



WP 8

Multi-criteria real-time monitoring of materials and building components



Funded by
the European Union

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01. WORKPACKAGE OVERVIEW / DEPENDENCIES



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OBJECTIVE

- (i) To design a real-time digital service to monitor in long-term and in a sustainable manner the **multi-criteria performance of façade and structural systems**.
- (ii) To devise effective predictive maintenance of façades by leveraging on data-driven performance models, low-cost sensing and knowledge on potential resilience losses

TASKS / TIMELINE

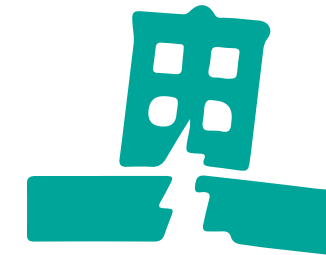
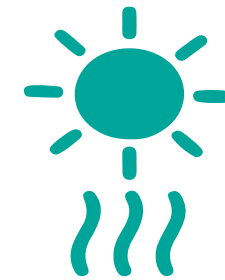
Task No.	Tasks	Start	End	Duration	Oct-23	Nov-23	Dec-23	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-23	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
4.1.1	Identification of requirements of the monitoring system and relevant information gathered by it	2023-10-01	2024-06-30	9																								
4.1.2	Development of the data acquisition and collection architecture on a schematic level	2024-03-01	2024-12-31	10																								
4.1.3	Design seamless technical integration of components into the façade and structural elements	2024-10-01	2025-09-30	12																								

DELIVERABLES

Deliverables	Tasks	Task		Deadline
D4.1.1	Digital control system for facades	4.1	PFE	M24 (Sep-25)
D4.1.2	Digital control system for timber material	4.1	RINA	M24 (Sep-25)
D4.1.3	Maintenance and optimization tool for facades	4.1	PFE	M24 (Sep-25)

WP 8 - MULTI-CRITERIA REAL-TIME MONITORING OF MATERIALS AND BUILDING COMPONENTS

OBJECTIVE



- (i) To design a real-time digital service to monitor in long-term and in a sustainable manner the multi-criteria performance of façade and structural systems.

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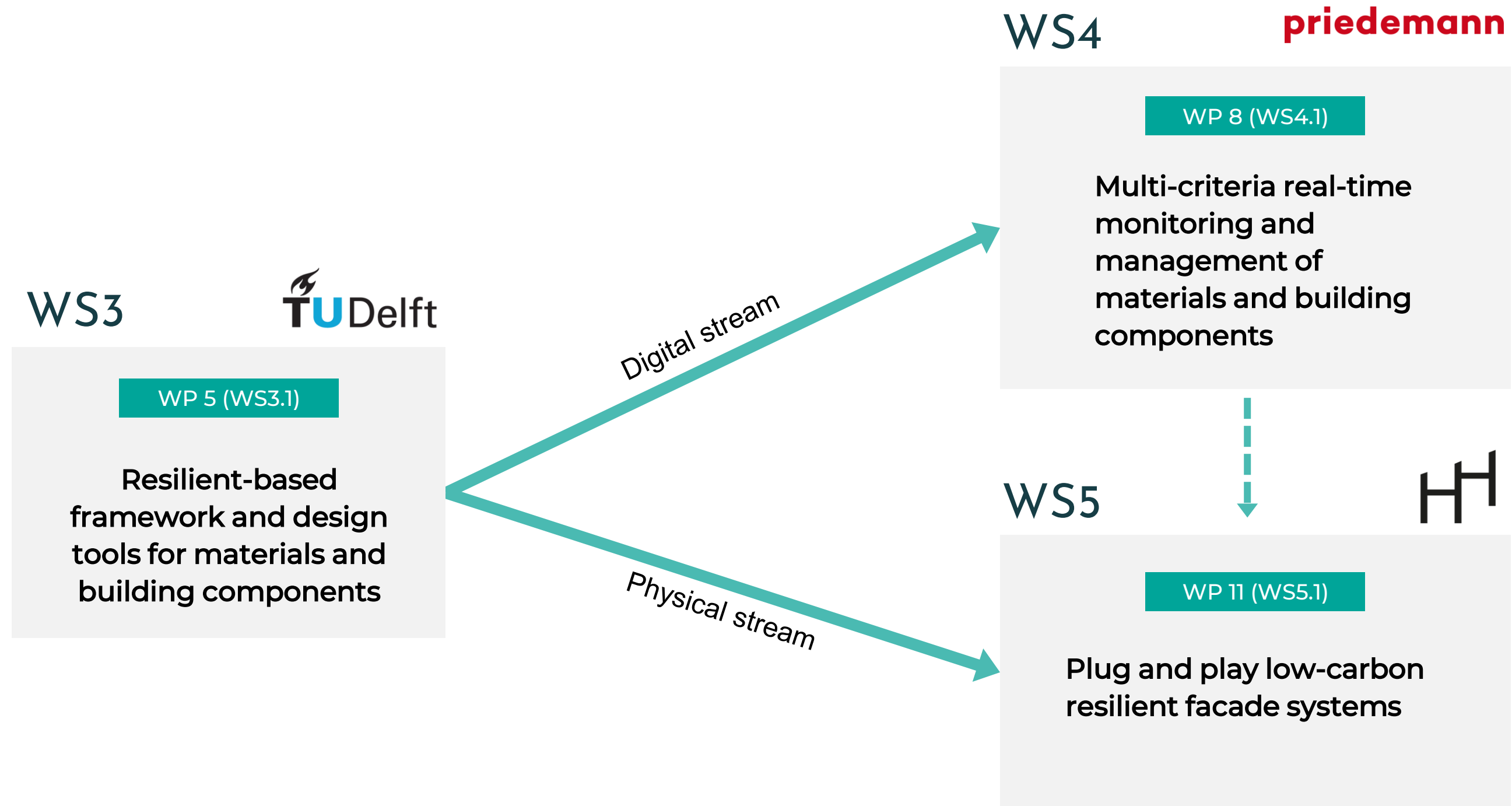
**Performance
Indicators**

**Hazard-related
Indicators**

What to Monitor?

When to Monitor?

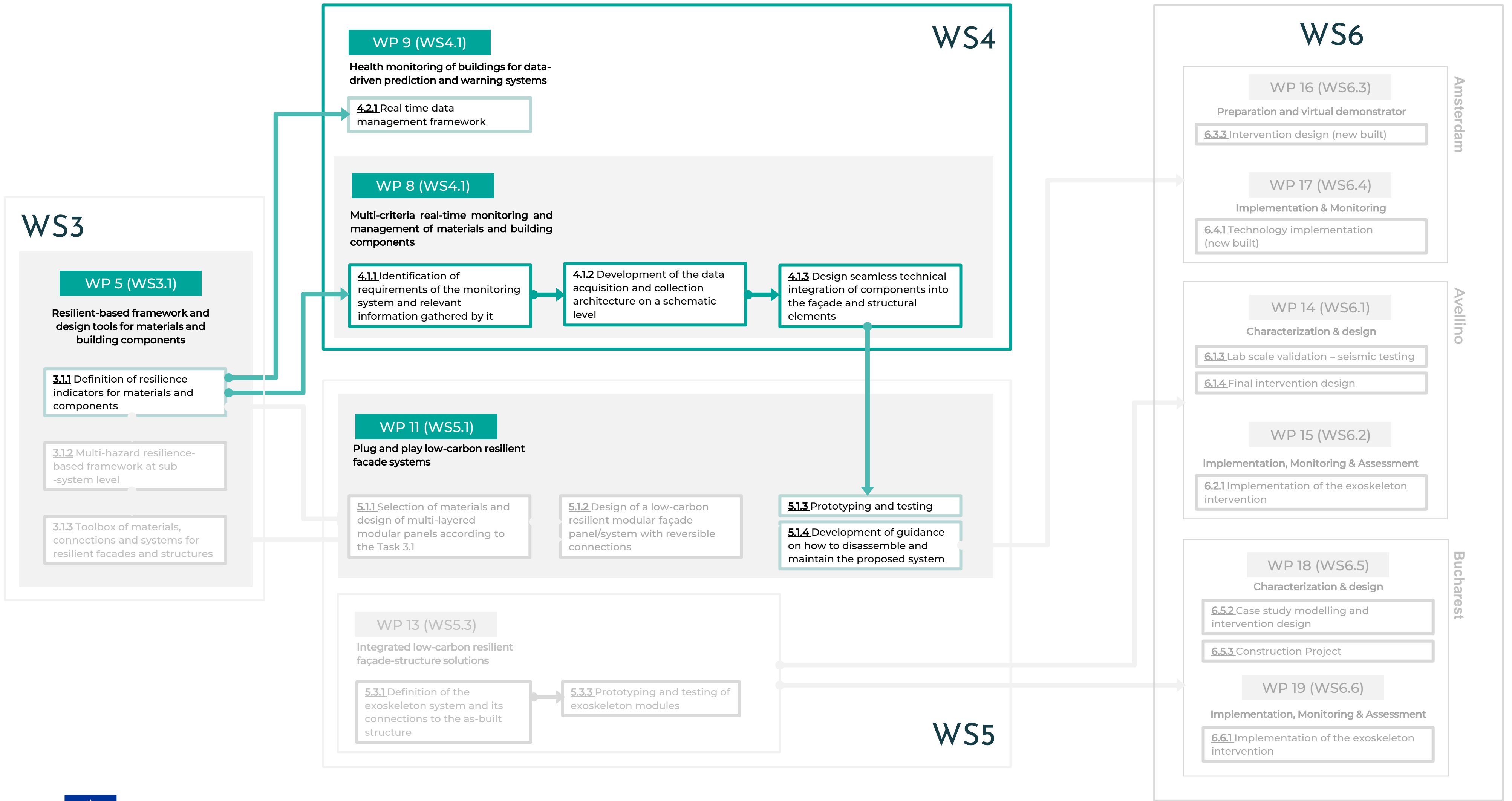
How to Monitor?



OVERVIEW



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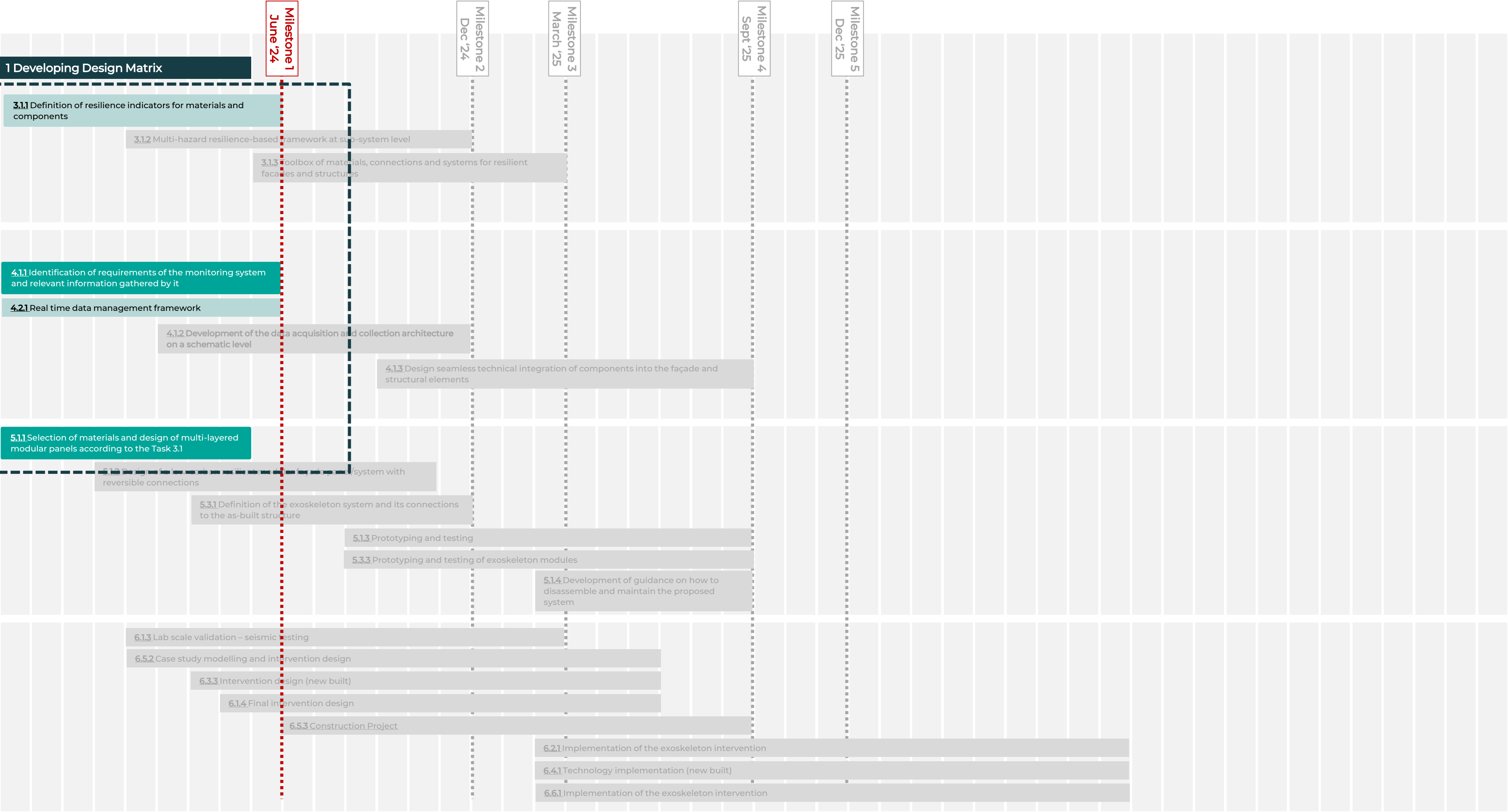


WS3

WS4

WS5

WS6

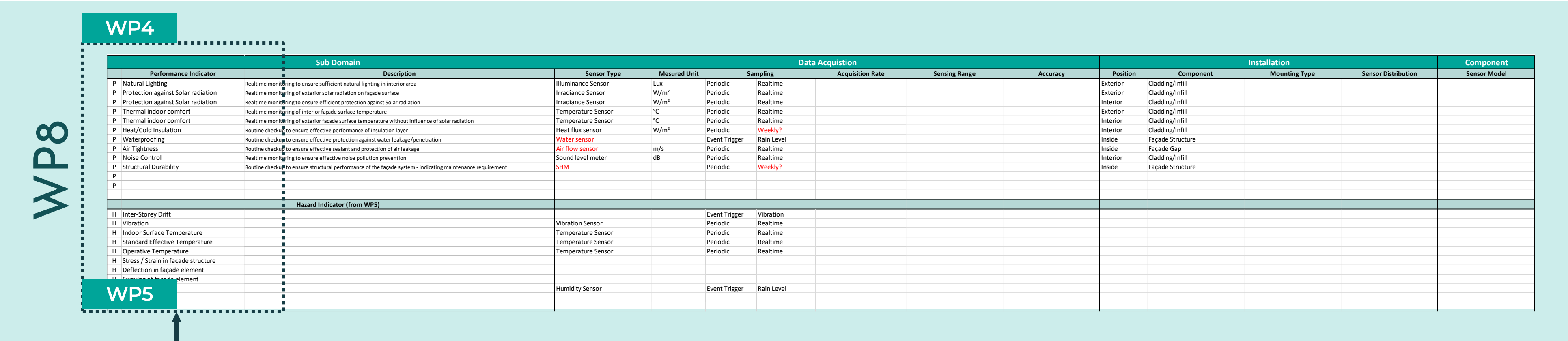


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02. SENSOR SELECTION MATRIX



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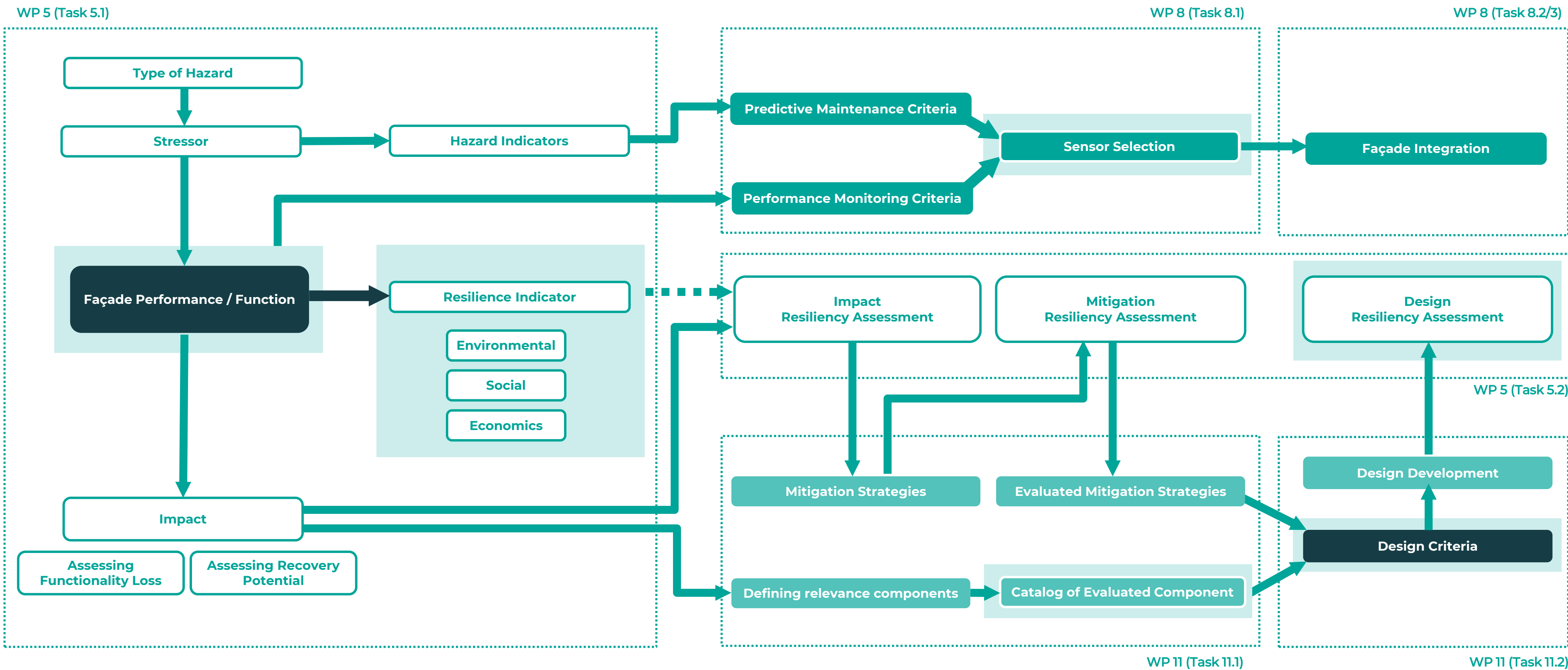
https://tud365.sharepoint.com/:x:/r/sites/Project101123467MULTICARE/Gedeelde%20documenten/General/WS3.%20Multi-hazard%20resilience%20and%20sustainability%20assessment,%20design/WP5/MULTICARE_WP5,8,11%20Matrix.xlsx?d=w4d06b52658cf4ce89f5ca9c402774a8e&csf=1&web=1&e=HqqJOz

MATRIX OVERVIEW (WIP)

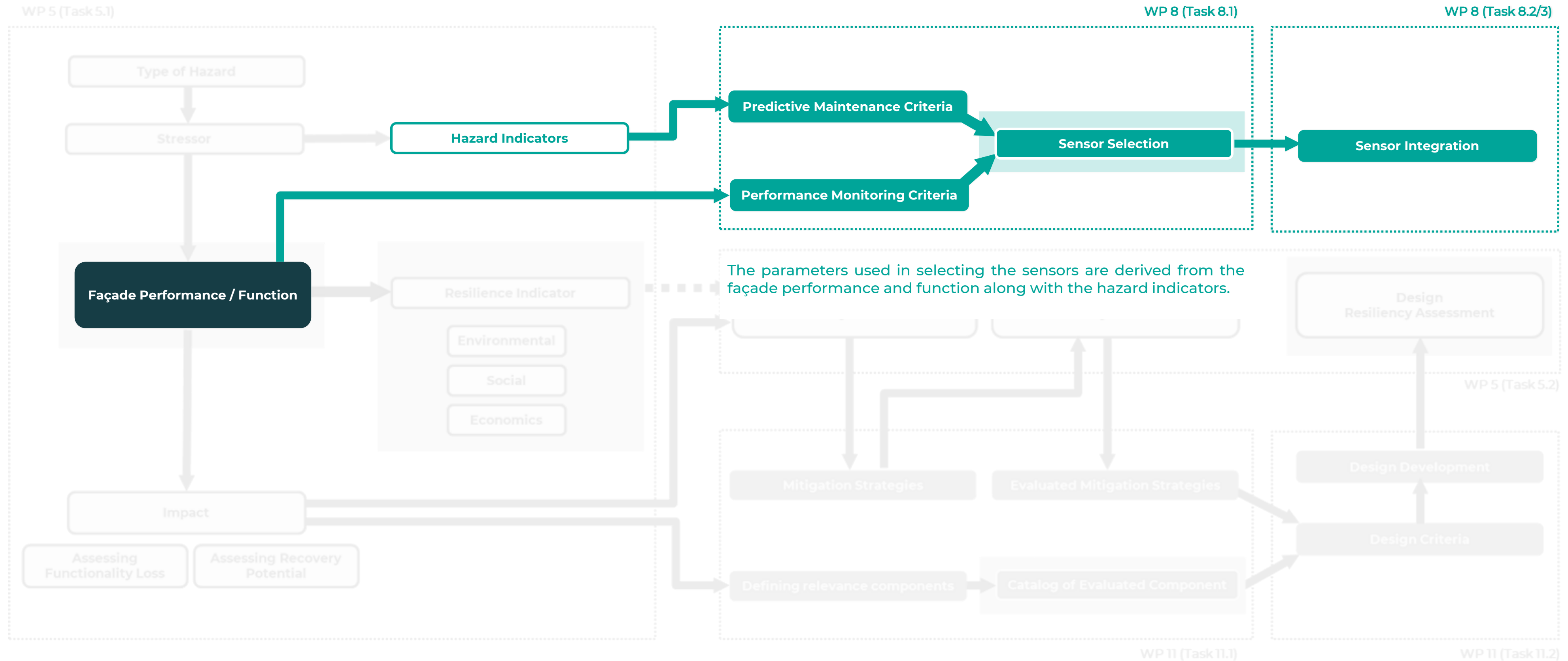


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METRICS METHODOLOGY



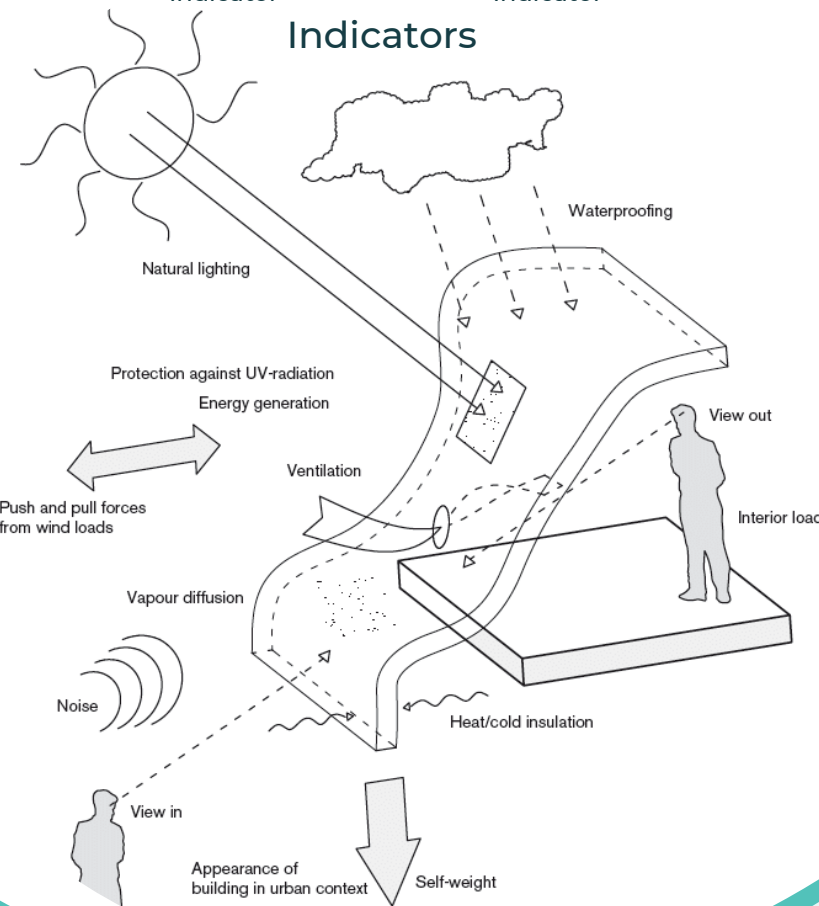
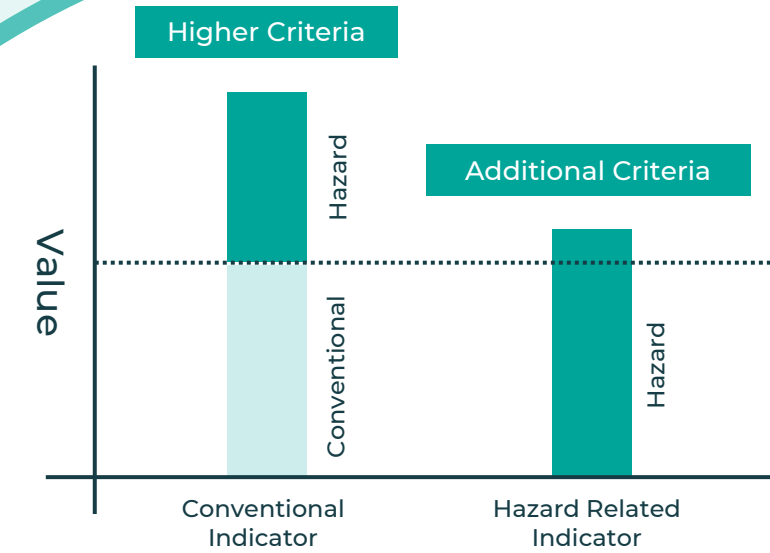
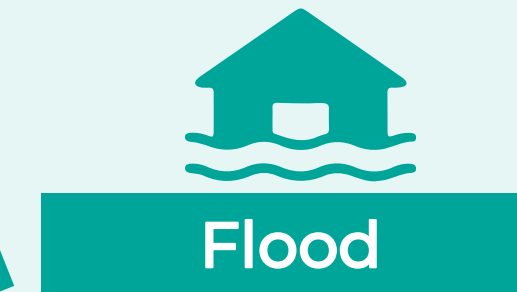
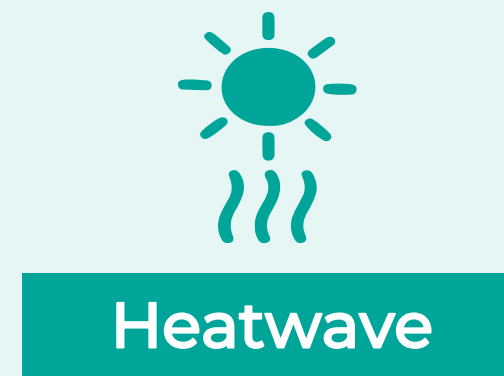
WP8 - SENSOR SELECTION METRICS



What to Monitor?

When to Monitor?

How to Monitor?



Hazard Impact Indicator

Due to the impact of the hazards, higher indicator criteria and/or additional hazard-related indicators are included.

Performance Indicator

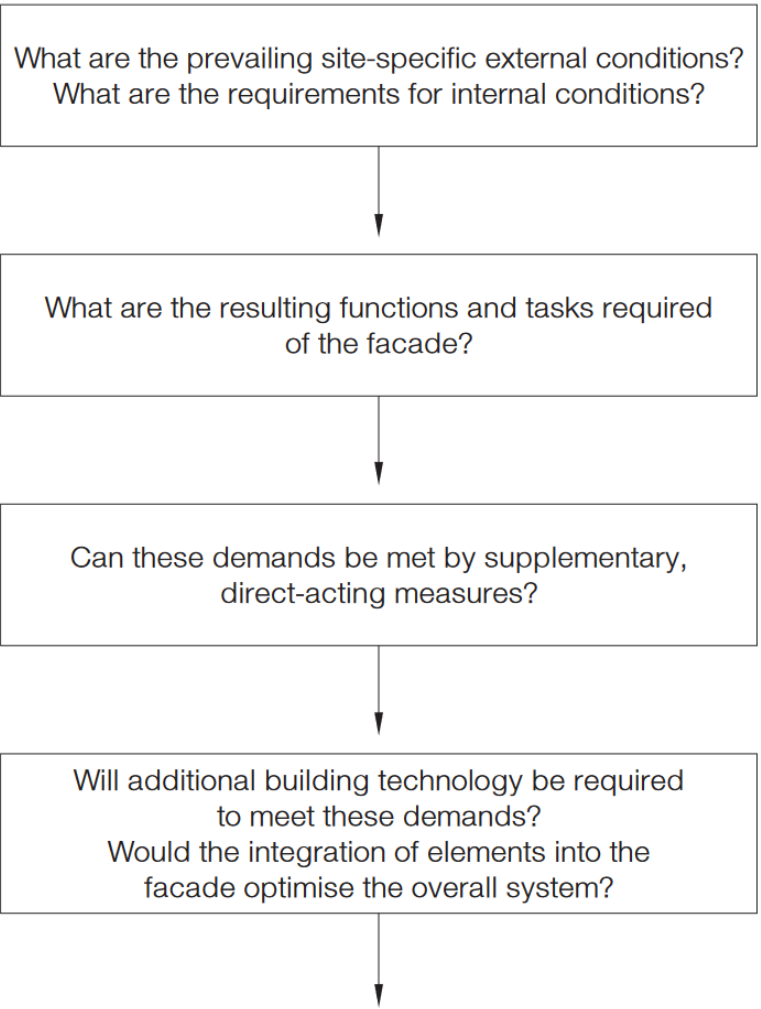
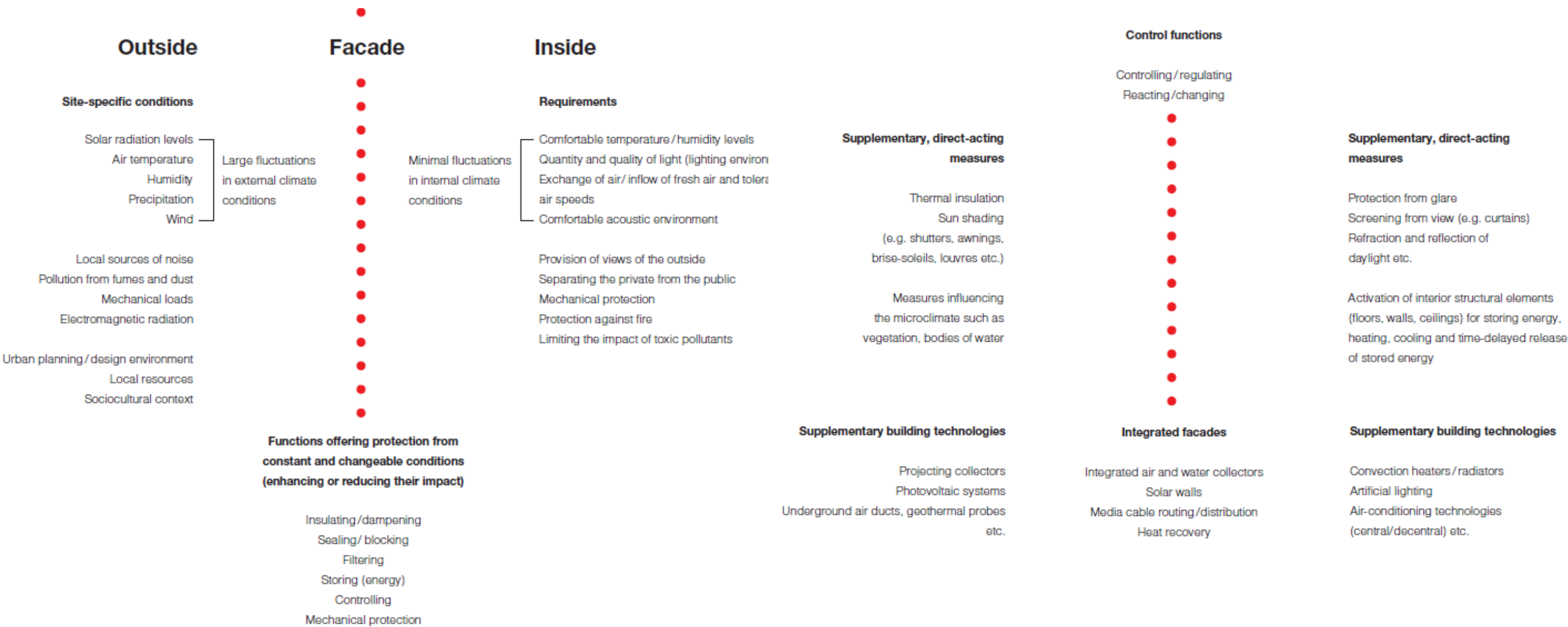
Conventional Façade Performance indicator

Knaack, U., Klein, T., Bilow, M., & Auer, T. (2007). *Façades—Principles of Construction*. Birkhäuser Basel. <https://doi.org/10.1007/978-3-7643-8281-0>

What to Monitor?

When to Monitor?

How to Monitor?



Herzog, T., Krippner, R., & Lang, W. (2012). Facade Construction Manual. Birkhäuser.

FAÇADE FUNCTION

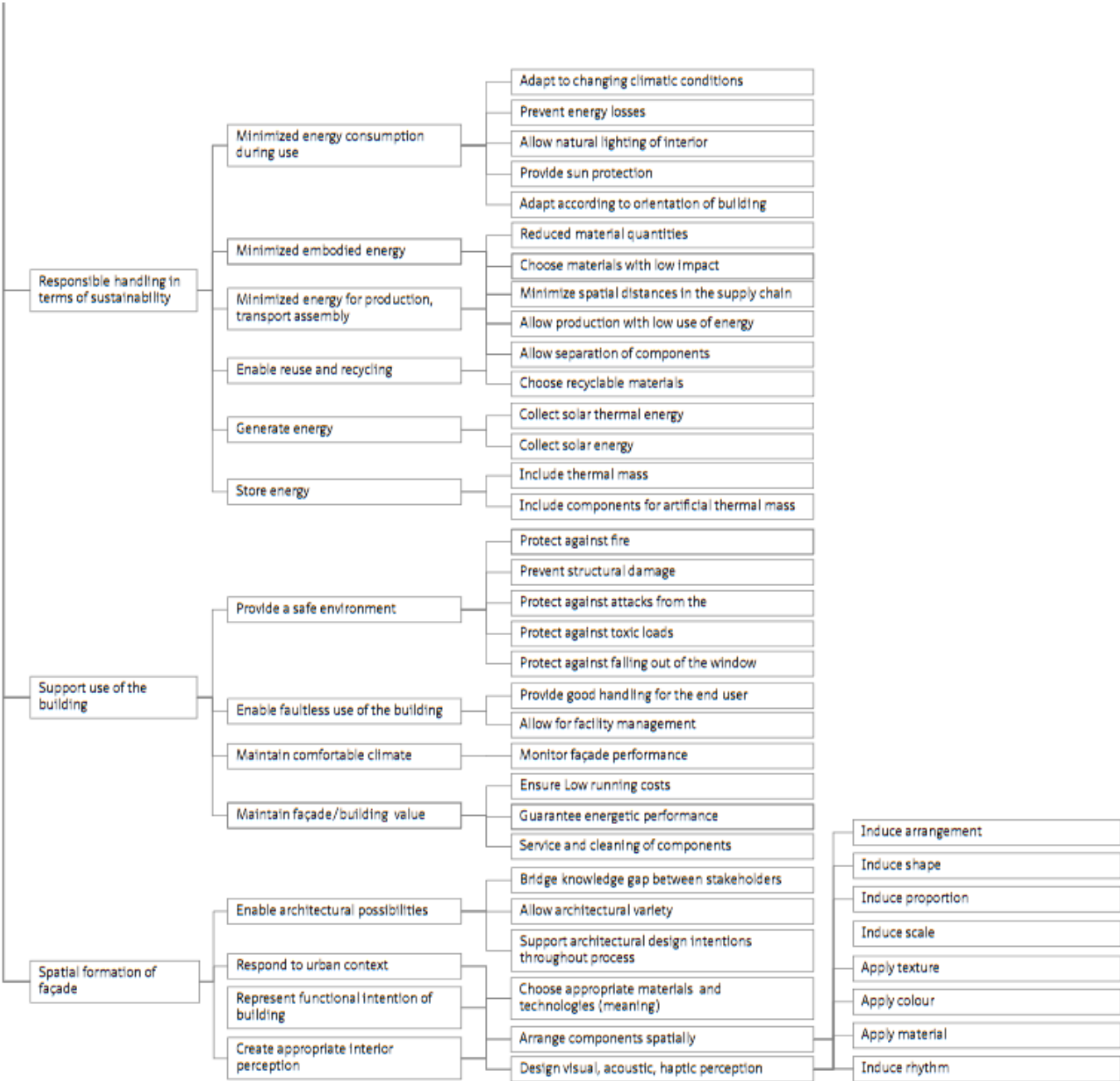
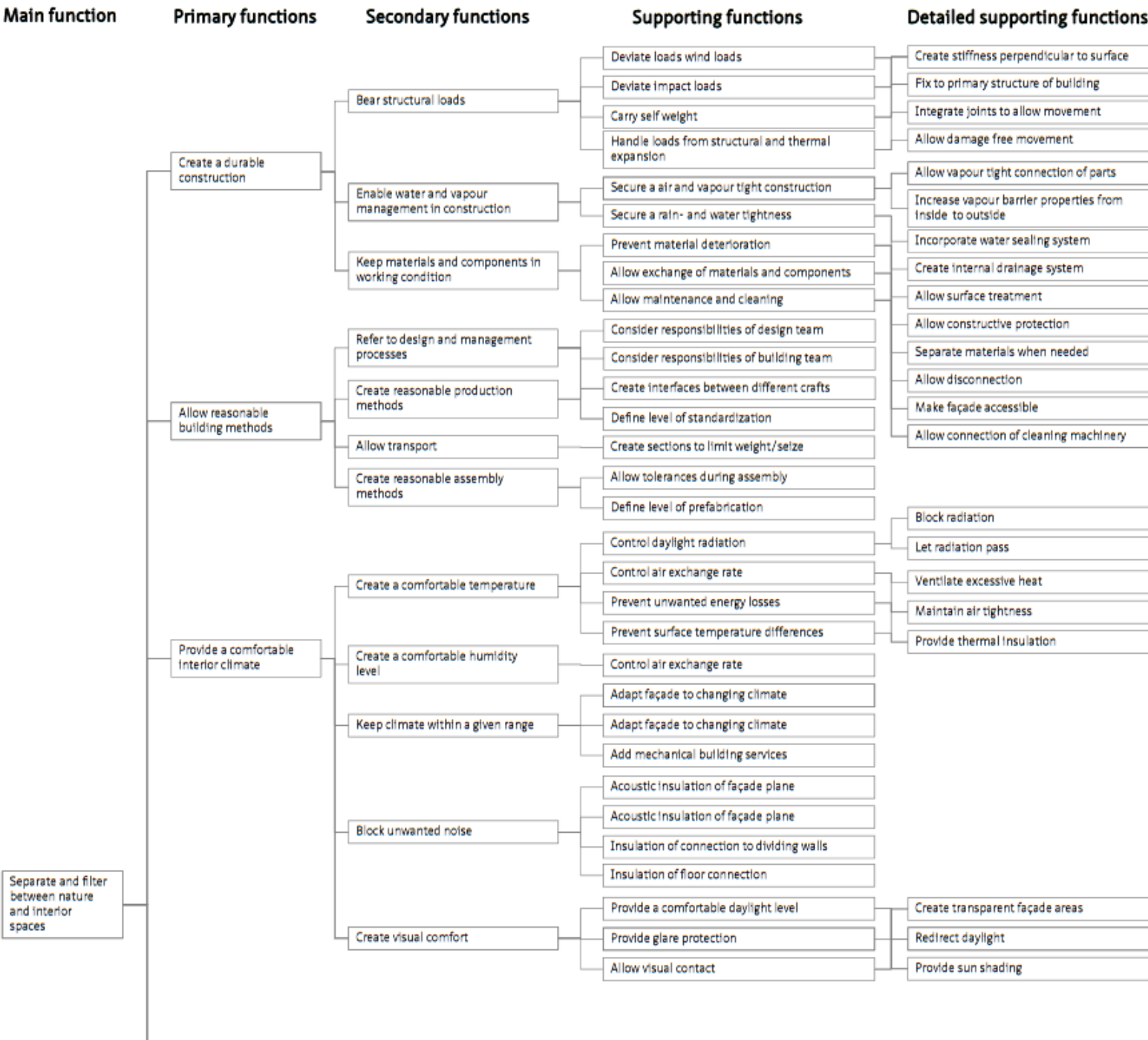


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What to Monitor?

When to Monitor?

How to Monitor?



Klein, T. (2013). Integral facade construction: Towards a new product architecture for curtain walls. TU Delft.

FAÇADE FUNCTION TREE



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What to Monitor?

When to Monitor?

How to Monitor?

Table 1
Environmental parameters to be monitored to characterise the impact of façades on comfort according international standards and after previous work [10].

Comfort domain	Occupant-centred metrics	Façade characteristics	Environmental parameters at the façade	Environmental parameters at occupant position
Thermal comfort [28,41,42]	PMV [28,41,42] PMV ^a [43] ^a PPD [28,41,42] Top [28,40,41] DR [28,41,42] PD [28,41,42] RH [44]Degree Hours [44] PPDweighted [44]	U-Value [45–49] g-value [50–53] Thermal inertia [54] Air tightness [55–58]	Surface temperature [41,42] Air temperature [41,42] Irradiance [43] ^a Solar beam direction [43] ^a Air velocity [41,42] Air flow rate [28,41,42] Air flow temperature [28,41,42]	Air temperature [28,41,42] MRT [28,41,42] Irradiance on the occupant [43] ^a
		Vent location and dimension	Air flow rate moisture content [28,41,42]	Air velocity [28,41,42]
Visual comfort [59–61]	DT [59] ET [59]	Light transmittance [51–53,62] Light reflectance [51]		Horizontal illuminance at desk level [59,60,64] Contrast illuminance [60] Vertical Illuminance at eye level [59] Luminance [59]
	fDGP, exceed [59] DGP [59] DGPe [59]	Openings size and location [59] Shading factor [63] Blinds Openness coefficient [63] Blinds Colour rendering index [63]	Illuminance [60] Light beam direction	
Air quality comfort [28,65–67]	View out [59]		Light colour [60]	View [59]
	PD [28] CO2 (ppm) [28,65] TVOC (µg/m3) [28] CH2O (µg/m3) [28,66] C1A/C1B VOC (µg/m3) [28] R value [28] CO (mg/m3) [66] C6H6 [66] C10H8 (µg/m3) [66] NO2 (µg/m3) [66] PAHs [66] C2HCl3 [66] C2Cl4 (µg/m3) [66]	Air tightness [55–58] Vent location and dimension [28] Material pollutant emission [68] Airborne Sound Insolation [58,71] Sound absorption [72] Sound reflectance [72] Type of actuation system Mode of actuation Level of automation Interactive scenario Interface Mass [58] Stiffness of the façade [58,76]	Air flow rate [28] Air flow pollutant content [28,66] Air flow moisture content [28]	Air pollutant content [28,66] Air moisture content [28] Air CO2 content [28]
Acoustic comfort [28,69,70]	Rn (Bq/m3) [66] L _{eq} [dbA] [28]			
Interaction			Noise level Noise frequency characteristics Not applicable	Noise level [28,73] Noise frequency characteristics Not applicable
Vibration [74,75]			Acceleration (tri-axis) [77,78]	Acceleration (tri-axis) [77,78]

Table 5. Most frequent KPIs found in the literature starting from Table 4.

Indicator	Frequency
Thermal comfort	10 times
Energy consumption	10 times
CO ₂ /GHG emission	6 times
Indoor air quality	5 times
Renewable energy sources	4 times
Daylight factor	4 times
Discomfort hours (27–28 °C)	3 times
Daylight requirement	3 times
Investment costs	3 times
Degree of satisfaction	3 times
Wellbeing	3 times
Solid waste	2 times
Solar radiation	2 times
Accessibility	2 times
Initial costs	2 times
Degree of privacy	2 times
Eco-efficiency	2 times

Luna-Navarro, A., Fidler, P., Law, A., Torres, S., & Overend, M. (2021). Building Impulse Toolkit (BIT): A novel IoT system for capturing the influence of façades on occupant perception and occupant-façade interaction. Building and Environment, 193, 107656.

Mosca, F., & Perini, K. (2022). Reviewing the Role of Key Performance Indicators in Architectural and Urban Design Practices. Sustainability, 14(21), 14464. <https://doi.org/10.3390/su142114464>

PARAMETERS IN FAÇADE MONITORING



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What to Monitor?

When to Monitor?

How to Monitor?

Period
Of High
Temperature



Heatwave

Hazard Impact Indicator

For effective predictive maintenance
of façade / Additional Indicators to
considered

Based on indicators defined in WP5

Weatherproofing

Natural
Lighting

Protection
against
Solar
radiation

Insulation

Noise
Control

Structure
Durability

Self-
Weight

Ventilation

Vapor
Diffusion

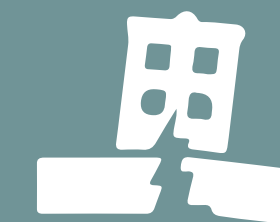
Water
Exposure



Flood

Water
Impact

Vibration



Seismic

Inter-Storey Drift

Performance Indicator

For long term monitoring of
multicriteria performance of façade
system.
Based on KPI defined in WP2

What to Monitor?

When to Monitor?

How to Monitor?

Parameter	Characteristics
Goal	Sense-only , sense and react
Sampling	Periodic, event-triggered
Sensed Phenomenon	Single, Multiple ; discrete, distribute
Data Rate	Low, high
Mobility	Mobiles nodes, mobile base-station
Connectivity	Connected, intermittent, sporadic
Processing	Filtering, compression, aggregation, tracking, event detection, classification, decision making ; Node, network , gateway, server
Storage	Caching, persistent; Node, network, gateway, server
Services	Localization, time synchronization, authentication, encryption, reprogramming, reconfiguration
Communication Primitives	Single-hop unicast, multi-hop unicast, single-hop broadcast, flooding, collection, cluster

Oppermann, F. J., Boano, C. A., & Römer, K. (2014). A decade of wireless sensing applications: Survey and taxonomy. In: The Art of Wireless Sensor Networks. Volume 1: Fundamentals, pp. 11-50. Berlin/Heidelberg, Germany: Springer. [http s://doi.org/10.1007/978-3-642-40009-4_2](http://doi.org/10.1007/978-3-642-40009-4_2)

SENSOR PARAMETER



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WP 4 - KPI

HOW TO MONITOR THE FAÇADE ?

Definition of Sensor Model

Sub Domain		Data Acquisition								Installation				Component
	Performance Indicator	Description	Sensor Type	Mesured Unit	Sampling	Acquisition Rate	Sensing Range	Accuracy		Position	Component	Mounting Type	Sensor Distribution	Sensor Model
P	Natural Lighting	Realtime monitoring to ensure sufficient natural lighting in interior area	Illuminance Sensor	Lux	Periodic	Realtime				Exterior	Cladding/Infill			
P	Protection against Solar radiation	Realtime monitoring of exterior solar radiation on façade surface	Irradiance Sensor	W/m²	Periodic	Realtime				Exterior	Cladding/Infill			
P	Protection against Solar radiation	Realtime monitoring to ensure efficient protection against Solar radiation	Irradiance Sensor	W/m²	Periodic	Realtime				Interior	Cladding/Infill			
P	Thermal indoor comfort	Realtime monitoring of interior façade surface temperature	Temperature Sensor	°C	Periodic	Realtime				Exterior	Cladding/Infill			
P	Thermal indoor comfort	Realtime monitoring of exterior facade surface temperature without influence of solar radiation	Temperature Sensor	°C	Periodic	Realtime				Interior	Cladding/Infill			
P	Heat/Cold Insulation	Routine checkup to ensure effective performance of insulation layer	Heat flux sensor	W/m²	Periodic	Weekly?				Interior	Cladding/Infill			
P	Waterproofing	Routine checkup to ensure effective protection against water leakage/penetration	Water sensor		Event Trigger	Rain Level				Inside	Façade Structure			
P	Air Tightness	Routine checkup to ensure effective sealant and protection of air leakage	Air flow sensor	m/s	Periodic	Realtime				Inside	Façade Gap			
P	Noise Control	Realtime monitoring to ensure effective noise pollution prevention	Sound level meter	dB	Periodic	Realtime				Interior	Cladding/Infill			
P	Structural Durability	Routine checkup to ensure structural performance of the façade system - indicating maintenance requirement	SHM		Periodic	Weekly?				Inside	Façade Structure			
P														
Hazard Indicator (from WP5)														
H	Inter-Storey Drift				Event Trigger	Vibration								
H	Vibration		Vibration Sensor		Periodic	Realtime								
H	Indoor Surface Temperature		Temperature Sensor		Periodic	Realtime								
H	Standard Effective Temperature		Temperature Sensor		Periodic	Realtime								
H	Operative Temperature		Temperature Sensor		Periodic	Realtime								
H	Stress / Strain in façade structure													
H	Deflection in façade element													
H	Swaying of façade element													
H	Water Leakage		Humidity Sensor		Event Trigger	Rain Level								
H	Humidity Level													
H														

WP 5 – Hazard related Indicators



https://tud365.sharepoint.com/:x:/r/sites/Project101123467MULTICARE/Gedeelde%20documenten/General/WS3.%20Multi-hazard%20resilience%20and%20sustainability%20assessment,%20design/WP5/MULTICARE_WP5,8,11%20Matrix.xlsx?d=w4d06b52658cf4ce89f5ca9c402774a8e&csf=1&web=1&e=HqqJOz

SENSOR SELECTION MATRIX



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NEXT STEPS:

- Finalize the Sensor Parameter for Selection Matrix
- Defining relevant sensors for façade monitoring
- Define design specification for Sensor System

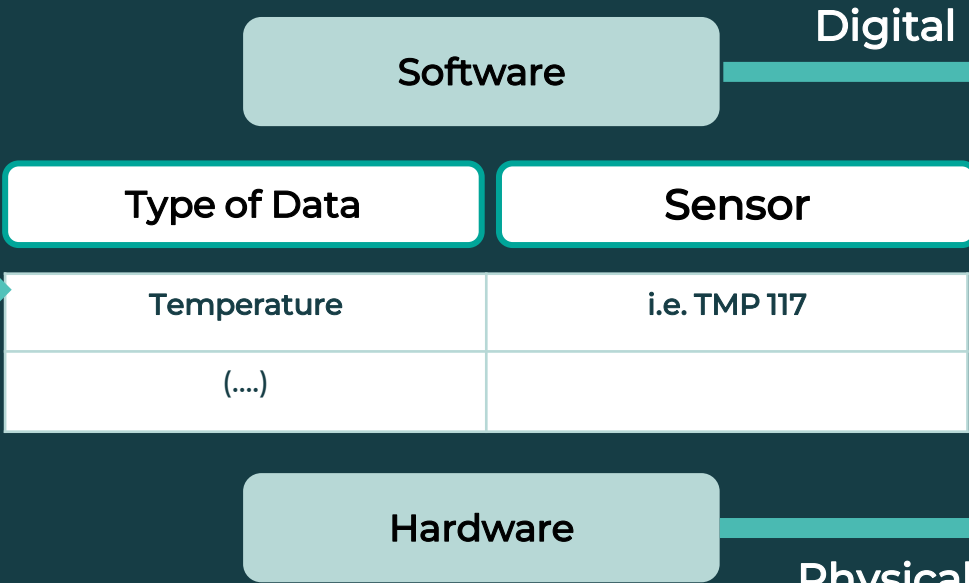
Definition of Design Specification for Sensor System	
General Requirements	Waterproof level, UV tolerance, Size (...)
Real-Time Sensing	Data Transmission Protocol (...)
Data Logging	Data format, Naming Convention, Data storage, Accessibility, Right Management (...)
Processing	Type of software required, Processing Protocol (...)
Visualization	Type of visualization, Which data to show (...)

4.1.1

Hazard Indicator and Sensor Matrix

Design Specification for Sensor System

Develop Sensor Schematic



OUTLOOK



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THANK YOU

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