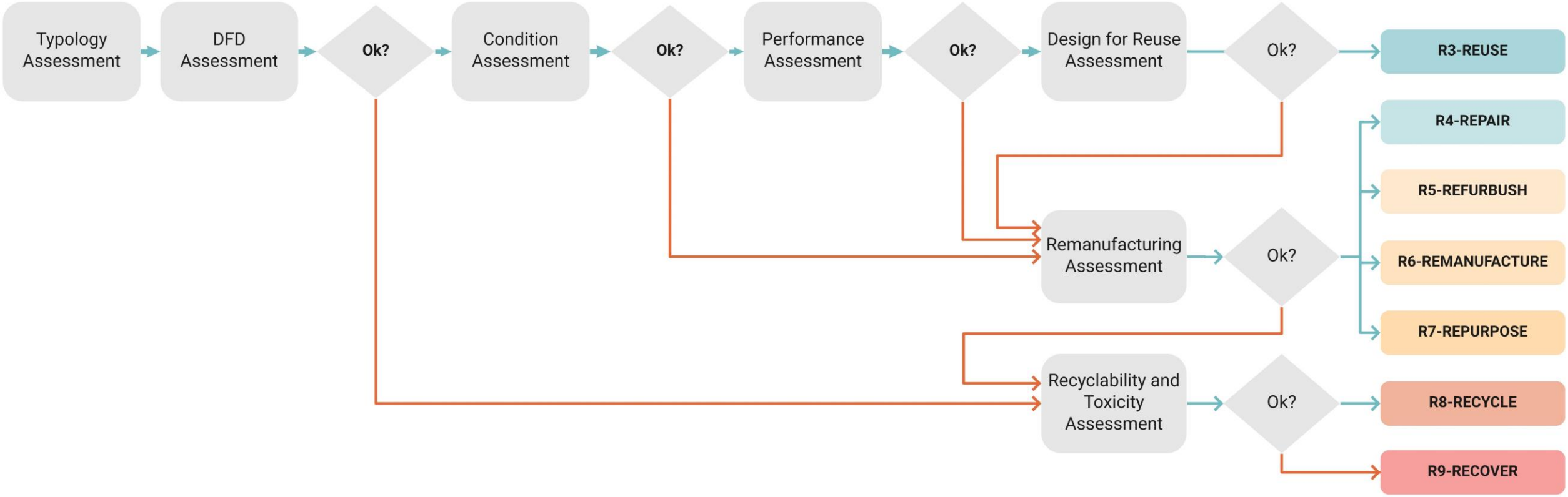


Properties

IDs	Instance ID	V_1
	Common Name	Primary Mullion
Manufacturers Data	Manufacturer Name	"Company Name"
	Manufacturer Location	"Location"
	Year of Dataset	"Insert date"
	Cost	"Insert date"
	Processes	AL_Extrusion,Rolled-in,...
Physical Properties	Crossection Area	0.04m2
	Length	3120mm
	Width	60 mm
	Height	50 mm
	Wall Thickness	1.1 mm
	Weight	336 kg
Design Data	Crossection Drawing	Link to 2d Drawing
	Crossection 3d	Link to 3d Model

Framework for Facade Product Passports

Framework for EoS Assessment


Typology Assessment
DFD Assessment
Ok?
Condition Assessment
Ok?
Performance Assessment
Ok?
Design for Reuse Assessment
Ok?
R3-REUSE
R4-REPAIR
R5-REFURBUSH
Remanufacturing Assessment
Ok?
R6-REMANUFACTURE
R7-REPURPOSE
Recyclability and Toxicity Assessment
Ok?
R8-RECYCLE
R9-RECOVER

Typology Assessment

DFD Assessment

Condition Assessment

Performance Assessment

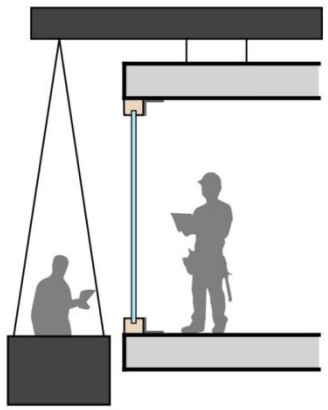
Design for Reuse Assessment

Remanufacturing Assessment

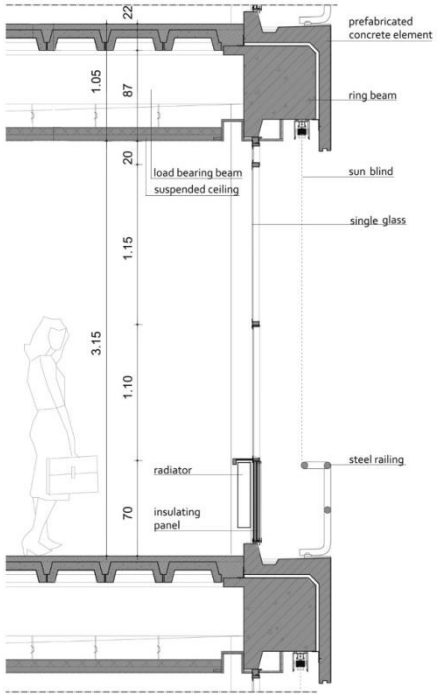
Recyclability and Toxicity Assessment

Criteria

Conponent Access



Information Extracted



Results

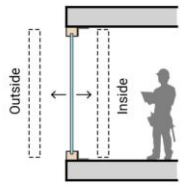
Component Access

- **Inside**
- **Outside**
- **Both Sides**

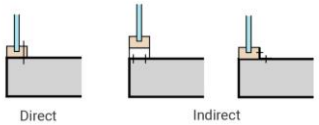
Typology Assessment | DFD Assessment | Condition Assessment | Performance Assessment | Design for Reuse Assessment | Remanufacturing Assessment | Recyclability and Toxicity Assessment

Criteria

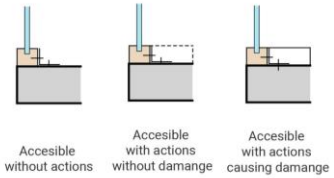
Disassembly Direction



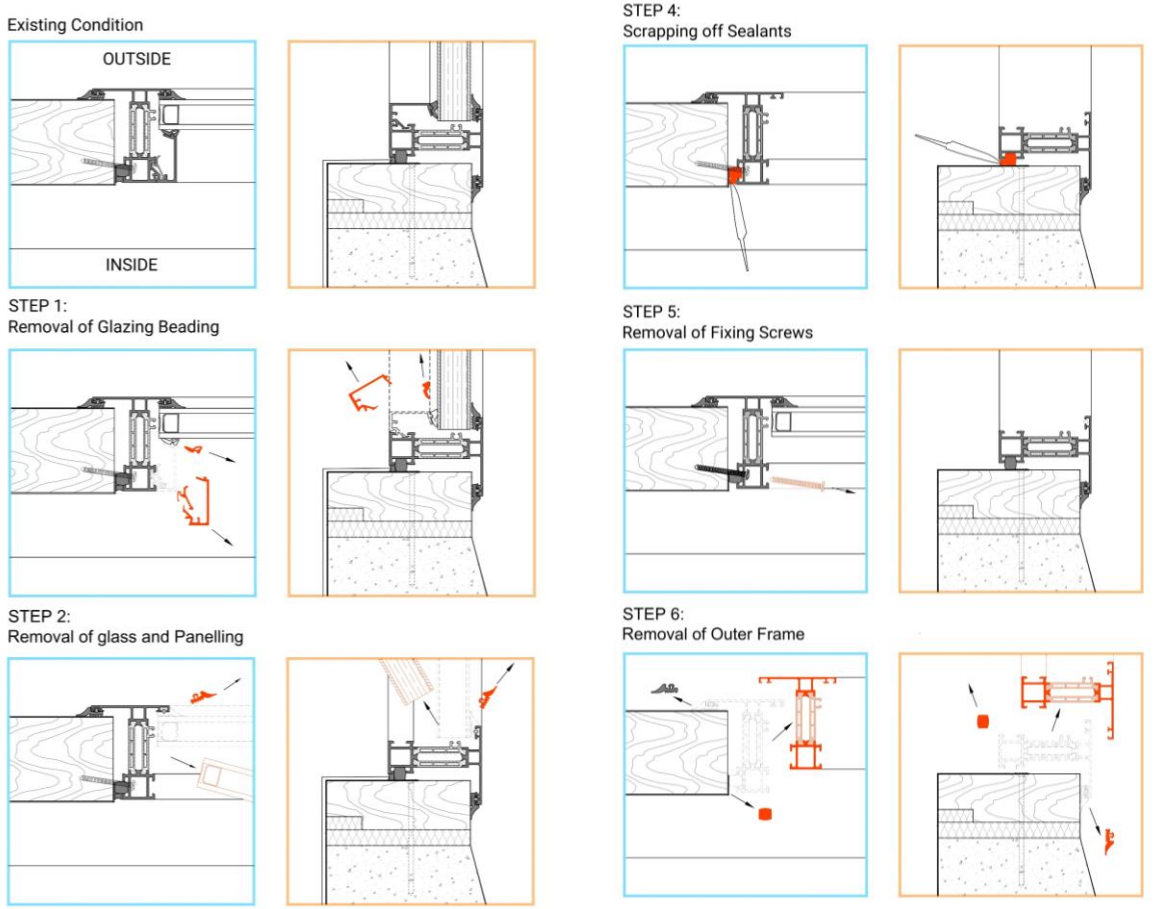
Connection Type



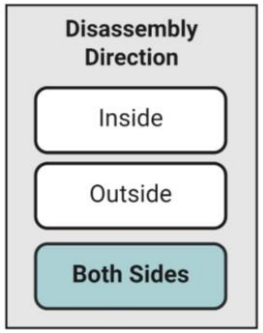
Connection Accesibility



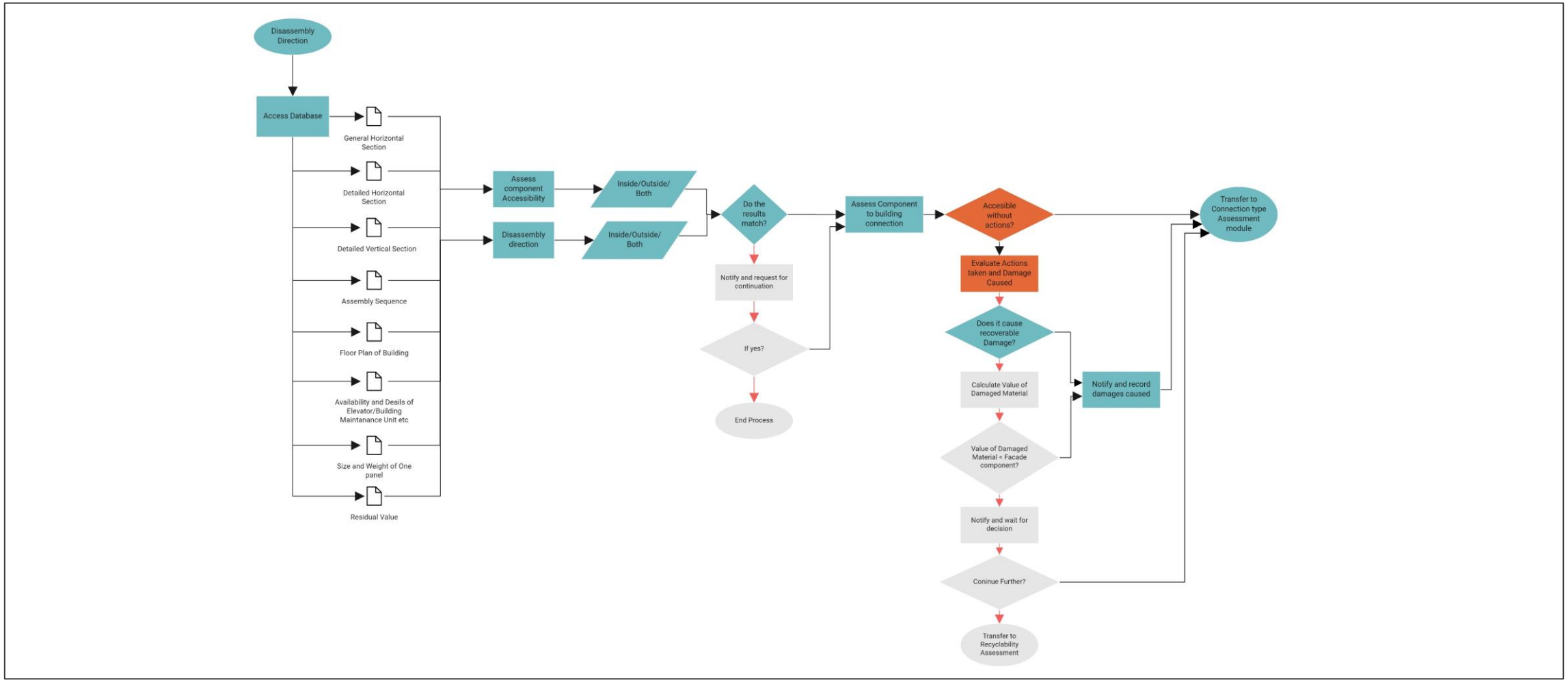
Information Extracted

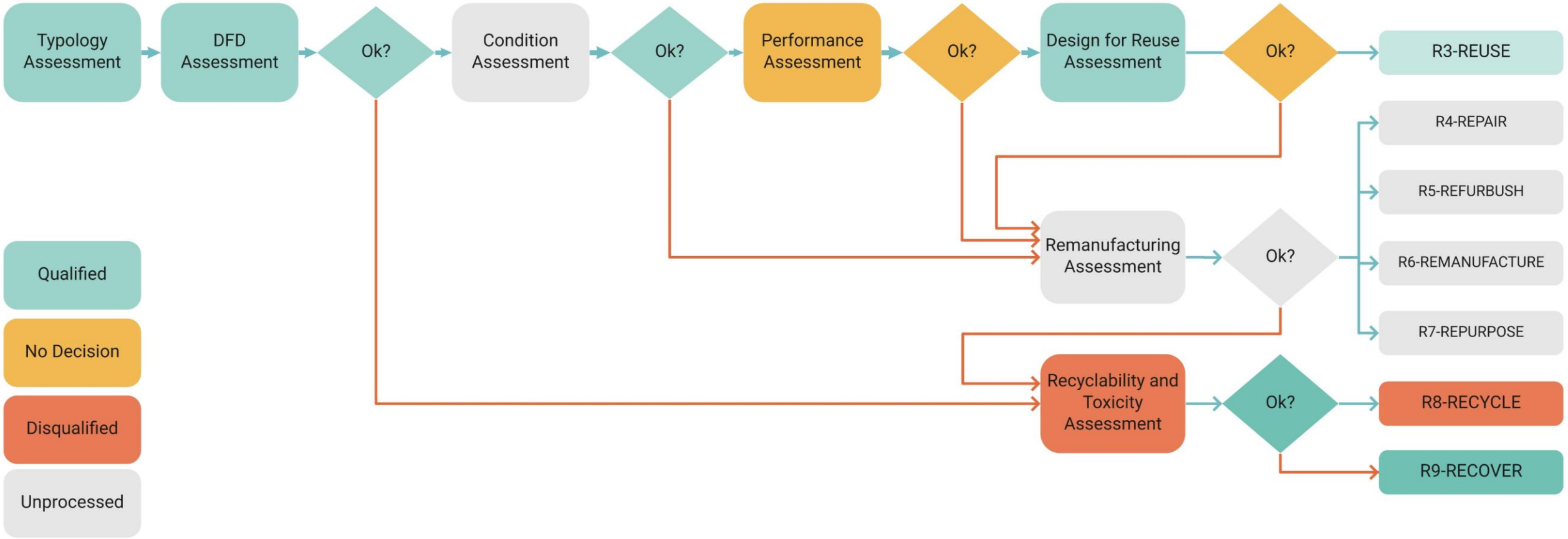


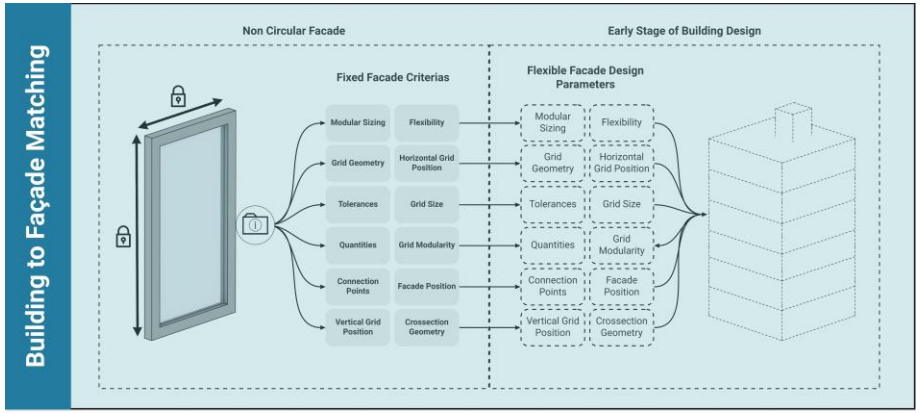
Results

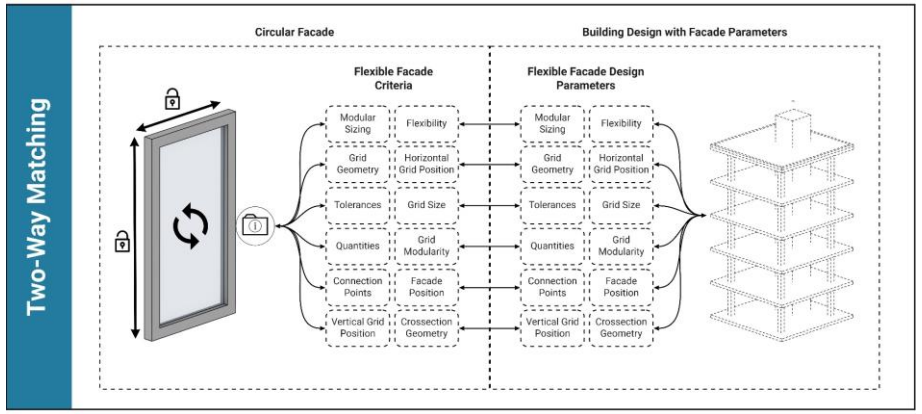


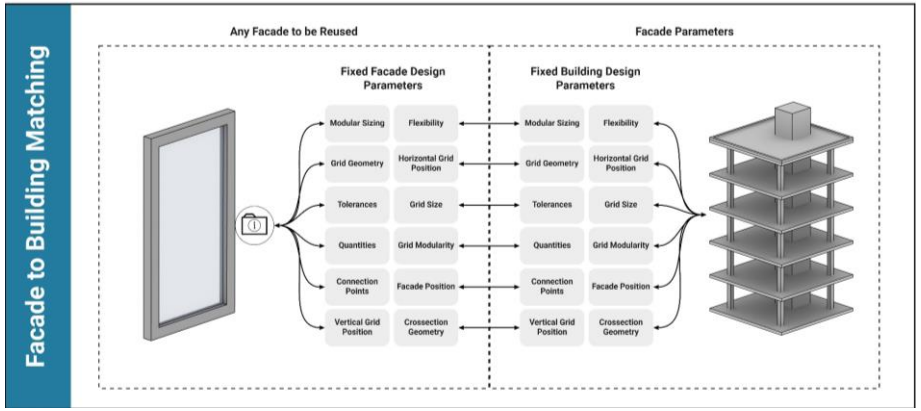
Research Framework | Facade Product passports | EoS Assessment | **Demonstrations** | Conclusions


Disassembly Direction
Access Database
General Horizontal Section
Detailed Horizontal Section
Detailed Vertical Section
Assembly Sequence
Floor Plan of Building
Availability and Deails of Elevator/Building Maintanance Unit etc
Size and Weight of One panel
Residual Value
Assess component Accessibility
Disassembly direction
Inside/Outside/ Both
Inside/Outside/ Both
Do the results match?
Notify and request for continuation
If yes?
End Process
Assess Component to building connection
Accesible without actions?
Evaluate Actions taken and Damage Caused
Does it cause recoverable Damage?
Calculate Value of Damaged Material
Value of Damaged Material < Facade component?
Notify and wait for decision
Coninue Further?
Transfer to Recyclability Assessment
Notify and record damages caused
Transfer to Connection type Assessment module


Typology Assessment
DFD Assessment
Ok?
Condition Assessment
Ok?
Performance Assessment
Ok?
Design for Reuse Assessment
Ok?
R3-REUSE
R4-REPAIR
R5-REFURBUSH
R6-REMANUFACTURE
R7-REPURPOSE
Remanufacturing Assessment
Ok?
Recyclability and Toxicity Assessment
Ok?
R8-RECYCLE
R9-RECOVER
Qualified
No Decision
Disqualified
Unprocessed







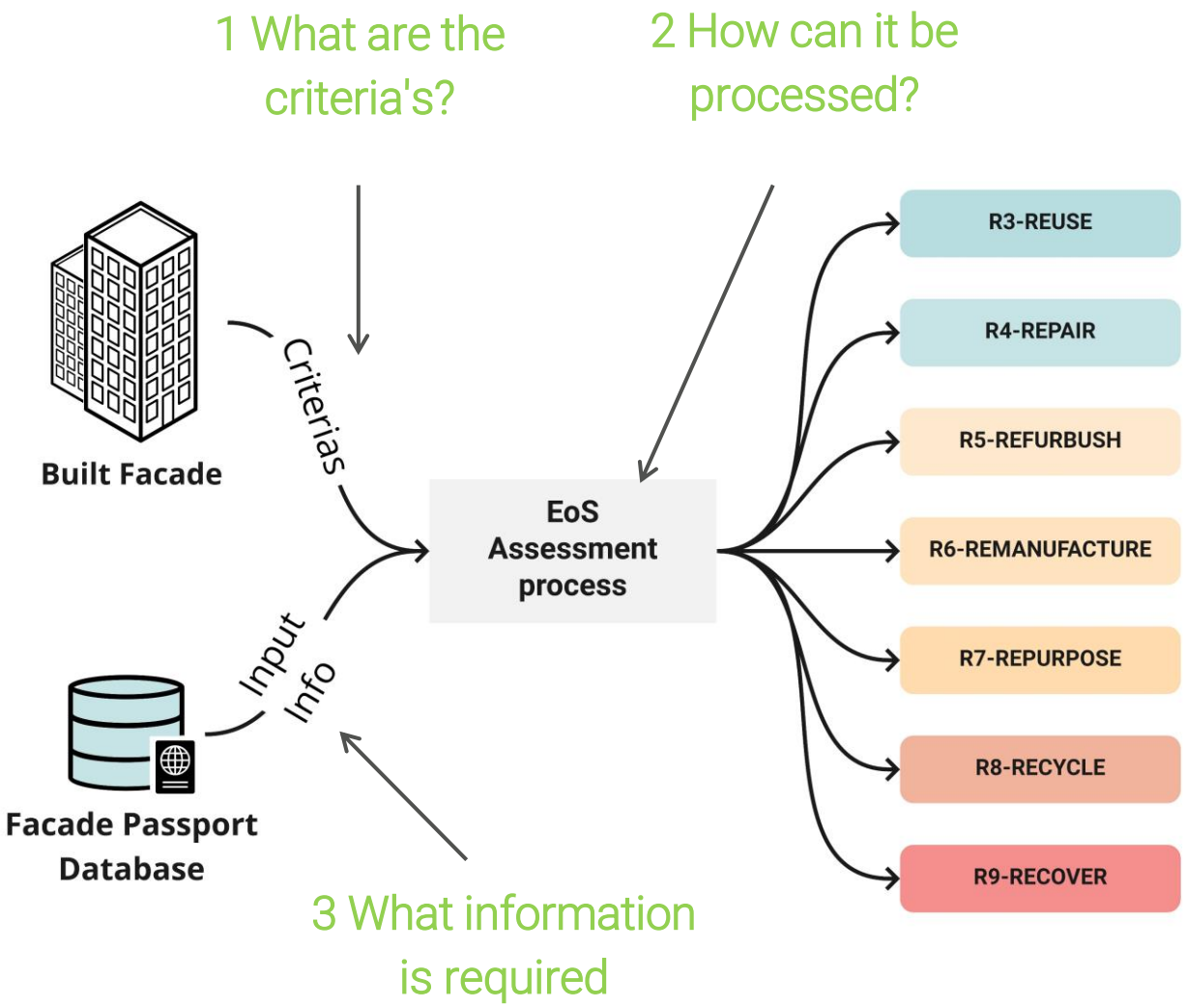
Results

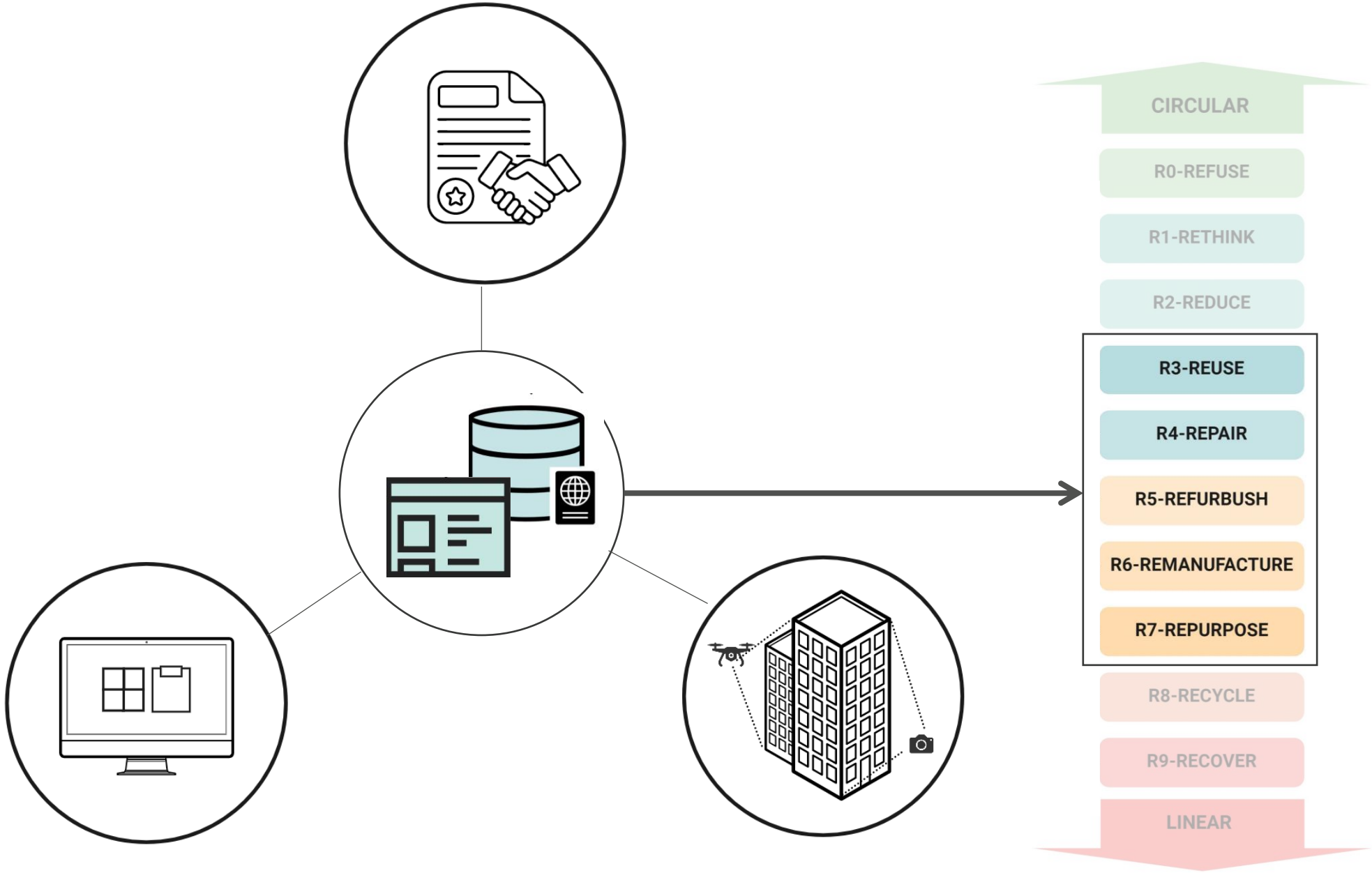
Dimensional Flexibility?

- **Fixed**
- Flexible

Modular Sizing?

- Modular
- **Specific**


1 What are the criteria's?
2 How can it be processed?
Built Facade
Criterias
Input Info
Facade Passport Database
EoS Assessment process
R3-REUSE
R4-REPAIR
R5-REFURBUSH
R6-REMANUFACTURE
R7-REPURPOSE
R8-RECYCLE
R9-RECOVER
3 What information is required


CIRCULAR
R0-REFUSE
R1-RETHINK
R2-REDUCE
R3-REUSE
R4-REPAIR
R5-REFURBUSH
R6-REMANUFACTURE
R7-REPURPOSE
R8-RECYCLE
R9-RECOVER
LINEAR

EOS Assessment Platform

Passport Viewer

EoS Assessment

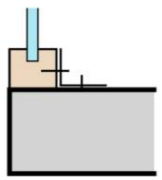
Typology Assessment | **DfD assessment** | Condition Assessment | Performance Assessment | Design Parameters | Re-Manufacturing Parameters | Recyclability Assessment

Assessment

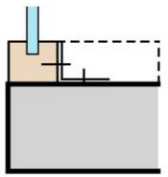
- [x] Disassembly Direction
- [x] Connection type
- [x] **Connection Accessibility**
- [x] Connection Details
- [x] Disassembly Direction
- [x] Disassembly Sequence

Connection Accessibility

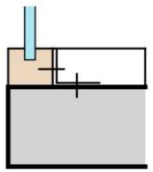
- [x] Accessible w/o actions



- [ ] Accessible with actions w/o damage



- [ ] Accessible with actions w/o damage



Any additional observations

Type here

SAVE

Passport Viewer

EoS Assessment

Typology Assessment | **DfD assessment** | Condition Assessment | Performance Assessment | Design Parameters | Re-Manufacturing Parameters | Recyclability Assessment

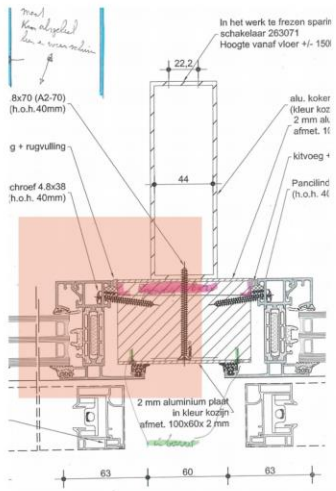
Assessment

- [x] Disassembly Direction
- [x] Connection type
- [x] Connection Accessibility
- [x] **Connection Details**
- [x] Disassembly Direction
- [x] Disassembly Sequence

Link to component

AP_L2758GH ✓

Drawing Preview



Highlight

Any additional notes

Type here

SAVE

Passport Viewer

EoS Assessment

Typology Assessment | DfD assessment | Condition Assessment | Performance Assessment | Design Parameters | Re-Manufacturing Parameters | Recyclability Assessment

EoS Assessment for 'EN-127XH' is complete!

Based on the current status and the regulations of the 9R's:

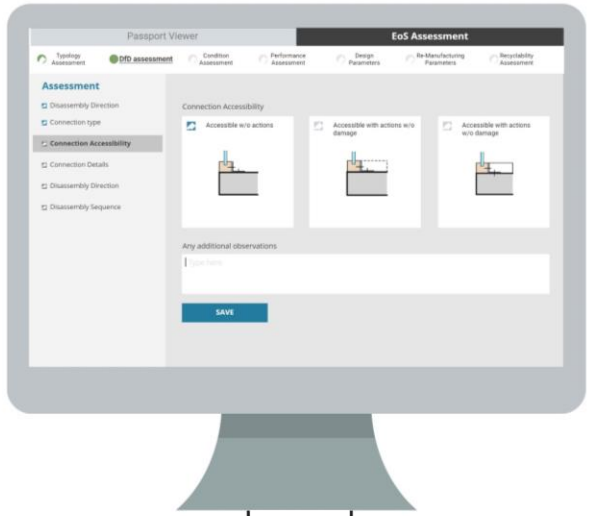
- 158 frames are ready for reuse
- 2 frames are not qualified for reuse

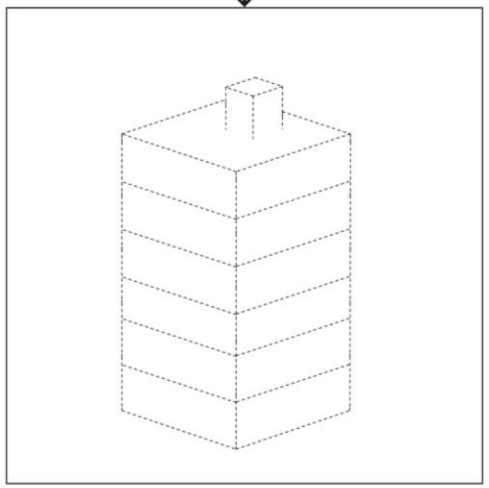
VIEW PROJECT

Project is saved in Passport viewer

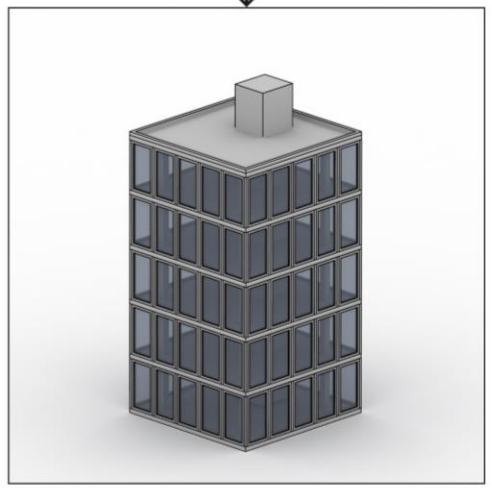
RECHECK DETAILS

EoS Assesment platform



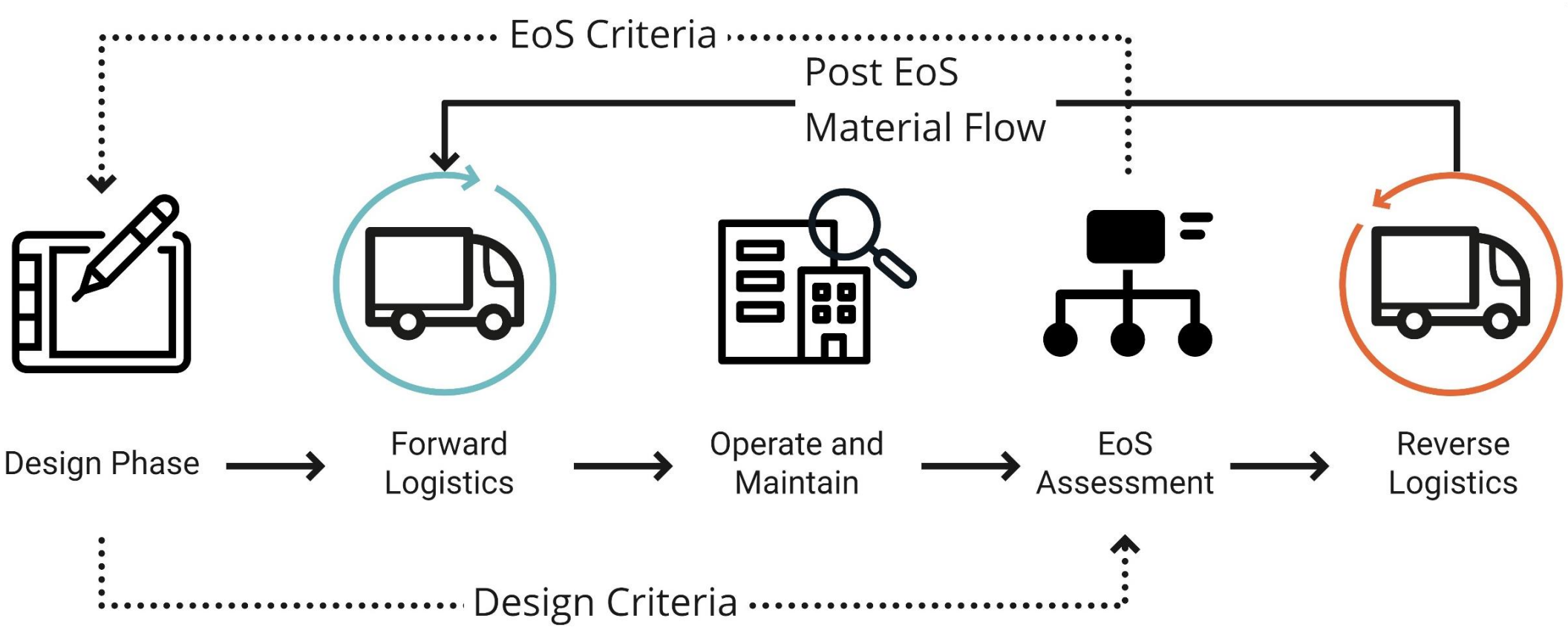


Enrich passports of New Buildings

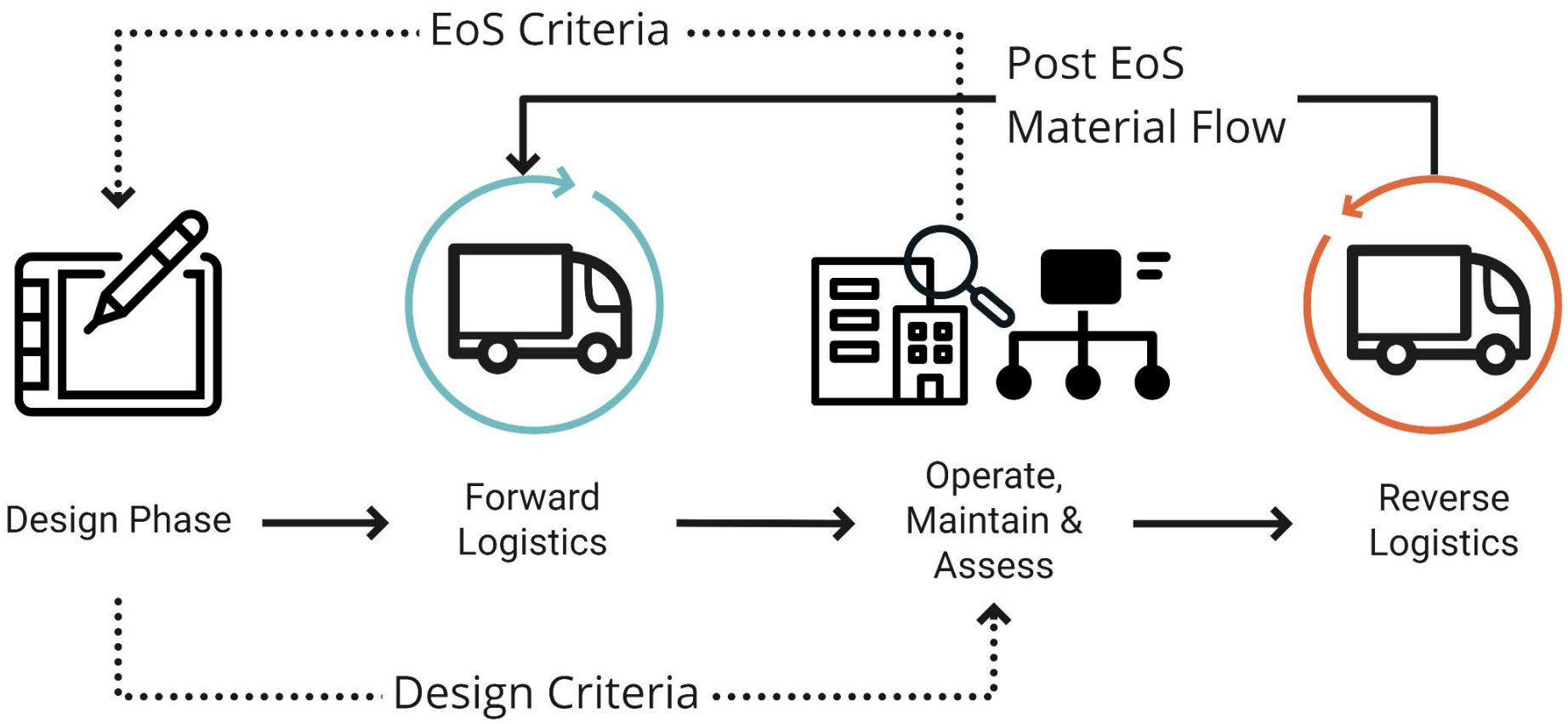


Assess Existing Buildings

CURRENT PROPOSED SCENARIO



EXPECTED TRANSITIONING



Recommendations

RECCOMENDATIONS TO THE INDUSTRY

Lead time
For Building Demolitions

RECCOMENDATIONS TO THE INDUSTRY

Lead time
For Building Demolitions

Information Exchange
Standards

RECCOMENDATIONS TO THE INDUSTRY

Lead time
For Building Demolitions

Information Exchange
Standards

Processable
Data

RECCOMENDATIONS TO THE INDUSTRY

Lead time
For Building Demolitions

Information Exchange
Standards

Processable
Data

Data
Transparency

Next Steps

NEXT STEPS

Façade Product Passports

- Prototype and test data structure for all materials and components in CiTG Façade
- Test other Building Facades which have lower quality information
- Create a conceptual information model

NEXT STEPS

Façade Product Passports

- Prototype and test data structure for all materials and components in CiTG Façade
- Test other Building Facades which have lower quality information
- Create a conceptual information model

EoS Assessment platform

- Testing and validating with other unitized facades
- Frameworks for other typologies.
- Integrate into a Product passport and EoS Assessment tool

Thank you!

Appendix

Existing Facades
Industry 4.0
?
Stakeholder
Perpsectives
Citcular Design
Principles
Buisness Models

Platform CB 23 Categorization	Integral Facade Construction(2013)	Proposed Product Levels based on processess	Corresponding Information Levels	Examples
Area				
Complex				
Structure	Building	Building	L7_Building	Building
Element	Building Part	Building Part	L6_Building Part	North facade, east facade
	Component	Component	L5_Component	Unitized Panel
	Sub-Component	Sub-Component	L4_Subcomponent	Primary frame, sunshading system
Construction Product	Element	Element	L3_Element	Products with actual sizes/function
	Commercial Material	Product	L2_Product	Profile systems, Double glazing
Material	Standard Material	Material	L1_Material	Extrusions, sheets
Raw Material	Material	Raw Material	L0_Raw Material	Aluminium,steel, glass

Adding

Transporting, installing

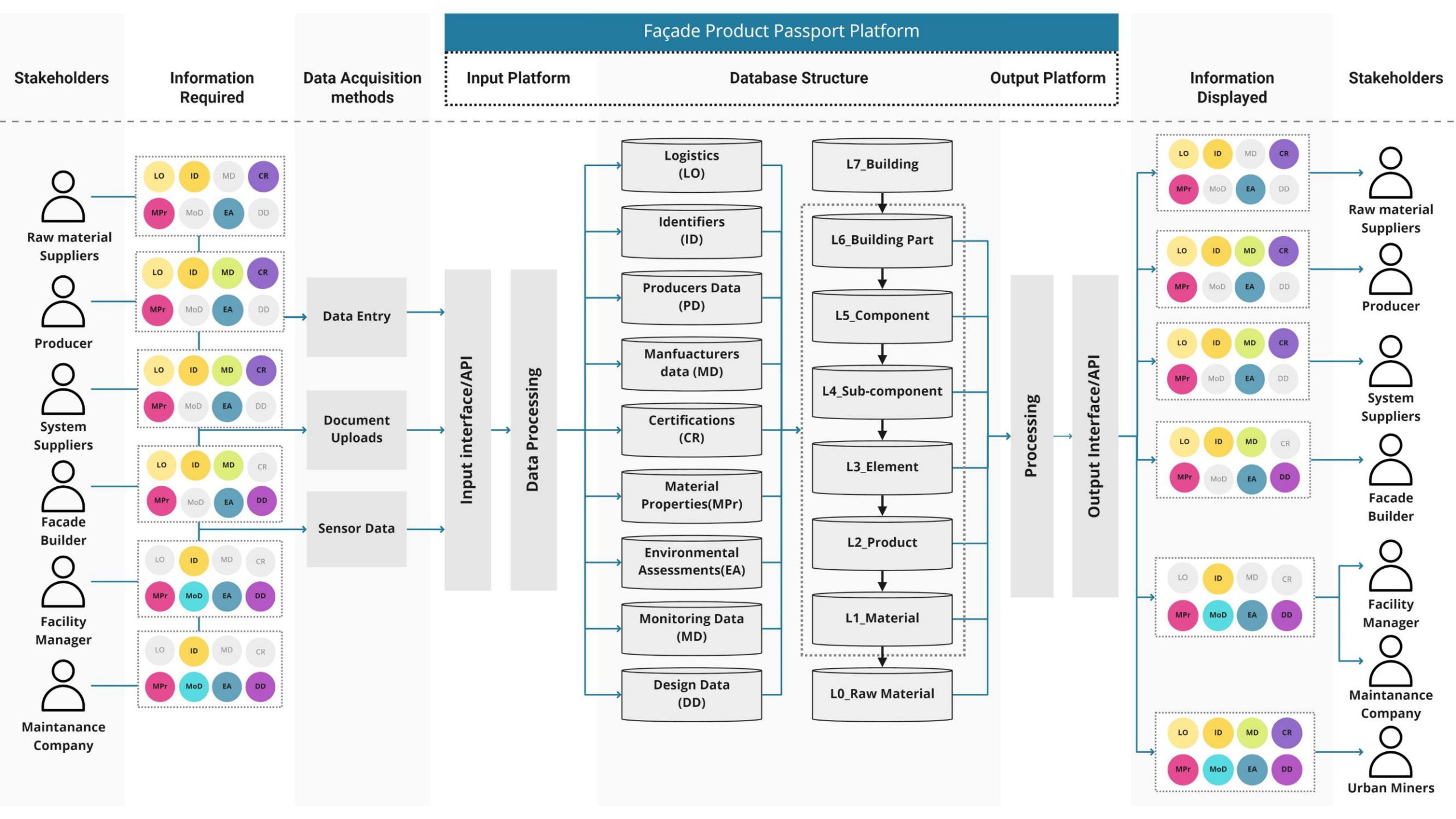
Joining, fixing

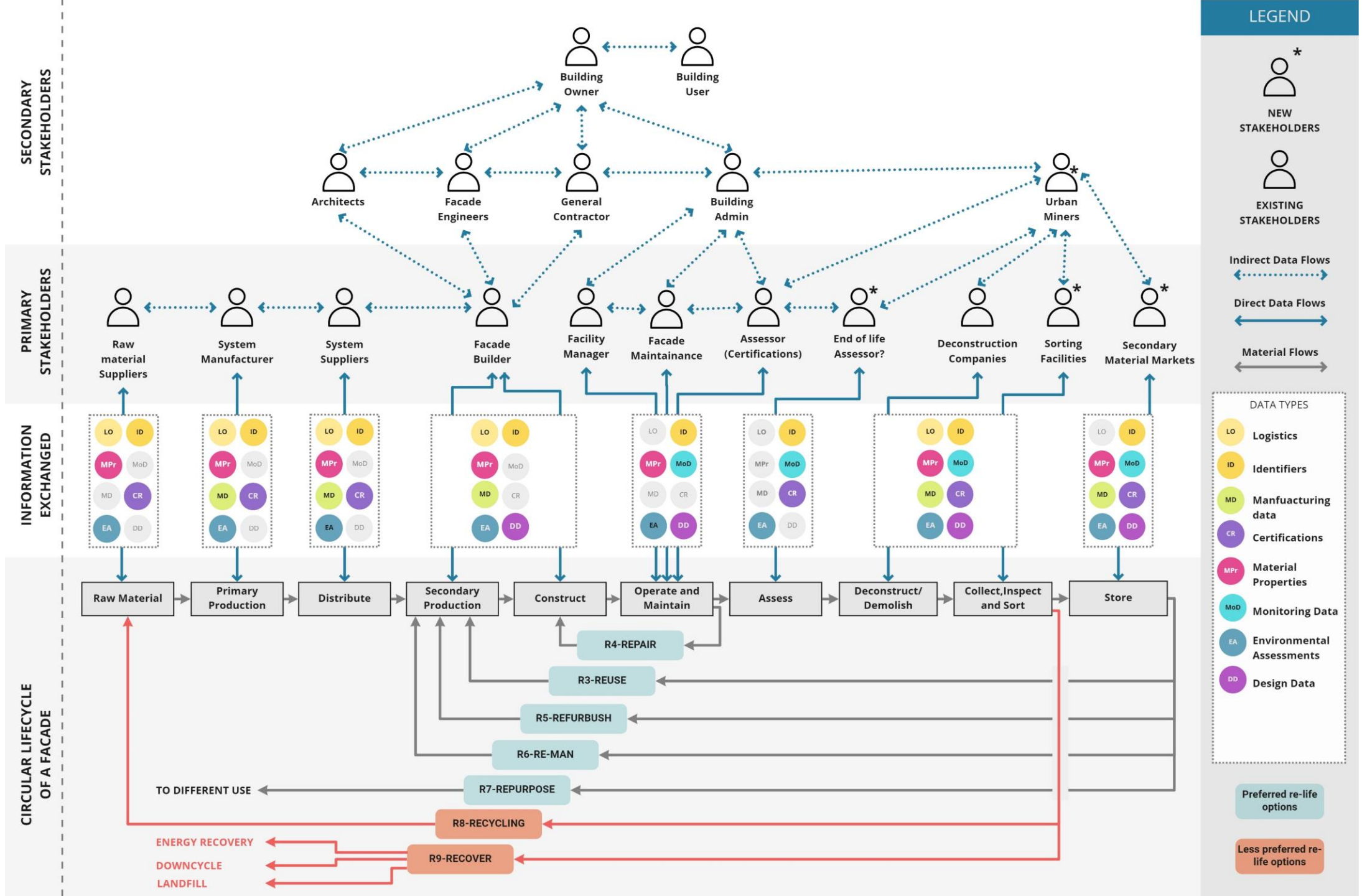
Joining, fixing

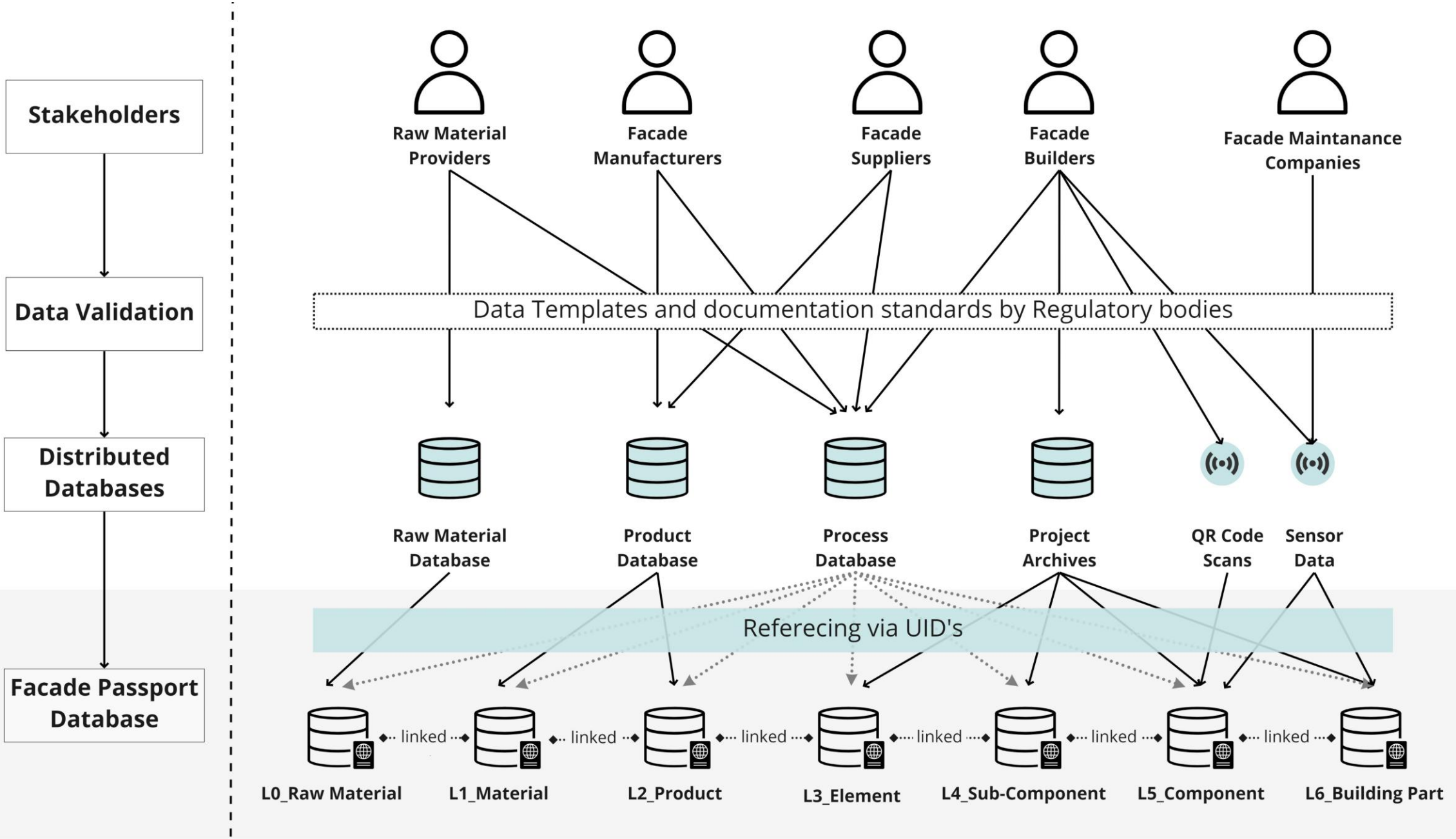
Sizing, Fabrication

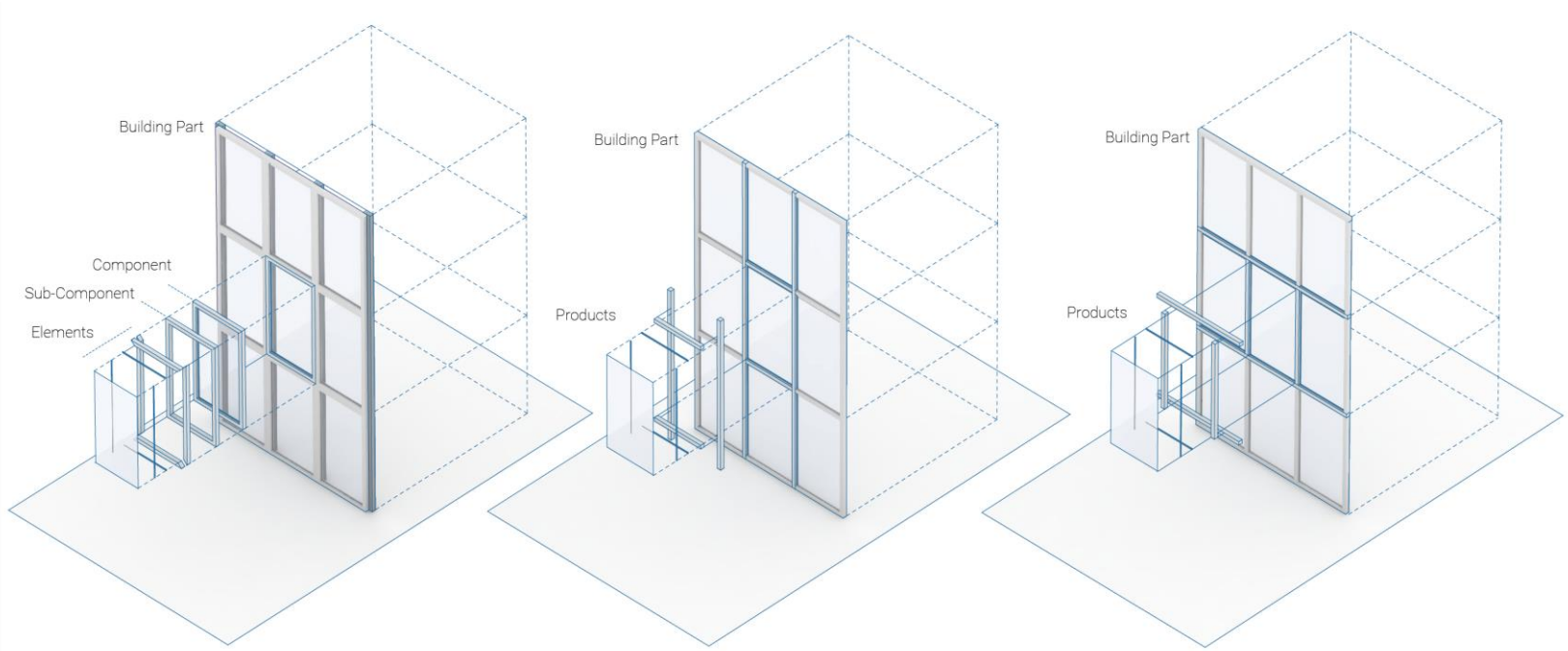
Treatment, assembly,

Primary Production

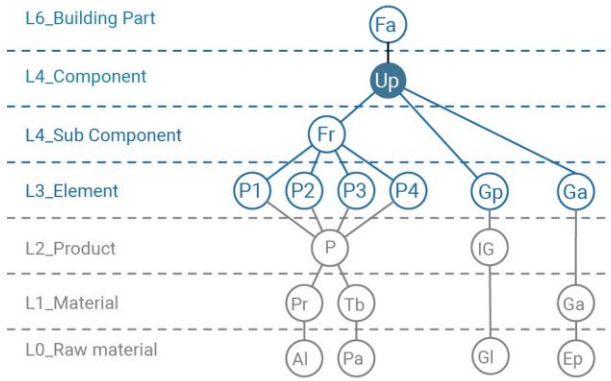

Façade Product Passport Platform
Stakeholders
Information Required
Data Acquisition methods
Input Platform
Database Structure
Output Platform
Information Displayed
Stakeholders
Raw material Suppliers
Producer
System Suppliers
Facade Builder
Facility Manager
Maintanance Company
LO ID MD CR MPr MoD EA DD
Data Entry
Document Uploads
Sensor Data
Input interface/API
Data Processing
Logistics (LO)
Identifiers (ID)
Producers Data (PD)
Manfuacturers data (MD)
Certifications (CR)
Material Properties(MPr)
Environmental Assessments(EA)
Monitoring Data (MD)
Design Data (DD)
L7_Building
L6_Building Part
L5_Component
L4_Sub-component
L3_Element
L2_Product
L1_Material
L0_Raw Material
Processing
Output Interface/API
Raw material Suppliers
Producer
System Suppliers
Facade Builder
Facility Manager
Maintanance Company
Urban Miners


SECONDARY STAKEHOLDERS
Building Owner
Building User
Architects
Facade Engineers
General Contractor
Building Admin
Urban Miners
PRIMARY STAKEHOLDERS
Raw material Suppliers
System Manufacturer
System Suppliers
Facade Builder
Facility Manager
Facade Maintainance
Assessor (Certifications)
End of life Assessor?
Deconstruction Companies
Sorting Facilities
Secondary Material Markets
INFORMATION EXCHANGED
LO ID MPr MoD MD CR EA DD
CIRCULAR LIFECYCLE OF A FACADE
Raw Material
Primary Production
Distribute
Secondary Production
Construct
Operate and Maintain
Assess
Deconstruct/ Demolish
Collect,Inspect and Sort
Store
R4-REPAIR
R3-REUSE
R5-REFURBUSH
R6-RE-MAN
TO DIFFERENT USE
R7-REPURPOSE
R8-RECYCLING
ENERGY RECOVERY
DOWNCYCLE
LANDFILL
R9-RECOVER
LEGEND
NEW STAKEHOLDERS
EXISTING STAKEHOLDERS
Indirect Data Flows
Direct Data Flows
Material Flows
DATA TYPES
LO Logistics
ID Identifiers
MD Manfuacturing data
CR Certifications
MPr Material Properties
MoD Monitoring Data
EA Environmental Assessments
DD Design Data
Preferred re-life options
Less preferred re-life options

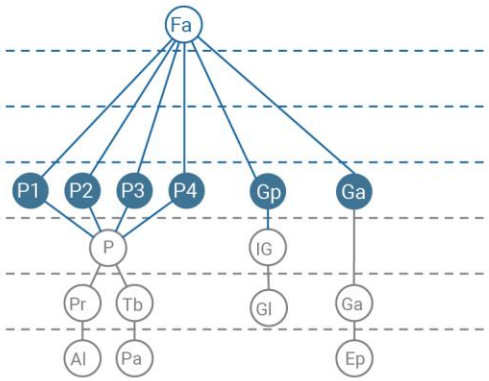

Stakeholders
Data Validation
Distributed Databases
Facade Passport Database
Raw Material Providers
Facade Manufacturers
Facade Suppliers
Facade Builders
Facade Maintanance Companies
Data Templates and documentation standards by Regulatory bodies
Raw Material Database
Product Database
Process Database
Project Archives
QR Code Scans
Sensor Data
Referecing via UID's
linked
L0_Raw Material
L1_Material
L2_Product
L3_Element
L4_Sub-Component
L5_Component
L6_Building Part



Unitized System



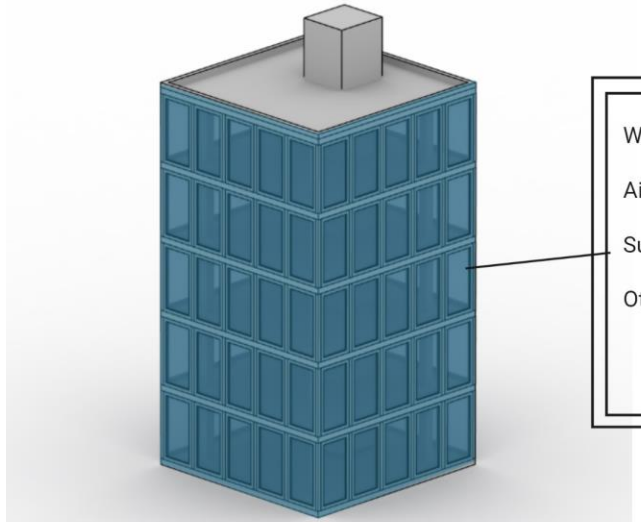
Mullion System



Transom System

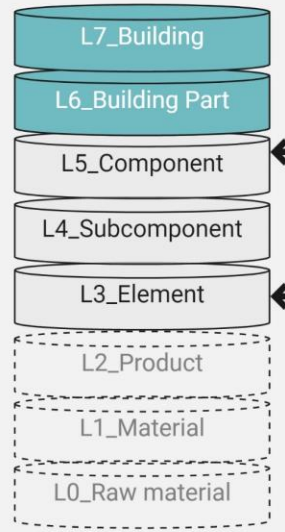
Fa- Building Facade
Up- Unitized Panel
Fr- Facade Frame
P1,2,3,4- Profile 1,2,3,4
P- Window Profile
Pr- Aluminium Extrusion
Al- Raw Aluminium
Gp- Glass Panel
Ga- Gasket
IG- Insulated Glass
Gl- Glass
Ep- EPDM Rubber

Routine maintenance with without digital platforms



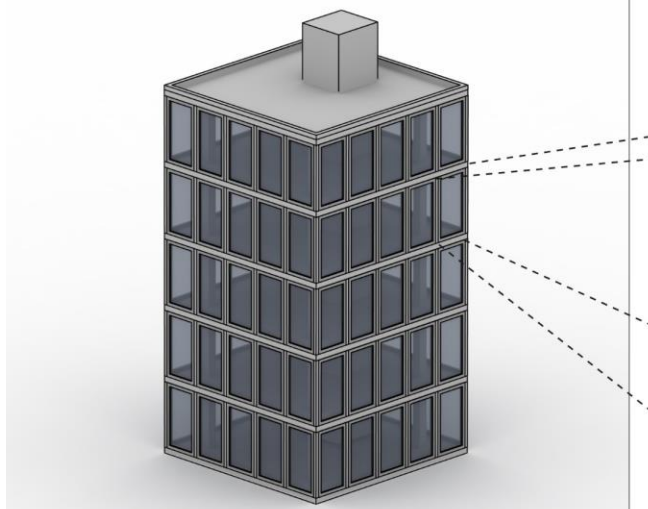
store

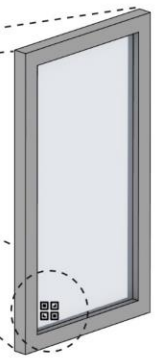
Document manager with checklists



No tracability to defects at lower level

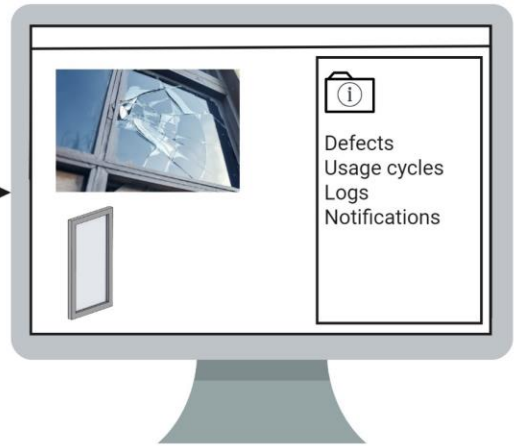
Routine maintenance with a digital platform



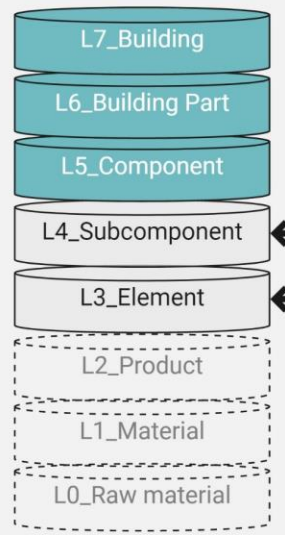


QR CODE

link



Platform with Maintainance records per component



No maintenance Data