Boosting Research for a Smart and Carbon Neutral Built Environment with Digital Twins (SmartWins)

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Kaunas University of Technology

SmartWins

The SmartWins Project at a glance

Project Title	Boosting Research for a Smart and Carbon Neutral Built Environment with Digital Twins
Project acronym:	SmartWins
Programme	Horizon Europe Framework Programme (HORIZON)
Call	Twinning (HORIZON-WIDERA-2021-ACCESS-03)
Type of Action	HORIZON-CSA HORIZON Coordination and Support Actions
Project Budget	1499974 €
KTU Budget	571875 €
Project Duration	01.10.2022-30.09.2025

The SmartWins Project Short Description

- **Artificial intelligence, digitalisation, and digital twin technologies** have led to many recent advancements.

- In collaboration with the Kaunas University of Technology, Lithuania, the EU-funded SmartWins project aims to assist the university's Sustainable Energy in the Built Environment research group **to improve its research capacities.**

- Relying on **research and cooperation with leading energy institutions and universities**, the project aims to discover novel ways to high-quality research on the topic of **next generation digital twins, applied for allowing the transition to a smart, sustainable, resilient and carbon neutral built environment.**

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What are the Twinning projects?

- Twinning aims to **enhance networking activities between the research institutions of the Widening countries and top-class leading counterparts at EU level** by linking it with at least two research institutions from two different EU MS.

- Twinning projects aim to build on the potential **of networking for excellence through knowledge transfer and exchange of best practice**.

- Twinning actions intend to help **raise the research profile of the institution from the Widening country** as well as the research profile of its staff including a special focus on strengthening the research management and administrative skills of the coordination institution from the Widening country.

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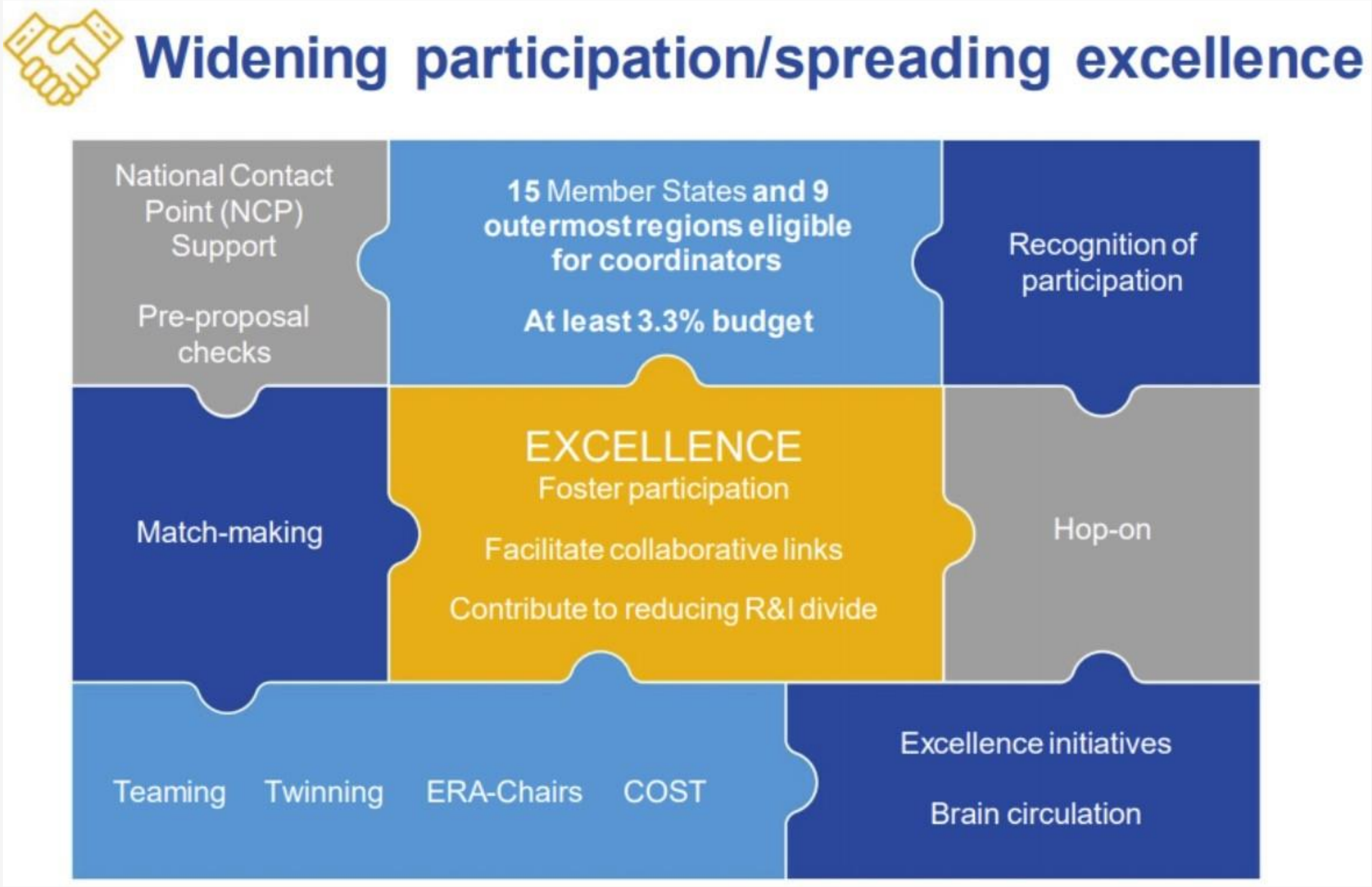
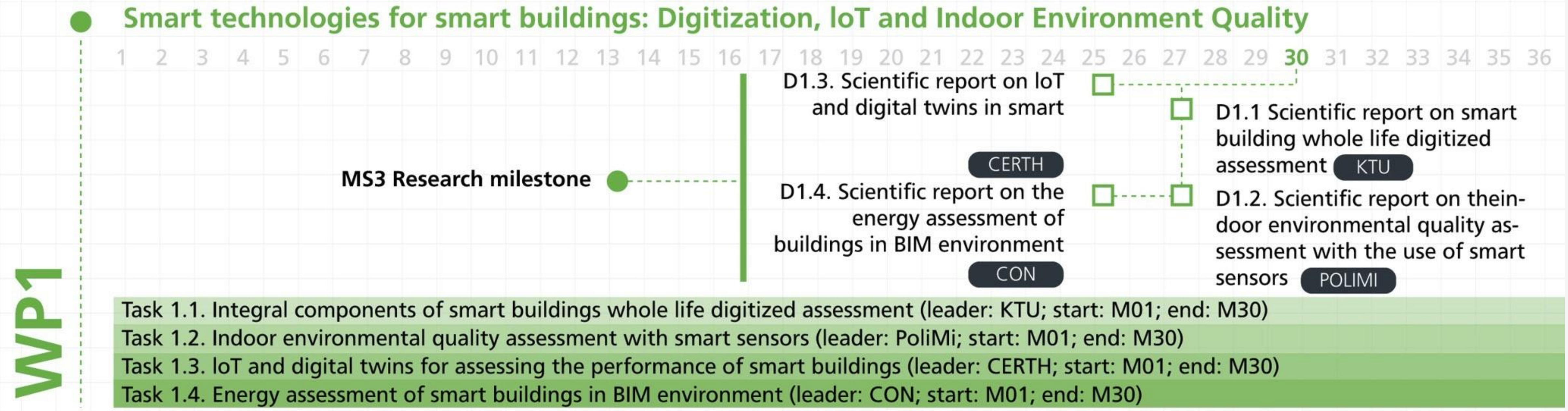
What are the Twinning projects?



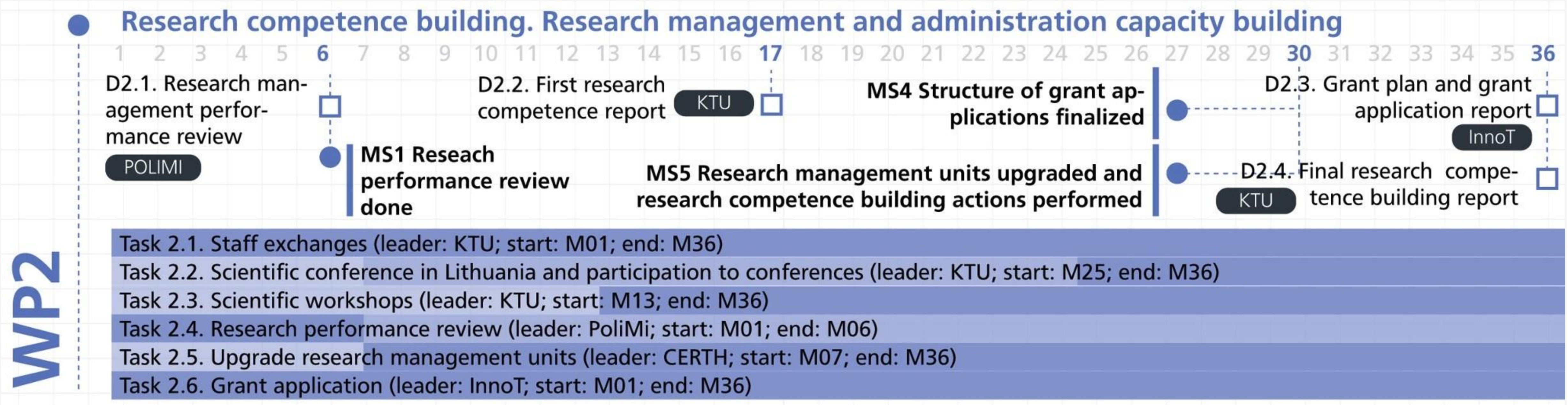
SmartWins Concept in a Nutshell

SmartWins Consortium – KTU Faculty of Civil Engineering and Architecture

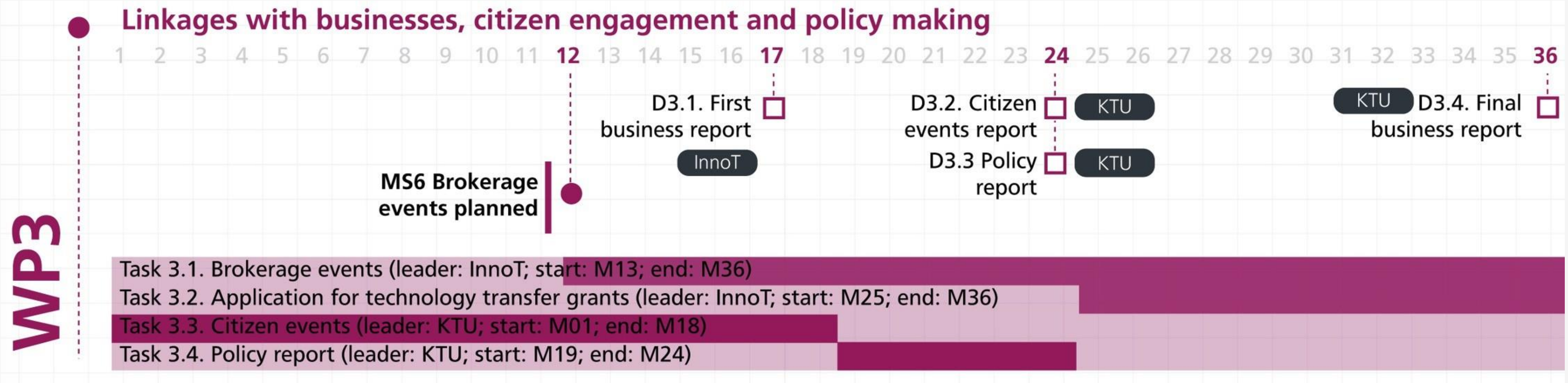
SmartWins Implementation Plan WP1



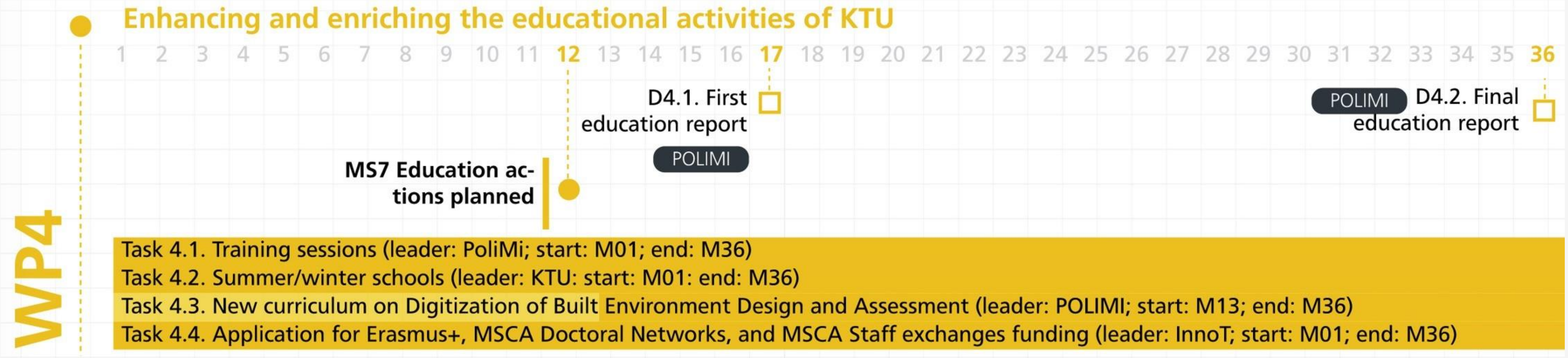
SmartWins Implementation Plan WP2



SmartWins Implementation Plan WP3



SmartWins Implementation Plan WP4



Objectives – Task 1.1

Objective: Improve KTU's research competence in sustainable building engineering using digital twins.

Task 1.1: Integral Components of Smart Buildings

- Leader: KTU
- Duration: M01 to M30
- Focus: Analyze life-cycle assessment and sustainability in building energy assessment; develop sustainability indicators; integrate BIM documents for environmental assessment.

Task 1.2 – Task 1.3

Task 1.2: Indoor Environmental Quality Assessment

- Leader: PoliMi
- Focus: Review and implement research on IEQ factors, tools, and measurements; evaluate indoor environmental quality using advanced tools.

Task 1.3: IoT and Digital Twins for Smart Buildings

- Leader: CERTH
- Focus: Develop monitoring and calculation procedures for operational energy assessment using smart sensors and digital twins; document current practices and data management.

Task 1.4 - Deliverables

Task 1.4: Energy Assessment in BIM Environment

- Leader: CON
- Focus: Incorporate energy and non-energy aspects in building assessments; develop asset-based methodology for BIM environment.

Deliverables:

- D1.1: Scientific report on smart building assessment (KTU, M30)
- D1.2: Report on indoor environmental quality (PoliMi, M30)
- D1.3: Report on IoT and digital twins (CERTH, M30)
- D1.4: Report on energy assessment in BIM (CON, M30)

WP1 – Achievements in Brief

Task 1.1 BIM to LCA application

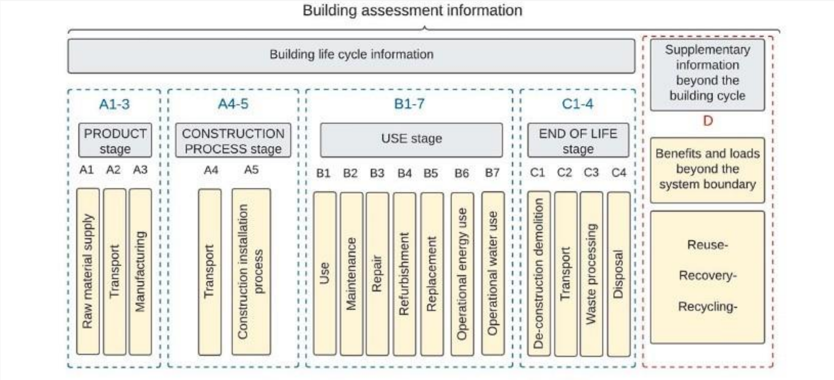
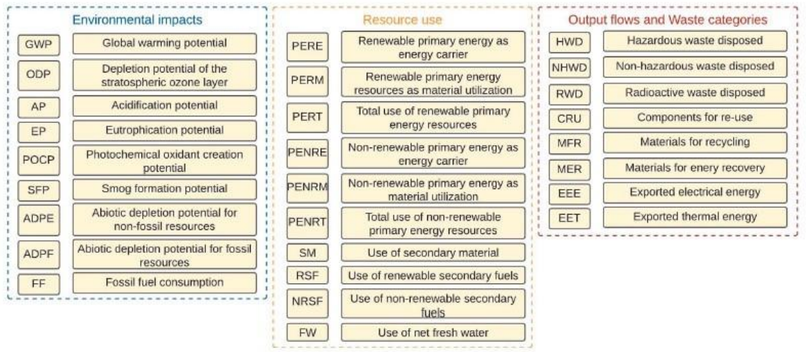


Fig. 3. Building's LCA stages according to EN 15978 [30].



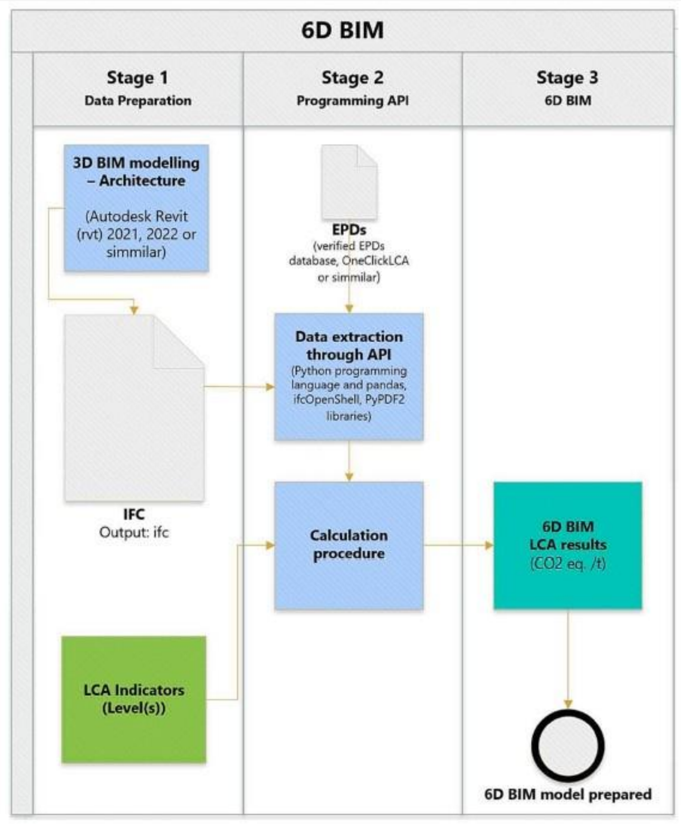


Fig. 8. 3D model of investigated pilot.

Table 2
Whole Building LCA assessment using the OneClickLCA software, cradle-to-gate phases (A1-A3 and A4-A5).

No.	Material	IfcMaterial	Mass, kg	Area, [m^2]	Volume, [m^3]	CO_2 e/ eq, t	GWP, kg CO_2 eq	ODP, kg CFC-11 eq	AP, kg SO_2 eq	EP, kg PO_4^{3-} eq	POCP, kg C_2H_4 eq	ADPE, kg Sb eq	ADPF, MJ eq
0	Glass wool insulation, blown, λ = 0.040 W/mK, 100 mm, 1.35 kg/m^2, 13.5 kg/m^3 (Knauf)	Fiberglass Batt		3529.79 m2	846.07	7.3773	1,31E + 00	1,35E-07	3,12E-03	4.05E-04	1,89E-04	7,46E-05	2,23E + 01
1	Red brick, average production, UK (The Brick Development Association)	Brick, Common		1173.62	347.38	128.2727	1,58E + 02	8,69E-05	1,35E + 00	5,00E-02	7,51E-02	4,34E-07	2,84E + 03
2	Sawn timber, planed, biogenic CO2 not substracted, 489 kg/m^3, Sägewerk Brilon (Fritz EGGER)	Wood_NL		946.93	(312.49 floor structure) 189.2	2.2954	−7,55E + 02	4,54E-10	2,53E-01	5,12E-02	8,24E-02	1,39E-05	3,21E + 02
3	PIR insulation boards, low emissivity foil faced, 66 mm, λ = 0.022 W/mK, R = 3 m^2K/W, 2.11 kg/m2, 32 kg/m^3, TR26, TT46 (Kingspan)	Rigid insulation		629.23	(266.79 floor structure) 96.9	26.1898	8,88E + 00	2,95E-07	4,80E-02	9,43E-03	1,15E-02	3,98E-05	1,99E + 02
4	Hollow core concrete slab, HDF22, C40/50, 220 mm, 306 kg/m^2, reinforcing 12.5 kg/ton (Strängbetong)	Concrete, Sand/ Cement Screed		629.23	266.79 (floor structure) 13.843	32.6401	1,36E + 02	3,09E-03	2,12E-01	4,44E-02	2,14E-02	5,06E + 02	2,96E-04
5	Metal framing components for gypsum plasterboard, 7750 kg/m^3, Gypframe (British Gypsum Saint Gobain)	Metal Stud Layer	85,250	–	–	136.9383	1,70E + 03	7,60E-06	6,40E + 00	3,60E-01	8,10E-01	2,30E-05	2,00E + 04
6	Copper sheet, stripes, 0.3–4.0 mm, 8940 kg/m^3, Nordic Standard (Aurubis)	Copper	25,000	–	–	21.5624	4,90E-01	6,16E-12	1,49E-03	1,20E-04	1,33E-04	1,30E-05	5,69E + 00

Reference: Klumbyte, E., Georgali, P. Z., Spudys, P., Giama, E., Morkunaite, L., Pupeikis, D., ... & Fokaides, P. (2023). Enhancing whole building life cycle assessment through building information modelling: Principles and best practices. Energy and Buildings, 296, 113401.

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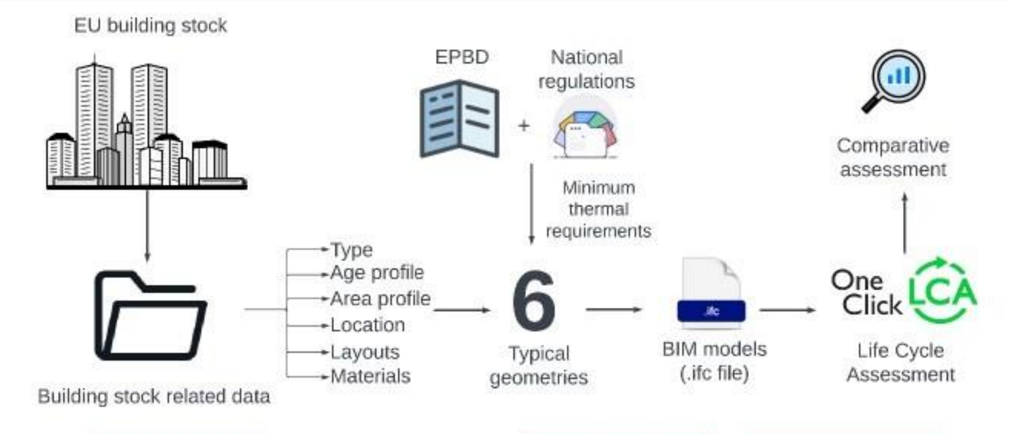
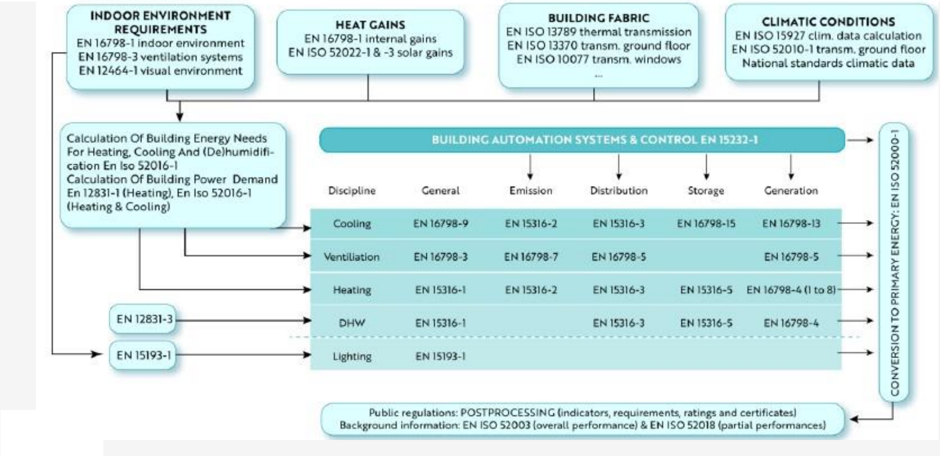
WP1 – Achievements in Brief

Task 1.1 A Comparative Life Cycle Assessment of Building Sustainability Across Typical European Building Geometries





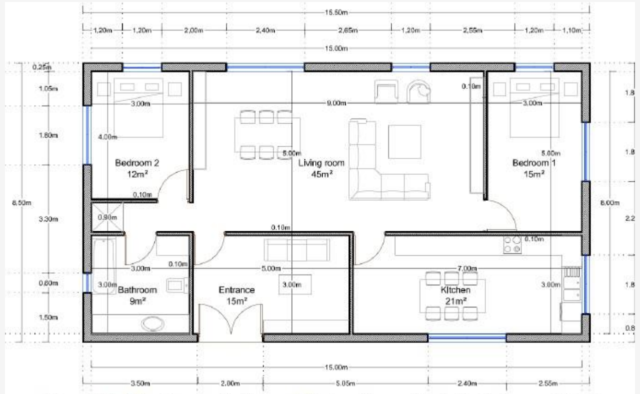
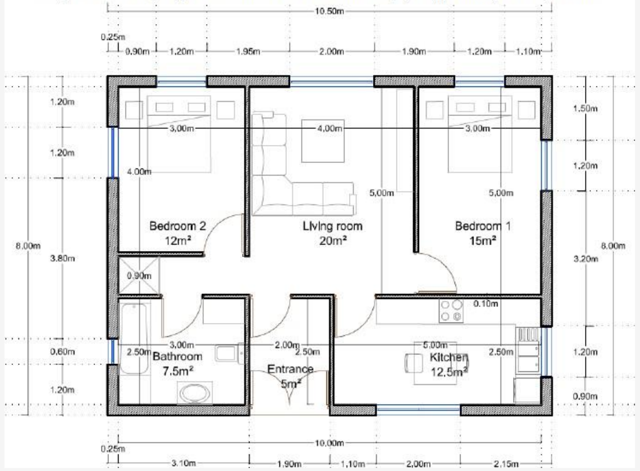
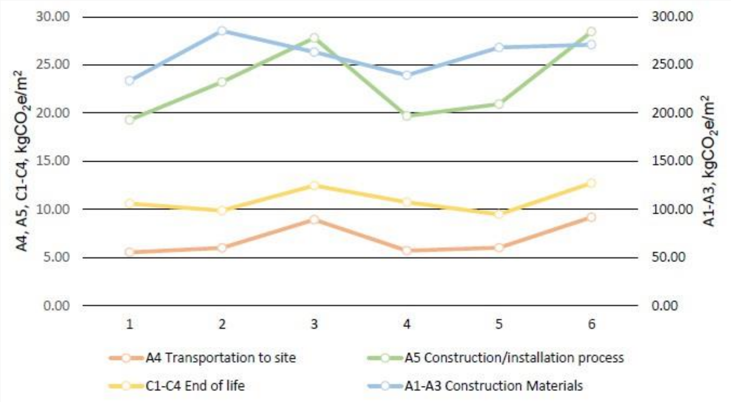
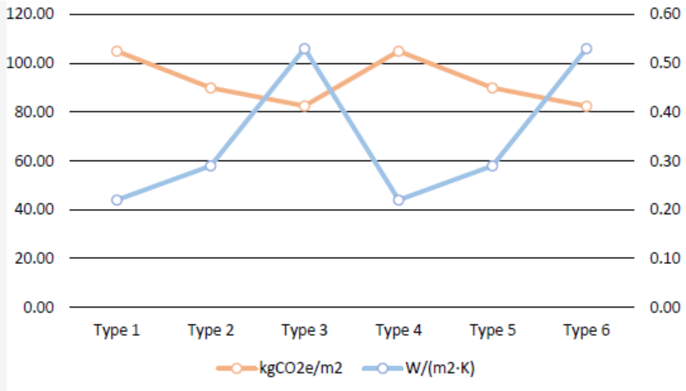


Figure 9. Building Type 1 - Northern and Western Europe, Single family houses, 120 m2



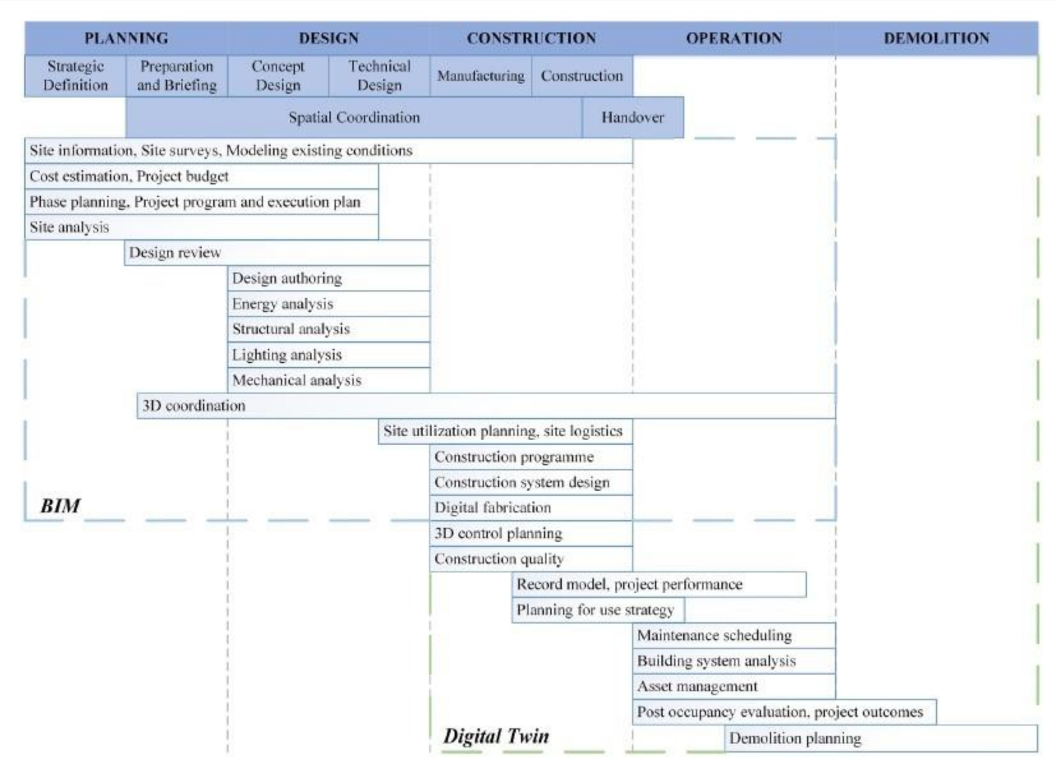


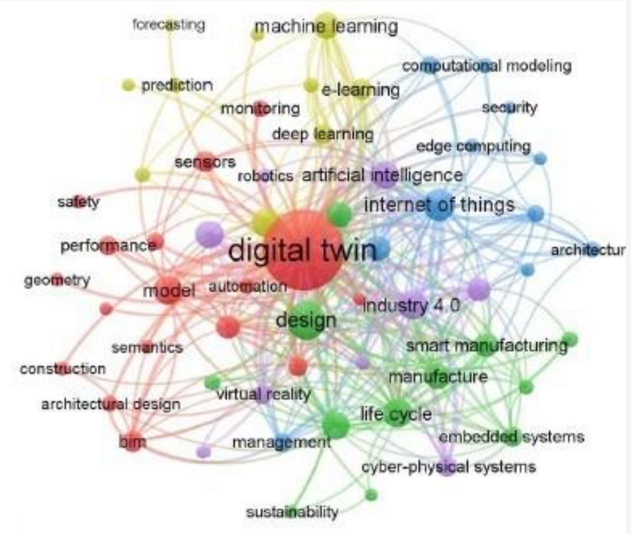


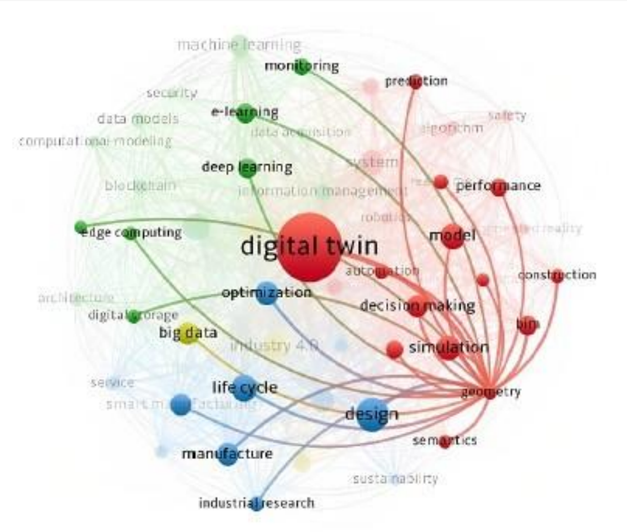
Reference: Spudys, P., Osadcha, I., Morkunaite, L., Clare, M.F., Georgali. P.Z., ... & Fokaides, P. (2024). A Comparative Life Cycle Assessment of Building Sustainability Across Typical European Building Geometries, Energy

WP1 – Achievements in Brief

Task 1.1 Geometric parameter updating in digital twin of built assets







Reference: Osadcha, I., Jurelionis, A., & Fokaides, P. (2023). Geometric parameter updating in digital twin of built assets: A systematic literature review. Journal of Building Engineering, 106704.

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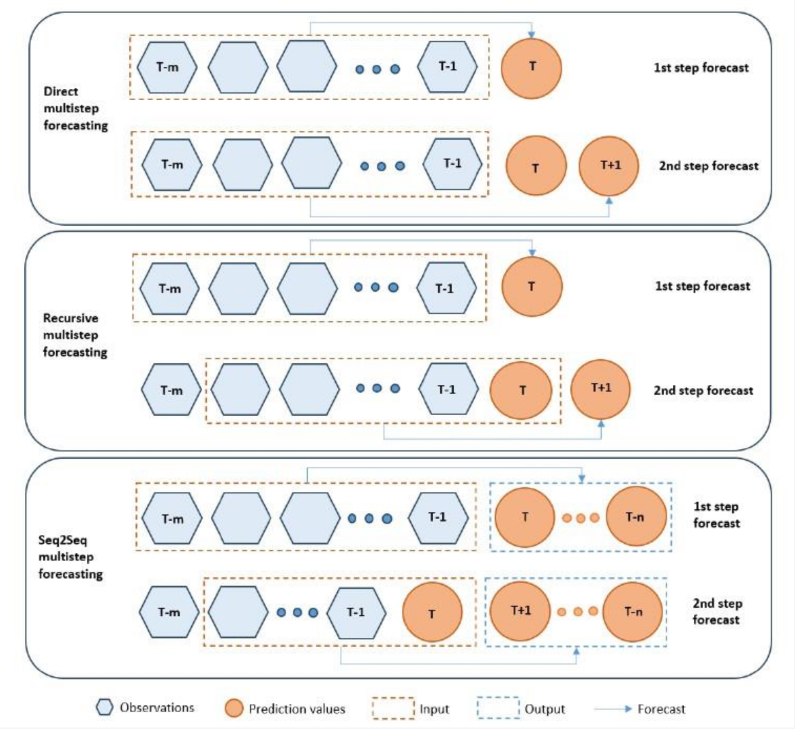
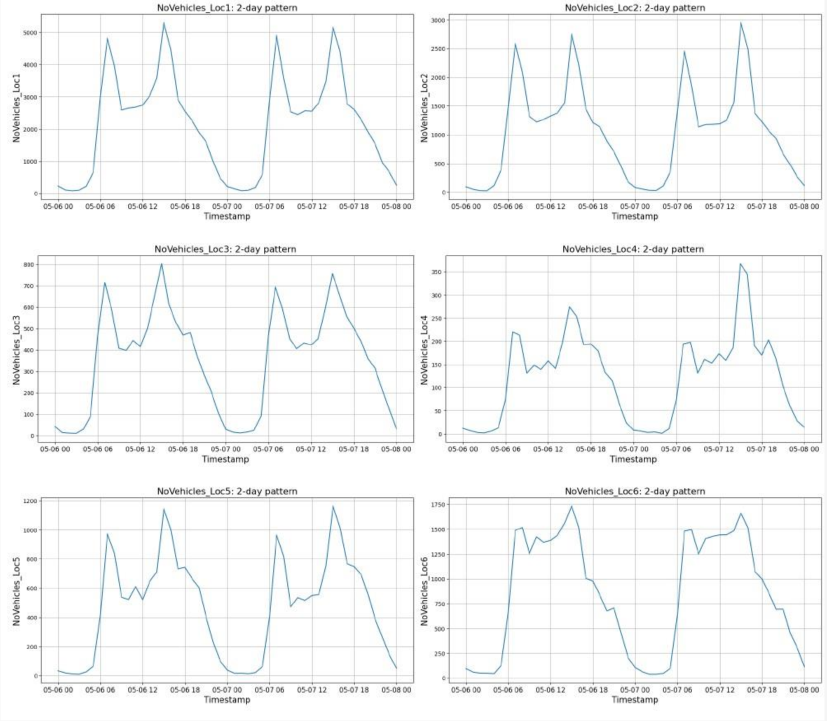
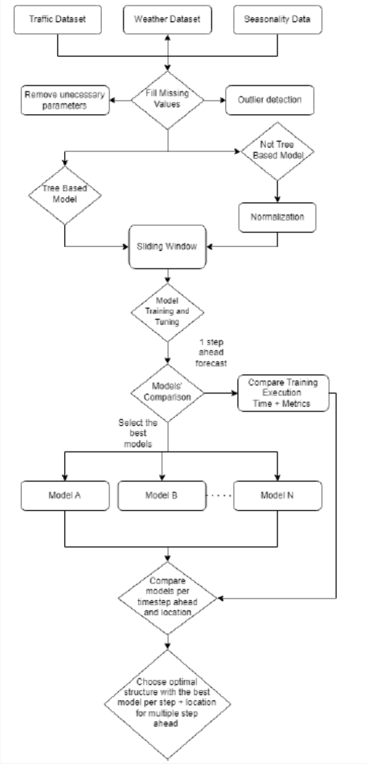
WP1 – Achievements in Brief

Task 1.3 Urban traffic congestion prediction: A multi-step approach utilizing sensor data and weather information







Reference: Tsalikidis, N., Mystakidis, A., Koukaras, P., Ivaškevicius ,M., Morkunaite, L., …& Tzovaras D. (2024). Urban traffic congestion prediction: A multi-step approach utilizing sensor data and weather information. Smart Cities,(MDPI)

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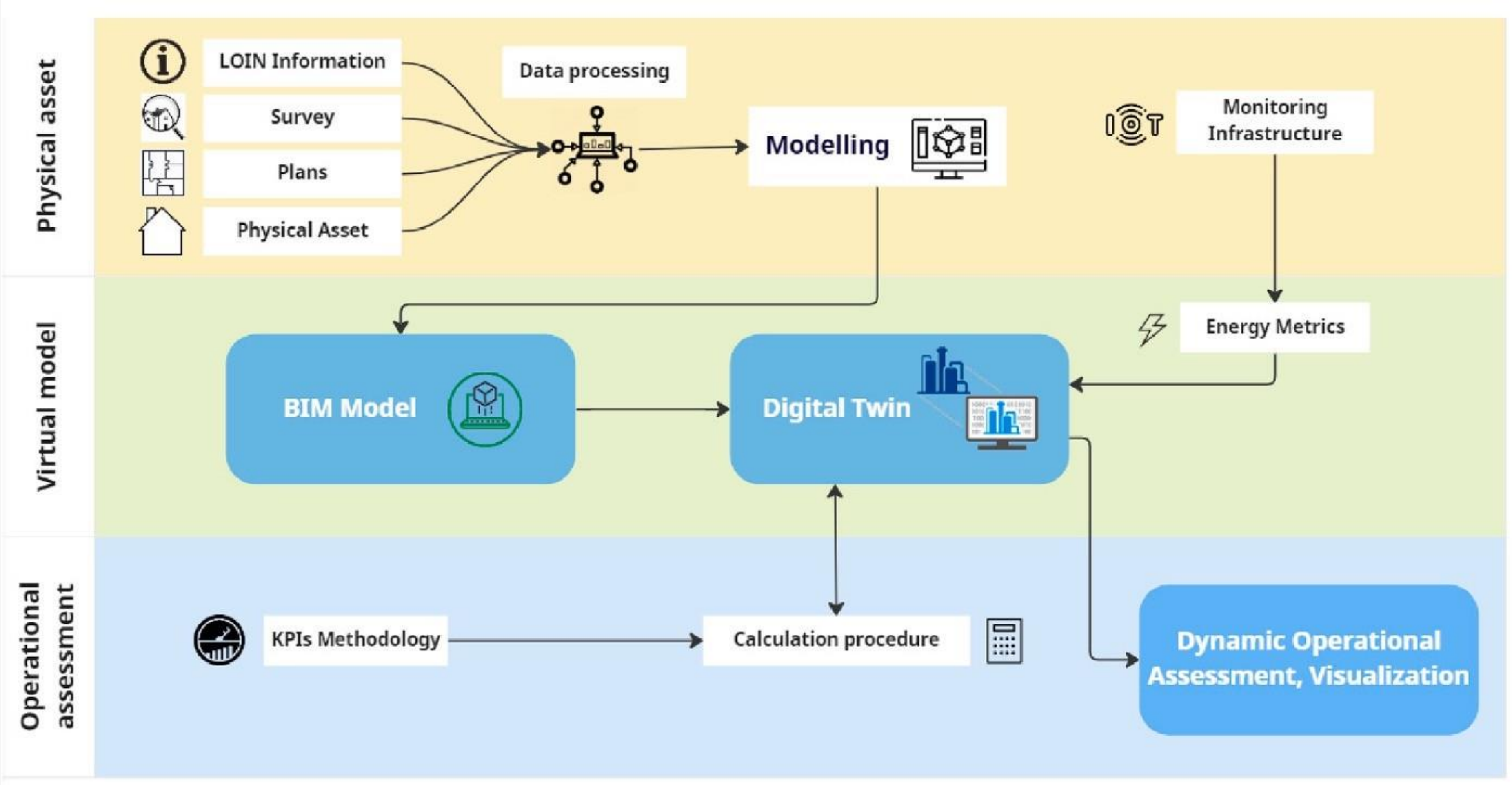
First evidences on Smart Operational Rating



Spudys, P., Afxentiou, N., Georgali, P. Z., Klumbyte, E., Jurelionis, A., & Fokaides, P. (2023). Classifying the operational energy performance of buildings with the use of digital twins. Energy and Buildings, 290, 113106.

First evidences on Smart Operational Rating Assessed Indicators

Indicator	Unit
Total Power/Occupancy	kWh/occupants
Total Power/Occupancy Hours	kWh/h*occupants
Total Power/Area	kWh/m^2
Total Power/Volume	kWh/m^3
Heating Consumption per Energy Carrier/Occupancy	kWh/occupants
Heating Consumption per Energy Carrier/Occupancy-hours	kWh/h*occupants
Heating Consumption per Energy Carrier/Area	kWh/m^2
Heating Consumption per Energy Carrier/Volume	kWh/m^3
Cooling Consumption per Energy Carrier/Occupancy	kWh/occupants
Cooling Consumption per Energy Carrier/Occupancy-hours	kWh/h*occupants
Cooling Consumption per Energy Carrier/Area	kWh/m^2
Cooling Consumption per Energy Carrier/Volume	kWh/m^3
Weather-Normalized Heating & Cooling Energy Cons.	---

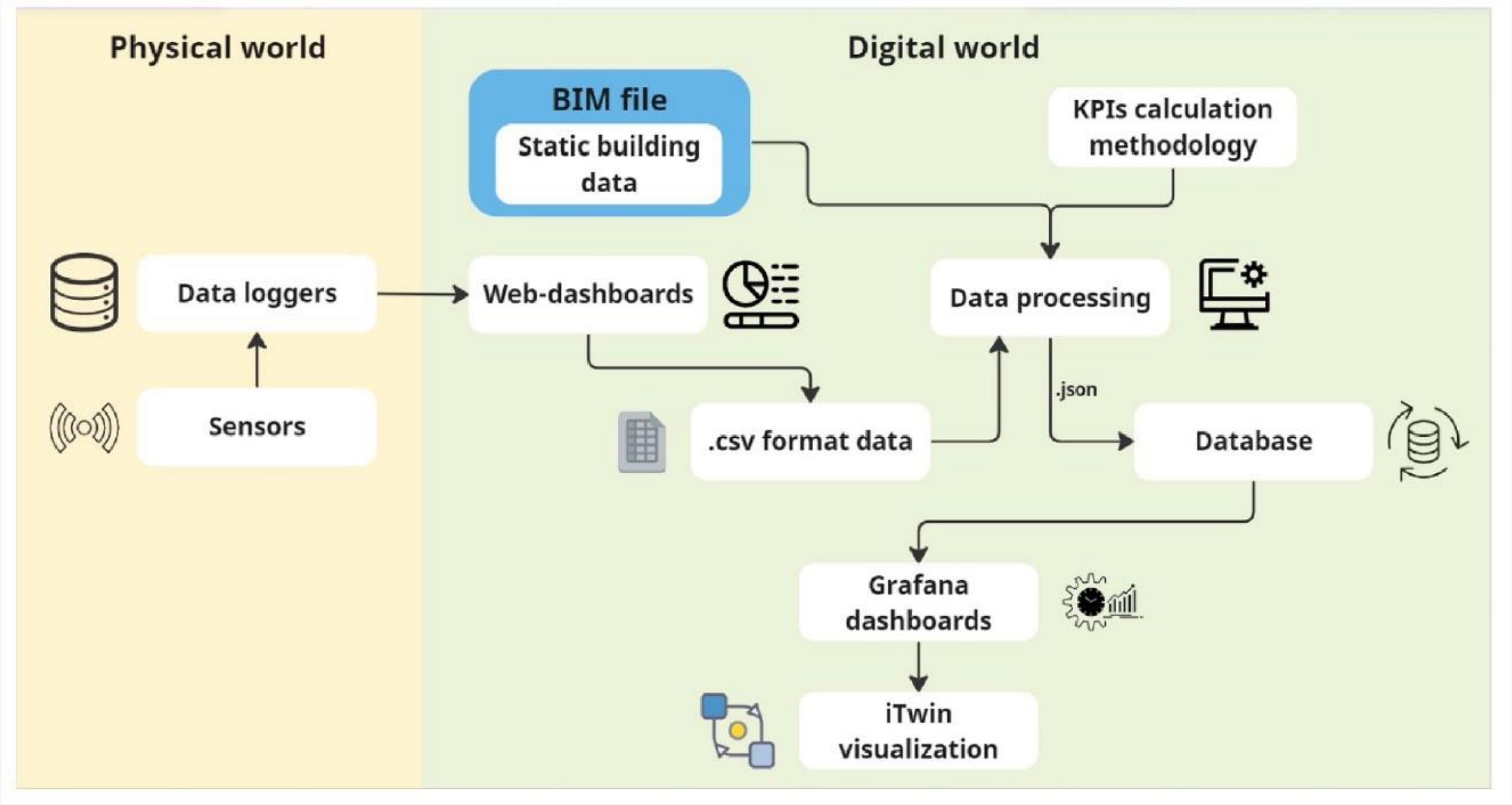
Indicator	Unit
Lighting/Occupancy	kWh/occupants
Lighting/Occupancy-Hours	kWh/h*occupants
Lighting/Area	kWh/m^2
Lighting/Volume	kWh/m^3
Electrical Appliances Energy Consumption/Occupancy	kWh/occupants
Electrical Appliances Energy Consumption/Occupancy-hours	kWh/h*occupants
Electrical Appliances Energy Consumption/Area	kWh/m^2
Electrical Appliances Energy Consumption/Volume	kWh/m^3
DHW Consumption per Energy Carrier/Occupancy	kWh/occupants
DHW Consumption per Energy Carrier/Occupancy-hours	kWh/h*occupants
DHW Consumption per Energy Carrier/Area	kWh/m^2
DHW Consumption per Energy Carrier/Volume	kWh/m^3

Spudys, P., Afxentiou, N., Georgali, P. Z., Klumbyte, E., Jurelionis, A., & Fokaides, P. (2023). Classifying the operational energy performance of buildings with the use of digital twins. Energy and Buildings, 290, 113106.

First evidences on Smart Operational Rating
Worked Example – Frederick University Building

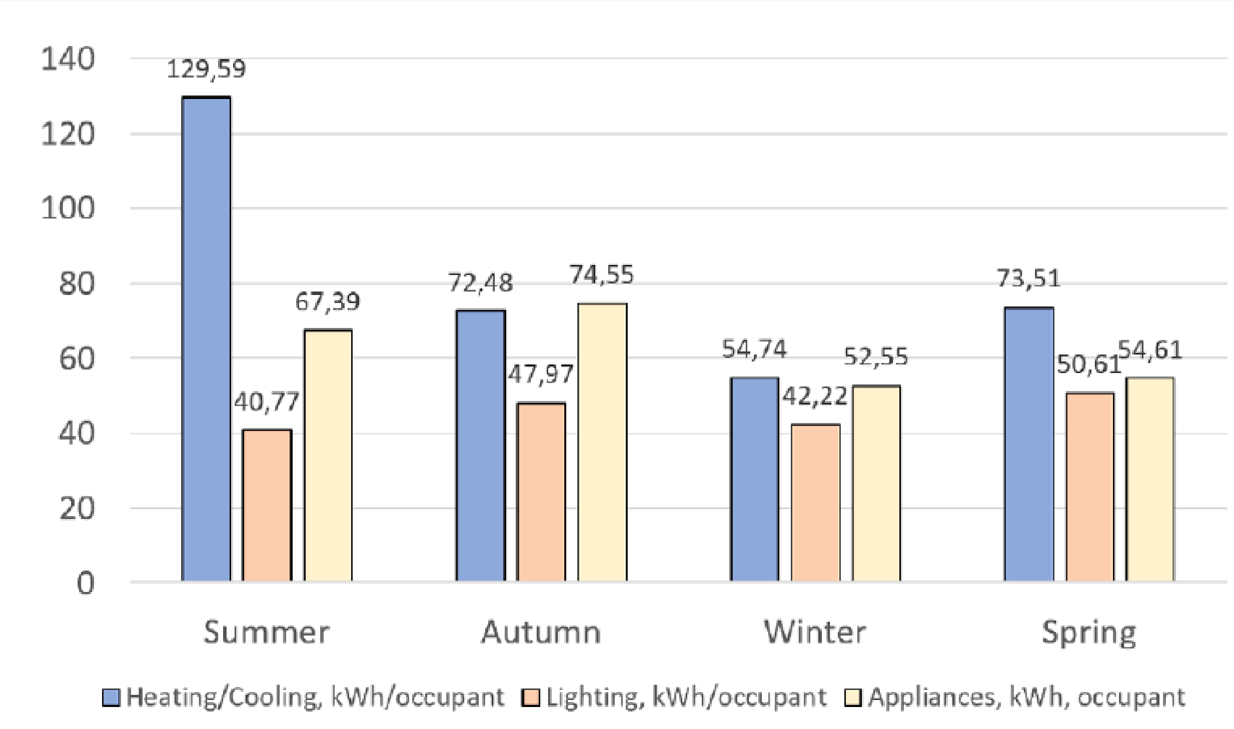
Spudys, P., Afxentiou, N., Georgali, P. Z., Klumbyte, E., Jurelionis, A., & Fokaides, P. (2023). Classifying the operational energy performance of buildings with the use of digital twins. Energy and Buildings, 290, 113106.

First evidences on Smart Operational Rating
Physical VS Digital World



Spudys, P., Afxentiou, N., Georgali, P. Z., Klumbyte, E., Jurelionis, A., & Fokaides, P. (2023). Classifying the operational energy performance of buildings with the use of digital twins. Energy and Buildings, 290, 113106.

First evidences on Smart Operational Rating
Operational Assessment

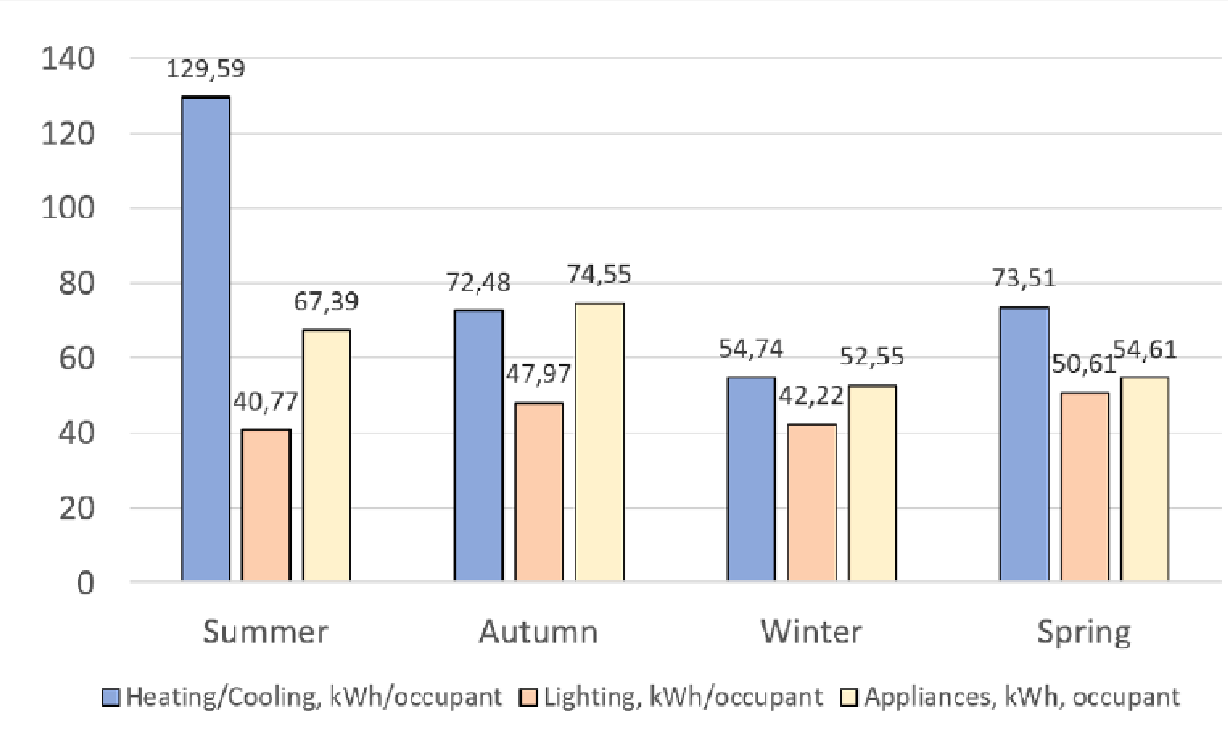


Spudys, P., Afxentiou, N., Georgali, P. Z., Klumbyte, E., Jurelionis, A., & Fokaides, P. (2023). Classifying the operational energy performance of buildings with the use of digital twins. Energy and Buildings, 290, 113106.

Table 4
Seasonal operational Indicators.

Load	Amount				Unit
	Summer	Autumn	Winter	Spring	
Heating and Cooling/ Occupancy	129.59	72.48	54.74	73.51	kWh/ occupant
Heating and Cooling Consumption per Energy Carrier/ Occupancy-hours	16.19	9.07	6.85	9.19	kWh/ h*occupant
Heating and Cooling/ Area	9.89	5.53	4.18	5.62	kWh/m^2
Heating and Cooling/ Volume	3.28	1.83	1.38	1.85	kWh/m^3
Lighting/Occupancy (1st and 2nd floor)	40.77	47.97	42.22	50.61	kWh/ occupant
Lighting/Occupancy Hours (1st and 2nd floor)	5.09	6.00	5.65	6.33	kWh/ h*occupant
Lighting/Area (1st and 2nd floor)	3.14	3.70	3.48	3.90	kWh/m^2
Lighting/Volume (1st and 2nd floor)	1.05	1.24	1.17	1.30	kWh/m^3
Electrical Appliances Energy Consumption/ Occupancy (1st and 2nd floor)	67.39	74.55	52.55	54.61	kWh/ occupant
Electrical Appliances Energy Consumption/ Occupancy Hours (1st and 2nd floor)	8.43	9.33	6.57	6.83	kWh/ h*occupant
Electrical Appliances Energy Consumption/Area (1st and 2nd floor)	5.19	5.74	4.05	4.20	kWh/m^2
Electrical Appliances Energy Consumption/ Volume (1st and 2nd floor)	1.74	1.93	1.35	1.41	kWh/m^3

First evidences on Smart Operational Rating Operational Assessment

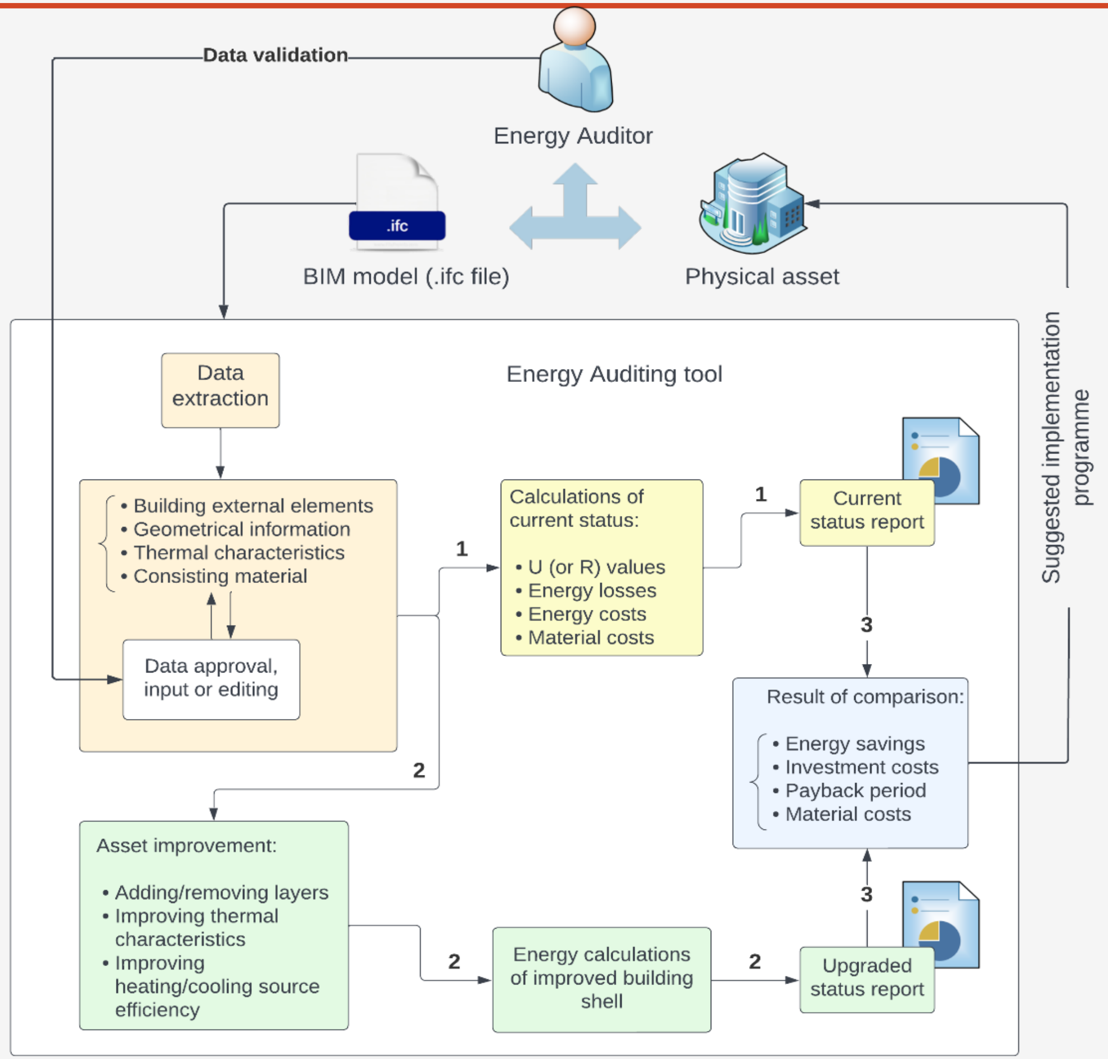


Spudys, P., Afxentiou, N., Georgali, P. Z., Klumbyte, E., Jurelionis, A., & Fokaides, P. (2023). Classifying the operational energy performance of buildings with the use of digital twins. Energy and Buildings, 290, 113106.

Table 5
Annual operational indicators.

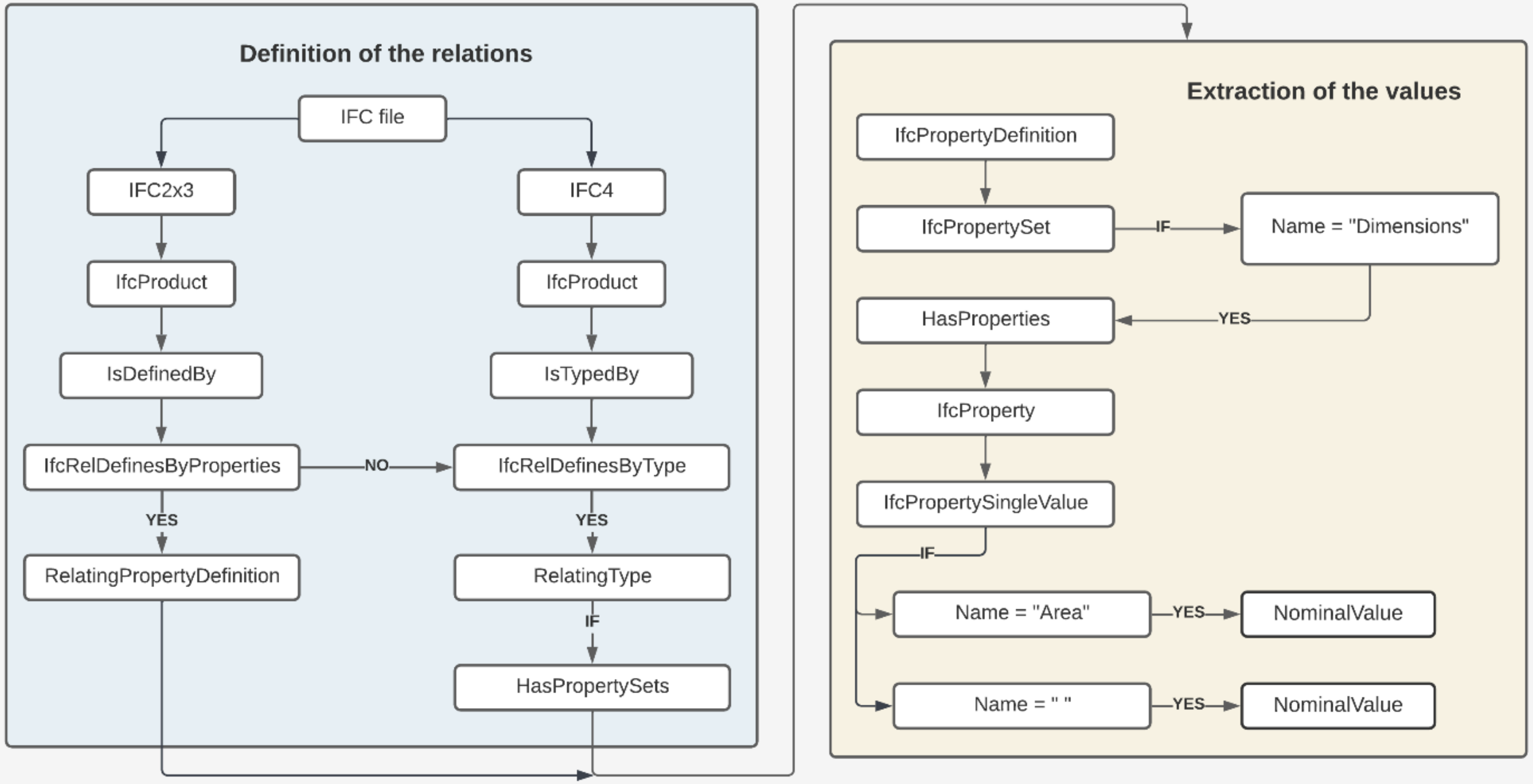
Load	Annual Amount	Unit
Total Power/Occupancy	1692.76	kWh/occupant
Total Power/Occupancy Hours	211.62	kWh/ h*occupants
Total Power/Area	128.22	kWh/m^2
Total Power/Volume	41.95	kWh/m^3
Heating Consumption per Energy Carrier/ Occupancy	95.76	kWh/ occupants
Heating Consumption per Energy Carrier/ Occupancy-hours	11.98	kWh/ h*occupant
Heating Consumption per Energy Carrier/Area	7.31	kWh/m^2
Heating Consumption per Energy Carrier/Volume	2.41	kWh/m^3
Cooling Consumption per Energy Carrier/ Occupancy	234.57	kWh/ occupants
Cooling Consumption per Energy Carrier/ Occupancy-hours	29.32	kWh/ h*occupant
Cooling Consumption per Energy Carrier/Area	17.91	kWh/m^2
Cooling Consumption per Energy Carrier/Volume	5.93	kWh/m^3
Lighting/Occupancy (1st and 2nd floor)	184.57	kWh/occupant
Lighting/Occupancy Hours (1st and 2nd floor)	23.07	kWh/ h*occupant
Lighting/Area (1st and 2nd floor)	14.22	kWh/m^2
Lighting/Volume (1st and 2nd floor)	4.76	kWh/m^3
Electrical Appliances Energy Consumption/ Occupancy (1st and 2nd floor)	249.10	kWh/occupant
Electrical Appliances Energy Consumption/ Occupancy Hours (1st and 2nd floor)	31.16	kWh/ h*occupant
Electrical Appliances Energy Consumption/Area (1st and 2nd floor)	19.18	kWh/m^2
Electrical Appliances Energy Consumption/ Volume (1st and 2nd floor)	6.43	kWh/m^3
Ground floor Power/Occupancy (October 2021 – May 2022)	928.76	kWh/occupant
Ground floor Power/Occupancy Hours (October 2021 – May 2022)	116.09	kWh/ h*occupant
Ground floor Power/Area (October 2021 – May 2022)	69.60	kWh/m^2
Ground floor Power/Volume (October 2021 – May 2022)	22.42	kWh/m^3

First evidences on Smart Energy Audits



Spudys, P., Jurelionis, A., & Fokaides, P. (2023). Conducting smart energy audits of buildings with the use of building information modelling. Energy and Buildings, 285, 112884.

First evidences on Smart Energy Audits
Flowchart of asset property values extraction



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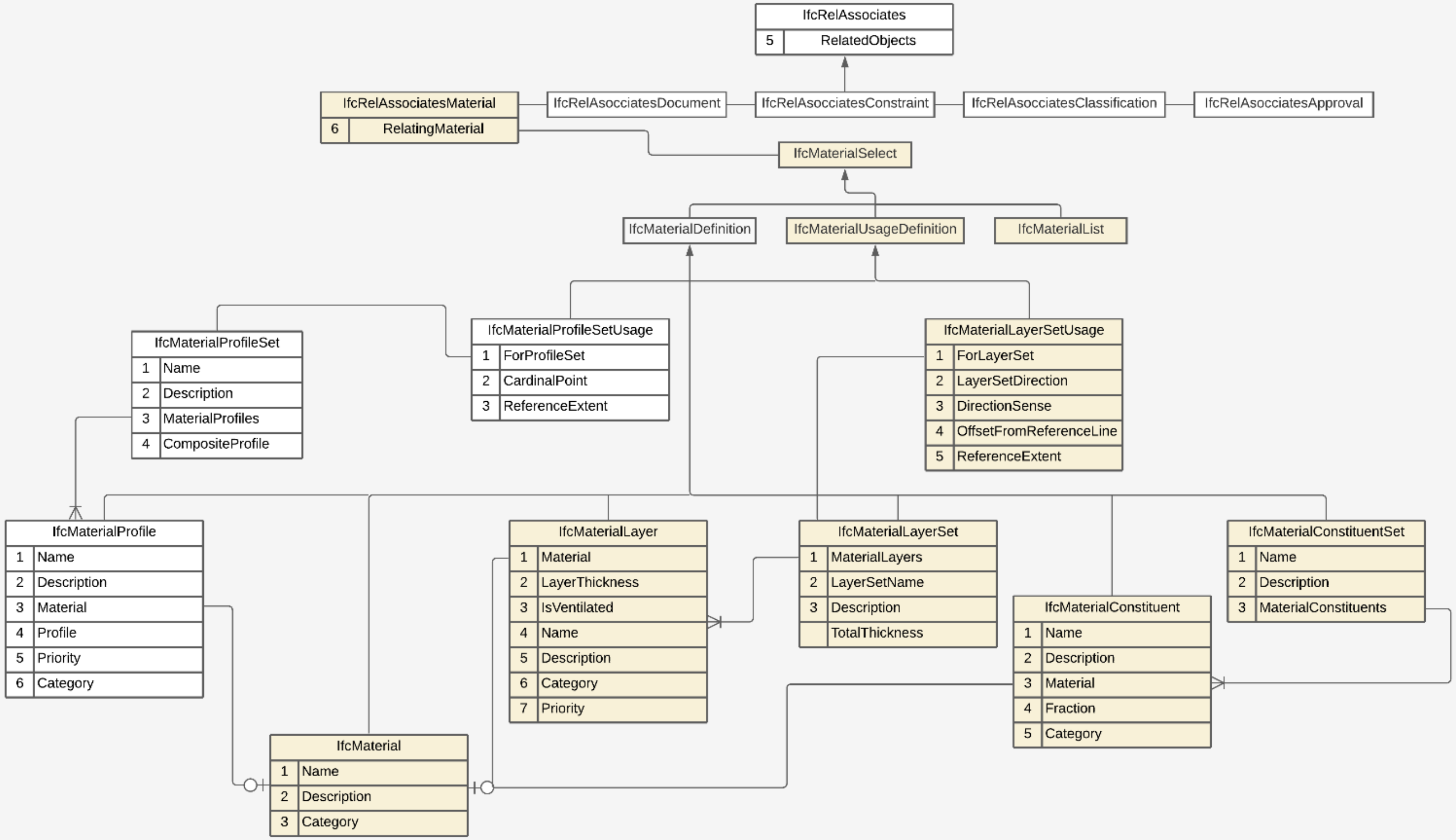
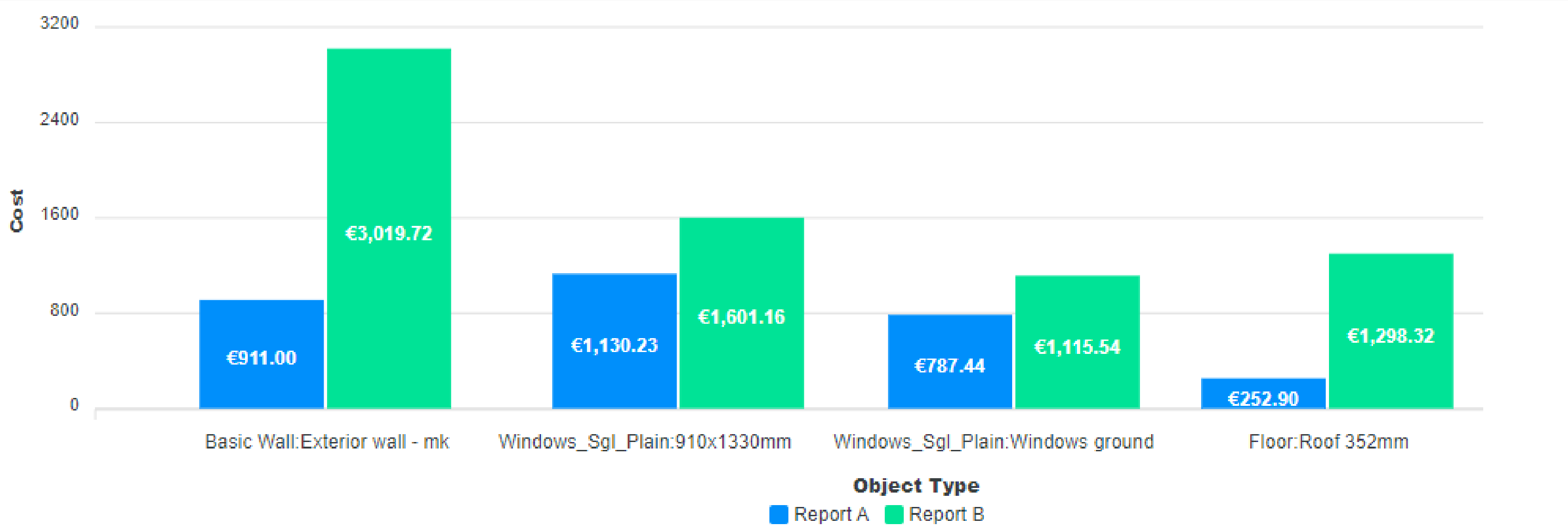
First evidences on Smart Energy Audits
Material Relationship Schema



Spudys, P., Jurelionis, A., & Fokaides, P. (2023). Conducting smart energy audits of buildings with the use of building information modelling. Energy and Buildings, 285, 112884.

First evidences on Smart Energy Audits Comparison Report



Group	Payback	Material Cost	Material Cost...	Heating Cost	Cooling Cost	Total Energy ...
Basic Wall:Exterior wall - mk	27.10	A: 57150.07 B: 3.43	A: 50.00 B: 0.00	A: 418.44 B: 1387.01	A: 492.56 B: 1632.71	A: 911.00 B: 3019.72
Windows_Sgl_Plain:910x1330mm	53.87	A: 25370.40 B: 0.06	A: 122.98 B: 0.00	A: 519.13 B: 735.44	A: 611.10 B: 865.72	A: 1130.23 B: 1601.16
Windows_Sgl_Plain:400X600	35.71	A: 604.80 B: 0.01	A: 81.53 B: 0.00	A: 18.67 B: 26.45	A: 21.97 B: 31.13	A: 40.64 B: 57.58

Spudys, P., Jurelionis, A., & Fokaides, P. (2023). Conducting smart energy audits of buildings with the use of building information modelling. Energy and Buildings, 285, 112884.

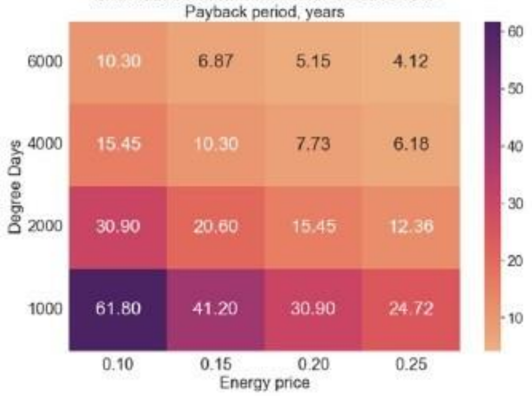
First evidences on Smart Energy Audits

Parametric assessment, payback period of potential energy upgrade

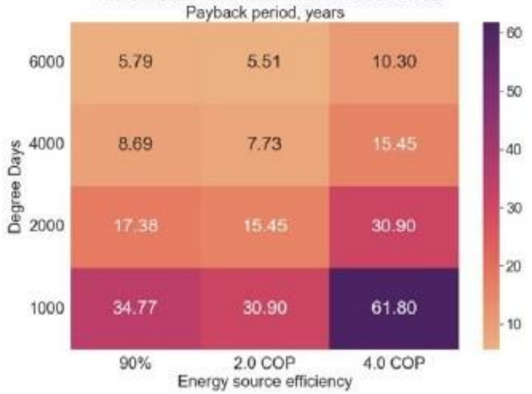
Payback period dependence on roof insulation thickness and climatic conditions

Payback period dependence on walls insulation thickness and climatic conditions

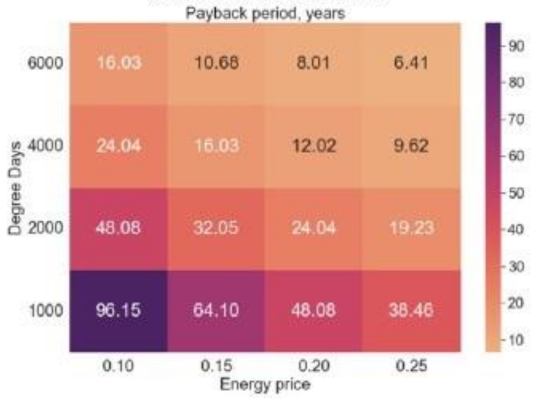
Payback period dependence on windows glazing and climatic conditions



Electricity price impact for the payback period of 10cm roof insulation, energy source COP=2



Energy source efficiency impact for the payback period of 10cm roof insulation for different climatic conditions. Fuel price 0,08 €/kWh, electricity price 0,20 €/kWh



Electricity price impact for the payback period of windows with triple glazing, energy source COP=2

Spudys, P., Jurelionis, A., & Fokaides, P. (2023). Conducting smart energy audits of buildings with the use of building information modelling. Energy and Buildings, 285, 112884.

Publications in WP1

Task 1.1

▪Klumbyte, E., Georgali, P. Z., Spudys, P., Giama, E., Morkunaite, L., Pupeikis, D., … & Fokaides, P. (2023). Enhancing whole building life cycle assessment through building information modelling: Principles and best practices. Energy and Buildings, 296, 113401.

▪Osadcha, I., Jurelionis, A., & Fokaides, P. (2023). Geometric parameter updating in digital twin of built assets: A systematic literature review. Journal of Building Engineering, 106704.

Task 1.3

▪Tsalikidis, N., Mystakidis, A., Koukaras, P., Ivaškevicius ,M., Morkunaite, L., …& Tzovaras D. (2024). Urban traffic congestion prediction: A multi-step approach utilizing sensor data and weather information. Smart Cities,(MDPI)

Publications under evaluation in WP1

Task 1.1

- Spudys, P., Osadcha, I., Morkunaite, L., Clare, M.F., Georgali. P.Z., … & Fokaides, P. (2024). A Comparative Life Cycle Assessment of Building Sustainability Across Typical European Building Geometries, Energy
- Osadcha, I., Jurelionis, A., & Fokaides, P.. Patterns and trends in the application of Radio Frequency Identification (RFID) technology in the construction industry: A Latent Semantic Analysis. Journal of Building and Environment

Boosting Research for a Smart and Carbon Neutral Built Environment with Digital Twins (SmartWins)

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