Interreg Danube Region

Co-funded by the European Union

Circular DigiBuild

Circular DigiBuild

Disruptive technologies, circular economy and the building industry in the Danube area

Deliverable D.2.2.2

Interreg Danube Region
Co-funded by the European Union
Circular DigiBuild

Author:
Mario Vašak (PP15 ICENT, Croatia)

Contributors:
Collin Michael Flesner (PP3 AWS, Austria)
Faruk Cerić (PP11 SERDA, Bosnia and Herzegovina)
Emiliyan Enev (PP2 ReCheck, Bulgaria)
Emil Stoyanov (PP2 ReCheck, Bulgaria)
Jan Valentin (Czech Technical University in Prague, Czech Republic)
Jana Vítková (PP5 INCIEN, Czech Republic)
Beatrix Weber (PP4 HSH, Germany)
Iryna Rudnieva (PP4 HSH, Germany)
Mario Vašak (PP15 ICENT, Croatia)
Bojan Milovanović (University of Zagreb Faculty of Civil Engineering, Croatia)
Krisztina Pohli (PP8 PBKIK, Hungary)
Rudolf Szigeti (PP8 PBKIK, Hungary)
Mihai Nagnibeda (PP16 BAC, Moldova)
Goran Janković (Gradionica, Montenegro)
Dragana Vujisić (PP13 ZWM, Montenegro)
Cristin Cistelecan (PP10 ADRWEST, Romania)
Milan Jovin (University of Novi Sad Faculty of Technical Sciences, Serbia)
Nataša Božić (PP7 UL, Slovenia)
Lucia Kurcz (PP6 SBA, Slovakia)
Gabriela Grmanová (Kempelen Institute of Intelligent Technologies, Slovakia)

Interreg Danube Region | Co-funded by the European Union

Circular DigiBuild

Table of Contents

Abstract

This report contains a collection of possible applicable solutions of digital technologies with emphasized circular economy principles in the buildings and construction sectors, that are being developed or practiced in Danube region countries. All countries from the region except Ukraine are covered. The solutions are categorized in specific categories of digital technologies to represent a catalogue that sparks new application ideas and motivates further collaboration and research in application of digital technologies in buildings and construction sectors in the Danube region, to make these sectors more efficient and sustainable.

Introduction

This report is created within the project *Boosting the uptake of emerging technologies in circular economy implementation in construction and buildings industry in Danube region to sustainably harness the twin transition for greener future* (acronym: Circular DigiBuild). The project's main objective is to commonly enhance **digitalisation-led circular economy innovations identification, piloting and transfer in construction and buildings industry** and **related**

policies in the Danube region, ensuring stable pre-conditions to shifting the focus to a more sustainable territorial development.

Three specific objectives that in synergy lead to the main objective are: (SO1) to enhance the Danube area COOPERATION to boost circularity in construction and buildings industry and improve related policies, (SO2) to valorise existing KNOWLEDGE and innovations in circular-economy-driven emerging technologies for construction and buildings industry, and (SO3) to CHANGE the framework conditions for fostering sustainable uptake of innovations in construction and buildings industry.

Activity 2.2 of the project falls within endeavours to achieve SO2 and has a very prominent role in achieving the overall objective since it aims to federate the existing knowledge and possible applicable solutions across the Danube region; not only the ones known to the partners, but also from the network formed. It relies on (I.) the initial analysis of the buildings and construction sector needs and opportunities identified through a Danube region wide survey within Activity 2.1, (II.) partners' knowledge in the fields of digital technologies, circular economy and buildings and construction, and (III.) on the national networks of experts and interested stakeholders formed thus far in the project through regional multi-stakeholders' groups (RMSGs).

Within the activity a systematic survey for valorising existing knowledge and identifying innovations in CE-driven emerging technologies for construction and buildings is performed and its results are presented in this report.

The three main aims of this report are the following:

- For practitioners: Harmonization in good practices in applications of digital technologies for the targeted sectors among the Danube region countries, and mixing with it some guiding examples from the rest of the world;
- For innovative companies and R&D institutions: Creating a ground for bringing up new ideas for application of digital technologies in construction and buildings sectors;
- For further Circular DigiBuild project execution: Show a broad spectrum of possibilities of digital technologies from which the consortium should finally, constrained by expertise and infrastructure available and budget,

prepare and run exemplary pilots of application of digital technologies in the buildings and construction sector within this project.

The report constitutes of two main parts. The first part is **Existing knowledge** related to digital technologies applied to achieve circular economy principles in the buildings and construction sector – in it the solutions of digital technologies are categorized in specific groups which allows a systematic view on the way digital technologies are pouring into the buildings and construction sectors. It can be used as a frame to contemplate the diversity of possible applications that can be conceived and developed, addressing diverse needs of a broad set of actors in the buildings and construction industry. The second main part is named **Possible applicable solutions** and it contains applications of digital technologies in the buildings and construction sector collected across countries of the Danube region. In it specific list of properties of these applications is introduced which is then characterized as part of the collection process for each selected application. Possible applicable solutions (PASs) are presented according to the categorization presented in the Existing knowledge part. The **Conclusion** gives a short view on the identified main technology gaps. In the Appendix all the collected PASs are listed in detail by countries.

It must be stressed that PASs are collected in a specific country by relying on a combination of the following: the previous knowledge and experience of partners, desktop research, experts engagement, consultation with regional multi-stakeholder groups and consultation with a general interested stakeholders on the level of the whole Danube area via an open webinar. The potential bias introduced with engagement of specific experts on the side of partners in individual countries, in terms of collection of only a specific type of solutions known to the experts, is counteracted with engagement of regional multistakeholder groups and with organization of the open webinar. PAS is assigned to a country if either the application is in the country, or the developer/executor of the technology belongs to the country. Further, PASs already used outside the Danube region countries and not in them, and with prospect to be used also in them, are categorized in the additional World section.

Existing knowledge

The existing circular-economy-driven digital technologies are organized in the following categories, subcategories and sub-subcategories.

a. **Acquiring and storing data**
    i. **Sensing technologies**
    ii. **Sensing data communication**
    iii. **Data structuring and techniques for ensuring data quality, accessibility and interoperability**
b. **Data processing for facilitating decision making**
    i. **Showing relevant statistics on raw data and using graphical tools to display the data in an informative way**
    ii. **Using raw data to produce new information for decision making by the aid of mathematical models designed from data and expert knowledge**
        1. **Estimation of specific variables or parameters that give new insights**
        2. **Prediction of time-dependent variables**
        3. **Explicit decision support**
c. **Expert software for analysis**
d. **On-line data processing for autonomous operation**

The categorization follows the logic of how digital technologies bring an additional value to various activities and, technically speaking, systems in the targeted sectors.

The essence for any digital service is always data which needs to be in a significant part obtained directly from the system (a.i), communicated (a.ii) and then stored and organized in a computer, most usually in a database (a.iii). Data organization is key for further interoperability of specific services.
Besides just simple reading of data from the database by a human, that may already facilitate some decision making, the available data can be further processed to assist humans in decision making for operating systems in the

targeted sectors, and such solutions are categorized in b. A specific subcategory is raw data graphical representation with some basic statistics (b.i), while more advanced digital features require certain knowledge about the system from which the raw data is taken, and the raw data combined with that knowledge is used in specific decision-support services for humans (b.ii). One type of such services is estimation of variables and parameters in the system that give new insights (b.ii.1), and it can be various: from condition monitoring of certain equipment, through estimation of variables that are directly not measured all the way to determining parameters of mathematical models describing behaviour of the considered system. Another type of services is data processing to predict the evolution of a certain time-dependent variable in the system from which raw data is sourced (b.ii.2), and then these predictions facilitate decision making. The third type of raw data processing is a step further in assisting humans – it has a logic behind, usually built around the knowledge about the system expressed via mathematical models, that directly computes advice what the human operator of the system should do at a specific moment to support efficient operation of the system. These belong to b.ii.3 sub-subcategory.

Various supportive software for experts to analyse and be able to design the system of interest in the building or construction sector is categorized in the category c. The data to feed the software usually comes from a creative human activity and from specific digital and non-digital forms. This software aids the building design process to architects or provides the analysis of a building behaviour through time simulations.

The last category d. contains digital solutions that have enough knowledge built in them to enable reliable autonomous acting back on the system based on acquired data, i.e. without the human in the loop, whereas the human takes supervisory and monitoring roles. Similar as in human activities, acting back requires sensing, reasoning and actuation points (in an illustrative way, one may also say – ‘eyes’, ‘brain’ and ‘arms’) and all these three parts are implemented as a specific engineered mix of digital solutions.

Possible applicable solutions

The following attributes are envisioned to describe a possible applicable solution (PAS) for the country-level collection activity:

- Name,
- Solution category,
- Description of the applicable solution,
- Input raw data,
- Other necessary/recommended digital objects,
- Enabler of other possible applicable solutions,
- Output results,
- Benefits expected in operation, especially emphasizing circular economy principles,
- Necessary human resources for installing and operating,
- Possible pitfalls and problems,
- Technology readiness level (TRL),
- For TRL>4, where it has been already applied,
- For TLR>1, who is the technology developer.

Technology readiness levels (TRLs) are defined as in General Annex G of Horizon 2020 work programme, and are as follows:

- TRL 1: basic principles observed,
- TRL 2: technology concept formulated,
- TRL 3: experimental proof of concept,
- TRL 4: technology validated in lab,
- TRL 5: technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies),
- TRL 6: technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies),
- TRL 7: system prototype demonstration in operational environment,
- TRL 8: system complete and qualified,
- TRL 9: actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space).

The numbers of collected possible applicable solutions in the Danube region and the rest of the world, separated by countries and by categorization presented in the preceding section, are provided in Table 1.

	Bulgaria	Austria	Germany	Czech Republic	Slovakia	Slovenia	Hungary	Romania	Bosnia and Herzegovina	Serbia	Montenegro	Croatia	Moldavia	World	Total
No.	10	23	11	11	10	10	5	5	6	12	2	23	4	19	132+19
a.i.	0	1	1	2	0	1	2	0	1	4	0	1	0	3	13+3
a.ii.	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2+0
a.iii.	1	7	7	3	0	2	0	4	3	2	1	2	4	6	36+6
b.i.	3	1	2	1	0	2	3	0	0	2	0	1	0	0	15+0
b.ii.1.	0	3	0	1	2	3	0	0	0	0	0	5	0	3	14+3
b.ii.2.	0	1	0	0	3	0	0	0	0	0	0	3	0	0	7+0
b.ii.3.	1	5	0	2	2	1	0	1	1	0	0	4	0	4	17+4
c.	0	0	0	1	0	1	0	0	0	1	1	3	0	1	7+1
d.	4	5	1	1	3	0	0	0	1	3	0	3	0	2	21+2

Table 1 Numbers of collected possible applicable solutions per country and per solution category

In the following the possible applicable solutions are listed first by the introduced existing knowledge categories, subcategories and sub-subcategories. All the PASs are presented in detail per each country, in the Appendix in tables Table 2 – Table

133. Each presented solution has a unique code composed of a two-letter country code followed by a dash and by a specific number, e.g. code SK-5 means PAS no. 5 from Slovakia (SK).
The catalogue is completed with relevant technologies from the world outside the Danube region, in tables Table 134 – Table 152. These solutions are denoted with a code composed of the letter 'W', the dash and a number, e.g. W-6 which means PAS no. 6 from the world outside the Danube region.

Solutions from the subcategory a.i. Sensing technologies
In the subcategory a.i. Sensing technologies the following PASs are identified:

- Laser scanning for building digitalization (Table 17 PAS AT-16) and surveying terrain (Table 86 PAS HU-1, Table 110 PAS RS-9);
- RFID IoT sensors for formwork (Table 56 PAS DE-5);
- IoT sensors for construction waste containers (Table 43 PAS CZ-3);
- Sensors for construction materials characterization (Table 49 PAS CZ-9);
- Corrosion sensors (Table 114 PAS SI-1);
- 2-frequency sensor for underwater measurement (Table 87 PAS HU-2);
- Drones for geodetic surveying (Table 28 PAS BA-4) and construction site monitoring (Table 103 PAS RS-2);
- Temperature/humidity/vibration sensors for construction monitoring (Table 104 PAS RS-3);
- Concrete sensors for strength monitoring (Table 112 PAS RS-11) and smart concrete sensors (Table 150 PAS W-17);
- Construction safety sensors for workers (Table 152 PAS W-19);
- Plug-in IoT sensors for joint indoor monitoring of temperature, relative humidity, pressure and CO_2 concentration (Table 64 PAS HR-2);
- IoT sensors for radon, particulate matter and CO_2 for indoor monitoring (Table 136 PAS W-3).

Solutions from the subcategory a.ii. Sensing data communication
In the subcategory a.ii. Sensing data communication the following PASs are identified:

- IoT cloud for smart energy metering (Table 31 PAS BG-1);
- LoRa WAN (Table 65 PAS HR-3).

Solutions from the subcategory a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability

In the subcategory a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability the following PASs are identified:

- GIS for urban planning (Table 108 PAS RS-7);
- Digital building logbook (Table 40 PAS BG-10, Table 48 PAS CZ-8);
- BIM-based materials passport system (Table 2 PAS AT-1, Table 52 PAS DE-1, Table 61 PAS DE-10, Table 94 PAS MD-4);
- Blockchain-based construction supply chain management (Table 5 PAS AT-4, Table 44 PAS CZ-4, Table 143 PAS W-10) and construction projects running (Table 11 PAS AT-10);
- Common data environment for construction projects (Table 16 PAS AT-15);
- Digital data solutions for tracking of expanded polystyrene material for collection and recycling (Table 19 PAS AT-18) and of stone wool for return (Table 20 PAS AT-19);
- AI-powered platform for construction project management (Table 22 PAS AT-21, Table 29 PAS BA-5, Table 67 PAS HR-5);
- Integration of smart materials database and urban mining platform (Table 54 PAS DE-3);
- Tracking/managing building materials across the building lifecycle (Table 55 PAS DE-4, Table 57 PAS DE-6, Table 96 PAS ME-2, Table 93 PAS MD-3, Table 146 PAS W-13);
- Cloud platform for digital elevation modelling from aerial maps and lidars (Table 99 PAS RO-3);
- Point cloud to BIM/3D technology (Table 41 PAS CZ-1, Table 100 PAS RO-4);
- Database for 3D-modelling based on UAV photogrametry (Table 119 PAS SI-6);
- BIM/openBIM (Table 101 PAS RO-5, Table 27 PAS BA-3, Table 30 PAS BA-6, Table 102 PAS RS-1, Table 92 PAS MD-2);
- Construction project management with automatic tendering (Table 138 PAS W-5);
- Building materials connection with financial instruments (Table 147 PAS W-14);
- Structuring product data in the construction supply chain and aligning them with valid standards (Table 142 PAS W-9);
- Smart waste management platform (Table 98 PAS RO-2);

- Secondary materials marketplace (Table 59 PAS DE-8, Table 60 PAS DE-9, Table 118 PAS SI-5);
- Database for monitoring of energy consumption of a buildings stock (Table 91 PAS MD-1);
- BIM-based operation and maintenance (O&M) database for the building (Table 148 PAS W-15);
- Building operation database in PostGre SQL for real-time predictive energy management (Table 66 PAS HR-4).

Solutions from the subcategory b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way

In the subcategory b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way the following PASs are identified:

- Buildings component catalogue for maintenance and renovation (Table 18 PAS AT-17);
- Preview and fetching data from national model buildings (Table 89 PAS HU-4);
- Platform for connecting stakeholders in circular construction for sharing knowledge, solutions and data (Table 62 PAS DE-11);
- Virtual reality visualization during architectural design (Table 51 PAS CZ-11) and on construction sites (Table 115 PAS SI-2);
- 3D viewers for 3D models of buildings (Table 88 PAS HU-3);
- Augmented reality for on-site support (Table 106 PAS RS-5);
- Software for real-time tracking of construction projects (Table 111 PAS RS-10).
- Structural health monitoring with moisture content, relative humidity and temperature (Table 121 PAS SI-8);
- Environmental monitoring for smart buildings and cities (Table 36 PAS BG-6);
- Management of shared building spaces for hybrid work policies (Table 35 PAS BG-5);
- Utilities consumption monitoring and data analysis (Table 37 PAS BG-7, Table 58 PAS DE-7, Table 68 PAS HR-6, Table 90 PAS HU-5).

Solutions from the sub-subcategory b.ii.1 Estimation of specific variables or parameters that give new insights

In the sub-subcategory b.ii.1 Estimation of specific variables or parameters that give new insights the following PASs are identified:

- Satellite data analyses for building stock identification (Table 24 PAS AT-23);
- Monitoring rockfall prone areas (Table 122 PAS SI-9);
- Determination of 3D model parameters from historical imaging (Table 140 PAS W-7);
- Automated carbon footprint calculator for a construction (Table 13 PAS AT-12);
- AI-powered point cloud to BIM conversion (Table 21 PAS AT-20);
- Machine learning models for identification of secondary raw materials (Table 46 PAS CZ-6);
- Structural health monitoring (Table 139 PAS W-6) and bolted joints monitoring (Table 144 PAS W-11);
- Monitoring adherence to safety regulations on construction sites (Table 117 PAS SI-4);
- Digital inspection of a bridge with a UAV (Table 120 PAS SI-7);
- Parameter estimation for models of heating/cooling actuators (Table 63 PAS HR-1) and of the building thermodynamic behaviour (Table 69 PAS HR-7);
- Estimation of number of people present and heat/CO_2 disturbances in the indoor environment (Table 70 PAS HR-8) and estimation of window opening conditions (Table 71 PAS HR-9);
- Monitoring congestion faults for fan coils (Table 72 PAS HR-10);
- Disaggregation of energy consumption in households (Table 127 PAS SK-4);
- Estimation of water quality parameters (Table 133 PAS SK-10).

Solutions from the sub-subcategory b.ii.2 Prediction of time-dependent variables

In the sub-subcategory b.ii.2 Prediction of time-dependent variables the following PASs are identified:

- Prediction model on construction material availability (Table 23 PAS AT-22);
- Prediction of micro-climate conditions from weather forecast (Table 73 PAS HR-11);

- Prediction of PV production (Table 124 PAS SK-1) and PV energy supply to the grid (Table 132 PAS SK-9);
- Prediction of electricity transmission losses (Table 128 PAS SK-5);
- Prediction of heat disturbances in building zones (Table 74 PAS HR-12);
- Prediction of electricity consumption of a specific set of loads (Table 75 PAS HR-13).

Solutions from the sub-subcategory b.ii.3 Explicit decision support

In the sub-subcategory b.ii.3 Explicit decision support the following PASs are identified:

- Optimized architectural design decisions (Table 123 PAS SI-10) and Digital tools for architectural competitions (Table 50 PAS CZ-10);
- AI-driven urban planning for circular cities (Table 8 PAS AT-7, Table 26 PAS BA-2);
- Real-estate feasibility and early-stage site planning tool (Table 134 PAS W-1);
- Suggesting lifting crane operation on the construction site (Table 77 PAS HR-15);
- Google maps for decision support in driving within new environments (Table 78 PAS HR-16);
- Safety management platform for construction sites (Table 141 PAS W-8);
- Augmented reality for sustainable building maintenance (Table 7 PAS AT-6);
- Optimizing winter road maintenance (Table 129 PAS SK-6);
- Digital twin for healthy buildings (Table 137 PAS W-4) and for recommendations in various building lifecycle phases (Table 42 PAS CZ-2);
- Robotic system for assessment of durability of structures and structural integrity (Table 84 PAS HR-22);
- Digital twin for building lifecycle management (Table 9 PAS AT-8) and AI-powered predictive maintenance of building systems (Table 14 PAS AT-13);
- AI-driven optimization of Heating, Ventilation and Air Conditioning (HVAC) system (Table 12 PAS AT-11, Table 76 PAS HR-14, Table 145 PAS W-12);
- Decision support in microgrid operation (Table 126 PAS SK-3);
- Energy-efficiency household plans (Table 97 PAS RO-1);
- IoT cloud for smart gas consumption monitoring and decision making for efficient gas distribution (Table 32 PAS BG-2).

Solutions from the category c. Expert software for analysis

In the category c. Expert software for analysis the following PASs are identified:

- Construction project organizational support software (Table 85 PAS HR-23);
- Virtual reality assisted planning of construction operations (Table 151 PAS W-18);
- Digital platform for 3D scanning and processing of constructions (Table 95 PAS ME-1);
- Digital twins for road construction, using secondary raw materials (Table 116 PAS SI-3);
- Automation of the pre-demolition audit (Table 47 PAS CZ-7);
- Digital twin technology for performing accurate simulations across various phases of the building life cycle (Table 105 PAS RS-4);
- Software for energy certification of buildings (Table 80 PAS HR-18);
- Building comfort variables and energy consumption simulation software (Table 79 PAS HR-17).

Solutions from the category d. On-line data processing for autonomous operation

In the category d. On-line data processing for autonomous operation the following PASs are identified:

- 3D printing with recycled construction materials (Table 6 PAS AT-5, Table 45 PAS CZ-5) and of construction components (Table 83 PAS HR-21, Table 107 PAS RS-6);
- Prefabrication of building components with digital optimization (Table 109 PAS RS-8);
- Robotics for scaffolding (Table 53 PAS DE-2);
- Autonomous construction equipment (Table 82 PAS HR-20, Table 113 PAS RS-12);
- Robotic deconstruction system (Table 10 PAS AT-9);
- Smart waste sorting bins for construction sites (Table 15 PAS AT-14) and AI-powered construction waste sorting (Table 3 PAS AT-2);
- Smart energy monitoring and control for energy management in buildings (Table 4 PAS AT-3, Table 25 PAS BA-1, Table 33 PAS BG-3, Table 34 PAS BG-4, Table 38 PAS BG-8, Table 39 PAS BG-9, Table 81 PAS HR-19, Table 130 PAS SK-7, Table 135 PAS W-2, Table 149 PAS W-16);

- Simulations of energy communities with automated decision making for balancing and grid stability (Table 131 PAS SK-8);
- Vehicle-2-everything (V2X) technology for construction sites energy management (Table 125 PAS SK-2).

Conclusion

As already elaborated, the listed possible applicable solutions (PASs) do not give a full insight into the state of digital technologies use for specific Danube region countries in the buildings and construction sector. Still, with the presented data the following technology gaps are identified that should be addressed by further and intensified cooperation in the Danube region.

- Limited technology adoption

  While numerous PASs have been identified, their adoption across the Danube region remains inconsistent. Countries with advanced infrastructure, such as Austria and Germany, demonstrate higher readiness, whereas others face barriers due to limited access to resources and technical expertise.

- Integration challenges

  The lack of interoperability between existing systems and emerging digital technologies hinders the seamless implementation of solutions such as BIM-based systems and IoT-enabled platforms. Still the highest focus of technologies development is in subcategory a.iii regarding data storage and interoperability within which integration issues are both being resolved and some new ones arising.

- Uneven technology maturity

  Many PASs remain in early stages of development (TRL 1–4), necessitating further research, development and pilot testing to achieve scalability.

Appendix – Possible applicable solutions by countries

Austria

Possible applicable solution AT-1	
Name	BIM-based Material Passport System
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	A Building Information Modelling (BIM) integrated system that creates and manages digital material passports for construction materials and components, tracking their lifecycle, composition, and recyclability.
Input raw data	Material specifications, supplier information, installation data, maintenance records
Other necessary/recommended digital objects	BIM software, cloud-based database, mobile app for on-site data collection
Enabler of other possible applicable solutions	Facilitates deconstruction planning, waste reduction, and material reuse strategies
Output results	Comprehensive material passports, recyclability reports, end-of-life scenarios for building components
Benefits expected in operation, especially emphasizing circular economy principles	Enhances material traceability, promotes circular economy principles by facilitating material reuse and recycling, reduces waste in construction and demolition processes
Necessary human resources for installing and operating	BIM specialists, materials experts, software developers, data analysts
Possible pitfalls and problems	Data accuracy and consistency, integration challenges with existing systems, user adoption
Technology readiness level (TRL)	7 - System prototype demonstration in operational environment
For TRL>4, where it has been already applied	Pilot project "Smart Building Vienna" in collaboration with the City of Vienna and Wien Energie

For TRL>1, who is the technology developer	Austrian Institute of Technology (AIT) in partnership with A-NULL Bausoftware GmbH

Table 2 PAS AT-1

Possible applicable solution AT-2	
Name	AI-Powered Construction Waste Sorting
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	An artificial intelligence system using computer vision to automatically identify and sort construction and demolition waste on-site, optimizing recycling and reuse processes.
Input raw data	Real-time images and video feeds of waste materials, material databases. The AI system uses high-resolution cameras and computer vision to assess construction and demolition waste. While it identifies and sorts materials based on real-time images, there is no robotic actuator currently in the system to physically place the waste into different boxes. The waste is identified and sorted virtually, with detailed reports generated on recycling potential and material recovery. The system's main function is to analyze and classify waste, enabling the optimization of recycling strategies, but physical sorting is handled manually or with additional robotic systems where needed.
Other necessary/recommended digital objects	High-resolution cameras, edge computing devices, cloud-based AI platform
Enabler of other possible applicable solutions	Enables precise waste management strategies and circular material flows
Output results	Sorted waste streams, recycling potential reports, material recovery statistics
Benefits expected in operation, especially emphasizing circular economy principles	Increases recycling rates, reduces landfill waste, improves resource efficiency in construction
Necessary human resources for installing and operating	AI engineers, waste management experts, on-site operators

Possible pitfalls and problems	Accuracy in diverse environmental conditions, handling of mixed or contaminated materials
Technology readiness level (TRL)	6 - Technology demonstrated in relevant environment
For TRL>4, where it has been already applied	Tested at Porr AG construction sites in Graz and Strabag SE projects in Linz
For TRL>1, who is the technology developer	TU Wien Institute of Computer Engineering in partnership with Brantner Green Solutions

Table 3 PAS AT-2

Possible applicable solution AT-3	
Name	IoT-Enabled Energy Management System for Buildings
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	A network of IoT sensors, smart meters and computer control devices that monitor and optimize energy consumption in buildings, integrating with renewable energy sources and storage systems.
Input raw data	Real-time energy consumption data, weather forecasts, occupancy patterns
Other necessary/recommended digital objects	Energy management software, cloud platform
Enabler of other possible applicable solutions	Supports integration of renewable energy systems and smart grid technologies
Output results	Energy consumption reports, optimization recommendations, predictive maintenance alerts
Benefits expected in operation, especially emphasizing circular economy principles	Reduces energy waste, lowers carbon footprint, optimizes use of renewable energy sources
Necessary human resources for installing and operating	IoT specialists, energy managers, data analysts
Possible pitfalls and problems	Data privacy concerns, system integration challenges, initial installation costs
Technology readiness level (TRL)	8 - System complete and qualified

For TRL>4, where it has been already applied	Implemented in the Erste Campus in Vienna and the LCT ONE building in Dornbirn
For TRL>1, who is the technology developer	Siemens Österreich in collaboration with Wien Energie and Netz Niederösterreich

Table 4 PAS AT-3

Possible applicable solution AT-4	
Name	Blockchain-based Construction Supply Chain Management
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	A blockchain platform that tracks and verifies the origin, quality, and sustainability credentials of construction materials throughout the supply chain.
Input raw data	Material specifications, supplier information, transportation data, sustainability certifications
Other necessary/recommended digital objects	Blockchain network, smart contracts, mobile app for data input and verification
Enabler of other possible applicable solutions	Supports circular economy initiatives by ensuring material traceability and quality
Output results	Transparent material provenance records, sustainability reports, supply chain optimization insights
Benefits expected in operation, especially emphasizing circular economy principles	Enhances trust in material sourcing, reduces fraud, supports sustainable procurement practices
Necessary human resources for installing and operating	Blockchain developers, supply chain experts, sustainability consultants
Possible pitfalls and problems	Scalability issues, industry-wide adoption challenges, energy consumption of blockchain networks
Technology readiness level (TRL)	5 - Technology validated in relevant environment
For TRL>4, where it has been already applied	Pilot project with major Austrian construction companies (STRABAG SE and Wienerberger AG) and material suppliers
For TRL>1, who is the technology developer	Austrian Blockchain Center in partnership with RIDDLE&CODE GmbH

Table 5 PAS AT-4

Possible applicable solution AT-5	
Name	3D Printing with Recycled Construction Materials
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	A 3D printing system that uses recycled construction waste as printing material, coupled with software for optimizing designs for circular economy principles.
Input raw data	3D model files, material composition data, structural requirements
Other necessary/recommended digital objects	3D printing hardware, material processing equipment, design optimization software
Enabler of other possible applicable solutions	Promotes on-site manufacturing and waste reduction in construction
Output results	3D printed building components, material usage reports, sustainability assessments
Benefits expected in operation, especially emphasizing circular economy principles	Reduces construction waste, lowers transportation costs, enables complex designs with less material
Necessary human resources for installing and operating	3D printing specialists, materials scientists, structural engineers
Possible pitfalls and problems	Material quality consistency, regulatory compliance for 3D printed structures, scalability
Technology readiness level (TRL)	6 - Technology demonstrated in relevant environment
For TRL>4, where it has been already applied	Demonstration projects for small-scale structures at the Smart City Demo Aspern project in Vienna & Pilot project at the Innsbrucker Kommunalbetriebe (IKB) recycling centre
For TRL>1, who is the technology developer	TU Graz Institute of Structural Design in collaboration with Incremental3D GmbH

Table 6 PAS AT-5

Possible applicable solution AT-6

Name	Augmented Reality for Sustainable Building Maintenance
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	An AR system that provides real-time information and guidance for building maintenance tasks, focusing on energy efficiency and sustainable practices.
Input raw data	Building schematics, equipment manuals, real-time sensor data
Other necessary/recommended digital objects	AR headsets or mobile devices, cloud-based information system, IoT sensors
Enabler of other possible applicable solutions	Enhances predictive maintenance and energy-efficient building operations
Output results	Visual maintenance guides, energy efficiency recommendations, equipment lifecycle tracking
Benefits expected in operation, especially emphasizing circular economy principles	Improves maintenance efficiency, extends equipment lifespan, reduces energy waste
Necessary human resources for installing and operating	AR developers, building systems engineers, UX designers
Possible pitfalls and problems	User adoption, hardware limitations, keeping digital information up-to-date
Technology readiness level (TRL)	7 - System prototype demonstration in operational environment
For TRL>4, where it has been already applied	Implemented in the Austria Centre Vienna and the T-Centre St. Marx, Tabakfabrik Linz
For TRL>1, who is the technology developer	A consortium led by Salzburg Research Forschungsgesellschaft mbH and ViewAR GmbH

Table 7 PAS AT-6

Possible applicable solution AT-7	
Name	AI-Driven Urban Planning for Circular Cities
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support

Description of the applicable solution	An AI system that analyses urban data to optimize city planning for circular economy principles, focusing on building placement, resource flows, and infrastructure design.
Input raw data	Geographic data, demographic information, resource consumption patterns, traffic data
Other necessary/recommended digital objects	GIS software, machine learning algorithms, data visualization tools
Enabler of other possible applicable solutions	Supports sustainable urban development and smart city initiatives
Output results	Urban development plans, resource flow optimizations, sustainability impact assessments
Benefits expected in operation, especially emphasizing circular economy principles	Improves resource efficiency in urban areas, reduces environmental impact, enhances quality of life
Necessary human resources for installing and operating	Urban planners, data scientists, environmental experts
Possible pitfalls and problems	Data privacy concerns, balancing multiple stakeholder interests, long-term prediction accuracy
Technology readiness level (TRL)	5 - Technology validated in relevant environment
For TRL>4, where it has been already applied	Pilot project for the new Seestadt Aspern district in Vienna, Smart City Graz project, focusing on the Waagner-Biro district
For TRL>1, who is the technology developer	Austrian Institute of Technology (AIT) in partnership with Wien 3420 aspern Development AG

Table 8 PAS AT-7

Possible applicable solution AT-8	
Name	Digital Twin for Building Lifecycle Management
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	A comprehensive digital twin platform that simulates and optimizes a building's entire lifecycle, from design to demolition, focusing on circular economy principles.

Input raw data	BIM data, real-time sensor data, occupancy information, energy consumption data
Other necessary/recommended digital objects	IoT sensors, cloud computing platform
Enabler of other possible applicable solutions	Supports predictive maintenance, energy optimization, and end-of-life planning
Output results	Lifecycle performance reports, optimization recommendations, predictive maintenance alerts
Benefits expected in operation, especially emphasizing circular economy principles	Extends building lifespan, reduces operational costs, optimizes resource use throughout lifecycle
Necessary human resources for installing and operating	Digital twin specialists, building systems engineers, data analysts
Possible pitfalls and problems	High initial setup costs, data integration challenges, keeping the digital twin synchronized with the physical building
Technology readiness level (TRL)	6 - Technology demonstrated in relevant environment
For TRL>4, where it has been already applied	Implemented for the OMV Head Office in Vienna
For TRL>1, who is the technology developer	A joint venture between Doka GmbH and Autodesk Austria GmbH

Table 9 PAS AT-8

Possible applicable solution AT-9	
Name	Robotic Deconstruction System
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	An AI-guided robotic system for precise deconstruction of buildings, maximizing material recovery and sorting for reuse or recycling
Input raw data	Building plans, material composition data, structural analysis
Other necessary/recommended digital objects	Robotic hardware, AI control software, material recognition sensors

Enabler of other possible applicable solutions	Enhances material recovery in demolition processes, supporting circular material flows
Output results	Detailed material recovery reports, sorted material streams, deconstruction efficiency metrics
Benefits expected in operation, especially emphasizing circular economy principles	Increases material recovery rates, improves worker safety, enables more precise and efficient deconstruction
Necessary human resources for installing and operating	Robotics engineers, AI specialists, demolition experts
Possible pitfalls and problems	High initial investment, regulatory approval for robotic demolition, adaptability to diverse building types
Technology readiness level (TRL)	4 - Technology validated in lab
For TRL>4, where it has been already applied	Not yet applied in real environment
For TRL>1, who is the technology developer	TU Wien Automation and Control Institute (ACIN) in collaboration with Umdasch Group Ventures

Table 10 PAS AT-9

Possible applicable solution AT-10	
Name	Smart Contract Platform for Circular Construction Projects
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	A blockchain-based smart contract platform that automates and enforces circular economy principles throughout construction projects, from material sourcing to waste management.
Input raw data	Project specifications, material data, regulatory requirements, sustainability goals
Other necessary/recommended digital objects	Blockchain network, smart contract templates, integration with supply chain management systems
Enabler of other possible applicable solutions	Facilitates transparent and automated enforcement of circular economy practices
Output results	Automated contract execution reports, compliance verifications, sustainability performance metrics

Benefits expected in operation, especially emphasizing circular economy principles	Ensures adherence to circular economy principles, reduces administrative overhead, increases transparency
Necessary human resources for installing and operating	Blockchain developers, legal experts, construction project managers
Possible pitfalls and problems	Legal recognition of smart contracts, interoperability with existing systems, handling of contract disputes
Technology readiness level (TRL)	5 - Technology validated in relevant environment
For TRL>4, where it has been already applied	Pilot implementation in the construction of the new Parlamentsgebäude in Vienna, Test project for a public housing development in St. Pölten, Lower Austria
For TRL>1, who is the technology developer	A consortium led by RIAT (Research Institute for Arts and Technology) and Capacity Blockchain Solutions GmbH

Table 11 PAS AT-10

Possible applicable solution AT-11	
Name	AI-Driven Optimization of Building Heating and Cooling Systems
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	An AI system that analyses environmental conditions to optimize heating/cooling settings dynamically based on occupancy patterns and weather forecasts.
Input raw data	Sensor data on temperature/humidity; occupancy sensors; weather forecasts.
Other necessary/recommended digital objects	AI algorithms; integration with existing HVAC systems; cloud storage for analytics
Enabler of other possible applicable solutions	Supports energy efficiency initiatives while improving occupant comfort levels
Output results	Optimized HVAC settings; energy savings reports; predictive maintenance alerts.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces energy consumption significantly while extending HVAC system lifespans through optimized operations.

Necessary human resources for installing and operating	HVAC engineers; AI specialists; facility managers.
Possible pitfalls and problems	Integration challenges with existing systems; reliance on accurate sensor data for effectiveness.
Technology readiness level (TRL)	6 - Technology demonstrated in relevant environment
For TRL>4, where it has been already applied	Implemented at several commercial buildings within Vienna's smart city projects
For TRL>1, who is the technology developer	Green Building Technologies GmbH

Table 12 PAS AT-11

Possible applicable solution AT-12	
Name	Automated Carbon Footprint Calculator for Construction Projects
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	A software tool that calculates the carbon footprint associated with different materials used throughout a construction project based on lifecycle assessments
Input raw data	Material specifications including source information
Other necessary/recommended digital objects	Lifecycle assessment databases
Enabler of other possible applicable solutions	Supports decision-making regarding material selection based on environmental impact
Output results	Carbon footprint reports per project phase
Benefits expected in operation, especially emphasizing circular economy principles	Encourages environmentally friendly material choices thus promoting sustainability within construction processes
Necessary human resources for installing and operating	Environmental consultants or engineers familiar with lifecycle assessments
Possible pitfalls and problems	Accuracy dependent upon quality input data available regarding material sourcing
Technology readiness level (TRL)	5 - Technology validated in relevant environment

For TRL>4, where it has been already applied	Used by several architectural firms across Austria during project planning phases
For TRL>1, who is the technology developer	ecoresponsible GmbH

Table 13 PAS AT-12

Possible applicable solution AT-13	
Name	AI-Powered Predictive Maintenance for Building Systems
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	An AI system that analyses historical maintenance data to predict when building systems (HVAC, lighting) will require servicing or replacement before failures occur
Input raw data	Historical maintenance logs, sensor data from building systems (temperature, humidity)
Other necessary/recommended digital objects	Machine learning algorithms, cloud storage for data analysis
Enabler of other possible applicable solutions	Supports overall building efficiency by reducing downtime and optimizing maintenance schedules
Output results	Maintenance alerts, cost-saving reports from reduced downtime, lifecycle analysis of building systems
Benefits expected in operation, especially emphasizing circular economy principles	Extends the lifespan of building systems through timely maintenance while reducing resource waste associated with premature replacements
Necessary human resources for installing and operating	Data scientists, facility managers, IT support staff
Possible pitfalls and problems	Data privacy concerns and reliance on accurate historical data for predictions
Technology readiness level (TRL)	6 - Technology demonstrated in relevant environment
For TRL>4, where it has been already applied	Pilot projects at the LCT ONE building in Dornbirn
For TRL>1, who is the technology developer	Developed by Siemens Österreich in collaboration with local universities

Table 14 PAS AT-13

Possible applicable solution AT-14	
Name	Smart Waste Sorting Bins for Construction Sites
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Smart bins equipped with sensors that automatically sort construction waste into different categories (e.g., metal, wood, plastic) using AI and machine learning algorithms
Input raw data	Real-time waste composition data from sensors, bin fill levels, and location data
Other necessary/recommended digital objects	Cloud-based data processing platform, mobile app for monitoring
Enabler of other possible applicable solutions	Supports recycling initiatives and waste reduction strategies on construction sites
Output results	Sorted waste reports, recycling efficiency metrics, and operational insights, autonomous waste sorting into designated compartments, providing both real-time data and pre-sorted materials ready for recycling
Benefits expected in operation, especially emphasizing circular economy principles	Increases recycling rates and reduces landfill waste, promoting a more circular approach to construction waste management
Necessary human resources for installing and operating	Waste management specialists, IT support for system integration
Possible pitfalls and problems	High initial costs, potential resistance from workers accustomed to traditional sorting methods
Technology readiness level (TRL)	6 - Technology demonstrated in relevant environment
For TRL>4, where it has been already applied	Pilot projects at construction sites managed by Strabag SE in Vienna
For TRL>1, who is the technology developer	A collaboration between TU Wien and a local waste management startup

Table 15 PAS AT-14

Possible applicable solution AT-15	
Name	Common Data Environment (CDE) for Construction Projects
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	CDE serves as a central information hub where all project data and information are linked and made available to relevant project participants in the cloud. It enables efficient collaboration without media breaks and information loss
Input raw data	Project documents, plans, schedules, and communications from various stakeholders
Other necessary/recommended digital objects	Cloud-based collaboration platform (e.g.,Autodesk Build)
Enabler of other possible applicable solutions	Improved project management, sustainability tracking, hybrid collaboration
Output results	Centralized project information, real-time updates, improved communication
Benefits expected in operation, especially emphasizing circular economy principles	Reduces paper waste, improves resource efficiency, enables better decision-making for sustainable construction practices
Necessary human resources for installing and operating	IT personnel for initial setup, project managers and team members for ongoing use
Possible pitfalls and problems	Requires buy-in from all stakeholders, potential data security concerns
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Tirol kliniken project
For TRL>1, who is the technology developer	Autodesk (for the specific implementation mentioned)

Table 16 PAS AT-15

Possible applicable solution AT-16	
Name	Laser Scanning for Building Digitalization
Solution category (from the Existing knowledge)	a.i. Sensing technologies

Description of the applicable solution	Uses laser scanning technology to create precise 3D digital representations of buildings, providing detailed point clouds for planning and renovation purposes
Input raw data	Laser scan data of building interiors and exteriors
Other necessary/recommended digital objects	NavVis IVION collaboration platform
Enabler of other possible applicable solutions	BIM modeling, virtual site inspections, precise measurements for renovations
Output results	Detailed point clouds, 3D models, photorealistic insights
Benefits expected in operation, especially emphasizing circular economy principles	Reduces planning errors, saves time and costs, enables more efficient renovations and repurposing of existing buildings
Necessary human resources for installing and operating	Trained technicians for scanning, data processing specialists
Possible pitfalls and problems	Large data volumes, potential privacy concerns in occupied buildings
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	KDO - Klinik Donaustadt
For TRL>1, who is the technology developer	NavVis (for the specific technology mentioned)

Table 17 PAS AT-16

Possible applicable solution AT-17	
Name	Digital Building Component Catalog
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	A digital version of the Building Component Catalog, which is essential for assessing building damages. It provides detailed information about various building components, their properties, and potential issues.
Input raw data	Building component specifications, material properties, damage assessment criteria

Other necessary/recommended digital objects	Database management system, user interface for easy navigation
Enabler of other possible applicable solutions	Improved damage assessment, more efficient building inspections, standardization of building component information
Output results	Detailed information on building components, damage assessment guidelines, reference data for experts
Benefits expected in operation, especially emphasizing circular economy principles	Facilitates accurate damage assessment, potentially leading to more targeted repairs and less waste. Supports informed decision-making in building maintenance and renovation.
Necessary human resources for installing and operating	Building experts, software developers for maintenance and updates, data entry specialists
Possible pitfalls and problems	Requires regular updates to stay current with new building technologies and materials. Ensuring widespread adoption among experts might be challenging.
Technology readiness level (TRL)	7 (estimated, as the exact level of digitalization is not specified)
For TRL>4, where it has been already applied	Used by building experts and surveyors across Austria, particularly in Styria
For TRL>1, who is the technology developer	Engineering Chamber of Styria (Ingenieurkammer Steiermark)

Table 18 PAS AT-17

Possible applicable solution AT-18	
Name	EPSolutely - Digital Solutions for EPS Recycling
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability

Description of the applicable solution	Aims to enhance the recycling rate of expanded polystyrene (EPS) through digital solutions. It involves collecting and analysing data on EPS waste to improve material flow understanding and integrating technologies for automated waste recognition and processing. EPSolutely focuses on collecting EPS offcuts during insulation board cutting, using QR-coded bags and an app for tracking and coordinating recycling.
Input raw data	Data on EPS waste quantity and quality, recycling process metrics
Other necessary/recommended digital objects	Automated recognition systems, machine learning algorithms for waste sorting
Enabler of other possible applicable solutions	Improved recycling processes, enhanced resource management, reduced environmental impact
Output results	Organized data on EPS waste streams, including details of quantity, quality, and contamination levels, a centralized tracking system using QR codes and barcodes to monitor the collection and movement of EPS offcuts and demolition waste,
Benefits expected in operation, especially emphasizing circular economy principles	Aims to increase the recycling rate of EPS in Austria to 80% by 2025, optimized material flows, reducing landfill waste and promoting sustainable material use
Necessary human resources for installing and operating	Data analysts, waste management specialists, technology developers
Possible pitfalls and problems	Requires collaboration across sectors for data sharing and technological integration
Technology readiness level (TRL)	6 (assuming ongoing development and testing)
For TRL>4, where it has been already applied	various pilot projects in Austria (https://porr.at/en/media/press-releases/press-releases/press-release/news/epsolutely-pledges-to-combat-polystyrene-waste/)
For TRL>1, who is the technology developer	Fraunhofer Austria, HIRSCH Servo, PORR Umwelttechnik

Table 19 PAS AT-18

Possible applicable solution AT-19	
Name	Rockcycle Austria - Digital Return Service for Stone Wool Insulation
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Rockcycle provides a digital return service for stone wool insulation materials. It includes online tools for coordinating returns and tracking waste streams digitally to ensure environmentally responsible recycling.
Input raw data	Logistics data, material return requests, recycling process information
Other necessary/recommended digital objects	Online logistics coordination platform, digital tracking systems
Enabler of other possible applicable solutions	Closed-loop production cycles, improved waste management efficiency
Output results	Organized data on stone wool waste material collection, Digital reports on return requests and recycling status, Metrics on material usage efficiency and waste reduction, Data for monitoring environmental impact and closed-loop compliance
Benefits expected in operation, especially emphasizing circular economy principles	Verified recycling processes, facilitates a closed-loop system for stone wool insulation materials, reducing landfill use and construction waste
Necessary human resources for installing and operating	Logistics coordinators, IT support staff for platform management
Possible pitfalls and problems	Dependence on user adoption of digital tools; requires robust logistics infrastructure
Technology readiness level (TRL)	7 (assuming established digital logistics solutions)
For TRL>4, where it has been already applied	Implemented across various residential construction projects in Austria (specific projects not available)
For TRL>1, who is the technology developer	ROCKWOOL

Table 20 PAS AT-19

Possible applicable solution AT-20	
Name	AI-Powered Point Cloud to BIM Conversion
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Utilizes artificial intelligence to automatically generate BIM models from point cloud data, including classification of building elements.
Input raw data	Point cloud data from laser scans
Other necessary/recommended digital objects	AI algorithms, BIM software
Enabler of other possible applicable solutions	Rapid creation of digital twins, automated building analysis, lifecycle assessments
Output results	Classified BIM models, building element inventories
Benefits expected in operation, especially emphasizing circular economy principles	Accelerates the digitization of existing buildings, enabling more efficient renovation planning and material reuse strategies
Necessary human resources for installing and operating	AI specialists, BIM modelers
Possible pitfalls and problems	Accuracy of AI-generated models may require human verification
Technology readiness level (TRL)	6 (estimated)
For TRL>4, where it has been already applied	Schönbrunn Palace restoration
For TRL>1, who is the technology developer	Austrian startups, BIMIT, Advenser, ASTRUM IT

Table 21 PAS AT-20

Possible applicable solution AT-21	
Name	Reebuild - AI-Driven Construction Management Platform
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability

Description of the applicable solution	Reebuild offers an AI-powered platform for construction management, automating document processing, cost management, and material management. It uses machine learning to capture, structure, and distribute data from various sources like invoices, delivery notes, and construction contracts.
Input raw data	Construction documents (invoices, delivery notes, contracts), project costs, material data
Other necessary/recommended digital objects	Machine learning algorithms, cloud-based data storage, mobile app
Enabler of other possible applicable solutions	Improved project management, real-time cost tracking, automated reporting, sustainability documentation
Output results	Structured project data, real-time cost analyses, automated document processing, material tracking
Benefits expected in operation, especially emphasizing circular economy principles	Reduces paper waste, improves resource efficiency through better material management, enables CO2 documentation and certification data management
Necessary human resources for installing and operating	IT personnel for initial setup and integration, project managers and team members for ongoing use
Possible pitfalls and problems	Requires buy-in from all stakeholders, potential challenges in integrating with existing systems
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Various construction projects in Austria (detailed information not available)
For TRL>1, who is the technology developer	Reebuild (Startup)

Table 22 PAS AT-21

Possible applicable solution AT-22	
Name	Virtual City Twin Vienna - Urban Metabolism Analysis
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables

Description of the applicable solution	The Virtual City Twin project aims to model and analyse the urban metabolism of Vienna. This approach utilizes statistical data to understand material flows, resource usage, and building ages within the urban environment, facilitating better resource management and sustainability practices.
Input raw data	Statistical data on building ages, material compositions, urban infrastructure metrics
Other necessary/recommended digital objects	Data analytics platforms, machine learning algorithms for predictive modelling
Enabler of other possible applicable solutions	Improved urban planning, enhanced resource management, sustainable city development
Output results	Predictive models of material availability, insights into resource flows, potential recycling opportunities
Benefits expected in operation, especially emphasizing circular economy principles	Supports sustainable urban development by enabling to optimize resource use and enhancing recycling efforts across the city.
Necessary human resources for installing and operating	Data scientists, urban planners, IT specialists for system integration
Possible pitfalls and problems	Requires comprehensive data collection and integration; potential challenges in modelling complex urban systems.
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	Pilot studies or initial implementations in Vienna
For TRL>1, who is the technology developer	City of Vienna in collaboration with research institutions

Table 23 PAS AT-22

Possible applicable solution AT-23	
Name	Floodlight Satellite Data Analysis for Building Stock Identification
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights

Description of the applicable solution	Floodlight uses satellite data to identify existing building structures and gather related data. This approach can be particularly useful for large-scale urban analysis and planning.
Input raw data	Satellite imagery, geospatial data
Other necessary/recommended digital objects	Machine learning algorithms, geospatial analysis tools
Enabler of other possible applicable solutions	Urban planning, building stock assessment, sustainability analysis
Output results	Building structure identification, urban layout analysis
Benefits expected in operation, especially emphasizing circular economy principles	Enables efficient large-scale analysis of building stock, supporting better urban planning and potential renovation strategies
Necessary human resources for installing and operating	Data scientists, geospatial analysts, urban planners
Possible pitfalls and problems	Accuracy limitations based on satellite data resolution, potential privacy concerns
Technology readiness level (TRL)	7 (estimated, as the company has been invited to establish in Vienna)
For TRL>4, where it has been already applied	Projects in California, potential projects in Vienna
For TRL>1, who is the technology developer	Floodlight, led by Nate Wyne

Table 24 PAS AT-23

Bosnia and Herzegovina

Possible applicable solution BA-1	
Name	Building Management System - Reducing energy use and carbon emissions through automation
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation

Description of the applicable solution	Digital building automation offers a whole-lifecycle carbon approach to make energy more visible, drive efficiency, eliminate waste, and decarbonize buildings. It optimizes operational efficiency to reduce utility costs and expenses, improves occupant comfort and well-being, meets sustainable building regulations and stakeholder demands, enables green building certifications, extends the lifecycle, and optimizes the performance of building equipment.
Input raw data	Data from field devices, protection devices, measurement equipment and actuators installed in the building.
Other necessary/recommended digital objects	Field devices with communication capabilities based on certified and open communication protocols.
Enabler of other possible applicable solutions	It provides key insights into building operations by constantly monitoring systems and identifying faults to proactively address building's inefficiencies, improve maintenance planning, optimise services, and improve OPEX.
Output results	Direct digital commands for building heating/cooling equipment.
Benefits expected in operation, especially emphasizing circular economy principles	Meet sustainable building regulations, comply with environmental, social, and governance (ESG) reporting and emissions regulations. Reduced utility costs and expenses, decreased energy waste, decreased carbon footprint, buildings become more adaptable, sustainable, and healthier for tenants.
Necessary human resources for installing and operating	System Integrators and Installers trained and certified for Building Management System integration
Possible pitfalls and problems	Integration challenges with existing field devices without communication abilities, user adoption
Technology readiness level (TRL)	TRL 9 - actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

For TRL>4, where it has been already applied	Numerous applications worldwide, some of them in Bosnia and Herzegovina as well. Some global references: Moorfields Eye Hospital, London, UK; University of Nottingham, UK; UST Digital Transformation Solutions Company, India; ASCOTT The Ascott Limited, Singapore; Resorts World Las Vegas, USA; Hyatt Regency, multiple locations worldwide; Marriott International, multiple locations worldwide; Hilton Garden Inn…
For TRL>1, who is the technology developer	Schneider Electric

Table 25 PAS BA-1

Possible applicable solution BA-2	
Name	Data collection, processing, analysis and modelling in urban planning
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Digital procedures, methods and approaches in urban data analysis of building placement, infrastructure, traffic, economy, demographic, environment, etc. to develop and improve urban plan design
Input raw data	On-site data from construction facilities, geographic data, aerial imagery, traffic data, demographic data, cadastral maps
Other necessary/recommended digital objects	CAD software, GIS software, data visualization tools, mobile app for on-site data collection
Enabler of other possible applicable solutions	Supports sustainable urban development
Output results	Urban development plans
Benefits expected in operation, especially emphasizing circular economy principles	Improves resource efficiency in urban areas, reduces environmental impact, and enhances quality of life. The data and developed models can also be applied to other plans, such as spatial plans, detailed regulatory plans, and projects related to infrastructure design.

Necessary human resources for installing and operating	Urban planners, infrastructure designers, data analysts, GIS analysts, environmental experts, traffic designers and planners, on-site operators
Possible pitfalls and problems	Data accuracy and consistency, balancing multiple stakeholder interests
Technology readiness level (TRL)	TRL 5 - technology validated in relevant environment
For TRL>4, where it has been already applied	Numerous municipalities and cities in BiH: Banja Luka, Prijedor, Prnjavor, Trebinje, Gradiška, Mrkonjić Grad, Teslić, Šamac, Vukosavlje, Milići Banovići, Donji Vakuf, Usora, Rogatica, Gacko
For TRL>1, who is the technology developer	Urbis centar d.o.o. Banja Luka

Table 26 PAS BA-2

Possible applicable solution BA-3	
Name	BIM Revit Architectural Modelling and Consulting
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility, and interoperability
Description of the applicable solution	Grupa Arh specializes in creating accurate Revit 3D BIM models and 2D CAD drawings from cloud data points or PDFs, aligned with BIM execution plans and project workflows. It ensures the integrity of BIM models and their usability throughout the building lifecycle, supporting efficient collaboration and error-free construction projects.
Input raw data	Cloud data points, PDFs and CAD drawings, project workflows and BIM execution plans
Other necessary/recommended digital objects	BIM software, cloud storage for data exchange
Enabler of other possible applicable solutions	Facilitates lifecycle management of buildings, supports sustainable design practices and reduces construction errors, enables integration with energy efficiency tools and material tracking systems
Output results	Accurate 3D BIM models, detailed 2D CAD drawings, improved project workflows and collaboration

Benefits expected in operation, especially emphasizing circular economy principles	Reduces resource waste through precise planning and modelling, ensures adaptability and reusability of construction components, enhances collaboration for efficient construction processes
Necessary human resources for installing and operating	BIM consultants, architects and CAD specialists, project managers
Possible pitfalls and problems	High reliance on data quality from source inputs, integration challenges with older systems or workflows
Technology readiness level (TRL)	TRL 9 - actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
For TRL>4, where it has been already applied	Applied in construction projects supported by Grupa Arh: BBI Centre Sarajevo, Sarajevo City Centre, Al Jazeera Balkans Headquarters building - Sarajevo, Gorilla Nest Lodges Kinigi – Rwanda, Bosmal City Centre Sarajevo, Hotel Europe Sarajevo, Sarajevo International Airport,...
For TRL>1, who is the technology developer	Grupa Arh

Table 27 PAS BA-3

Possible applicable solution BA-4	
Name	Drone for geodetic surveying with software tool for aerial data processing
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Solutions for collecting, processing, analysing and displaying aerial data used in geodetic surveying and a user-friendly, extendable application and API for drone image processing.
Input raw data	Aerial images and videos
Other necessary/recommended digital objects	Cloud-based platform
Enabler of other possible applicable solutions	Enables fast and simple processing of recorded materials
Output results	Maps, point clouds, 3D models and DEMs

Benefits expected in operation, especially emphasizing circular economy principles	Improves resource efficiency in geodetic surveying
Necessary human resources for installing and operating	Geodetic engineers, spatial planners, data analysts
Possible pitfalls and problems	User adoption, integration with traditional surveying
Technology readiness level (TRL)	TRL 9 - actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
For TRL>4, where it has been already applied	Many different fields and companies.
For TRL>1, who is the technology developer	DJI/OpenDroneMap

Table 28 PAS BA-4

Possible applicable solution BA-5	
Name	Impulse - construction progress tracking platform
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Impulse is a comprehensive construction analytics platform that helps project teams track progress, identify issues, and measure performance in real-time. By providing clear and actionable insights into construction projects, Impulse enables users to monitor the percentage of project completion, detect bottlenecks, and analyse subcontractor performance week-to-week.
Input raw data	Basic project information: client name, location, address, typology, surface area; Project documentation: general arrangement drawings, design documents, and project schedule in the native file (ASTA, P6/Primavera or Microsoft Project) determining the schedule of tasks/activities (start/end/duration); Project info sheet (approved by the client): spatial scope/zones of the project, tracking scope/zones, a list of tracking tasks/activities, and chosen package of deliverables.

Other necessary/recommended digital objects	360° camera, phone & laptop/PC.
Enabler of other possible applicable solutions	Digital automation and data-driven insights that streamline project management. It integrates with scheduling tools, uses 360° site scans, and supports BIM and PDF reporting to optimize workflows and reduce on-site time, enabling better coordination across project teams and ensuring on-time delivery.
Output results	Weekly/biweekly/monthly 360° images, SidebySide comparison of a certain space throughout weeks/months, Work-in-place tracking followed by PDF reports, Spotlights issue detection, Actual vs planned reporting followed by PDF reports, Schedule integration, 3D BIM integration.
Benefits expected in operation, especially emphasizing circular economy principles	Making sure clients hit the deadline saving time & money; Flagging issues (partial or full removals, incomplete installs, mismatches); Reduced time spent on-site – goes hand in hand with the previous answers; Reduced carbon footprint because clients no longer need to go on-site to check the progress; Helping clients coordinate meetings with owners, representatives, and trades.
Necessary human resources for installing and operating	Site scanners, designers & site supervision specialists.
Possible pitfalls and problems	Impulse training sessions with the clients are usually needed – making them used to an online platform.
Technology readiness level (TRL)	TRL 9 - actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
For TRL>4, where it has been already applied	List of clients: Mace, Gilbane, Canary Wharf, Olympia, Hines, Beck London, Turner, 8build, Sciame, Turner, and many more - a full list available at disperse.io Number of projects: more than 150+!
For TRL>1, who is the technology developer	Disperse, with headquarters in Sarajevo

Table 29 PAS BA-5

Possible applicable solution BA-6	
Name	BIM Modelling; BIM Asset Development
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	BIM services, offering digital models that incorporate advanced design, engineering, and construction data. These models enhance project planning, execution, and sustainability by addressing challenges such as design errors, cost estimation, and efficient project visualization.
Input raw data	Architectural, structural, and MEP (Mechanical, Electrical, and Plumbing) designs; Laser scan data or paper-based project documentation; Material specifications and energy performance data
Other necessary/recommended digital objects	Revit BIM models; 4D simulations (time-based construction sequencing); Digital material catalogues for lifecycle analysis
Enabler of other possible applicable solutions	BIM models enable integration with other digital tools such as IoT for real-time monitoring, lifecycle assessment (LCA) platforms, and material passport systems for circular economy applications.
Output results	Detailed 3D/4D models optimized for energy and resource efficiency; Comprehensive project documentation, including QTO (Quantity Takeoff) and cost estimates; Enhanced visualization and simulation capabilities for construction planning
Benefits expected in operation, especially emphasizing circular economy principles	Reduction of waste by optimizing resource usage during design and construction; Improved decision-making with real-time project data integration; Easier adaptation of deconstruction and material reuse practices, enabling circularity
Necessary human resources for installing and operating	BIM specialists; Architects and engineers trained in BIM software like Revit; Project managers for interpreting and utilizing BIM outputs
Possible pitfalls and problems	Initial high investment in training and software licensing; Interoperability challenges between different software platforms; Potential resistance to adopting digital workflows in traditional construction environments.

Technology readiness level (TRL)	TRL 9 - actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)
For TRL>4, where it has been already applied	Large-scale construction projects in Europe and globally.
For TRL>1, who is the technology developer	BIM solutions at Walter AEC are powered by leading software platforms such as Autodesk Revit, combined with the company's extensive expertise in BIM consulting and engineering

Table 30 PAS BA-6

Bulgaria

Possible applicable solution BG-1	
Name	IoT Cloud For Smart Energy Metering
Solution category (from the Existing knowledge)	a.ii. Sensing data communication
Description of the applicable solution	IoT cloud platform to manage a network of smart metering devices, comprising four energy meters across all office circuits.
Input raw data	Energy consumption data collected from IoT devices
Other necessary/recommended digital objects	Machine learning algorithms, user interface with dashboards, a cloud-based data storage system to handle incoming data streams.
Enabler of other possible applicable solutions	Facilitates integration with building management systems for optimized energy usage. Enables predictive maintenance by analysing energy consumption patterns. Supports the implementation of energy-saving initiatives and policies.
Output results	Detailed reports on energy consumption patterns. Real-time alerts for unusual energy usage. Analytical insights to inform energy-saving strategies.
Benefits expected in operation, especially emphasizing circular economy principles	Enhanced resource efficiency. Enhanced transparency in energy consumption, leading to more efficient use of resources. Identification and elimination of energy losses, contributing to sustainability goals.

Necessary human resources for installing and operating	Technicians for the installation of smart meters. IT professionals to manage the cloud platform and ensure data security. Analysts to interpret data and provide actionable insights.
Possible pitfalls and problems	Initial setup costs, potential data privacy concerns and dependence on reliable internet connectivity.
Technology readiness level (TRL)	TRL 9: The technology is fully operational and has been deployed commercially.
For TRL>4, where it has been already applied	Dais Software
For TRL>1, who is the technology developer	Blueberry Software

Table 31 PAS BG-1

Possible applicable solution BG-2	
Name	IoT Cloud for Smart Gas Monitoring
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Solution to transform the existing gas meters into intelligent IoT-enabled devices using impulse meters and the Nb-Fi protocol, enabling automated data collection, real-time monitoring, and comprehensive analysis with enhanced accuracy and efficiency.
Input raw data	Geospatial data of gas infrastructure components, operational data from gas distribution networks, data sets from gas meters
Other necessary/recommended digital objects	Real-time sensors and monitoring devices within the gas infrastructure.
Enabler of other possible applicable solutions	Integration with predictive maintenance systems. Enhancement of energy management systems.
Output results	A comprehensive digital representation of gas infrastructure. AI-generated insights to inform and optimize energy efficiency and gas distribution strategies.

Benefits expected in operation, especially emphasizing circular economy principles	Reduction in operational costs - manual meter reading visits to remote locations became a thing of the past, leading to substantial savings in labor and transportation expenses. Real-time insights into gas consumption patterns and enhanced decision-making capabilities leading to optimized resource utilization
Necessary human resources for installing and operating	Software engineers for system integration and maintenance. Data analysts.
Possible pitfalls and problems	Ensuring data accuracy and consistency across the digital twin. Managing the complexity of the gas infrastructure within the digital model.
Technology readiness level (TRL)	TRL 9: The technology is fully operational and has been deployed commercially.
For TRL>4, where it has been already applied	AresGas
For TRL>1, who is the technology developer	Blueberry Software

Table 32 PAS BG-2

Possible applicable solution BG-3	
Name	Platform with IoT data that tracks usage, controls energy costs and reduces CO_2 footprint
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	IoT solution that integrates thermostats, sensors, and a smart platform to enable real-time monitoring, remote control, and automation.
Input raw data	Indoor temperature and humidity levels, CO_2 concentrations, status of windows and doors (open/closed), occupancy information.
Other necessary/recommended digital objects	LoRaWAN® gateways for device communication, cloud-based data storage and analytics infrastructure, user interfaces for facility managers.
Enabler of other possible applicable solutions	Integration with existing Building Management Systems (BMSs), scalability to incorporate additional IoT devices for broader building automation.

Output results	Real-time data on environmental conditions and energy usage. Automated control over heating systems based on occupancy and air quality. Alerts for abnormal conditions, such as elevated CO_2 levels or open windows during heating. Optimised ESG performance.
Benefits expected in operation, especially emphasizing circular economy principles	Significant reduction in energy consumption and heating costs. Enhanced indoor air quality, leading to improved occupant well-being. Contribution to sustainability goals by lowering the building's carbon footprint.
Necessary human resources for installing and operating	Technicians for installing IoT devices and setting up the network, IT professionals to manage the platform, facility managers trained to interpret data and adjust settings as needed.
Possible pitfalls and problems	Potential challenges in integrating with legacy systems, ensuring data security and privacy and dependence on reliable network connectivity for real-time monitoring.
Technology readiness level (TRL)	TRL 9: The solution is fully operational and commercially deployed.
For TRL>4, where it has been already applied	DSK Bank, subsidiary of OTP Group, office building with 5700 m^2 in Sofia, Bulgaria
For TRL>1, who is the technology developer	MClimate

Table 33 PAS BG-3

Possible applicable solution BG-4	
Name	Smart heating solution
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Platform with LoRaWAN®-enabled devices, including smart thermostats and humidity and temperature sensors.
Input raw data	Indoor temperature and humidity levels, heating system operational status, occupancy patterns.

Other necessary/recommended digital objects	LoRaWAN® gateways to facilitate communication between devices and the central platform.
Enabler of other possible applicable solutions	Enables energy consumption analysis, facilitating further optimization initiatives.
Output results	Automated control of heating systems based on predefined schedules and occupancy.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in energy consumption and associated costs. Contribution to sustainability goals by minimizing environmental impact.
Necessary human resources for installing and operating	Facility managers trained to use the platform, technicians for installing the sensors.
Possible pitfalls and problems	Ensuring reliable network coverage for LoRaWAN® devices. Need for ongoing maintenance to ensure system efficacy.
Technology readiness level (TRL)	TRL 9: The solution is fully operational and has been deployed in real-world settings.
For TRL>4, where it has been already applied	Applied in two health centres in Asturias, Spain, resulting in optimized heating management and cost reductions.
For TRL>1, who is the technology developer	MClimate

Table 34 PAS BG-4

Possible applicable solution BG-5	
Name	OfficeRnD Hybrid -- a hybrid workplace management platform
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	Platform to streamline desk and room reservations, manage shared spaces, and support hybrid work policies.
Input raw data	Employee schedules and workspace bookings, availability of desks, rooms, and other resources, organizational policies regarding hybrid work.

Other necessary/recommended digital objects	Integration with calendar applications (e.g., Microsoft Teams, Outlook), user interfaces for employees to manage bookings, administrative dashboards for monitoring space utilization.
Enabler of other possible applicable solutions	Facilitates the adoption of flexible work arrangements, supports data-driven decisions for space optimization.
Output results	Efficient management of office spaces and resources.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in real estate maintenance costs due to optimized space usage. Decreased physical office footprint, leading to lower energy consumption. Optimized use of existing resources. Promotion of sustainable work practices through flexible arrangements.
Necessary human resources for installing and operating	IT personnel for system integration and maintenance. Facility managers to oversee space utilization and policy enforcement.
Possible pitfalls and problems	Potential technical issues during integration with existing systems. Resistance to change from employees accustomed to traditional work models.
Technology readiness level (TRL)	TRL 9: The solution is fully operational and commercially deployed.
For TRL>4, where it has been already applied	Implemented by Tavistock in the United States to manage hybrid work arrangements and shared office spaces.
For TRL>1, who is the technology developer	OfficeRnD

Table 35 PAS BG-5

Possible applicable solution BG-6	
Name	Senstate Technologies -- environmental monitoring solutions for smart buildings and cities
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way

Description of the applicable solution	Senstate offers a comprehensive platform that integrates advanced sensor networks to monitor environmental parameters in cities and buildings. The system provides real-time data collection, analysis, and visualization to support informed decision-making for urban and real estate management.
Input raw data	Air quality metrics: concentrations of gases (e.g., CO_2, NO_2), particulate matter (PM2.5, PM10), and meteorological data. Water quality indicators: physical, chemical, and biological parameters from rivers, lakes, and reservoirs. Traffic data: counts and flow rates of pedestrians, vehicles, and bicycles.
Other necessary/recommended digital objects	IoT sensors and devices for data acquisition. Communication networks (e.g., Wi-Fi, mobile data) for data transmission. Cloud-based data storage and processing infrastructure.
Enabler of other possible applicable solutions	Integration with urban planning tools.
Output results	Alerts and notifications for threshold exceedances or anomalies. Reports and insights to guide policy-making and operational decisions.
Benefits expected in operation, especially emphasizing circular economy principles	Improved resource efficiency by enabling data-driven urban management. Promotion of sustainable development by providing transparency and accountability.
Necessary human resources for installing and operating	IT professionals to manage the platform's infrastructure and security. Technicians for sensor installation and maintenance.
Possible pitfalls and problems	Ensuring data accuracy and reliability from diverse sensor networks. Maintaining system scalability and performance as the network expands.
Technology readiness level (TRL)	TRL 8: The system is complete and qualified through testing and demonstration.
For TRL>4, where it has been already applied	Pilot projects in Gabrovo, Bulgaria, involving air quality monitoring in industrial zones and urban areas.
For TRL>1, who is the technology developer	Senstate Technologies

Table 36 PAS BG-6

Possible applicable solution BG-7	
Name	IoT-based remote monitoring solutions designed to optimize the consumption of utilities such as water, energy, and gas.
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	IoT-based remote monitoring solutions designed to optimize the consumption of resources and utilities such as water, energy, and gas.
Input raw data	Consumption metrics from water, gas, and energy meters. Environmental parameters such as water pressure and tank levels. Air quality indicators.
Other necessary/recommended digital objects	IoT-enabled data loggers compatible with existing utility meters. Cloud-based data storage and analytics platform.
Enabler of other possible applicable solutions	Enhancement of predictive maintenance systems through detailed consumption analytics.
Output results	Real-time monitoring dashboards displaying utility consumption and environmental data. Detailed reports for regulatory compliance and operational optimization.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in resource wastage through precise monitoring and timely interventions. Improved operational efficiency leading to cost savings. Enhanced sustainability by promoting responsible resource consumption.
Necessary human resources for installing and operating	Technicians for installing data loggers and integrating them with existing meters. Analysts to interpret data and provide actionable insights.
Possible pitfalls and problems	Challenges in integrating with legacy systems lacking digital interfaces. Dependence on stable communication networks for real-time data transmission.
Technology readiness level (TRL)	TRL 9: The technology is fully operational and commercially deployed.

For TRL>4, where it has been already applied	Implemented in various sectors, including water utilities, industries, hotels, and agriculture, to monitor and optimize utility consumption.
For TRL>1, who is the technology developer	ThingsLog

Table 37 PAS BG-7

Possible applicable solution BG-8	
Name	Suite of smart automation devices
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	A solution that integrates smart relays, plugs, sensors, and a centralized mobile application to automate and manage various building systems.
Input raw data	Environmental data such as temperature, humidity, and light levels. Real-time energy consumption metrics from connected devices.
Other necessary/recommended digital objects	Shelly mobile application for device control and monitoring. Compatible smart home platforms (e.g., Alexa, Google Home) for voice control. Wi-Fi or Bluetooth connectivity for device communication.
Enabler of other possible applicable solutions	Integration with renewable energy systems to optimize self-consumption. Enhancement of building management systems through detailed energy analytics.
Output results	Automated control of appliances based on schedules or sensor inputs. Detailed reports on energy consumption patterns.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in energy consumption and associated costs. Extension of appliance lifespan through optimized usage.
Necessary human resources for installing and operating	Technicians for installing and configuring devices. IT support for integration with existing networks and platforms.
Possible pitfalls and problems	Compatibility issues with legacy appliances or systems. Ensuring data privacy and security. Dependence on stable internet.

Technology readiness level (TRL)	TRL 9: The technology is fully operational and commercially deployed.
For TRL>4, where it has been already applied	Shelly's devices have been implemented in various residential and commercial settings to enhance energy efficiency and automation.
For TRL>1, who is the technology developer	Shelly is developed by Allterco Robotics, a company specializing in IoT and smart home solutions.

Table 38 PAS BG-8

Possible applicable solution BG-9	
Name	Building automation systems utilizing KNX technology.
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	KNX-based automation systems that allow users to manage multiple building functions through dedicated devices or mobile applications, providing a unified platform for controlling lighting, climate, security, and more.
Input raw data	User commands and preferences, sensor data and status information from various building systems
Other necessary/recommended digital objects	KNX-compatible sensors and actuators and communication infrastructure supporting KNX protocols.
Enabler of other possible applicable solutions	Integration with energy management systems for optimized resource usage. Compatibility with renewable energy sources and smart grids. Support for advanced security and surveillance systems.
Output results	Centralized control and monitoring of building systems. Automated responses based on sensor inputs and predefined scenarios.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in energy consumption through efficient system management. Support for sustainable building practices by integrating various systems.
Necessary human resources for installing and operating	Certified KNX installers and system integrators.

Possible pitfalls and problems	Need for interoperability among devices from different manufacturers. Initial installation costs and complexity.
Technology readiness level (TRL)	TRL 9: The technology is fully operational and commercially deployed.
For TRL>4, where it has been already applied	Implemented in various residential and commercial buildings to enhance automation and energy efficiency.
For TRL>1, who is the technology developer	Smart Buildings Solutions

Table 39 PAS BG-9

Possible applicable solution BG-10	
Name	Digital building logbook
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	A centralized digital space where property owners, tenants, and investors can manage various types of building data, including real-time sensor information, documentation, and maintenance history. The platform ensures data integrity and accessibility throughout the property's lifecycle.
Input raw data	Real-time data from sensors and IoT devices (e.g., energy consumption, indoor air quality). Static information such as documents, certificates, contracts, and maintenance records.
Other necessary/recommended digital objects	Compatibility with various data sources and formats for seamless data aggregation.
Enabler of other possible applicable solutions	Facilitates compliance reporting by providing structured and certified data. Enhances collaboration among stakeholders through transparent data sharing. Supports sustainability assessments by tracking environmental performance metrics.
Output results	Structured and normalized building data accessible through a unified dashboard. Certified and timestamped records stored in an immutable

	environment. Comprehensive reports on building performance, sustainability, and well-being.
Benefits expected in operation, especially emphasizing circular economy principles	Eliminates information asymmetry, improving collaboration among stakeholders. Enhances property value by providing transparent and reliable performance data. Supports circular economy principles by enabling tracking of construction materials and promoting sustainable building practices.
Necessary human resources for installing and operating	IT professionals for system integration and maintenance. Facility managers trained to utilize the platform for data input and monitoring. Experts in ontologies, data models and semantics.
Possible pitfalls and problems	Challenges in integrating data from diverse sources with varying formats. Ensuring data privacy and security, especially when dealing with sensitive information. Dependence on the accuracy and reliability of input data from sensors and other devices
Technology readiness level (TRL)	TRL 8: The system is complete and has been qualified through testing and demonstration.
For TRL>4, where it has been already applied	The Digital Building Logbook has been presented to the Ontochain ecosystem, indicating its application in real-world scenarios.
For TRL>1, who is the technology developer	ReCheck B.V.

Table 40 PAS BG-10

Czech Republic

Possible applicable solution CZ-1	
Name	BIM tools
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	PointCloud-to-BIM technology facilitates the creation of digital twins from laser-scanned data of buildings and construction sites. The process leverages automation to significantly reduce the time required for data conversion, enabling the transformation of a

	single floor within 1–2 hours. The aim is to enhance existing tools for faster and more accurate modelling.
Input raw data	Point cloud data from laser scanning of buildings and structures.
Other necessary/recommended digital objects	Advanced BIM software for model creation, hardware for 3D laser scanning, and cloud-based storage for data processing.
Enabler of other possible applicable solutions	Supports digital twin creation, building renovation planning, and integration into facility management systems.
Output results	Automated, accurate BIM models created from point cloud data, enabling rapid documentation and analysis of existing buildings.
Benefits expected in operation, especially emphasizing circular economy principles	Efficiency accelerates the modelling process compared to manual methods; BIM model also offers precision which improves the accuracy and minimizes human error; also supports adaptive reuse of buildings by providing detailed digital documentation for renovation projects.
Necessary human resources for installing and operating	Laser scanning technicians, BIM modelers, and software specialists.
Possible pitfalls and problems	Data quality variability in the quality of legacy drawings may impact accuracy; complexity requires advanced algorithms for converting 2D drawings into 3D models; adoption barriers may face resistance in industries unfamiliar with BIM technologies; at the moment, not many BIM specialists/experts.
Technology readiness level (TRL)	5 - Application nearing completion and field testing, indicating readiness for pilot deployment
For TRL>4, where it has been already applied	Ongoing project RECONMATIC, focusing on the automation of digital twin creation. Concept of implementing the BIM method in the Czech Republic.
For TRL>1, who is the technology developer	NA

Table 41 PAS CZ-1

Possible applicable solution CZ-2	
Name	Digital twins
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Digital twins are virtual replicas of physical assets, systems, or processes that are used to simulate, monitor, and optimize performance. In the building industry, digital twins have applications throughout the lifecycle of a building, from design to demolition. They can be used for visualisation, simulation or scenario testing.
Input raw data	Architectural Plans: CAD drawings, 3D models, or BIM (Building Information Modelling) data, Structural Engineering Data: Load-bearing details, material properties, and structural models, environmental conditions, energy consumption
Other necessary/recommended digital objects	Simulation software
Enabler of other possible applicable solutions	Digital logbooks, pre-demolition audits, energy efficiency
Output results	Predictions, recommendations, whole life-cycle
Benefits expected in operation, especially emphasizing circular economy principles	Optimisation of resource use and waste creation during building lifetime, predictions
Necessary human resources for installing and operating	Engineers, digital twin experts
Possible pitfalls and problems	Ensuring the validity and sameness of the digital twin, keeping it up to date, set up financial and time costs
Technology readiness level (TRL)	2 - technology concept formulated
For TRL>4, where it has been already applied	NA
For TRL>1, who is the technology developer	DUET project, RECONMATIC project, Concept of implementing the BIM method in the Czech Republic

Table 42 PAS CZ-2

Possible applicable solution CZ-3	
Name	IoT solution for smart container
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	An IoT-based pilot solution for monitoring and managing construction waste containers. The system uses sensors installed in the container to track its fill level and analyse the type of waste it contains. This enables efficient waste collection.
Input raw data	Real-time data from IoT sensors, sensor data analysing the type and composition of waste
Other necessary/recommended digital objects	IoT platform for aggregating and analysing sensor data, mobile or applications for tracking container status and scheduling collections, GPS tracking systems
Enabler of other possible applicable solutions	Supports smart logistics for waste collection, provides data for analytics on waste generation, can be integrated with recycling and sorting facilities for automated waste management
Output results	Real-time status updates on container fill levels, improved scheduling of waste collection, insights into the composition of waste
Benefits expected in operation, especially emphasizing circular economy principles	Reduced fuel consumption and emissions due to optimized waste collection routes, improved recycling efficiency, prevention of waste overflow, reducing environmental impact, data-driven insights to encourage sustainable waste management
Necessary human resources for installing and operating	Waste management operators, IoT experts
Possible pitfalls and problems	Sensor accuracy and durability in harsh conditions (e.g., construction sites), resistance to adoption due to initial costs or perceived complexity, data privacy concerns if integrated with third-party platforms
Technology readiness level (TRL)	4 - technology validated in lab

For TRL>4, where it has been already applied	NA
For TRL>1, who is the technology developer	RECONMATIC project

Table 43 PAS CZ-3

Possible applicable solution CZ-4	
Name	Blockchain
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	In the construction industry, blockchain technology can track materials, manage contracts, and ensure transparent project management. The system minimizes waste and increases transparency in the process.
Input raw data	Real-time production data, delivery schedules and transportation data, on-site requirements and consumption data
Other necessary/recommended digital objects	IoT sensors, integration with platforms, GPS tracking systems
Enabler of other possible applicable solutions	Can integrate with predictive analytics tools for demand forecasting, facilitates real-time decision-making across supply chain stakeholders
Output results	Optimized delivery schedules, reduced waste in supply and use, transparent logs for all supply chain transactions
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in material waste, increased efficiency and better resource management, improved transparency and improved trust among involved stakeholders, more sustainable supply chain
Necessary human resources for installing and operating	Blockchain developers, supply chain specialists to align the system with operational needs
Possible pitfalls and problems	Initial cost and complexity of implementation, potential data privacy concerns among stakeholders, resistance to adoption
Technology readiness level (TRL)	5 - Application nearing completion and field testing, indicating readiness for pilot deployment

For TRL>4, where it has been already applied	Blockchain-based concrete supply management solutions are nearing pilot deployment with testing in real-world environments led by the Greek branch of the RECONMATIC team. The application connects manufacturers, transporters, and construction sites in real-time to optimize concrete delivery and minimize waste. However, in the Czech Republic, the solution has not yet been widely adopted due to market resistance to the high level of transparency it introduces.
For TRL>1, who is the technology developer	NA

Table 44 PAS CZ-4

Possible applicable solution CZ-5	
Name	3D printing with recycled construction materials
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	It leverages additive manufacturing technologies to produce structures and components while reducing environmental impact. This method integrates 3D printing with the reuse of materials such as concrete, plastics, and metals recovered from demolition sites or industrial waste
Input raw data	Architectural and structural information, material composition, 3D models
Other necessary/recommended digital objects	3D printers, technologies to turn waste into recycled input
Enabler of other possible applicable solutions	Construction waste reuse
Output results	3D printed buildings and their components
Benefits expected in operation, especially emphasizing circular economy principles	Sustainability, cost efficiency, speed, local resource utilisation
Necessary human resources for installing and operating	Architects, engineers, technology experts, builders, building equipment operators

Possible pitfalls and problems	Material quality control, technology adaptation, structural integrity, logistical barriers, economic viability
Technology readiness level (TRL)	6 - technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
For TRL>4, where it has been already applied	Prvok 3D printed house
For TRL>1, who is the technology developer	NA

Table 45 PAS CZ-5

Possible applicable solution CZ-6	
Name	Machine learning models for SDO (Secondary Raw Material)
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Designed to identify mineral-based materials with high accuracy. These models are used as input for robotic sorting systems.
Input raw data	Data of waste particles, including size, texture, and material properties.
Other necessary/recommended digital objects	Imaging devices, spectrometers, robotic sorting hardware, database of material properties.
Enabler of other possible applicable solutions	Robotic sorting systems, real-time waste management solutions, supports circular economy initiatives by improving material recovery rates.
Output results	Recognition of mineral-based waste particles.
Benefits expected in operation, especially emphasizing circular economy principles	Faster waste sorting processes, increased material recovery.
Necessary human resources for installing and operating	Data scientists, machine learning engineers, robotic technicians, recycling operators.
Possible pitfalls and problems	Data quality requires high-quality training data to achieve accurate recognition; hardware integration poses challenges in integrating machine learning

	models with existing robotic sorting systems; scaling issues.
Technology readiness level (TRL)	4 - technology validated in lab
For TRL>4, where it has been already applied	Current use is limited to laboratory testing and validation phases.
For TRL>1, who is the technology developer	Developed by Associate Professor Václav Nežerka, leveraging advanced machine learning techniques for material identification.

Table 46 PAS CZ-6

Possible applicable solution CZ-7	
Name	Automation of the pre-demolition audit
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	Automation of the pre-demolition audit uses advanced technologies to streamline the assessment process required before demolishing a building. This audit identifies materials that can be reused, recycled, or safely disposed of, aligning demolition practices with sustainability and circular economy goals.
Input raw data	Material database, LCA, BIM, structural data
Other necessary/recommended digital objects	Material analysis software, auditing software
Enabler of other possible applicable solutions	BIM, laser scanning, material analysis, digital twin, scenario modelling
Output results	High efficiency and sustainability of the demolition process, major decrease in waste, increase in material reuse
Benefits expected in operation, especially emphasizing circular economy principles	Efficiency, accuracy, cost saving, sustainability, regulatory compliance
Necessary human resources for installing and operating	Audit experts, software experts, people on the ground during demolition

Possible pitfalls and problems	Upfront costs, standardisation, data integration, complexity with large buildings
Technology readiness level (TRL)	3 - experimental proof of concept
For TRL>4, where it has been already applied	NA
For TRL>1, who is the technology developer	RECONMATIC and CTU Prague are working on an automated pre-demolition audit, which will be connected to the PointCloud-to-BIM and Paper drawing-to-BIM processes. We expect this process to be completed in about a year. Currently only being developed, not yet applied, will be tested at CirkAréna project.

Table 47 PAS CZ-7

Possible applicable solution CZ-8	
Name	Digital building logbook
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	A Digital Building Logbook is an advanced, centralized repository for storing and managing all essential data related to a building throughout its lifecycle. It integrates information about design, construction, operation, maintenance, and even eventual demolition or repurposing. The logbook is a key enabler of data-driven decision-making in the building industry, contributing to efficiency, sustainability, and compliance.
Input raw data	Material data, supplier data, renovation logs, maintenance data, operative data
Other necessary/recommended digital objects	Cloud-based storing software, BIM data
Enabler of other possible applicable solutions	Cloud technologies, BIM, material reuse, pre-demolition audits, digital twins
Output results	Material passports, scenarios, predictions, end of life recommendations

Benefits expected in operation, especially emphasizing circular economy principles	Transparency, efficiency, sustainability, waste decrease, optimisation of resources, regulatory compliance, cost saving
Necessary human resources for installing and operating	Logbook experts, software experts, data analysts
Possible pitfalls and problems	Implementation costs, cybersecurity threats, data standardisation
Technology readiness level (TRL)	2 - technology concept formulated
For TRL>4, where it has been already applied	NA
For TRL>1, who is the technology developer	UCEEB Prague

Table 48 PAS CZ-8

Possible applicable solution CZ-9	
Name	Sensors for scanning materials
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Sensors for scanning materials play a vital role in the building industry by identifying, analysing, and monitoring materials in construction and demolition processes.
Input raw data	NA
Other necessary/recommended digital objects	Material database
Enabler of other possible applicable solutions	Digital logbooks, BIM
Output results	Improve efficiency, safety, and sustainability by providing real-time data about material properties, composition, and condition.
Benefits expected in operation, especially emphasizing circular economy principles	Non-destructive testing, hazardous material detection, energy efficiency, life cycle monitoring, improved safety, cost efficiency, precision, sustainability
Necessary human resources for installing and operating	Engineers, sensor experts

Possible pitfalls and problems	High complexity, integration issues, high initial costs
Technology readiness level (TRL)	6 - technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
For TRL>4, where it has been already applied	Companies like Redrock Construction s.r.o. specialize in the development and production of technological solutions in construction, which may include the use of advanced sensors for material analysis.
For TRL>1, who is the technology developer	NA

Table 49 PAS CZ-9

Possible applicable solution CZ-10	
Name	Digital tools for architectural competitions
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	A digital application designed to streamline the organization of architectural competitions. The tool enables comparison of competing designs, calculates resources needed for construction, and supports better decision-making by providing transparent and data-driven evaluations. Its goal is to make competitions more efficient while ensuring better resource management and improved project realization.
Input raw data	Competition entries, resource requirements for proposed designs, financial data, criteria for evaluation.
Other necessary/recommended digital objects	Databases for resource costs, project benchmarks, criteria for evaluating architectural designs.
Enabler of other possible applicable solutions	Can be integrated into project management systems, urban planning workflows, resource optimization tools.
Output results	Transparent evaluations of competition submissions, resource requirement breakdowns, optimized recommendations for project realization.

Benefits expected in operation, especially emphasizing circular economy principles	Improved resource management, efficient competition workflow simplifying the submission and evaluation process, enhanced transparency, potential for integration by linking to other project phases.
Necessary human resources for installing and operating	Competition organizers, architects, urban planners, IT professionals for system setup and maintenance
Possible pitfalls and problems	Resistance to change as stakeholders may hesitate to adopt a new digital approach due to established habits, usability concerns requiring the application to be intuitive and not create extra workload for participants, market perception challenges, as architectural competitions are not always seen as a high-priority area for digital innovation.
Technology readiness level (TRL)	4 - technology validated in lab
For TRL>4, where it has been already applied	Currently undergoing testing with experienced organizers in the architectural sector
For TRL>1, who is the technology developer	Developed by Urbiq

Table 50 PAS CZ-10

Possible applicable solution CZ-11	
Name	VR in architectural design and collaboration platform
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	VR enables immersive and interactive design, visualization, and collaboration in architecture and construction. It allows stakeholders to experience spaces and structures before they are built, VR supports sustainable practices by optimizing designs, reducing material waste, and improving construction efficiency.
Input raw data	3D architectural models, BIM data, CAD files, material specifications.

Other necessary/recommended digital objects	VR hardware, compatible computer systems, software for managing and visualizing VR environments. Integration with BIM and other data management tools.
Enabler of other possible applicable solutions	Supports digital twin technology, AI-driven design optimization, can be integrated with project management platforms for streamlined workflows.
Output results	Immersive visualizations of architectural designs, higher collaboration outcomes, reduced design errors, better communication among stakeholders, better prediction of resource use and therefore potential to use resources more sustainably.
Benefits expected in operation, especially emphasizing circular economy principles	VR allows for virtual prototyping, early detection of design flaws, designs can be iteratively evaluated for energy efficiency and resource use, increased understanding of project impacts through realistic simulations.
Necessary human resources for installing and operating	Architects, designers, construction engineers with knowledge of VR applications, IT professionals for hardware and software setup, project managers for integrating VR into workflows.
Possible pitfalls and problems	Costs for hardware, software, and training, learning curve, compatibility issues
Technology readiness level (TRL)	7 - system prototype demonstration in operational environment
For TRL>4, where it has been already applied	The platform has been utilized by students at the Faculty of Civil Engineering of the Czech Technical University in Prague for designing architecture in virtual reality.
For TRL>1, who is the technology developer	Developed by a team of architects in collaboration with the Czech Technical University. Here's the specific product.

Table 51 PAS CZ-11

Germany

Possible applicable solution DE-1	
Name	Concular Digital Resource Passports

Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Concular provides digital "resource passports" for buildings to catalogue materials and components used, enabling efficient material recovery and reuse. The system integrates with other circularity tools and databases for lifecycle assessment.
Input raw data	Product and material specifications, including lifecycle and environmental data.
Other necessary/recommended digital objects	Compatible with environmental product declarations and circularity assessments.
Enabler of other possible applicable solutions	Supports sustainable deconstruction and recycling practices.
Output results	Comprehensive material records for circular economy management.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces environmental footprint by enabling resource reuse and extending material lifecycle.
Necessary human resources for installing and operating	Facility managers, sustainability experts, and data entry operators.
Possible pitfalls and problems	Data management complexity and initial costs.
Technology readiness level (TRL)	6-7
For TRL>4, where it has been already applied	Applied in pilot projects like in Heidelberg's circular construction projects.
For TRL>1, who is the technology developer	Concular platform

Table 52 PAS DE-1

Possible applicable solution DE-2	
Name	Kewazo Smart Robotics for Scaffolding
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Kewazo employs robotics for scaffolding logistics in construction sites, reducing material waste and enhancing efficiency by optimizing the use and assembly of scaffolding materials.

Input raw data	Building and site layout, scaffolding material specifications.
Other necessary/recommended digital objects	IoT sensors for tracking material use and robot performance.
Enabler of other possible applicable solutions	Supports efficient material usage, reduces labor costs, and integrates with site management tools.
Output results	Robotic optimization of scaffolding deployment.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces material waste, increases worker safety, and lowers overall project costs.
Necessary human resources for installing and operating	Robotics operator, technician for setup and ongoing support.
Possible pitfalls and problems	High initial setup cost and limited adaptability to highly variable site conditions.
Technology readiness level (TRL)	7 – currently tested on construction sites across Germany
For TRL>4, where it has been already applied	Pilot implementations in major German cities.
For TRL>1, who is the technology developer	KEWAZO

Table 53 PAS DE-2

Possible applicable solution DE-3	
Name	Züblin Circular Construction & Recycling Hub (C3) Digital System
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility, and interoperability
Description of the applicable solution	Züblin's digital framework supports the C3 Circular Construction Centre in Bremen by cataloguing and tracking construction and demolition materials, ensuring high-quality recycling into secondary raw materials. The system integrates with smart material databases and urban mining platforms, providing real-time lifecycle assessments and enabling efficient reuse in construction processes.
Input raw data	Composition and source data for demolition waste, environmental metrics of materials, and data on recovered material properties.

Other necessary/recommended digital objects	Environmental Product Declarations (EPDs), GIS integration for regional material flows, and BIM for lifecycle mapping.
Enabler of other possible applicable solutions	Facilitates sustainable building design, deconstruction practices, and regional circular economy networks by providing a blueprint for other recycling hubs.
Output results	Detailed reports on material usability, quality, and potential applications; data visualization for decision-makers; and insights into lifecycle impacts of construction materials.
Benefits expected in operation, especially emphasizing circular economy principles	Drastically reduces landfill dependency and raw material extraction. Supports the development of high-value secondary materials for future projects. Promotes sustainability across the regional construction ecosystem.
Necessary human resources for installing and operating	Circular economy specialists, software developers, material scientists, and operators skilled in digital construction technologies.
Possible pitfalls and problems	Initial setup and integration costs. Data standardization and interoperability challenges across regions.
Technology readiness level (TRL)	6-7 (Demonstrated in the C3 operational environment with ongoing R&D to enhance material separation and digital integration).
For TRL>4, where it has been already applied	The system is operational in the C3 Circular Construction Centre, serving as a model for urban mining and recycling facilities in Germany and beyond.
For TRL>1, who is the technology developer	Züblin, in collaboration with Strabag SE and academic institutions like the University of Stuttgart

Table 54 PAS DE-3

Possible applicable solution DE-4	
Name	Schüco modular building facades with digital support
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility, and interoperability

Description of the applicable solution	Schüco develops modular building facades designed for material reuse and recycling. Their digital tools allow tracking and managing facade elements across their lifecycle, ensuring that materials can be disassembled and reused.
Input raw data	Material specifications, building design data.
Other necessary/recommended digital objects	Digital twin of the building facade, material passports.
Enabler of other possible applicable solutions	Supports long-term maintenance planning, facilitates component reuse, and reduces environmental impact.
Output results	Building components that are easily repurposable, detailed data on material composition.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces waste by enabling facade recycling and material recovery, lowers lifecycle costs, and decreases resource consumption.
Necessary human resources for installing and operating	Skilled technicians for digital twin management, engineers for facade installation.
Possible pitfalls and problems	High upfront costs and complexity in integrating the digital twin across all stages.
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Multiple projects across Germany and Europe.
For TRL>1, who is the technology developer	Schüco International KG, Germany.

Table 55 PAS DE-4

Possible applicable solution DE-5	
Name	PERI digital formwork
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	PERI has developed digital formwork solutions and uses RFID and IoT technologies to track materials, reducing waste in concrete formwork and enhancing material reuse through precise planning and monitoring.

Input raw data	Formwork usage data, construction site layout.
Other necessary/recommended digital objects	RFID tags, IoT sensors for tracking formwork life cycles.
Enabler of other possible applicable solutions	Optimizes resource allocation on-site, supports accurate demand planning, and reduces material loss.
Output results	Real-time usage data, insights for resource management, and end-of-life tracking for formwork materials.
Benefits expected in operation, especially emphasizing circular economy principles	Decreased formwork waste, extended material lifespan, and cost savings.
Necessary human resources for installing and operating	Site managers, skilled IoT technicians.
Possible pitfalls and problems	Sensor maintenance requirements and initial deployment costs.
Technology readiness level (TRL)	8 – Pilot-tested in German construction sites.
For TRL>4, where it has been already applied	Various pilot projects in Germany.
For TRL>1, who is the technology developer	PERI GmbH, Germany.

Table 56 PAS DE-5

Possible applicable solution DE-6	
Name	Xella digital platform for managing building materials recycling
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Xella Group employs a digital platform to track and manage the recycling of building materials like concrete and insulation. Their system supports efficient use of materials, reducing waste and enabling a circular economy within construction. The Xella Group offers sustainable and innovative

	building materials, insulation materials, and services in relation to the building envelope.
Input raw data	Site material data, composition of demolition waste.
Other necessary/recommended digital objects	Building information modelling (BIM) for real-time material tracking.
Enabler of other possible applicable solutions	Contributes to sustainable material sourcing, reduces raw material dependency.
Output results	Recyclable construction materials, data on material composition and recyclability.
Benefits expected in operation, especially emphasizing circular economy principles	Enhances resource efficiency, supports circular material flows, and reduces carbon footprint.
Necessary human resources for installing and operating	Material management personnel, technicians familiar with BIM.
Possible pitfalls and problems	Recycling limitations for some materials and variability in material quality.
Technology readiness level (TRL)	7 – implemented in several sites.
For TRL>4, where it has been already applied	Active in multiple sites across Germany.
For TRL>1, who is the technology developer	Xella Group, Germany.

Table 57 PAS DE-6

Possible applicable solution DE-7	
Name	Energiecontrolling by N+P
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	Provides energy monitoring and data analysis for construction and operational sites, tracking energy usage across utilities (electricity, water, gas, heat).

Input raw data	Energy consumption data from site meters.
Other necessary/recommended digital objects	IoT-enabled meters, data analysis software.
Enabler of other possible applicable solutions	Allows energy efficiency optimizations and predictive maintenance.
Output results	Resource consumption breakdown by location and period.
Benefits expected in operation, especially emphasizing circular economy principles	Reduced resource consumption, enhanced sustainability, and compliance with environmental standards.
Necessary human resources for installing and operating	Facility managers, energy analysts.
Possible pitfalls and problems	Initial setup complexity and data accuracy challenges.
Technology readiness level (TRL)	7 - Real-world implementations
For TRL>4, where it has been already applied	Various industrial and commercial buildings in Germany.
For TRL>1, who is the technology developer	N+P Informationssysteme GmbH.

Table 58 PAS DE-7

Possible applicable solution DE-8	
Name	Circular Berlin – Haus der Materialisierung
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Haus der Materialisierung is a hub in Berlin supporting the reuse of secondary materials through innovative projects and research. It includes a digital inventory system for material availability and an exchange marketplace.
Input raw data	Information on material origin, quality, and current usability.
Other necessary/recommended digital objects	Open-source inventory and monitoring tools.

Enabler of other possible applicable solutions	Facilitates collaborative reuse efforts among designers, builders, and researchers.
Output results	An optimized framework for reusing secondary materials in construction and other sectors.
Benefits expected in operation, especially emphasizing circular economy principles	Increased recycling rates, lower environmental impact, and reduced raw material dependency.
Necessary human resources for installing and operating	Researchers, material suppliers, and sustainability advocates.
Possible pitfalls and problems	Dependency on active user participation and data accuracy.
Technology readiness level (TRL)	5-6
For TRL>4, where it has been already applied	Localized in Berlin but expandable as a model for other urban areas.
For TRL>1, who is the technology developer	Circular Berlin.

Table 59 PAS DE-8

Possible applicable solution DE-9	
Name	Restado – Reuse Marketplace
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility, and interoperability
Description of the applicable solution	Restado is an online marketplace dedicated to connecting sellers and buyers of surplus and used building materials. It fosters the reuse of materials that would otherwise become waste, thereby promoting sustainability and reducing costs.
Input raw data	Listings of construction materials with details on type, dimensions, condition, and location.
Other necessary/recommended digital objects	Cloud-based platform for hosting listings and user accounts.
Enabler of other possible applicable solutions	Facilitates cost-effective sourcing of materials for eco-friendly construction projects.
Output results	Matched buyers and sellers of second-hand construction materials.

Benefits expected in operation, especially emphasizing circular economy principles	Reduces construction waste, saves resources, and provides a cost-efficient alternative to purchasing new materials.
Necessary human resources for installing and operating	Platform developers, customer support, and sustainability consultants.
Possible pitfalls and problems	Quality assurance of listed materials and limited geographic availability.
Technology readiness level (TRL)	6-7
For TRL>4, where it has been already applied	Active across Germany, Restado serves construction companies and individuals seeking affordable, sustainable materials.
For TRL>1, who is the technology developer	Restado GmbH.

Table 60 PAS DE-9

Possible applicable solution DE-10	
Name	Madaster Platform
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability (Material Passporting)
Description of the applicable solution	Madaster is a digital platform that creates "material passports" for buildings, recording detailed information about materials and products used within the structure. This database allows for better tracking and reuse of materials at the end of a building's life cycle, facilitating the transition from traditional wasteful demolition to a sustainable circular process.
Input raw data	Data on construction materials, including type, quantity, and condition.
Other necessary/recommended digital objects	Cloud storage for scalable database access.
Enabler of other possible applicable solutions	Supports sustainable construction and recycling by aiding the identification and tracking of recyclable materials.

Output results	Detailed material passport with material quality, location, and recyclability information.
Benefits expected in operation, especially emphasizing circular economy principles	Supports resource conservation, enhances recyclability, and lowers costs related to new material sourcing.
Necessary human resources for installing and operating	Building owners, facility managers, and technical specialists for platform maintenance.
Possible pitfalls and problems	Requires comprehensive data entry and initial costs.
Technology readiness level (TRL)	Technology Readiness Level (TRL): 6-7
For TRL>4, where it has been already applied	Used across various construction projects in Germany for sustainable material management.
For TRL>1, who is the technology developer	Madaster Foundation.

Table 61 PAS DE-10

Possible applicable solution DE-11	
Name	International Circular Construction Cluster (ICCC)
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display data.
Description of the applicable solution	ICCC is an international collaborative platform that promotes circular construction practices. It focuses on the reuse of building materials, integrating BIM (Building Information Modeling) technologies, and implementing renewable materials and innovative business models. The platform connects stakeholders across industries to share knowledge, solutions, and tools for transitioning to sustainable construction practices.
Input raw data	Data on material lifecycles, waste streams, and construction resources (e.g., volumes, properties, and reuse potential).
Other necessary/recommended digital objects	BIM databases, digital twins, and material tracking systems.
Enabler of other possible applicable solutions	Facilitates collaboration between companies, policymakers, and researchers to develop scalable and innovative circular economy solutions.

Output results	Reports on material efficiency, waste reduction strategies, and optimized design recommendations.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in construction waste, improved resource efficiency, and a shift towards sustainable building practices.
Necessary human resources for installing and operating	Architects, engineers, construction project managers, data analysts, and sustainability experts.
Possible pitfalls and problems	High initial cost for platform integration, data standardization challenges, and the need for widespread stakeholder buy-in.
Technology readiness level (TRL)	6-7 (Demonstrated in a relevant environment and ready for prototype testing in operational settings).
For TRL>4, where it has been already applied	Used in pilot projects and international collaborations for sustainable construction practices.
For TRL>1, who is the technology developer	A collaborative network of industry and academic partners.

Table 62 PAS DE-11

Croatia

Possible applicable solution HR-1	
Name	Estimation of parameters of heating/cooling actuators in building zones
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	This application estimates parameters of models of building heating/cooling actuators that relate their input medium temperature, local room air temperature and actuator actuation with thermal power that is exerted from the actuator to the room air. It requires regular data from controllers in building zones and measurements from a common duct performed by a calorimeter.
Input raw data	Data from zone controllers (temperature and controller actuations), common duct calorimeter power measurements and duct starting temperature
Other necessary/recommended digital objects	Building operation database is recommended

Enabler of other possible applicable solutions	Estimation of parameters of building thermodynamic models (solutions of category b.ii.1, e.g. solution HR-7); Predicting heat disturbances in building zones (b.ii.2), Suggesting equipment faults (b.ii.2), Monitoring equipment performance (combination of b.ii.1 and b.i), Graphical representation to building operators how much thermal power each room consumes (combination of b.ii.1 and b.i), Smart building operation software (d)
Output results	Parameters of heating/cooling actuators that relate heating/cooling power to common duct starting temperature, actuator actuation and room temperature
Benefits expected in operation, especially emphasizing circular economy principles	Estimation procedure requires small amount of sensors and thus has low installation costs, and also contributes to reduction of electronic waste in long term endeavour to raise smartness of the buildings stock, while it enables: (I.) determining of thermodynamic model of a building that serves for optimal management of the building and informed renovation decision making, (II.) actuators faults detection, (III.) informed monitoring of building current power consumption and cumulative energy consumption on the rooms level
Necessary human resources for installing and operating	Currently skilled expert required for installing, with further development it is expected to be plug-and-play for installing, no human needed for operating
Possible pitfalls and problems	Requires a calorimeter to be installed on a common duct, requires collected historical data, i.e. results are not immediate. Stationary conditions on the duct system should be established for a data sample to be valid which may reduce the amount of valid data for identification.
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	King ICT building, Buzinski prilaz, Buzin, Croatia
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 63 PAS HR-1

Possible applicable solution HR-2	
Name	IoT sensors in buildings and construction -- easily configurable plug-in sensors for joint monitoring of temperature, relative humidity, CO2 concentration (air freshness) and air pressure in individual buildings zones
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Collection of data from the building
Input raw data	None, the sensors actually generate the input data
Other necessary/recommended digital objects	Properly formatted database where the measurements are collected for further analysis and software modules for further processing or data display that sit behind the database
Enabler of other possible applicable solutions	Graphical data display to users with raw data or basic statistics for the raw data such that the building can be monitored (solutions category b.i); Different analyses for finding possible energy inefficient behaviour or data processing to compute models of building elements (b.ii.1); Alignment of the existing building model in its specific parameters with the actual building behaviour (b.ii.1)
Output results	Sequence of measurement data from individual rooms
Benefits expected in operation, especially emphasizing circular economy principles	Reduction of energy waste by enabling detection of energy inefficient operation and/or faulty equipment, Enabler of digital technologies for smart buildings energy management that reduces operation costs and makes buildings flexible prosumers on energy grids which enlarges the share of green energy integrated
Necessary human resources for installing and operating	Requires experts to enable data communication and gathering in order to make the sole measurements useful

Possible pitfalls and problems	Sensory equipment requires maintenance which becomes a significant work when their number is large; Those remote ones that are not grid-supplied also require periodic batteries replacement if they are not harvesting energy from the environment; Sensors themselves without a database and proper data processing in majority of cases do not make any contribution to energy and cost efficiency such that data collection must be established and managed as well
Technology readiness level (TRL)	9, but new sensing technologies continuously in development
For TRL>4, where it has been already applied	In many buildings, e.g. the City of Zagreb performed already several such installations in its own public buildings, UNIZG-FER skyscraper building in Zagreb had such sensory equipment installed on two floors to examine possibilities for energy management with their use
For TRL>1, who is the technology developer	E.g. Didactum Security Gmbh – product Multisensor ZBS-122 Full

Table 64 PAS HR-2

Possible applicable solution HR-3	
Name	Low-power wireless communication LoRa
Solution category (from the Existing knowledge)	a.ii. Sensing data communication
Description of the applicable solution	Low-power data communication that enables to communicate data from devices on remote locations with challenging communication conditions (e.g. underground, in reinforced concrete etc.)
Input raw data	Sensory data
Other necessary/recommended digital objects	Database for storing the communicated data
Enabler of other possible applicable solutions	Management of highly distributed infrastructure like utility grids with utility meters and distanced sensors for specific variables or a large construction site

Output results	Data delivered to a central computer with implemented database
Benefits expected in operation, especially emphasizing circular economy principles	Enabled smart operations with real-time data from the infrastructure or construction site
Necessary human resources for installing and operating	Experts should perform the installation of base stations and remote communication units on end-devices
Possible pitfalls and problems	Significant number of base stations are needed to cover data collection from underground points or points with some reinforced concrete surroundings
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	City of Zagreb has tested it on a smaller scale with satisfactory behaviour assessed and currently its widening to the whole city area is considered
For TRL>1, who is the technology developer	Lora Alliance gathers more than 50 manufacturers around the world who develop devices compatible with the LoRa protocol

Table 65 PAS HR-3

Possible applicable solution HR-4	
Name	Building operation database with underlying data organisation that allows efficient data access for processing and preview based on PostgreSQL
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Building operation database developed through installation of databases on approximately 10 buildings across the Danube region, started with the Interreg Danube 3Smart project in period 2017-19. A skeleton is built for further replication, with achieved scalability, fast and reliable real-time data fetching, and rational memory usage for historical data
Input raw data	Data communicated from sensors, building automation system and web services like weather forecast or interface of the grid operators

Other necessary/recommended digital objects	Sensors and controllers from the building automation system, weather stations and communication network with communication controllers from one side (subcategories a.i and a.ii); plethora of software modules that process data in the database in various ways (subcategories b.i, b.ii, b.iii)
Enabler of other possible applicable solutions	Practically central digital enabler of all smart digital solutions in buildings or on construction sites
Output results	Systematically stored raw data and also processed data through various software modules
Benefits expected in operation, especially emphasizing circular economy principles	The building database opens plethora of efficiency possibilities related to digital technologies (categories c and d)
Necessary human resources for installing and operating	IT expert is usually needed to set-up the database
Possible pitfalls and problems	Connecting different databases or using software developed for one database with some other may often pose incompatibility and data inconsistency problems -- for that reason there is a high need to closely follow standards which should be on the other hand broad enough to cover multiple needs
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing skyscraper building – five years of continuous and reliable operation directly on top of the building automation system and interfacing numerous data processing and optimization procedures for smart building operation, other instances were implemented for data collection at the following sites: Klimaoprema building in Gradna near Samobor, Croatia; King ICT building in Buzin, Croatia; primary school in Strem, Austria; retirement care centre in Strem, Austria; Elektroprivreda HZHB building in Tomislavgrad, Bosnia and Herzegovina, EON grid operator building in Debrecen, Hungary
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 66 PAS HR-4

Possible applicable solution HR-5	
Name	PlanRadar: Construction, Facility Management & Real Estate Platform
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Software platform for digital documentation, communication & reporting in construction, facility management and real estate
Input raw data	Digital construction site project in a BIM-compatible form, integrates data from other platforms used for scheduling and file sharing like Office 365 (Outlook, Sharepoint, etc.)
Other necessary/recommended digital objects	Digital construction plans in a BIM-compatible form
Enabler of other possible applicable solutions	Site construction diaries, Subcontractor task management & communication, Inspections, checklists & safety audits, Defect management & snagging, Handovers, Evidence collection & claims management
Output results	Coordination of a complex set of actors within the construction company and its subcontractors in the construction site, digital reports that can be taken from one part of building lifecycle to the other -- e.g. from construction to usage
Benefits expected in operation, especially emphasizing circular economy principles	Reduced consumption of materials and time, less waste generated on the construction site, easy and completely digital data takeover from one building lifecycle part to the other
Necessary human resources for installing and operating	Quick start-up for using, intuitive and adaptable to different existing workflows of construction companies

Possible pitfalls and problems	The software is meant for digital documentation and logging while it does not offer back-end engines for optimization of specific construction operation as decision support for end-users, though it is a very complex and sensitive field, and it is questionable whether construction companies are willing to explore optimized process compared to their business as usual operation
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Construction company Kamgrad, Construction engineering institute IGH, and others
For TRL>1, who is the technology developer	PlanRadar company, with headquarters in Vienna

Table 67 PAS HR-5

Possible applicable solution HR-6	
Name	Computing and showing statistics on energy use and comfort conditions in buildings with Plotly package in Python
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	Free graphical display solution for data taken from databases
Input raw data	Data series with timestamps in various formats
Other necessary/recommended digital objects	Database with real-time access capability
Enabler of other possible applicable solutions	Various monitoring applications where graphical presentation is important for intuitive interaction with end-users
Output results	Graphical displays of real-time data trends and its related statistics
Benefits expected in operation, especially emphasizing circular economy principles	Operators are concisely informed about the current system state which makes their monitoring more efficient, leading to savings in energy, water and materials

Necessary human resources for installing and operating	After the database is built with known data fetching procedure an IT expert experienced in Python programming and SCADA is necessary to effectively build up the runtime visual environment of Plotly
Possible pitfalls and problems	Data in the database must be consistent and verified to make the graphical representation informative for monitoring
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing skyscraper building, on top of the PostgreSQL database for predictive building management and control
For TRL>1, who is the technology developer	Plotly software company, with headquarters in Montreal, Canada

Table 68 PAS HR-6

Possible applicable solution HR-7	
Name	Estimation of parameters of a building thermodynamic model
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Creation of simplified dynamic building models on the zone level which resemble temperature behaviour on granular time scales within a day and thus enable monitoring and predictive control of heating and cooling processes in buildings
Input raw data	Recorded transients of temperatures merged with weather data and data of room comfort controllers operation, with models of room actuators obtained as output of the solution HR-1
Other necessary/recommended digital objects	Building operation database (e.g. solution HR-4)

Enabler of other possible applicable solutions	Estimation of heat disturbances, of people present in zones (HR-8) or windows opening state (HR-9), smart building management and control
Output results	Simple thermodynamic models of different heated/cooled parts of the building
Benefits expected in operation, especially emphasizing circular economy principles	Possibility to assess building operation with predictive control that gives an accurate estimate of the achievable benefits, use of models further in monitoring and predictive building management and control for a considerable reduction of energy use and costs, unleashing also demand response abilities of the building in support to rise of green energy share in the energy systems
Necessary human resources for installing and operating	Expert support needed
Possible pitfalls and problems	Data needs to be collected for a considerable period of time (several weeks) to get the necessary data informativeness for identification of the thermodynamic models of rooms
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing skyscraper building -- identified all 248 controllable zones based on collected several weeks of data
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 69 PAS HR-7

Possible applicable solution HR-8	
Name	Estimation of the number of people present in building zones and heat/CO2 disturbances
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights

Description of the applicable solution	Software solution for on-line estimation of the number of people and heat disturbance from people and equipment in the room based on temperature and CO_2 data series combined together with identified simplified building thermodynamic models (solution HR-7)
Input raw data	Data from temperature (and CO_2 sensors, if exist), data on zone controllers actuation
Other necessary/recommended digital objects	Building operational database (HR-4), room thermodynamic models (HR-7) and models of zone thermal actuators (HR-1)
Enabler of other possible applicable solutions	Data series on the number of building users present in building zones enables to have precise data on building usage and heat/CO_2 disturbances for the purposes of prediction for on-line management as well as precise assessment of benefits achievable through smart building operation
Output results	Data series on the estimated number of building users and heat/CO_2 disturbances present in building zones
Benefits expected in operation, especially emphasizing circular economy principles	Reduction of energy use through predictive building control relied on this data, Enabling better decisions on management of space usage in buildings which can bring significant additional savings in energy and energy cost, and potentially also increase building flexibility for demand response
Necessary human resources for installing and operating	Expert is needed for putting the estimation into operation, after other necessary digital objects are present
Possible pitfalls and problems	The estimation procedures relies on well-functioning sensors such that the set of sensors of buildings needs to be maintained to obtain a good accuracy in estimation
Technology readiness level (TRL)	3
For TRL>4, where it has been already applied	-
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 70 PAS HR-8

Possible applicable solution HR-9	
Name	Estimation of windows opening conditions
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Software solution for on-line estimation of the windows opening condition in the room based on temperature and CO2 data series combined together with identified simplified building thermodynamic models (solution HR-7)
Input raw data	Data from temperature (and CO2 sensors, if exist), data on zone controllers actuation
Other necessary/recommended digital objects	Building operational database (HR-4), room thermodynamic models (HR-7) and models of zone thermal actuators (HR-1)
Enabler of other possible applicable solutions	Data series on the windows opening conditions in building zones enables to detect energy inefficient practices and use the information to stop heating/cooling as with hard-wired sensors for windows opening
Output results	Data series on the windows opening conditions in building zones
Benefits expected in operation, especially emphasizing circular economy principles	Reduction of energy use through predictive building control relied on this data, Reduction of energy inefficient practices in building usage by turning the heating/cooling actuators off when building windows are detected to be open
Necessary human resources for installing and operating	Expert is needed for putting the estimation into operation, after other necessary digital objects are present
Possible pitfalls and problems	The estimation procedures relies on well functioning sensors such that the set of sensors of buildings needs to be maintained to obtain a good accuracy in estimation
Technology readiness level (TRL)	3

For TRL>4, where it has been already applied	**-**
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 71 PAS HR-9

Possible applicable solution HR-10	
Name	Suggesting air congestion faults for fan coils
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Detecting fan coil air congestion based on measured return temperature from the fan coil
Input raw data	Measurement of the return medium temperature from the fan coil and measurement of the starting medium temperature on the heat supply duct
Other necessary/recommended digital objects	Building operation database
Enabler of other possible applicable solutions	Graphical representation of fan coils faults for easier monitoring and building maintenance
Output results	Detected air-congested fan coils
Benefits expected in operation, especially emphasizing circular economy principles	Increased comfort in building usage, especially in spring-summer and autumn-winter turnover periods where often fan coils can be congested with air
Necessary human resources for installing and operating	If database exists with available return medium temperature sensors, the software upgrade is relatively easy, but should be done by an expert
Possible pitfalls and problems	Requires return medium sensors on fan coils which are expensive in terms of workforce needed for the installation
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing, skyscraper building
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing (the solution is patented in Croatia)

Table 72 PAS HR-10

Possible applicable solution HR-11	
Name	Predicting micro-climate conditions from weather forecast and local measurements
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables
Description of the applicable solution	Weather forecast when applied to local microclimate conditions of a building or a construction site may induce a significant error and lead to wrong decision making -- thus the idea is to use local measurements coupled with past weather forecasts to build weather forecast corrector for the site that provides accurate nowcasting and a gradual transition to the weather forecast results in time instants further in the future
Input raw data	Weather forecast, local weather measurements (various data can be present, e.g. temperature, solar irradiance, wind pressure, humidity, and their various subsets used)
Other necessary/recommended digital objects	Database of measurements and weather forecasts
Enabler of other possible applicable solutions	Smart predictive management of a building or a construction site, based on precise nowcasting
Output results	Corrected weather forecast with anticipated local measurements and forecasting errors done in the past in similar conditions
Benefits expected in operation, especially emphasizing circular economy principles	More efficient short-term decision that improves the effectiveness of resources use in the building or on the construction site
Necessary human resources for installing and operating	Machine learning expert is needed to put the solution into operation
Possible pitfalls and problems	The data must undergo a machine learning procedure which significantly depends on data quality and its informativeness
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing skyscraper building, weather sensors

	for agriculture purposes in various points across Croatia
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 73 PAS HR-11

Possible applicable solution HR-12	
Name	Predicting heat disturbances in buildings zones
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables
Description of the applicable solution	Persons and equipment present in the building space are additional heat sources that significantly influence the comfort conditions in the building and machine learning procedures are used to predict the future influence of building use on the comfort conditions such that it can be exploited for optimal predictive operation of the building
Input raw data	Estimated heat disturbances in building zones and possibly other variables
Other necessary/recommended digital objects	Building operation database (HR-4), Heat disturbances estimator (HR-8)
Enabler of other possible applicable solutions	Predictive building management and control
Output results	Predicted heat disturbances in building zones
Benefits expected in operation, especially emphasizing circular economy principles	Gains in operation (less energy use and cost) achieved via accurate prediction of building usage by capitalizing it through predictive building control
Necessary human resources for installing and operating	Expert needed for installation
Possible pitfalls and problems	Machine learning procedures involved to create prediction models strongly depend on data integrity and accuracy -- thus the building sensory set must be maintained
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing skyscraper building

For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 74 PAS HR-12

Possible applicable solution HR-13	
Name	Predicting energy consumption of a specific set of loads in a building
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables
Description of the applicable solution	Energy consumption of lighting or different equipment that is not managed but more or less at-will used by humans constitutes a significant portion of the overall consumption and should be predicted for optimal total signature on the billing meters. The solution is meant for prediction of data series of energy consumption of a specific set of loads
Input raw data	Past energy consumption of the loads -- these data can be also indirectly obtained from some other measured consumptions and the measured total site consumption on the billing meter
Other necessary/recommended digital objects	Building operation database (HR-4)
Enabler of other possible applicable solutions	Predictive energy management of the site
Output results	Predicted time series of energy consumption of a specific set of loads
Benefits expected in operation, especially emphasizing circular economy principles	Reduced energy cost and improved accuracy in site energy consumption flexibility which increases share of renewable energy in the energy grid
Necessary human resources for installing and operating	IT and energy expert
Possible pitfalls and problems	Predictions reside on the assumption of repetitive operation compared to patterns seen in the past, if there is a change in human behaviour the prediction will have errors for some time before the machine learning procedure adapts to the newly emerged behaviour

Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	University of Zagreb Faculty of Electrical Engineering and Computing skyscraper building
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 75 PAS HR-13

Possible applicable solution HR-14	
Name	Suggesting the day-ahead setup for preparation of the heating/cooling medium for a set of heat users (rooms/buildings/districts)
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Starting medium temperature determines the amount of thermal power that can be delivered to heat users, but with raising power capacity also the losses that incur along the heat duct are raised. Thus the starting medium temperature must be set on a proper level to assure heat delivery under minimized losses and this can be done via a decision support system
Input raw data	Predicted heating needs of heat consumers (zones or buildings or city districts), utility pricing schemes and states of heat storages
Other necessary/recommended digital objects	More comfortable use requires a database from which the data is sourced, but for the advice issued once a day the data entry can be also performed manually into the software solution
Enabler of other possible applicable solutions	Management of primary energy supply for the heat production
Output results	Suggestions for the building operator to set the operation of the heat/cold production system
Benefits expected in operation, especially emphasizing circular economy principles	Reduced heat losses in ducts for heat/cold delivery
Necessary human resources for installing and operating	An application can be tailored for a specific system and then the operator can use it day by day

Possible pitfalls and problems	The actual heat consumption may differ from predictions during the execution of the suggestions which will require a re-computation or a local automation system that triggers to rectify the situation when the discrepancy compared to the plan arises
Technology readiness level (TRL)	3
For TRL>4, where it has been already applied	-
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 76 PAS HR-14

Possible applicable solution HR-15	
Name	Suggesting the operation sequence of the lifting crane on the construction site
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	The digital solution should compute and suggest the sequence of lifting operations to the lifting crane operator based on the issued lifting requirements on the construction site
Input raw data	Lifting requirements
Other necessary/recommended digital objects	On-line application and communication infrastructure on the construction site
Enabler of other possible applicable solutions	Management of robotic operations in specific parts of the construction site
Output results	Suggestion of a sequence of future lifting crane actions
Benefits expected in operation, especially emphasizing circular economy principles	Reduced energy consumption of the lifting crane on the site, raised effectiveness of the construction operations in different parts of the site
Necessary human resources for installing and operating	It should be an application ran by the lifting crane operator with established wireless communication with different parts of the construction site that pose lifting requirements

Possible pitfalls and problems	Potential change of the standard construction sites practices to which the workers are well used to
Technology readiness level (TRL)	1
For TRL>4, where it has been already applied	-
For TRL>1, who is the technology developer	-

Table 77 PAS HR-15

Possible applicable solution HR-16	
Name	Using Google maps navigation to efficiently transport construction material to a construction site
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Route of transport is given to the user and he is step by step guided to reach the destination
Input raw data	Required target destination; initial destination is read out from the GPS of the device
Other necessary/recommended digital objects	-
Enabler of other possible applicable solutions	Autonomous transport of construction materials to the construction site
Output results	Route for transport and step-by-step guiding instructions
Benefits expected in operation, especially emphasizing circular economy principles	Reduced CO2 impact of material transport to the construction site as the drivers are directed through less congested routes and also there are no lost-driver situations
Necessary human resources for installing and operating	None
Possible pitfalls and problems	Distraction during driving, often changing available routes for vehicles around bigger construction sites that are not updated in the Google maps app
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	It is applied widely already now

For TRL>1, who is the technology developer	Google

Table 78 PAS HR-16

Possible applicable solution HR-17	
Name	Building comfort variables and energy consumption simulation software IDA ICE
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	Software for running simulations of building operation for a specific building design
Input raw data	Building specifications in a digital form, potentially BIM-compatible or data can be entered manually from drawings and on-site measurements (if the building exists)
Other necessary/recommended digital objects	Building specification in a digital form, software that can easily render new digital description for the simulator if some parameter for the design is changed
Enabler of other possible applicable solutions	Identification of simplified building rooms models (HR-7) to assess the optimal building operation based on exhibited simulation data
Output results	Simulations of different building variables (temperature, humidity, air freshness) for specific environmental and building usage boundary conditions, with analysis of exhibited energy consumption and comfort
Benefits expected in operation, especially emphasizing circular economy principles	Enables to bridge the building design specifications towards the building operation optimization, opening up significant possibilities in joint optimization of the design and the operation of the building with significant savings induced for the whole building lifecycle
Necessary human resources for installing and operating	Expert user in building simulation
Possible pitfalls and problems	Simulations may be time-consuming
Technology readiness level (TRL)	9

For TRL>4, where it has been already applied	In Croatia, model of the skyscraper building of the University of Zagreb Faculty of Electrical Engineering and Computing has been created and simulated by using this software
For TRL>1, who is the technology developer	Equa Simulation AB, with headquarters in Stockholm, Sweden

Table 79 PAS HR-17

Possible applicable solution HR-18	
Name	MGIPU Energetski certifikator – software for energy certification of buildings issued by the Ministry of construction and physical planning of the Republic of Croatia
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	Software for computation of heating and cooling energy requirements for the building and of primary energy requirements based on the installed thermo-technical and energy systems in the building with data export to a digital building certificate
Input raw data	Building construction data and data on its thermo-technical and energy systems
Other necessary/recommended digital objects	Database
Enabler of other possible applicable solutions	Certified buildings stock database
Output results	Energy consumption data for a specific building design and data for energy certificates
Benefits expected in operation, especially emphasizing circular economy principles	Effects of different building design decisions on energy consumption can be tested
Necessary human resources for installing and operating	Qualified energy auditors can use the software without any external support
Possible pitfalls and problems	Energy consumption is assessed with very simplified profiles of building usage, and the effect of smart building control on performance is not taken into account

Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Applied by energy auditors to compute data for energy certificates of a large number of buildings since 2017
For TRL>1, who is the technology developer	University of Zagreb Faculty of Organization and Informatics

Table 80 PAS HR-18

Possible applicable solution HR-19	
Name	3Smart building operation software
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Software for predictive control and management of heating/cooling processes in buildings and of major building energy storages
Input raw data	Data from building zones and central heating/cooling medium preparation acquired through the regular building automation system on top of which this software is leaned, data from energy meters, data from the weather station and the weather forecast service
Other necessary/recommended digital objects	Basic/classical building automation system with which a reliable interaction is ensured such that the comfort of the building users can be never threatened due to some issues in communication with the building operation database or due to some computational delays or errors, Building operation database (HR-4), Various applications of estimation, prediction and optimization that use the data from the database (e.g. HR-7, HR-8, HR-9, HR-11, HR-12, HR-13) and provide the data back to the database
Enabler of other possible applicable solutions	Aggregation of buildings in a large flexibility provider
Output results	Commands towards heating/cooling actuators, towards the central heating/cooling medium preparation plant and towards energy storages computed by a predictive control algorithm

Benefits expected in operation, especially emphasizing circular economy principles	Significant reduction of energy consumption and energy costs, induced building operation as a flexible consumer that can provide demand response service and increase the potential for integration of renewable energy in the energy system
Necessary human resources for installing and operating	IT and building automation experts
Possible pitfalls and problems	The system relies on availability of data from sensors such that the sensory data must be maintained; the correct operation of the building operation database should be monitored as well
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Skyscraper building of the University of Zagreb Faculty of Electrical Engineering and Computing
For TRL>1, who is the technology developer	University of Zagreb Faculty of Electrical Engineering and Computing

Table 81 PAS HR-19

Possible applicable solution HR-20	
Name	Autonomous transport of the construction material within the construction site
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Autonomous vehicles distribute the construction material along the construction site, operated jointly with an autonomous crane and drones
Input raw data	Digital operational plans for a particular day in which needed quantities of material are specified, and these are updated continuously as the work progresses
Other necessary/recommended digital objects	Software for the construction site daily management
Enabler of other possible applicable solutions	Optimization of materials delivery to the construction site, Aggregation of flexible energy consumption on the construction site

Output results	Smooth and efficient operation of the construction site
Benefits expected in operation, especially emphasizing circular economy principles	Reduced consumption of energy and materials
Necessary human resources for installing and operating	System is adaptable such that the installation is easy. Construction site operators operate the system.
Possible pitfalls and problems	Human workers safety could be compromised if the wet or dirty building materials compromise the sensory abilities of the autonomous vehicles
Technology readiness level (TRL)	1
For TRL>4, where it has been already applied	-
For TRL>1, who is the technology developer	-

Table 82 PAS HR-20

Possible applicable solution HR-21	
Name	Autonomous robotic system for 3D concrete printing
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	The mini concrete factory simultaneously monitors the amount of material in three silos, two liquid chemical tanks, the amount of glass fibres, as well as the flow of material to the extruder, which extrudes 3D printed material using a seven-axes robot.
Input raw data	Required concrete shapes and drawings
Other necessary/recommended digital objects	Construction site management software
Enabler of other possible applicable solutions	Robotized construction
Output results	Built 3d concrete shapes
Benefits expected in operation, especially emphasizing circular economy principles	Construction-scale 3D printing has a wide range of applications within the private, commercial, industrial and public sectors. Potential benefits of these technologies include faster construction, lower

	labour costs, greater complexity and/or accuracy, greater integration of functions and less waste generated.
Necessary human resources for installing and operating	The mini factory must be set-up on-site and operated by construction and robotics experts
Possible pitfalls and problems	The material palette that can be used for 3D printed concrete is limited, particularly due to nozzle extrusion and the deposition process of concrete layers, which introduces the challenge of premature collapsing
Technology readiness level (TRL)	4
For TRL>4, where it has been already applied	-
For TRL>1, who is the technology developer	Diateh

Table 83 PAS HR-21

Possible applicable solution HR-22	
Name	Robotic system for assessment of durability of structures and structural integrity
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Robotic system used to inspect the concrete structures
Input raw data	Construction services subject to the inspection
Other necessary/recommended digital objects	Digital logbook for the concrete structures
Enabler of other possible applicable solutions	Predictive maintenance and renovation measures planning
Output results	Pointed specific problematic points in the concrete structures
Benefits expected in operation, especially emphasizing circular economy principles	Detecting problems in structural integrity and eliminating them on time before a significant damage occurs, thus postponing major renovations
Necessary human resources for installing and operating	Robotic system operators

Possible pitfalls and problems	Required experience in concrete structure inspection
Technology readiness level (TRL)	4
For TRL>4, where it has been already applied	
For TRL>1, who is the technology developer	University of Zagreb

Table 84 PAS HR-22

Possible applicable solution HR-23	
Name	Volum3 organizational support software
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	Organizational support software in creating construction projects and their transfer to the construction site
Input raw data	Construction projects, meeting schedulers, tenders and similar
Other necessary/recommended digital objects	BIM-based construction project
Enabler of other possible applicable solutions	-
Output results	Concurrent project data delivered to all team members
Benefits expected in operation, especially emphasizing circular economy principles	Better organization, increased efficiency
Necessary human resources for installing and operating	-
Possible pitfalls and problems	Overlapping with other necessary tools for construction site management
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Over 1000 companies globally

For TRL>1, who is the technology developer	Volum3, Zagreb, Croatia

Table 85 PAS HR-23

Hungary

Possible applicable solution HU-1	
Name	3D images for land surveying (Geodesy)
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Using a laser scanner for surveying. The device has special mirrors that take photos. These can be produced in 3D.
Input raw data	Photographs of the study area.
Other necessary/recommended digital objects	Data storage in the cloud
Enabler of other possible applicable solutions	It facilitates the design and preparation of final drawings.
Output results	Digital 3D images of terrain for construction operations
Benefits expected in operation, especially emphasizing circular economy principles	Create more accurate, simpler drawings. More cost-effective planning processes
Necessary human resources for installing and operating	Surveyor designer
Possible pitfalls and problems	In the study area, cloud backup depends on the coverage of the Internet network. Slower data backup is possible.
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Several land surveying companies in Hungary
For TRL>1, who is the technology developer	Lechner Non-Profit Ltd

Table 86 PAS HU-1

Possible applicable solution HU-2

Name	2-frequency sonar for underwater measurements
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Sonar mounted on a boat or drone ship, e.g. to survey watercourse (bridge building, mining). The data obtained during the measurement is stored on a device attached to the sonar. They are read out and used later.
Input raw data	Data collected by sonar
Other necessary/recommended digital objects	A device to aid the stability of the measuring boat.
Enabler of other possible applicable solutions	Investigate the structure of the riverbed (silt, stone). This information can help bridge builders, for example.
Output results	Data for underwater design drawings
Benefits expected in operation, especially emphasizing circular economy principles	Preparation of more accurate underwater maps
Necessary human resources for installing and operating	Surveyor designer
Possible pitfalls and problems	Data backup is currently complicated
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Several land surveying companies in Hungary
For TRL>1, who is the technology developer	Bay Zoltán Applied Research Public Benefit Nonprofit Ltd., University of Miskolc

Table 87 PAS HU-2

Possible applicable solution HU-3	
Name	National Register of Building - 3D Viewer
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way

Description of the applicable solution	The 3D viewer is an angular module for displaying 3D models, mainly buildings, embedded in a web page. Includes two navigation solutions, a navigation tool called "Viewcube", a page menu that can be loaded with any content, any number of point and time-based lighting, location and time-based lighting, a spherical panorama background
Input raw data	Building location data
Other necessary/recommended digital objects	Using the Three.js JavaScript library to display the 3D visuals.
Enabler of other possible applicable solutions	Greenfield development, building visualisation, data storage.
Output results	It provides multiple measurement options, predefined path entry, group switching on and off of model elements, and a number of helpers that can be useful for admin tasks, for example
Benefits expected in operation, especially emphasizing circular economy principles	Complex information on different buildings available in one place.
Necessary human resources for installing and operating	Building designers, geoinformatics specialist
Possible pitfalls and problems	-
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	National Register of Building
For TRL>1, who is the technology developer	Hungarian software development company

Table 88 PAS HU-3

Possible applicable solution HU-4	
Name	National Model Plan Catalogue
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	The app is a complex platform for builders to access residential building designs that meet a wide range

	of needs, taking into account functionality, sustainability, environmental and urban character.
Input raw data	Selection of a specific design.
Other necessary/recommended digital objects	Construction project design software able to directly use the data from the Catalogue
Enabler of other possible applicable solutions	The catalogue of sample designs may be continuously updated with new modern housing designs by architects-designers
Output results	Complete construction drawings, with data capture option
Benefits expected in operation, especially emphasizing circular economy principles	Once you have selected the designs you want to explore, it will provide you with a detailed sample design, making it not only much cheaper, but also significantly speeding up the previously lengthy process of starting construction.
Necessary human resources for installing and operating	Building designers, geoinformatics specialist
Possible pitfalls and problems	-
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	National Register of Building
For TRL>1, who is the technology developer	Hungarian software development company

Table 89 PAS HU-4

Possible applicable solution HU-5	
Name	Settlement Public buildings Cadastre
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	A system for storing data on public buildings, their premises, assets, documents, energy, operation and investments.
Input raw data	3D BIM model based premises management, data processing.

Other necessary/recommended digital objects	BIM-based software
Enabler of other possible applicable solutions	Specific data analyses that give new insights
Output results	Instant display of real-time data from smart meters and sensors installed in premises. Generation of various reports.
Benefits expected in operation, especially emphasizing circular economy principles	Cost-effective design and construction, using the application simplifies data processing
Necessary human resources for installing and operating	Building designers, geoinformatics specialist
Possible pitfalls and problems	-
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	National Register of Building
For TRL>1, who is the technology developer	Hungarian software development company

Table 90 PAS HU-5

Moldavia

Possible applicable solution MD-1	
Name	EMIS Platform (Energetical Management Information System)
Solution category (from the Existing knowledge)	a.iii. Data structuring and ensuring data quality, accessibility, and interoperability
Description of the applicable solution	The collection, storage, and analysis of energy and water consumption data for public buildings in the Republic of Moldova
Input raw data	Data regarding energy and water consumption (quantity)

Other necessary/recommended digital objects	Smartphones/tablets/laptops to be used in the process of data collection
Enabler of other possible applicable solutions	Specific data-based analyses for deeper insight into the energy consumption of a specific subset of encompassed public buildings
Output results	A database with raw data, which can be used to understand which buildings need urgent intervention for renovation. Also, the data could be used to analyse how specific types of buildings behave over time in terms of water and energy consumption.
Benefits expected in operation, especially emphasizing circular economy principles	Governmental buildings are usually of bigger sizes and account for a significant percentage among the total amount of existing buildings, it's important to apply circular economy principles such that they serve as an example of good practices for the public and the market, thus, renovating them or helping them use efficient energy and water consumption systems is very important. The potential interventions can also be used as pilots to further use the practices to renovate other buildings.
Necessary human resources for installing and operating	Field agents to collect the data (usually volunteers)
Possible pitfalls and problems	Lack of budget to finance data collection and further data management
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	EMIS was developed and launched by UNDP in Croatia in 2006, and subsequently used in Bosnia and Herzegovina, Serbia, and since 2023 in Moldova as well, implemented by Green CityLab NGO and UNDP Moldova, currently having data collected for more than 5400 building in Moldova
For TRL>1, who is the technology developer	Developed by Croatian Agency for Transactions and Mediation in Immovable Properties (APN), with the initiative and help of UNDP in Croatia

Table 91 PAS MD-1

Possible applicable solution MD-2	
Name	BIM systems for new constructions
Solution category (from the Existing knowledge)	a.iii. Data structuring and ensuring data quality, accessibility, and interoperability
Description of the applicable solution	Use of BIM software for new constructions (buildings, bridges, roads, etc.) to better manage the process, making it more efficient and reducing waste
Input raw data	Digital models of constructions, buildings
Other necessary/recommended digital objects	Modelling software, access to other databases (road infrastructure, buildings infrastructure)
Enabler of other possible applicable solutions	Improves the future process of demolishing
Output results	Clear overview of a construction in a digital environment
Benefits expected in operation, especially emphasizing circular economy principles	Better calculation of resources needed, to reduce overconsumption. Increases the possibility to make the building more energy efficient.
Necessary human resources for installing and operating	Specialists in BIM and architects
Possible pitfalls and problems	These tools can be expensive or developers might not want to use them
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	First BIM-powered project in Moldova for the construction of an important intersection at the border of the city (https://model.allbim.net/primul-proiect-bim-de-infrastructura-in-moldova/)
For TRL>1, who is the technology developer	ALLBIM from Romania

Table 92 PAS MD-2

Possible applicable solution MD-3	
Name	A program for tracking construction materials
Solution category (from the Existing knowledge)	a.iii. Data structuring and ensuring data quality, accessibility, and interoperability

Description of the applicable solution	Construction materials introduced on the market (from local production or import) with assigned code, such that they can be tracked around the whole chain, through a digital platform, which helps in reaching a decentralized digital overview of new constructions
Input raw data	Codes of all finished construction materials introduced on the market for commercialization
Other necessary/recommended digital objects	Cloud storage
Enabler of other possible applicable solutions	Tracking construction materials can also track overuse of resources for new constructions, thus, makes it possible to build more efficiently and reduce resources consumption
Output results	Flow of construction materials at the disposal for analysis, also it is possible to track materials from a part of a building/construction, also after being removed/recycled/reused
Benefits expected in operation, especially emphasizing circular economy principles	Coding and tracking construction materials have a positive impact and could facilitate reducing, reusing and recycling these resources
Necessary human resources for installing and operating	Specialists which can develop such a program/platform for the database and tracking system
Possible pitfalls and problems	It would impose an obligation of construction materials producers to code and declare all materials produced and sold/listed on the market
Technology readiness level (TRL)	1
For TRL>4, where it has been already applied	**-**
For TRL>1, who is the technology developer	This was proposed as a solution by our RMSG member Simpals LTD - a tech/developer company, which has developed many local platforms and is also involved in implementing projects in Romania

Table 93 PAS MD-3

Possible applicable solution MD-4	
Name	Digitalization of the building' passports
Solution category (from the Existing knowledge)	a.iii. Data structuring and ensuring data quality, accessibility, and interoperability
Description of the applicable solution	A digital database of all lands and constructions to better track the materials and make sure people report all new constructions on their lands, even small ones, and declare which materials have been used and the quantity
Input raw data	Updated land and building passports (paper ones)
Other necessary/recommended digital objects	Software, collection tools of data (phones, tablets, laptops)
Enabler of other possible applicable solutions	Can help find unauthorised constructions or non-declared constructions
Output results	Systematized data on existing constructions and materials used. Such an assessment can help improve policies and decision making to improve the sector and implement circular economy principles
Benefits expected in operation, especially emphasizing circular economy principles	Updating existing data and building a digital map of all existing constructions would help understand the real quantity of construction materials used around the country, which materials are being misused, which unauthorised constructions exist
Necessary human resources for installing and operating	Data entry agents, specialists to build the platform/program, data storage and operating machines to sustain the platform
Possible pitfalls and problems	A lot of resources to update existing database and then transpose it to a digital database
Technology readiness level (TRL)	3
For TRL>4, where it has been already applied	Applied only in some cities/regions of Moldavia with digitalization still not made systematically
For TRL>1, who is the technology developer	Moldavian national institutions

Table 94 PAS MD-4

Montenegro

Possible applicable solution ME-1	
Name	Artec Studio 19 – Digital platform for 3D scanning and processing
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	Comprehensive software for 3D scanning, editing, reverse engineering, and quality inspection. Supports various scanning technologies and photogrammetry tools.
Input raw data	3D scan data from LiDAR, laser, structured light scanners, and photogrammetry images/videos (e.g., captured via smartphone).
Other necessary/recommended digital objects	Photogrammetry datasets, calibration files for scanners, hardware integration drivers, and model reference datasets.
Enabler of other possible applicable solutions	Enables reverse engineering, manufacturing prototyping, 3D model creation, and quality inspection workflows in industries like construction and product design.
Output results	High-fidelity 3D models, CAD-ready designs, inspection reports, and optimized outputs for manufacturing and reverse engineering.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces material waste by improving design precision and facilitating efficient reverse engineering; enables lifecycle assessments for design improvements.
Necessary human resources for installing and operating	Skilled operators with knowledge of 3D scanning hardware and Artec Studio software; minimal training required for experienced CAD or BIM professionals.
Possible pitfalls and problems	Potential compatibility issues with third-party devices or older scanning equipment; requires high-end computing resources for large-scale projects.
Technology readiness level (TRL)	TRL 9 (Fully developed and commercially available).
For TRL>4, where it has been already applied	Widely applied in industries such as construction, automotive, aerospace, healthcare (e.g., orthotics), cultural heritage restoration, and design prototyping.

For TRL>1, who is the technology developer	Developed by Artec 3D, a leading company in the field of professional 3D scanning solutions and software development with one of its developing facilities in Bar, Montenegro

Table 95 PAS ME-1

Possible applicable solution ME-2	
Name	CinderOSS Tool -- Digital platform for circular economy in urban construction
Solution category (from the Existing knowledge)	a.iii. Data structuring and ensuring data quality, accessibility, and interoperability
Description of the applicable solution	CinderOSS enables seamless integration of secondary raw materials (SRM) into construction workflows by managing data, regulations, and stakeholders.
Input raw data	Material properties for SRM (secondary raw materials), Construction and demolition waste composition, Project specifications, environmental data and regional regulations
Other necessary/recommended digital objects	BIM libraries with SRM attributes, Digital material exchange systems, Regulatory compliance tools
Enabler of other possible applicable solutions	Facilitates circular construction adoption, data-driven decision-making, logistics optimization, and cross-industry material reuse workflows.
Output results	Circular construction project plans, environmental and economic impact reports, SRM traceability and material flow data
Benefits expected in operation, especially emphasizing circular economy principles	Reduces resource extraction by increasing SRM reuse, Promotes waste-to-resource conversion, Reduces environmental impact and project costs
Necessary human resources for installing and operating	Engineers and technicians familiar with construction workflows, waste management, and software tools for SRM tracking and reporting.
Possible pitfalls and problems	Limited SRM supply in certain regions, challenges in stakeholder engagement and regulatory compliance, requires collaboration across industries

Technology readiness level (TRL)	TRL 8 (System demonstrated in operational environment).
For TRL>4, where it has been already applied	Pilots in Slovenia, Spain, North Macedonia, and the Netherlands have validated the system's effectiveness in circular construction projects.
For TRL>1, who is the technology developer	University of Montenegro developed as part of the CINDERELA H2020 project consortium, with contributions from research institutions and private industry

Table 96 PAS ME-2

Romania

Possible applicable solution RO-1	
Name	Renergia – households energy consumption analyser and advisor
Solution category (from the Existing knowledge)	b.ii.3 - Explicit decision support
Description of the applicable solution	Renergia is a mobile application developed by Energy Advisor, the first start-up affiliated with the Technical University of Cluj-Napoca. It analyses household energy consumption and provides personalized energy efficiency plans. Using advanced AI algorithms, statistical, and probabilistic methods, the application estimates electrical and thermal energy consumption, detects anomalies, and offers recommendations to optimize usage. Implementing these measures can reduce energy bills by up to 30%. (energy-center.ro)
Input raw data	Information about household electrical and thermal equipment, thermal insulation details of the house, current energy consumption data
Other necessary/recommended digital objects	Access to a database of energy-efficient equipment, a sizing tool for photovoltaic systems
Enabler of other possible applicable solutions	Renergia offers users an estimation tool for photovoltaic system sizing, facilitating the transition to renewable energy sources and their integration

	into households. (energy-center.ro)
Output results	Monthly and annual energy consumption estimates, personalized energy efficiency plans, evaluation of household carbon footprint
Benefits expected in operation, especially emphasizing circular economy principles	Reduction of energy waste, energy bill reductions of up to 30%, decrease in CO_2 emissions through optimized consumption, promotion of renewable energy sources, improved comfort and resilience of households
Necessary human resources for installing and operating	Users can independently install and run the application, implementation of recommended measures may require consultancy and installation services from energy efficiency and photovoltaic system specialists
Possible pitfalls and problems	Potentially required consultancy and installation services from energy efficiency and photovoltaic system specialists
Technology readiness level (TRL)	TRL 7 - System prototype tested in operational environment
For TRL>4, where it has been already applied	The application was launched internationally during COP28 and is available to users in Romania. (energy-center.ro)
For TRL>1, who is the technology developer	Energy Advisor, the first start-up affiliated with the Technical University of Cluj-Napoca

Table 97 PAS RO-1

Possible applicable solution RO-2	
Name	Sigurec – Selective Recycling and Waste Management
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Sigurec is a smart waste management solution that facilitates selective recycling through user-friendly collection points and mobile services. It integrates advanced digital technologies to monitor and reward users for their recycling efforts. The platform promotes sustainability by efficiently managing

	recyclable waste and redirecting it into circular production chains.
Input raw data	Types and quantities of recyclable materials collected (e.g., plastic, paper, glass, electronic waste), user data for reward tracking and system optimization.
Other necessary/recommended digital objects	Mobile application for users to track recycling efforts and rewards, IoT-enabled smart bins for real-time monitoring of waste collection, database for recyclable material tracking.
Enabler of other possible applicable solutions	Sigurec supports broader waste management strategies by integrating with municipal systems, enabling efficient sorting, and directing materials to appropriate recycling facilities, contributing to urban sustainability goals.
Output results	Enhanced data collection for waste management optimization.
Benefits expected in operation, especially emphasizing circular economy principles	Increased rates of recycling and reduced landfill waste, reduction in environmental pollution through proper recycling practices, real-time monitoring of recycling activities, incentive-based participation from users through rewards, contribution to resource recovery and material reuse, decreased reliance on virgin raw materials, increased community engagement in sustainable practices
Necessary human resources for installing and operating	Technical staff for setting up and maintaining IoT-enabled collection points, customer support teams for mobile app assistance, recycling facility operators for material processing
Possible pitfalls and problems	Low user engagement without adequate incentives, technical malfunctions in IoT-enabled systems could disrupt operations, challenges in integrating with existing municipal waste systems
Technology readiness level (TRL)	TRL 8 – System completed and qualified through tests and demonstrations.

For TRL>4, where it has been already applied	Sigurec has been implemented in several Romanian cities, including Bucharest and Cluj-Napoca, with dedicated collection points and partnerships with local recycling facilities.
For TRL>1, who is the technology developer	Green Group, a leading waste recycling and management company in Romania.

Table 98 PAS RO-2

Possible applicable solution RO-3	
Name	Effective site monitoring with aerial data
Solution category (from the Existing knowledge)	a.iii Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Transformation of construction projects with advanced drone solutions. Seamlessly integrating technology, the technology provides unparalleled benefits in site analysis and project oversight. From aerial surveys to real-time monitoring, this technology enhances accuracy, cuts costs, and optimizes efficiency, ensuring project success. Services: construction monitoring and construction inspection.
Input raw data	Accurate 2D/3D aerial maps and topographic surveys. Using LiDAR technology
Other necessary/recommended digital objects	Cloud storage provided
Enabler of other possible applicable solutions	This technology can be used in oil and gas industry sector (pipeline integrity, infrastructure assessment and rapid emergency response), renewable energy sector (use professional drones to conduct aerial inspections of solar farms, wind turbines, and other renewable infrastructure, providing crucial data for maintenance and performance optimization), confined spaces inspection (streamlining inspections and monitoring environmental conditions to ensure a safer working environment), 3D digital twin and virtual tours (enhances spatial models with high-resolution aerial data and creates digital replicas,

	enabling immersive virtual experiences across urban planning, architecture, tourism, and real estate)
Output results	PDF report, orthomosaic maps and digital elevation model (DEM), in format geoTIFF, point cloud (format LAS/LAZ), collaborative cloud platform, stockpiles volumes
Benefits expected in operation, especially emphasizing circular economy principles	Precise data collection efficiently and cost-effectively, comprehensive data for site planning, cost-effective volume calculations, and terrain analysis, aiding every construction phase.
Necessary human resources for installing and operating	Operator, drone and auxiliary equipment provided
Possible pitfalls and problems	None
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Cluj, Alba and more than 20 other cities in Romania
For TRL>1, who is the technology developer	Skyline Drones

Table 99 PAS RO-3

Possible applicable solution RO-4	
Name	3D scanning services for architecture
Solution category (from the Existing knowledge)	a.iii Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Scanning services in the field of architecture are represented by current activities of capturing data in the field, processing and generating the scanned 3D model and post-processing the resulting 3D model

	for its subsequent use in design software (ArchiCAD, Revit, Sketchup, etc.).
Input raw data	Cloud of points recorded
Other necessary/recommended digital objects	None
Enabler of other possible applicable solutions	Terrains (Orthophotoplanes): Urban planning - from urbanistic studies to territorial planning; Architecture - solution-studies for the location and configuration of buildings; Construction - site monitoring and real estate developments; Agriculture - for analysing and measuring land areas dedicated to different agricultural crops; Landscape studies - for conservation projects and also for protection and enhancing natural landscapes (parks, rivers, mountain landscapes, etc.) projects
Output results	3D PIECES: Optimized point cloud; Textured and optimized 3D models: .obj with high quality .png/.jpg texture files, .fbx, .glb/.gltf; Remodeled 3D models: Archicad files, IFC, 3D .dwg, High quality 3D model/point cloud hosted by the company on Nira.app online platform; 2D & ARCHITECTURAL PIECES: high quality orthoprojections exported as .tiff/.png/.jpg files, model sections exported as .dwg files, architectural plans available as .pdf and .dwg files; DOCUMENTS: Field Calibration Report, Diagnostic Report, Refinement Report
Benefits expected in operation, especially emphasizing circular economy principles	Three-dimensional survey deliverable in the format needed by the client - convertible into the formats requested by the beneficiary 2D, simplified 3D, editable .dwg, vectorial pdf, etc, Complex project survey - historical building facades, interior spaces, building complexes, roof framing, etc. Standard project survey - facades, building envelopes (roofs). Scanning of complex architectural elements - facades of historic buildings, frames, wood or metal joinery,

	stairways or other architectural elements with complex geometry.
Necessary human resources for installing and operating	Operator and scanning equipment provided
Possible pitfalls and problems	None
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Church and national theatre in Timisoara, and many other buildings and constructions
For TRL>1, who is the technology developer	Cyberscanning

Table 100 PAS RO-4

Possible applicable solution RO-5	
Name	openBIM for decision making and Digital Twins
Solution category (from the Existing knowledge)	a.iii Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	A collaborative process within the BIM framework, that is vendor-neutral and ensures interoperability, Open and neutral standards, Reliable data exchanges, Collaborative workflows, Flexibility of technology choice and Sustainability.
Input raw data	Information requirements from all project stakeholders, starting with the intended use of the asset (operation and maintenance), construction (project implementation) and design and concept.
Other necessary/recommended digital objects	Information management platform, common data environment
Enabler of other possible applicable solutions	Using clearly defined information requirements, a fully functional Digital Twin can be developed. On this line, IoT devices are required, a platform that enable data collection, consolidation and storage

	(e.g. MS Azure, Amazon cloud, etc,) and a platform for data visualization (e.g. powerBI, Unreal Engine, Unity)
Output results	Clear information - structured and unstructured data (geometric data, metadata, other); information storage structure for easy to find data
Benefits expected in operation, especially emphasizing circular economy principles	Clear and reusable project related information; open and transparent data workflows
Necessary human resources for installing and operating	BIM manager (defines the organization information requirements); BIM coordinator (defines the asset information requirements, defines the project information requirements, checks/accepts data)
Possible pitfalls and problems	Limited IT infrastructure; limited knowledge of the framework in the work field, resistance to change of 'old operation modes'
Technology readiness level (TRL)	7

For TRL>4, where it has been already applied	- Digital Twin for the maintenance and operation of motorways - https://app.box.com/s/yiy7lnxmieihysp69jpnb1jms17pohmq - "Sustainable" interdisciplinary planning and construction of a district police authority in Germany (Bergheim) - https://app.box.com/s/vtw23aj78m53qzrdr6i3k7qzl0cshoo3 - Multi-domain openBIM Digital Engineering Certification and Handover for JiuQuan-Ejina Railway - https://app.box.com/s/x4dltrn01n3r3u8se8spjgma28cn9kl6 - ChorusLife: Creation and maintenance of an openBIM Digital Twin for asset management - https://www.buildingsmart.org/wp-content/uploads/2022/10/358-ASSET-ChorusLife-Creation-and-maintenance-of-an-openBIM-Digital-Twin-for-asset-managem.pdf - Wellington Railway Station Façade Condition Assessment - https://www.buildingsmart.org/wp-content/uploads/2022/10/425-FM-Wellington-Railway-Station-Facade-Condition-Assessment.pdf - Handover to FM with openBIM - Marshal's Office, West Pomerania - https://www.buildingsmart.org/wp-content/uploads/2022/10/352-Handover-Handover-to-FM-with-openBIM-Marshals-Office-West-Pomerania.pdf - Implementation of BIM-based building permit process in Estonia - https://www.buildingsmart.org/wp-content/uploads/2022/10/376-TECHNOLOGY-Mirella-Hilgenkamp.pdf - smartBRIDGE Hamburg - https://app.box.com/s/a9ncbu96vfizvrb8zb7rs4delx09tid4

For TRL>1, who is the technology developer	Politechnika University of Bucharest

Table 101 PAS RO-5

Serbia

Possible applicable solution RS-1	
Name	Building Information Modelling (BIM)
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Centralized digital models for managing project data.
Input raw data	Architectural and engineering designs, schedules
Other necessary/recommended digital objects	Cloud storage, BIM-compatible tools
Enabler of other possible applicable solutions	Supports prefabrication, real-time monitoring
Output results	Collaborative 3D models, improved communication
Benefits expected in operation, especially emphasizing circular economy principles	Resource efficiency, reduced errors, adherence to circular economy
Necessary human resources for installing and operating	BIM specialists, engineers, IT staff
Possible pitfalls and problems	High implementation costs, workforce training gaps
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Used in global projects and Belgrade's metro design.
For TRL>1, who is the technology developer	Autodesk, Nemetschek

Table 102 PAS RS-1

Possible applicable solution RS-2	
Name	Drones for Construction Site Monitoring
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Aerial imaging for real-time site analysis.

Input raw data	Topographic data, real-time video feeds
Other necessary/recommended digital objects	GIS software, image processing tools
Enabler of other possible applicable solutions	Enhances site safety, integrates with GIS
Output results	High-resolution maps, hazard identification
Benefits expected in operation, especially emphasizing circular economy principles	Faster project execution, improved safety
Necessary human resources for installing and operating	Drone pilots, data analysts
Possible pitfalls and problems	Weather dependence, limited flight duration
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Used globally and in Serbia for highway monitoring.
For TRL>1, who is the technology developer	DJI, Parrot

Table 103 PAS RS-2

Possible applicable solution RS-3	
Name	IoT Sensors for Construction Monitoring
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Sensors for tracking site conditions and performance.
Input raw data	Temperature, humidity, vibration, equipment usage
Other necessary/recommended digital objects	IoT platforms, mobile apps
Enabler of other possible applicable solutions	Enables predictive maintenance, supports BIM integration
Output results	Real-time alerts, resource optimization
Benefits expected in operation, especially emphasizing circular economy principles	Cost reduction, reduced downtime, better material management
Necessary human resources for installing and operating	Engineers, technicians

Possible pitfalls and problems	High upfront costs, data security concerns
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Applied in Serbia's public infrastructure monitoring.
For TRL>1, who is the technology developer	Bosch, Honeywell

Table 104 PAS RS-3

Possible applicable solution RS-4	
Name	Digital Twin Technology
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	Real-time virtual replicas of physical assets.
Input raw data	BIM models, sensor data, operational data
Other necessary/recommended digital objects	Cloud systems, visualization software
Enabler of other possible applicable solutions	Facilitates predictive maintenance, integration with IoT
Output results	Real-time simulations, optimized operations
Benefits expected in operation, especially emphasizing circular economy principles	Energy savings, reduced downtime, circular management of resources
Necessary human resources for installing and operating	Software developers, engineers
Possible pitfalls and problems	Complex integration, high data storage requirements
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Piloted in Novi Sad's building retrofitting projects
For TRL>1, who is the technology developer	Siemens, General Electric

Table 105 PAS RS-4

Possible applicable solution RS-5

Name	Augmented Reality (AR) for On-Site Support
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	AR tools for worker training and equipment guidance.
Input raw data	Equipment specifications, 3D models
Other necessary/recommended digital objects	AR devices (e.g., HoloLens), mobile apps
Enabler of other possible applicable solutions	Improves worker safety and accuracy, enhances BIM collaboration
Output results	Interactive training modules, reduced errors
Benefits expected in operation, especially emphasizing circular economy principles	Safer operations, faster installation
Necessary human resources for installing and operating	AR device operators, IT specialists
Possible pitfalls and problems	High device costs, steep learning curve
Technology readiness level (TRL)	6
For TRL>4, where it has been already applied	Piloted in Belgrade metro and vocational training.
For TRL>1, who is the technology developer	Microsoft, Trimble, Unity Technologies

Table 106 PAS RS-5

Possible applicable solution RS-6	
Name	3D Printing for Construction Components
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Digital manufacturing of custom components, reducing waste
Input raw data	Digital blueprints, material specifications
Other necessary/recommended digital objects	3D printers, CAD software

Enabler of other possible applicable solutions	Reduces supply chain dependency, integrates with BIM
Output results	Custom components, faster construction
Benefits expected in operation, especially emphasizing circular economy principles	Circular material use, reduced transportation emissions
Necessary human resources for installing and operating	Engineers, CAD specialists
Possible pitfalls and problems	High initial costs, regulatory challenges
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Tested in Serbia at the Faculty of Civil Engineering.
For TRL>1, who is the technology developer	ICON, Apis Cor, COBOD

Table 107 PAS RS-6

Possible applicable solution RS-7	
Name	GIS for Urban Planning
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Mapping and analysis tools for urban and infrastructure planning.
Input raw data	Satellite imagery, cadastral data
Other necessary/recommended digital objects	GIS software, remote sensing tools
Enabler of other possible applicable solutions	Disaster management, real-time IoT integration
Output results	Optimized infrastructure layouts, spatial analysis
Benefits expected in operation, especially emphasizing circular economy principles	Better land use efficiency, circular development principles
Necessary human resources for installing and operating	GIS experts, urban planners
Possible pitfalls and problems	Licensing costs, rural data quality issues

Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Used in Serbia for Smart City projects in Belgrade.
For TRL>1, who is the technology developer	Esri, Hexagon, QGIS

Table 108 PAS RS-7

Possible applicable solution RS-8	
Name	Prefabrication with Digital Optimization
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Optimized production of prefabricated building components.
Input raw data	BIM models, structural engineering data
Other necessary/recommended digital objects	Robotic assembly lines, ERP systems
Enabler of other possible applicable solutions	Supports modular construction, reduces on-site labour
Output results	Prefabricated modules, faster project delivery
Benefits expected in operation, especially emphasizing circular economy principles	Lower energy use, reduced material waste
Necessary human resources for installing and operating	Skilled factory workers, quality control engineers
Possible pitfalls and problems	Dependence on transport infrastructure, limited design flexibility
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Used for modular housing and schools in Serbia.
For TRL>1, who is the technology developer	Katerra, Broad Group

Table 109 PAS RS-8

Possible applicable solution RS-9

Name	Laser Scanning for Site Surveying
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	LiDAR technology for high-precision 3D data capture.
Input raw data	3D point clouds, terrain data
Other necessary/recommended digital objects	CAD software, GIS systems
Enabler of other possible applicable solutions	Enables accurate as-built documentation, supports BIM
Output results	Detailed 3D maps, improved site analysis
Benefits expected in operation, especially emphasizing circular economy principles	Reduced errors, faster project approvals
Necessary human resources for installing and operating	Survey engineers, data analysts
Possible pitfalls and problems	High equipment costs, potential data processing errors
Technology readiness level (TRL)	8
For TRL>4, where it has been already applied	Used in Serbia for Belgrade-Niš highway surveys.
For TRL>1, who is the technology developer	Leica, Trimble, Faro

Table 110 PAS RS-9

Possible applicable solution RS-10	
Name	Construction Management Software (CMS)
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	Real-time tracking of construction progress and costs.
Input raw data	Schedules, budgets, workforce data

Other necessary/recommended digital objects	Mobile apps, cloud platforms
Enabler of other possible applicable solutions	Integrates with IoT and BIM, improves transparency
Output results	Centralized dashboards, automated reports
Benefits expected in operation, especially emphasizing circular economy principles	Greater efficiency, lower administrative workload
Necessary human resources for installing and operating	Project managers, IT staff
Possible pitfalls and problems	Reluctance to adopt, legacy system integration issues
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Used in Serbia for Morava Corridor highway projects.
For TRL>1, who is the technology developer	Procore, Oracle Primavera

Table 111 PAS RS-10

Possible applicable solution RS-11	
Name	Concrete Sensors for Strength Monitoring
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Wireless monitoring of concrete curing and strength.
Input raw data	Concrete mix design, temperature and humidity data
Other necessary/recommended digital objects	Mobile apps, IoT platforms
Enabler of other possible applicable solutions	Ensures structural quality, reduces curing time delays
Output results	Strength development curves, real-time alerts
Benefits expected in operation, especially emphasizing circular economy principles	Improved safety, minimized material waste

Necessary human resources for installing and operating	Engineers, site managers
Possible pitfalls and problems	Sensor malfunctions, compatibility with specific mixes
Technology readiness level (TRL)	7
For TRL>4, where it has been already applied	Tested in Serbia for bridge construction on Belgrade bypass.
For TRL>1, who is the technology developer	Giatec, Converge, SmartRock

Table 112 PAS RS-11

Possible applicable solution RS-12	
Name	Autonomous Construction Equipment
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	AI-driven machines for precision construction tasks.
Input raw data	Site maps, operational parameters
Other necessary/recommended digital objects	IoT-enabled equipment, navigation software
Enabler of other possible applicable solutions	Enhances safety, reduces fuel consumption
Output results	Consistent quality, faster task completion
Benefits expected in operation, especially emphasizing circular economy principles	Lower labour costs, reduced emissions
Necessary human resources for installing and operating	Technicians, autonomous equipment operators
Possible pitfalls and problems	High acquisition costs, workforce resistance
Technology readiness level (TRL)	6
For TRL>4, where it has been already applied	Demonstrated in Serbia in quarry operations.
For TRL>1, who is the technology developer	Komatsu, Caterpillar, Built Robotics

Table 113 PAS RS-12

Slovenia

Possible applicable solution SI-1	
Name	Corrosion sensors - continuous monitoring of corrosion over a long period of time
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Monitoring and analysing corrosion processes affecting steel reinforcement (ordinary carbon steel, stainless steel, and coated reinforcement) in various concrete environments, such as concretes made from sustainable cements, carbonated concretes and concretes contaminated by aggressive ions, saturated concretes with limited oxygen access and concretes with protective coatings and with the use of corrosion inhibitors.
Input raw data	Electrical resistance sensors and coupled multi-electrode arrays (CMEA) data, supplemented by advanced techniques like X-ray microtomography (microCT), spectroscopy (XRD, Raman), and microscopy (SEM, optical)
Other necessary/recommended digital objects	Data storage, wireless data transmission systems
Enabler of other possible applicable solutions	Can enable predictive maintenance platforms, promote the use of sustainable materials by assessing their long-term durability, can provide valuable data for lifecycle assessment (LCA) models and material passports
Output results	Ability to continuously monitor corrosion over a long period of time, which is not possible with classical electrochemical methods. In combination with a developed system for wireless data transmission and low energy consumption it enables reading data from real objects for several years.
Benefits expected in operation, especially emphasizing circular economy principles	Optimized maintenance of objects, material improvements, resource efficiency, improved safety

	with better monitoring of potential structural failures;
Necessary human resources for installing and operating	Corrosion engineers, material scientists, IT/networking specialists, data analysts, field technicians
Possible pitfalls and problems	Complex data management and the need for skilled personnel to interpret results accurately, sensor durability in harsh environments and integration issues in existing structures can raise maintenance demands and affect long-term reliability, cybersecurity risks
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	Laboratory conditions, on test fields in a natural environment (island of Krk, Port of Koper) and on real reinforced concrete structures (e.g. viaduct Črni Kal, bridge over the Grobelno railway, bridge to the island of Krk).
For TRL>1, who is the technology developer	Laboratory for Metals, Corrosion and Anti-Corrosion Protection at the Slovenian National Building and Civil Engineering Institute (ZAG)

Table 114 PAS SI-1

Possible applicable solution SI-2	
Name	On-site visualization using BIM and extended reality - Trimble XR10 with HoloLens 2
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way
Description of the applicable solution	The Trimble XR10 with HoloLens 2 is an advanced augmented reality (AR) tool for construction sites, offering enhanced project visualization, improved workflow coordination, and easy integration of 3D BIM models into real environments. It facilitates better communication, quick access to data, and visualization of work sequences.
Input raw data	3D BIM data, project data, geospatial and positional data

Other necessary/recommended digital objects	Trimble Connect AR + MR program, 3D and 4D BIM
Enabler of other possible applicable solutions	Remote assistance, monitoring of construction sites, training and skills development of the workforce, presentations for clients (marketing)
Output results	The Trimble XR10 with HoloLens 2 provides real-time visualization of 3D models overlaid onto the construction site, enabling accurate measurements, clash detection, and progress tracking. This results in more efficient project management, better design validation, and greater overall accuracy in construction.
Benefits expected in operation, especially emphasizing circular economy principles	Better understanding of project elements, better coordination of the workflow, determining necessary construction tasks, improved team collaboration, quick identification of issues, reducing rework and delays;
Necessary human resources for installing and operating	AR technology specialists, BIM specialists, construction project manager, IT support staff
Possible pitfalls and problems	Language barriers (commands are predominantly in English), the device's weight and discomfort during extended use, reduced visibility in strong sunlight, and a limited battery life of about 2 hours, technical glitches during software updates, data security, training and skills gap
Technology readiness level (TRL)	3
For TRL>4, where it has been already applied	Retirement Home Šmarje pri Jelšah – dislocated unit Kozje
For TRL>1, who is the technology developer	Trimble Inc. and Microsoft; Experiment in Slovenia conducted by University of Maribor, Faculty of Civil Engineering, Transportation Engineering and Architecture and GIC Gradnje d.o.o.

Table 115 PAS SI-2

Possible applicable solution SI-3

Name	Digital Twins for road construction, using secondary raw materials
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	The solution involves integrating sensor data with BIM on a 300-meter access road built on a degraded former gravel pit site, as part of the CINDERELA project. Designed with CE principles, the road uses sustainable, recycled materials such as recycled aggregate for the subgrade and base course, and recycled grind asphalt for the surface course. Despite the small scale, the study highlights challenges that could arise in larger DT road projects, utilizing various BIM modelling and coordination tools, custom BIM sensors, and embedded sensor data structures for cross-functional integration.
Input raw data	2D CAD design, geometric survey data, BIM data, sensor data, federated BIM
Other necessary/recommended digital objects	Database, web service
Enabler of other possible applicable solutions	Real-time monitoring, predictive maintenance
Output results	Proof of concept for secondary raw materials integration with DT technology, a functional prototype of a digital twin, identification of key challanges in implementation useful for future developments
Benefits expected in operation, especially emphasizing circular economy principles	Better material tracking, optimized resource allocation, lifecycle management, safety improvements, scenario testing
Necessary human resources for installing and operating	Civil engineers, BIM specialists, data analysts, technical staff, construction workers, project manager, software developers
Possible pitfalls and problems	Managing a large number of small sensors and handling high-frequency data acquisition, the complexity of data processing and translating raw sensor data into actionable insights, management of BIM libraries

Technology readiness level (TRL)	3
For TRL>4, where it has been already applied	Road project in Maribor, Slovenia
For TRL>1, who is the technology developer	Slovenian National Building and Civil Engineering Institute (ZAG)

Table 116 PAS SI-3

Possible applicable solution SI-4	
Name	Building applications for smart and safe construction with the DECENTER Fog Computing and Brokerage Platform
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	The DECENTER Fog Computing and Brokerage Platform is a cutting-edge solution developed through a collaborative EU-South Korean Horizon 2020 project. It is designed to facilitate the development and deployment of smart applications across various industries, including construction, by enabling resource sharing through automated Smart Contracts. Unlike other systems, DECENTER offers a flexible, multi-domain infrastructure that supports efficient and secure data sharing and resource allocation. This flexibility enables IoT devices and multiple computing tiers to work collaboratively, enhancing the performance and scalability of distributed applications. The DECENTER Fog Computing and Brokerage Platform integrates IoT, AI, Cloud computing, and Blockchain to enable seamless development of smart, microservices-based applications. It supports federated Cloud-to-Edge environments, facilitating AI-powered processing of IoT data across the computing continuum. This makes DECENTER a highly advanced Fog Computing platform.

Input raw data	Sensor data from IoT devices, camera video streams, identification data on workers and visitors, vehicle details, inventory or resource status data
Other necessary/recommended digital objects	AI models and algorithms, BIM data, smart contracts, digital twins, data storages, BIM models
Enabler of other possible applicable solutions	Predictive models for maintenance, energy management, remote monitoring, real-time progress tracking
Output results	DECENTER enhances safety by monitoring construction workers to ensure they wear appropriate safety gear and tracking their locations. In case of a safety issue, the site manager is notified, showcasing DECENTER's high-quality service and quick response time. It supports construction-site surveillance by detecting and identifying vehicles and people entering or exiting, distinguishing between workers and visitors. This scenario uses optimized AI models and Smart Contracts to manage secure access and data privacy. It also monitors and tracks resources, waste, and assets on-site, issuing alerts to the manager when resources change. The platform integrates various AI models to improve monitoring of inventory, machinery, and materials. DECENTER monitors environmental conditions as well, like weather and noise to ensure optimal working conditions and enhance environmental protection. This scenario leverages IoT sensors and video streams, utilizing the embedded SensiNact IoT platform.
Benefits expected in operation, especially emphasizing circular economy principles	Quick anomaly detection, flexible AI model use, improved privacy through smart contracts and reduced costs by allowing temporary use of external infrastructures, high-quality service with rapid response times and simplified interoperability, enhanced safety and operational efficiency on-site
Necessary human resources for installing and operating	Cloud engineers, AI specialists, data scientists, data security and compliance officers, technical staff, IoT

	technicians, construction site managers and engineers
Possible pitfalls and problems	Challenges with integrating diverse technologies and ensuring seamless interoperability between AI models, sensors, and existing site infrastructure, data privacy and security, the platform's reliance on stable internet connectivity and cloud resources may pose risks in remote or poorly connected areas
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	Šumi center construction site, Dunajska cesta 63, Ljubljana, Slovenia
For TRL>1, who is the technology developer	Developed within the scope of European Union and South Korean Horizon 2020 research and innovation project DECENTER - Decentralised technologies for orchestrated cloud-to-edge intelligence

Table 117 PAS SI-4

Possible applicable solution SI-5	
Name	Digital services for circular economy in construction sector - CinderOSS, or CINDERELA One-Stop-Shop service
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	CinderOSS, the CINDERELA One-Stop-Shop service, is a digital platform designed to support Secondary Raw Material (SRM) based construction products and circular economy business models (CEBM). It integrates data on SRM products, local legislation, market trends, product characteristics, and best practices across Europe into a centralized and user-friendly database. The platform consists of five modules—CEBM, Legal, Market, Production and Construction, and Research and Development—offering cohesive, webshop-like navigation to streamline access to relevant resources for stakeholders like investors, companies, and policymakers.

Input raw data	Data on SRM products, local legislation, market trends, product characteristics, and best practices across Europe
Other necessary/recommended digital objects	Database infrastructure, content management system (CMS), user interface, APIs, data integration tools
Enabler of other possible applicable solutions	Circular supply chain mapping, data-driven decision making, optimization of waste management
Output results	User-friendly digital environment that facilitates circular economy business models in construction, provides detailed, traceable information on SRM-based products, local legislation, market trends, and best practices across Europe. Its modular database enables users to easily access relevant data, fostering transparency, efficiency and adoption of sustainable practices.
Benefits expected in operation, especially emphasizing circular economy principles	Increased stakeholder collaboration, adoption of circular practices in construction, development of new circular business models
Necessary human resources for installing and operating	Software developers, data analysts, UX designers, project managers, CE specialists, policy/legislation experts
Possible pitfalls and problems	Regular data updates, user adoption, scalability, cybersecurity
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	Ljubljana, on two places, overall applications map
For TRL>1, who is the technology developer	Developed within the scope of H2020 project CINDERELA, led by Slovenian National Building and Civil Engineering Institute (ZAG)

Table 118 PAS SI-5

Possible applicable solution SI-6	
Name	3D building modelling using spatial extract-transform-load (ETL) solutions, leveraging UAV photogrammetry

Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	3D building modelling using spatial ETL solutions, leveraging UAV photogrammetry as a cost-effective alternative to traditional methods like airborne laser scanning. The process focuses on creating 3D models consistent with the CityGML LOD2 standard from UAV-generated dense image matching point clouds. It was tested in a semi-urban area, highlighting the efficiency, flexibility, and affordability of spatial ETL solutions for geospatial applications, making 3D modelling accessible to smaller entities.
Input raw data	Geospatial data, UAV photos, UAV photogrammetric point clouds, segmented photogrammetric data
Other necessary/recommended digital objects	3D building modelling algorithms, visualization tools, topographic databases
Enabler of other possible applicable solutions	Urban planning and development – 3D city models, building renovation and restoration – 3D building models, large-scale topographic mapping, digital twins for construction projects;
Output results	The developed workflow for data-driven 3D building modelling offers a flexible and modifiable process for various point cloud datasets, ensuring accurate results. It supports applications such as large-scale topographic mapping, 3D city modelling, spatial planning, and analyses like visibility, energy demand, and solar potential. The workflow emphasizes a holistic and transparent approach, delivering 3D building models consistent with the OGC CityGML standard at LOD2.
Benefits expected in operation, especially emphasizing circular economy principles	More efficient planning for construction projects – more efficient use of resources, improved decision making, accurate 3D models can help identify building components that can be repurposed or recycled, lifecycle management
Necessary human resources for installing and operating	Data analysts, GIS specialists, project managers, UAV pilots, software engineers

Possible pitfalls and problems	Potentially high implementation costs for smaller entities, data quality and accuracy, legal and regulatory constraints (UAV flights), integration with other existing systems (especially if those systems are not designed to handle the CityGML standard or the specific LOD2 requirements)
Technology readiness level (TRL)	6
For TRL>4, where it has been already applied	Slovenian countryside, near the village of Vače, with a coverage of approximately 200 × 200 m2
For TRL>1, who is the technology developer	3D model developed by University of Ljubljana, Faculty of Civil and Geodetic Engineering

Table 119 PAS SI-6

Possible applicable solution SI-7	
Name	Digital inspection of bridges with UAV
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Verifying the use of UAVs for damage detection on an 8.9-meter-long bridge section: Equipped with cameras, thermal sensors, ultrasonic sensors, and an infrared scanner, the UAV collected geotagged data to create a precise 3D model. This model identified structural features, cracks, concrete delamination, and reinforcement bars. The UAV accurately detected cracks wider than 0.2 mm and identified delamination areas comparable to traditional methods but with greater efficiency and consistency. This highlights UAVs' potential to enhance damage detection by reducing reliance on inspector skills and enabling non-destructive, data-driven assessments.
Input raw data	UAV images, thermal images, other sensor data, geotag data
Other necessary/recommended digital objects	3D modelling software, visualization platforms/tools, cloud storage, databases (UAV flights, sensor data, geospatial etc.)

Enabler of other possible applicable solutions	Structural health monitoring, construction quality control, digital twin models development, damage detection
Output results	The UAV-based damage detection operation produces precise 3D models of structures in .dwg format, annotated with identified cracks, delaminated areas, and reinforcement bars. It accurately detects cracks wider than 0.2 mm and delamination using overlapping optical and thermal imaging, offering results comparable to traditional methods but with greater efficiency and consistency. Geotagged data ensures accurate spatial referencing, while the process reduces reliance on inspector skills and enables time-saving, non-destructive inspections.
Benefits expected in operation, especially emphasizing circular economy principles	More efficient maintenance planning, more efficient use of resources, using non-destructive methods for inspections, increased lifespan of structures
Necessary human resources for installing and operating	Data analysts, UAV pilots, structural engineers, IT support staff, 3D modelling specialists, inspectors
Possible pitfalls and problems	Regulatory challenges (UAV flight regulations), environmental conditions, need for high-skilled personnel, data security
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	Test site in Slovenia – not specified
For TRL>1, who is the technology developer	Slovenian National Building and Civil Engineering Institute (ZAG) and IGEA d.o.o, Ljubljana

Table 120 PAS SI-7

Possible applicable solution SI-8	
Name	Structural health monitoring with Moisture Content (MC), Relative Humidity (RH) and temperature sensors
Solution category (from the Existing knowledge)	b.i. Showing relevant statistics on raw data and using graphical tools to display the data in an informative way

Description of the applicable solution	In the InnoRenew CoE building, 11 resistance-based MC sensors and 51 RH and temperature sensors were installed in 2020 to monitor moisture levels and environmental conditions in the Cross-laminated Timber (CLT) structure. Measurements began in April 2022 after building commissioning, focusing on high-risk areas like kitchens, bathrooms, and exterior walls. Manual moisture content (MC) measurements were also conducted weekly during construction at 289 floor locations using resistance and capacitance moisture meters. Thermal imaging was employed as a secondary method to detect wet spots, and weather station data was used for correction and analysis.
Input raw data	Sensor data (moisture content, relative humidity, temperature), thermal imaging data, weather data (from nearby weather stations)
Other necessary/recommended digital objects	Cloud-based data storage, BIM model, integration platform, visualizing tools
Enabler of other possible applicable solutions	Predictive maintenance, smart building integration, energy efficiency optimization, digital twin development, quality control
Output results	Real-time data on moisture content (MC), relative humidity (RH), and temperature within the CLT structure and building envelope. This data is processed to identify moisture trends, detect potential risks like wet spots or mold-prone areas, and ensure compliance with moisture thresholds during construction and operation. The system provides actionable insights for maintenance, durability assessment, and optimization of moisture control strategies, enhancing the building's long-term performance and sustainability.
Benefits expected in operation, especially emphasizing circular economy principles	Prolonged building lifespan, material preservation, reduced waste, sustainable maintenance (targeted data-driven interventions)
Necessary human resources for installing and operating	Software developers, sensor technicians, data analysts, structural engineers, IT support

Possible pitfalls and problems	Sensor malfunctions or calibration issues, sensor maintenance, environmental interferences, data security, integration challenges
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	InnoRenew CoE building, Izola, Slovenia
For TRL>1, who is the technology developer	InnoRenew Center of Excellence

Table 121 PAS SI-8

Possible applicable solution SI-9	
Name	Monitoring of rockfall prone areas
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	In the RI-SI-EPOS project, co-funded by Slovenia and the EU, a range of advanced geotechnical sensors were installed in eastern Slovenia in 2021 to monitor rockfalls and related risks. Equipment included rain gauges, air temperature and humidity sensors, tiltmeters, rock stress and deformability kits, laser distance gauges, crack meters, and temperature sensors at various depths. These sensors are connected via LoRaWAN, enabling long-range, low-power wireless communication and in-situ data logging to ensure minimal data loss. The monitoring areas were chosen based on rockfall frequency, risk to infrastructure, and rock diversity, with data helping to assess factors like fractures, exfoliation, and discontinuities in different rock types.
Input raw data	Environmental data, geospatial data, sensor data (temperature, humidity, near surface rock temperature), data from tiltmeters, crack meters, and laser distance gauges
Other necessary/recommended digital objects	Communication infrastructure, data cloud storages, visualization platforms, data processing software, automated alert system

Enabler of other possible applicable solutions	Infrastructure risk assessments, early warning systems, data integration for digital twins
Output results	The system outputs real-time geotechnical and environmental data, including measurements of rock stress, deformation, temperature, humidity, and rainfall. It provides insights into rock stability by identifying fractures, discontinuities, and deformation trends, enabling early detection of rockfall risks. Processed data is stored securely and visualized using GIS or 3D models, allowing for effective monitoring, analysis, and decision-making.
Benefits expected in operation, especially emphasizing circular economy principles	Extended lifespan of infrastructure, sustainable/targeted maintenance, possibility to build early warning systems for disaster prevention
Necessary human resources for installing and operating	Sensor technicians, data analysts, geotechnical engineers, IT and network specialists, GIS specialists, environmental scientists
Possible pitfalls and problems	Sensor malfunctions, connectivity issues, integration challenges, data security, limited coverage (may not be sufficient for large or geographically dispersed monitoring areas)
Technology readiness level (TRL)	5
For TRL>4, where it has been already applied	Smrekovec volcanic complex, eastern Slovenia
For TRL>1, who is the technology developer	Developed within »Development of research infrastructure for the international competitiveness of the Slovenian RRI Space – RI-SI-EPOS« project by Geological Information Centre, University of Ljubljana Faculty of Civil and Geodetic Engineering and University of Ljubljana Biotechnical Faculty

Table 122 PAS SI-9

Possible applicable solution SI-10	
Name	Digital Framework for Regenerative Design
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support

Description of the applicable solution	Digital framework aimed at transitioning from sustainability to regenerative design in the built environment, integrating Building Information Modelling (BIM) and computational design. It promotes positive impacts on both human and natural systems. It uses digital tools to evaluate climate, human well-being, and ecological indicators, supporting carbon reduction, comfort, and ecological restoration. The solution provides dynamic, quantifiable feedback to refine designs iteratively for positive human and environmental impacts.
Input raw data	Building geometries, environmental parameters, material properties, weather data, urban context details
Other necessary/recommended digital objects	BIM platforms, computational design tools, life cycle assessment software, simulation engines
Enabler of other possible applicable solutions	Urban planning, lifecycle assessments, green certification processes
Output results	The framework generates insights such as optimized design metrics for carbon reduction, daylight performance, thermal comfort, and ecological benefits. It outputs quantifiable indicators, comparative analyses of alternative designs and strategies for achieving regenerative goals.
Benefits expected in operation, especially emphasizing circular economy principles	Optimization of resource use, wate reduction, enhanced efficiency and durability of buildings, minimizing ecological disruptions in built environment
Necessary human resources for installing and operating	Architects, environmental engineers, BIM specialists, designers
Possible pitfalls and problems	Need for high technical expertise, issues with tool interoperability, incomplete input data, data safety
Technology readiness level (TRL)	6
For TRL>4, where it has been already applied	Residential project in Ljubljana, Slovenia
For TRL>1, who is the technology developer	Case implemented by University of Ljubljana Faculty of Civil and Geodetic Engineering and Royal Institute

	of Technology, School of Architecture and the Built Environment

Table 123 PAS SI-10

Slovakia

Possible applicable solution SK-1	
Name	Photovoltaic Prediction and Transfer Learning Collaboration
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables
Description of the applicable solution	This project aims to develop accurate solar energy forecasts, even for newly installed solar panels with limited data. Through transfer learning, which reuses knowledge from other datasets, the models offer reliable forecasts by training on similar data, helping make predictions that support efficient energy planning and usage.
Input raw data	Historical data on photovoltaic (PV) production, weather forecasts
Other necessary/recommended digital objects	Large datasets from similar PV installations in the region, models for transfer learning
Enabler of other possible applicable solutions	The data and models developed in this project can be applied to other renewable energy projects, grid management solutions, and fault prediction systems for energy infrastructure
Output results	Provides day-ahead and intraday forecasts for PV energy production
Benefits expected in operation, especially emphasizing circular economy principles	Improved PV production predictions support efficient use of renewable energy and can reduce dependency on non-renewable sources
Necessary human resources for installing and operating	Data scientists, machine learning engineers for model development, IT support to handle data collection and storage, and energy sector specialists to ensure practical model application.
Possible pitfalls and problems	Data limitations for new PV installations may affect accuracy. Potential challenges include adapting

	models for different climates, ensuring data privacy, and accessing real-time weather data.
Technology readiness level (TRL)	TRL 6-7: This solution has been tested in real-world environments and is partially operational. The approach has been validated in similar European PV installations and is being refined for larger application.
For TRL>4, where it has been already applied	Applied in PV installations across Central Europe, specifically for short-term PV prediction
For TRL>1, who is the technology developer	Developed by Kempelen Institute of Intelligent Technologies (KInIT) in collaboration with SFÉRA, with expertise in renewable energy forecasting and advanced machine learning techniques, particularly transfer learning

Table 124 PAS SK-1

Possible applicable solution SK-2	
Name	V4Grid V2X Technology for Construction Sites
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	The V4Grid project allows construction sites to use electric vehicles (EVs) as flexible energy resources through V2X (Vehicle-to-Everything) technology. EVs can store energy and send it back to the construction site's grid as needed.
Input raw data	Data on EV battery charge levels, energy consumption patterns on construction sites, and weather data for predicting solar energy availability
Other necessary/recommended digital objects	Smart energy meters on construction sites, bi-directional chargers, AI-powered energy monitoring and forecasting software
Enabler of other possible applicable solutions	Supports renewable energy sources (solar panels) for energy generation on-site, reduces dependency on external energy, enabling more remote and sustainable construction operations
Output results	Efficient energy distribution and usage on construction sites, Optimized EV charging and

	discharging cycles Increased uptime and energy availability on-site
Benefits expected in operation, especially emphasizing circular economy principles	Reduces reliance on fuel-based generators, lowering emissions; Improves resilience and self-sufficiency by creating an on-site energy buffer; Enhances resource use efficiency by storing and distributing renewable energy
Necessary human resources for installing and operating	Energy management technician; Electric vehicle charging and maintenance specialist
Possible pitfalls and problems	Potential conflicts between EVs' energy usage for transportation vs. energy sharing; Limited battery storage for large-scale energy requirements on large sites; Regulatory challenges on energy reselling or sharing policies
Technology readiness level (TRL)	TRL 6 – Technology demonstrated in a relevant environment
For TRL>4, where it has been already applied	Pilot programs and demonstrations across Europe, including energy and transport sectors
For TRL>1, who is the technology developer	Kempelen Institute of Intelligent Technologies and V4Grid project partners

Table 125 PAS SK-2

Possible applicable solution SK-3	
Name	Data Analysis and Modelling for Microgrid Support
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	This technology provides a model that simulates energy flow within microgrids, integrating elements like consumers, renewable energy sources (RES), and batteries. It allows for testing energy-sharing and management strategies.
Input raw data	Energy consumption patterns on construction sites; Data from renewable sources (solar and wind); Battery charge levels and environmental data (weather, seasonality)
Other necessary/recommended digital objects	High-capacity batteries; Smart meters to measure and optimize energy flow; Data visualization software for grid management

Enabler of other possible applicable solutions	Supports renewable energy integration on construction sites; Facilitates off-grid or remote site operations with limited access to traditional power sources
Output results	Optimizing panel and battery sizes helps prevent waste by matching installations to user needs, maximizing the use of green energy while minimizing costs and enhancing system longevity.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces reliance on traditional fuel generators, minimizing carbon footprint; Provides autonomous energy for remote construction sites; Enhances resource efficiency and resilience by using locally produced renewable energy
Necessary human resources for installing and operating	Energy technician; Data analyst for monitoring and optimizing energy use; Microgrid manager for configuration and troubleshooting
Possible pitfalls and problems	Energy flow variability due to RES volatility (e.g., limited solar power at night); Complexity of optimizing real-time distribution between batteries, EVs, and construction equipment demand
Technology readiness level (TRL)	TRL 5 – Technology validated in a relevant environment
For TRL>4, where it has been already applied	Used in research projects and pilot programs for construction site and industrial energy management
For TRL>1, who is the technology developer	SFÉRA and Kempelen Institute of Intelligent Technologies

Table 126 PAS SK-3

Possible applicable solution SK-4	
Name	AI for Smart Energy Households
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	This solution uses AI to analyse energy consumption data from smart meters, disaggregating usage by individual appliances. This helps customers understand their energy usage better.
Input raw data	Data from smart meters that capture household energy consumption, potentially in lower resolution.

Other necessary/recommended digital objects	AI algorithms for data processing, visualization tools for customer insights, and a user-friendly interface for interaction.
Enabler of other possible applicable solutions	Increases customer engagement and awareness of energy use, which could lead to other smart energy solutions and tools for efficiency.
Output results	Improved understanding of energy usage patterns, potential cost savings, and increased engagement in energy management by households.
Benefits expected in operation, especially emphasizing circular economy principles	Greater energy efficiency, reduced waste, and enhanced consumer control over energy usage, contributing to sustainability efforts.
Necessary human resources for installing and operating	Data scientists to develop AI models, software developers for user interface, and customer service representatives for user support.
Possible pitfalls and problems	Challenges in achieving precision with lower-resolution data, potential customer resistance to using new tools, and the need for ongoing maintenance and updates of AI models.
Technology readiness level (TRL)	TRL 5 - technology validated in relevant environment
For TRL>4, where it has been already applied	Similar disaggregation techniques have been successfully applied in other energy monitoring systems and pilot projects
For TRL>1, who is the technology developer	Developed by Zapadnoslovenska energetika (ZSE) in collaboration with Kempelen Institute of Intelligent Technologies

Table 127 PAS SK-4

Possible applicable solution SK-5	
Name	PREDICT: Predictive Model for Electricity Transmission Losses
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables
Description of the applicable solution	AI-based predictive model for forecasting transmission losses on power lines to reduce costs and increase stability

Input raw data	Historical data on network load, weather data, and data-engineered attributes
Other necessary/recommended digital objects	Smart meters, weather data stations
Enabler of other possible applicable solutions	Supports energy cost reduction, can be integrated into broader grid management solutions
Output results	Forecasts of transmission losses, alerts for potential inefficiencies or instabilities
Benefits expected in operation, especially emphasizing circular economy principles	Enhances energy efficiency by accurately predicting losses, reducing the need for extra power generation and grid load
Necessary human resources for installing and operating	Data scientists, energy analysts, network operators
Possible pitfalls and problems	Forecast inaccuracy due to variable weather or unexpected energy demands, requires regular data updates
Technology readiness level (TRL)	TRL 4 - technology validated in lab
For TRL>4, where it has been already applied	-
For TRL>1, who is the technology developer	Developed by Kempelen Institute of Intelligent Technologies

Table 128 PAS SK-5

Possible applicable solution SK-6	
Name	Softec: Optimizing Winter Road Maintenance
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Predictive modelling and optimization algorithms using AI and machine learning to enhance winter road maintenance, ensuring safer and faster winter commutes for drivers.
Input raw data	Real-time data from IoT devices (temperature, moisture, surface state), weather data from SHMÚ (Slovak Hydrometeorological Institute), radar precipitation data.

Other necessary/recommended digital objects	IoT devices for road monitoring, radar systems, AI algorithms for decision support, weather data stations.
Enabler of other possible applicable solutions	Supports better road maintenance strategies, can be integrated into broader traffic management and emergency response systems.
Output results	Improved models of current road conditions, forecasts of future road states, optimized dispatching plans for maintenance vehicles.
Benefits expected in operation, especially emphasizing circular economy principles	Reduces hazardous driving conditions, optimizes resource allocation for road maintenance, and minimizes environmental impact by ensuring efficient use of maintenance resources.
Necessary human resources for installing and operating	Data scientists, AI specialists, traffic management experts, maintenance personnel.
Possible pitfalls and problems	Dependence on accurate sensor data, potential inaccuracies in predictions due to unforeseen weather conditions, integration challenges with existing systems.
Technology readiness level (TRL)	TRL 5 - technology validated in a relevant environment
For TRL>4, where it has been already applied	Ongoing testing and application in winter road maintenance across regions with significant snowfall in Slovakia
For TRL>1, who is the technology developer	Developed by Softec in collaboration with Kempelen Institute of Intelligent Technologies.

Table 129 PAS SK-6

Possible applicable solution SK-7	
Name	KZ Dvory: Smart Energy Monitoring and Control
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	The system integrates edge devices for data collection, local storage and transfer to a cloud platform. The cloud enables online data processing, allowing for real-time actions based on collected data, such as disconnecting charging outlets to prevent battery overcharging.

Input raw data	Data from energy meters, including battery charge levels, energy consumption, and device operational states.
Other necessary/recommended digital objects	Modbus communication protocol, MQTT connector for data transfer, SQLite buffer for local storage, and Thingsboard PE for data visualization and historical storage.
Enabler of other possible applicable solutions	This setup can enable smart grid optimization, efficient energy management in residential and industrial applications, and integration with broader energy monitoring systems to enhance sustainability.
Output results	Visual dashboards for monitoring, historical data storage for analysis, and automated actions based on predefined conditions, such as preventing battery overcharging or optimizing energy distribution.
Benefits expected in operation, especially emphasizing circular economy principles	The solution supports efficient energy utilization by preventing unnecessary energy waste and ensuring optimal battery usage. It reduces costs, increases the lifespan of batteries, and promotes smarter energy usage aligned with sustainability goals.
Necessary human resources for installing and operating	IT professionals for system setup and maintenance, engineers for configuring edge devices, and energy managers to interpret data and implement optimization strategies.
Possible pitfalls and problems	Potential connectivity issues between edge devices and the cloud, security risks associated with IoT systems, and potential misconfigurations in automated responses that could disrupt energy flow.
Technology readiness level (TRL)	TRL 7: System prototype demonstrated in an operational environment.
For TRL>4, where it has been already applied	Applied in the KZ Dvory system for smart energy monitoring and control in real-world conditions, enabling efficient energy management.
For TRL>1, who is the technology developer	Local implementation by KZ Dvory, utilizing widely available IoT and cloud-based tools, such as Raspberry Pi, MQTT, and Thingsboard PE, for a comprehensive energy monitoring and control solution.

Table 130 PAS SK-7

Possible applicable solution SK-8	
Name	Simulations of Energy Communities
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	This solution involves using specialized software capable of processing large-scale datasets and performing advanced matrix operations, which are more efficient and scalable compared to traditional spreadsheet tools like Excel. It supports both data visualization and integration into online processing pipelines for real-time decision-making.
Input raw data	Large-scale energy datasets, including energy production, consumption patterns, pricing information, and grid dynamics from energy communities.
Other necessary/recommended digital objects	High-performance computational software (e.g., Python-based libraries, MATLAB, or similar tools), visualization libraries for presenting results, and data storage platforms for handling large datasets.
Enabler of other possible applicable solutions	This software can enhance decision-making in real-time energy management, enable predictive modelling, and optimize the energy balance in communities by integrating with IoT devices or cloud processing solutions.
Output results	The output includes visualizations of energy production, consumption, and optimization metrics, as well as automated decision-making capabilities based on predefined scenarios, like balancing community energy needs or improving grid stability.
Benefits expected in operation, especially emphasizing circular economy principles	The solution facilitates efficient energy utilization in local energy communities, reduces energy waste, and promotes renewable energy adoption through effective planning and decision-making based on large-scale data analysis.

Necessary human resources for installing and operating	Data scientists or analysts to configure the software and develop models, IT professionals to manage data integration and processing, and energy experts to interpret the analysis results and apply them in real-world scenarios.
Possible pitfalls and problems	The primary challenges include handling data from multiple sources with different formats, ensuring the software operates efficiently in real-time scenarios, and avoiding overfitting or inaccuracies in the decision-making models.
Technology readiness level (TRL)	TRL 5: Technology validated in a relevant environment
For TRL>4, where it has been already applied	Applied in pilot projects for simulating energy community scenarios, optimizing energy flows, and supporting planning in local grids.
For TRL>1, who is the technology developer	Developed by local and international organizations working on advanced data processing and simulation tools, leveraging energy sector expertise

Table 131 PAS SK-8

Possible applicable solution SK-9	
Name	Greenlogy: Forecasting one-day-ahead solar panel energy supply to the grid
Solution category (from the Existing knowledge)	b.ii.2. Prediction of time-dependent variables
Description of the applicable solution	Greenlogy focuses on creating a predictive model for forecasting one-day-ahead solar panel energy supply to the grid. This solution leverages advanced machine learning techniques to analyse data from smart meters and predict energy production.
Input raw data	The input data includes historical and real-time energy production data from smart meters, meteorological factors such as weather forecasts, solar position parameters, and static categorical factors like the day of the week or holidays.
Other necessary/recommended digital objects	Smart meters, cloud-based platforms for data aggregation and analysis, and machine learning models designed for energy prediction.

Enabler of other possible applicable solutions	The model can be extended to support grid stabilization strategies, renewable energy integration into the grid, and optimize energy trading on electricity markets.
Output results	The output is a predictive model capable of accurately forecasting solar energy production one day ahead, which can be directly implemented by energy companies to improve grid stability and energy management.
Benefits expected in operation, especially emphasizing circular economy principles	The predictive model enhances the integration of solar energy into the grid, reduces the risk of disruptions, and supports sustainable energy management by improving the predictability of this inherently unstable energy source.
Necessary human resources for installing and operating	Energy experts to analyse and validate the predictions, data scientists to refine and update the machine learning models, and IT professionals for maintaining the underlying infrastructure.
Possible pitfalls and problems	The primary challenges include dealing with the variability of meteorological data, maintaining accuracy with limited data from new installations, and ensuring the robustness of the model in different regions and conditions.
Technology readiness level (TRL)	TRL 7: System prototype demonstrated in operational environment
For TRL>4, where it has been already applied	The solution has been implemented for operational use by Greenlogy to predict solar energy supply in specific locations in Slovakia.
For TRL>1, who is the technology developer	Greenlogy, a Slovak company founded in 2021, specializes in supplying electricity generated from renewable energy sources and focuses on supporting the green transition - in collaboration with Kempelen Institute of INtelligent Technologies

Table 132 PAS SK-9

Possible applicable solution SK-10	
Name	MERATCH by GOSPACE LABS

Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	MERATCH provides an IoT-based system for real-time water quality monitoring in rivers and lakes. It includes advanced water quality sensors to identify trends, detect anomalies, and support decision-making for sustainable water resource management.
Input raw data	Real-time and historical water quality parameters, including chemical composition, temperature, and water level data from rivers and lakes.
Other necessary/recommended digital objects	IoT sensors, cloud-based storage systems, and data processing algorithms for hydrological modelling and anomaly detection.
Enabler of other possible applicable solutions	Can be used to build digital twins of aquatic environments, predict flash floods, monitor pollution sources, and evaluate the effects of climate change on water systems.
Output results	Reports on water quality trends, identification of pollution sources, predictions of water-related events (e.g., floods), and support for sustainable environmental policies.
Benefits expected in operation, especially emphasizing circular economy principles	Prevention of water contamination through early detection of pollutants; Improved water management by municipalities and water companies; Public awareness and policymaking support; Sustainable use of water resources
Necessary human resources for installing and operating	Experts in IoT sensor installation and maintenance; Hydrologists for interpreting data; IT professionals for managing data storage and analytics platforms
Possible pitfalls and problems	Sensor durability under harsh environmental conditions; High initial costs of installation; Potential data gaps due to sensor malfunctions or connectivity issues; Complex integration with existing water management systems
Technology readiness level (TRL)	TRL 6 Technology demonstrated in a relevant environment
For TRL>4, where it has been already applied	Pilot implementations in rivers and lakes for monitoring agricultural pollution and other human activities

For TRL>1, who is the technology developer	GOSPACE LABS s.r.o., a Slovak company specializing in IoT and water monitoring solutions

Table 133 PAS SK-10

Other parts of the world

Possible applicable solution W-1	
Name	TestFit - Real estate feasibility and early-stage site planning tool
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	TestFit automates and streamlines site planning and building configuration for architects and developers. By using AI-powered real-time tools, it enables rapid prototyping of site layouts, massing, and deal evaluation. It supports decision-making in urban development, focusing on zoning, unit mixes, building codes, and cost optimization.
Input raw data	Parcel data, measures and bounds for site outlines, topography information, zoning requirements and building codes, unit mix data, financial metrics for deal evaluation
Other necessary/recommended digital objects	Existing architectural or zoning documentation, integration with tools like Revit, SketchUp, AutoCAD (.dxf), and Excel (.csv).
Enabler of other possible applicable solutions	Detailed design documentation via integrations (e.g., Revit, SketchUp), data-driven urban planning and financial forecasting, iterative testing of mixed-use, multi-family, and industrial project typologies
Output results	3D visualizations of site layouts, real-time costing and quantity take-offs, optimized site plans adhering to zoning and building codes, comprehensive reports for client decision-making
Benefits expected in operation, especially emphasizing circular economy principles	Time savings: Faster feasibility studies and iterations, reducing resource use; Material optimization: Generates accurate quantity and minimizes waste in construction; Sustainability: Supports innovative and efficient urban designs; Cost efficiency: Early

	detection of financial or design constraints saves resources.
Necessary human resources for installing and operating	IT specialists (to set up and ensure compatibility with existing systems), architects or urban planners (for inputting data and analysing results), project managers (to coordinate feasibility and decision-making processes).
Possible pitfalls and problems	Dependence on high-quality input data (errors in parcel or zoning data could compromise results), integration challenges with existing tools or workflows, users may require training.
Technology readiness level (TRL)	TRL 8-9 (system complete and qualified, now also being proven in operational settings).
For TRL>4, where it has been already applied	Applied on more than 2000 projects per week
For TRL>1, who is the technology developer	TestFit Inc.

Table 134 PAS W-1

Possible applicable solution W-2	
Name	Smart Building F40
Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	A smart building equipped with photovoltaic panels, energy storage systems, and intelligent management systems (BEMS and EMS) that enable flexible energy demand and prosumer capabilities.
Input raw data	Energy consumption data, comfort level data, weather forecasts, energy market prices, battery status, and PV production data.
Other necessary/recommended digital objects	IoT sensors, smart meters, automated windows and shading systems, remote monitoring and control devices.
Enabler of other possible applicable solutions	Enables automated demand response, energy optimization strategies, and dynamic comfort control.

Output results	Optimized energy consumption, dynamic temperature control, reduced peak loads, and improved energy efficiency.
Benefits expected in operation, especially emphasizing circular economy principles	Reducing energy consumption and costs through automation, enhanced integration of renewable energy, prolonged lifespan of systems via predictive control, supports grid stability and reduces the need for additional grid infrastructure.
Necessary human resources for installing and operating	Energy managers, IoT specialists, software developers, HVAC technicians, and facility managers.
Possible pitfalls and problems	Still in piloting process
Technology readiness level (TRL)	TRL 6
For TRL>4, where it has been already applied	Pilot implementation in ENEA Casaccia Research Centre (Rome)
For TRL>1, who is the technology developer	Developed by ENEA and funded by the Italian Ministry of the Environment and Energy Security

Table 135 PAS W-2

Possible applicable solution W-3	
Name	Radoff Sense
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Advanced air quality monitoring device focused on detecting radon, particulate matter (PM), and CO_2 in indoor environments.
Input raw data	Radon levels, particulate matter (PM) concentrations, CO_2 levels, temperature, and humidity.
Other necessary/recommended digital objects	IoT connectivity platform, mobile app for real-time data access, AI-based analysis system.
Enabler of other possible applicable solutions	Data-driven insights for HVAC control systems, energy management optimization, and health risk mitigation strategies.
Output results	Real-time air quality metrics, alerts for hazardous conditions, recommendations for improving indoor air safety.

Benefits expected in operation, especially emphasizing circular economy principles	Improved indoor air quality, early detection and mitigation of radon exposure, supports circular economy by promoting healthier living spaces.
Necessary human resources for installing and operating	Device ready to use in household environments. Not sure if privacy allows for larger models data gathering.
Possible pitfalls and problems	Possible sensor calibration requirements, potential connectivity issues in low-signal environments, probable regular maintenance of sensors and battery.
Technology readiness level (TRL)	TRL 8
For TRL>4, where it has been already applied	Residential buildings, schools, office spaces, and healthcare facilities across Europe and North America.
For TRL>1, who is the technology developer	Radoff, Italy

Table 136 PAS W-3

Possible applicable solution W-4	
Name	DIGITALIS - DIGItal Twin for heALthy buIldingS
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	DIGITALIS aims to create and deploy digital twins for buildings to enhance their health, sustainability, and energy efficiency. Digital twins will simulate real-time building conditions, assess risks, and optimize operational strategies.
Input raw data	Structural data, environmental parameters, energy consumption, occupant behaviour, and IoT sensor data.
Other necessary/recommended digital objects	BIM models, AI-driven analytics platforms, historical data repositories, real-time IoT devices.
Enabler of other possible applicable solutions	Digital twins can support predictive maintenance, energy optimization, and dynamic resource allocation. They also enable scenario analysis and risk mitigation strategies.

Output results	Real-time simulations, predictive insights, optimized energy use, enhanced building health parameters, and maintenance schedules.
Benefits expected in operation, especially emphasizing circular economy principles	Optimizes resource use, reduces waste through predictive maintenance, lowers energy consumption, and increases building lifespan by identifying risks early. Contributes to net-zero goals by improving energy efficiency and occupant well-being.
Necessary human resources for installing and operating	Engineers, architects, data scientists, digital twin specialists, facility managers, and IT support teams.
Possible pitfalls and problems	Data interoperability challenges, integration complexities with legacy systems, high initial setup costs, and the need for skilled personnel for digital twin management.
Technology readiness level (TRL)	TRL 5-7: Demonstrated in a relevant environment, but ongoing development for full deployment.
For TRL>4, where it has been already applied	Ongoing implementations in academic and pilot projects focusing on health and sustainability in buildings.
For TRL>1, who is the technology developer	University of Rome - Sapienza, in collaboration with other academic and industrial partners.

Table 137 PAS W-4

Possible applicable solution W-5	
Name	EdilGo
Solution category (from the Existing knowledge)	a.iii. Data structuring and ensuring data quality, accessibility, and interoperability
Description of the applicable solution	Construction management platform that automates tendering processes, organizes supply requests, and enhances project planning with AI-driven insights.
Input raw data	Project specifications, supplier price lists, requests for quotes (RFQs), budget estimates.
Other necessary/recommended digital objects	Supplier databases, project templates, construction material catalogues.
Enabler of other possible applicable solutions	Facilitates supplier selection, cost estimation, and tender management.

Output results	Organized RFQs, budget analysis, feasibility studies, and optimized supply chains.
Benefits expected in operation, especially emphasizing circular economy principles	Streamlined procurement process, cost savings through optimized supply chains, enhanced project planning and resource allocation.
Necessary human resources for installing and operating	Project managers, procurement officers, and IT support staff.
Possible pitfalls and problems	Dependence on supplier data accuracy; potential integration challenges with legacy systems.
Technology readiness level (TRL)	TRL 6
For TRL>4, where it has been already applied	Applied in Italy for various construction projects to manage procurement and tendering processes.
For TRL>1, who is the technology developer	calcolostrutturale.com based in Milan, Italy

Table 138 PAS W-5

Possible applicable solution W-6	
Name	Displayed Structural Health Monitoring (SHM) Solution
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	A comprehensive monitoring system using IoT sensors, AI-powered algorithms, and a digital twin platform to assess infrastructure health, predict anomalies, and manage structural networks efficiently.
Input raw data	Structural variables (inclination, temperature), environmental data, and other sensor readings
Other necessary/recommended digital objects	IoT sensor nodes, solar-powered units, data fusion algorithms, digital twin dashboard
Enabler of other possible applicable solutions	Facilitates predictive maintenance, improves infrastructure management, supports decision-making for repairs and safety interventions
Output results	Key performance indicators (KPIs), structural health reports, real-time alerts, visual dashboards with insights

Benefits expected in operation, especially emphasizing circular economy principles	Reduced maintenance costs through early detection of anomalies, increased safety and resilience of infrastructures, enhanced sustainability by extending the lifespan of structures
Necessary human resources for installing and operating	Engineers for sensor deployment and maintenance, data analysts, infrastructure managers for decision-making based on insights
Possible pitfalls and problems	Challenges in sensor installation on complex sites, data inaccuracies due to environmental interference, potential cybersecurity risks
Technology readiness level (TRL)	TRL 6-7 (demonstrated in operational environments, ongoing real-world deployment)
For TRL>4, where it has been already applied	Used in monitoring bridges and viaducts across Italy and Europe, scalable to different types of infrastructure
For TRL>1, who is the technology developer	Displaid S.R.L. (Italy) in collaboration with academic institutions like Politecnico di Milano, TU Delft, and MIT

Table 139 PAS W-6

Possible applicable solution W-7	
Name	Archygram
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Archygram is a digital platform leveraging AI and photogrammetry to create accurate 3D models of lost or damaged architectural heritage using archival images and videos. It automates the process of capturing measurements and generating architectural plans from photos, including low-quality images. Its applications extend beyond cultural preservation to construction and real estate sectors.
Input raw data	Historical images, videos, and photographs captured with mobile devices.
Other necessary/recommended digital objects	Archival databases, photogrammetric software, AI algorithms for data synthesis.

Enabler of other possible applicable solutions	Facilitates digital reconstruction of cultural heritage, supports architectural restoration, and provides accurate 3D modelling
Output results	Precise 3D models, architectural drawings with metric accuracy, and interactive digital visualizations.
Benefits expected in operation, especially emphasizing circular economy principles	Enhances cultural heritage preservation, reduces environmental impact by promoting restoration over new construction, democratizes access to 3D modelling with low-cost tools, and supports circular economy principles through material reuse and reduced resource consumption.
Necessary human resources for installing and operating	Architects, AI specialists, photogrammetry experts, and software developers.
Possible pitfalls and problems	Dependence on image quality, potential data gaps in archival sources, and ongoing need for technological refinement and testing.
Technology readiness level (TRL)	TRL 4
For TRL>4, where it has been already applied	Not yet applied commercially; ongoing tests in various sectors, including cultural heritage and real estate.
For TRL>1, who is the technology developer	Archygram, Bolzano, Italy

Table 140 PAS W-7

Possible applicable solution W-8	
Name	Koone Construction
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	Koone Construction is a safety management platform for construction sites. It uses IoT devices and AI-based image analysis to monitor and identify risks. Smart HD cameras capture data and apply AI models to recognize hazardous events, enabling preventive strategies and real-time alerts. The system supports predictive safety analysis and automation.

Input raw data	HD images, IoT sensor data from smart cameras, and site-specific environmental data.
Other necessary/recommended digital objects	Machine Learning models, Deep Learning algorithms, cloud infrastructure (AWS), and Docker for data processing.
Enabler of other possible applicable solutions	Supports predictive safety analysis, integrates with IoT devices and blockchain for smart contracts, and automates safety protocols.
Output results	Real-time alerts, predictive safety analytics, automated risk mitigation strategies, and dashboard visualizations.
Benefits expected in operation, especially emphasizing circular economy principles	Enhances worker safety by preventing accidents, optimizes site management, improves productivity through automation, and ensures data privacy and compliance. It also contributes to sustainability by streamlining processes and reducing downtime.
Necessary human resources for installing and operating	IT specialists, AI and Machine Learning experts, site managers, and safety officers.
Possible pitfalls and problems	Dependence on network connectivity, potential privacy concerns, and the need for continuous AI model updates and testing.
Technology readiness level (TRL)	TRL 6
For TRL>4, where it has been already applied	Used in some construction sites in Italy for safety monitoring and automation
For TRL>1, who is the technology developer	Binoocle based in Bologna, distributed by Harpaceas in Italy

Table 141 PAS W-8

Possible applicable solution W-9	
Name	Cobuilder
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility, and interoperability
Description of the applicable solution	Cobuilder is a comprehensive software platform designed to optimize data management and information flow in the construction supply chain. It focuses on structuring and standardizing product

	data to ensure compliance with international standards, enhancing collaboration and efficiency.
Input raw data	Product specifications, material data, project requirements, BIM data, regulatory standards.
Other necessary/recommended digital objects	Data templates (DTs), Data dictionaries, IFC models, Information Delivery Specifications (IDS).
Enabler of other possible applicable solutions	Facilitates BIM integration, enhances supply chain collaboration, improves compliance management, and supports automated validation of project data.
Output results	Standardized data templates, interoperable digital models, enriched BIM models, product documentation, compliance reports.
Benefits expected in operation, especially emphasizing circular economy principles	Enhanced data quality and governance, improved interoperability and collaboration across stakeholders, streamlined project execution, circular economy benefits through optimized material use and digital documentation.
Necessary human resources for installing and operating	Data managers, BIM coordinators, supply chain managers, IT specialists, regulatory compliance officers.
Possible pitfalls and problems	Potential complexity in data standardization processes, initial setup and customization challenges, dependency on data input quality from external stakeholders
Technology readiness level (TRL)	TRL 7
For TRL>4, where it has been already applied	Deployed in construction projects across Europe, supporting supply chain data management and compliance.
For TRL>1, who is the technology developer	Cobuilder AS (Norway); in Italy it is operated thorugh Harpaceas

Table 142 PAS W-9

Possible applicable solution W-10	
Name	InnovationChain

Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	InnovationChain integrates Building Information Modeling (BIM) with blockchain technology to create digital platforms that enhance automation and notarization of workflows. These solutions ensure data integrity, improve productivity, and optimize lifecycle costs in construction projects.
Input raw data	BIM models, project documentation, contract data, supply chain information, asset lifecycle data.
Other necessary/recommended digital objects	Common Data Environment (CDE), blockchain ledger, smart contracts, digital twins.
Enabler of other possible applicable solutions	Facilitates data security, workflow automation, and project transparency; enables traceability and compliance management in construction.
Output results	Verified digital records, automated workflows, blockchain-registered transactions, enhanced BIM data integrity.
Benefits expected in operation, especially emphasizing circular economy principles	Improved project governance and data transparency, enhanced security and integrity through blockchain notarization, increased efficiency and reduced lifecycle costs, accelerated project timelines.
Necessary human resources for installing and operating	BIM specialists, blockchain developers, project managers, data governance experts, IT support.
Possible pitfalls and problems	Complexity of integrating BIM and blockchain technologies, high initial implementation costs, regulatory and compliance challenges.
Technology readiness level (TRL)	TRL 4
For TRL>4, where it has been already applied	Currently being developed for integration in construction workflows, focusing on proof-of-concept stages.
For TRL>1, who is the technology developer	InnovationChain, a joint venture between Harpaceas and RaiseUp

Table 143 PAS W-10

Possible applicable solution W-11

Name	IoT Tokbo Platform
Solution category (from the Existing knowledge)	b.ii.1. Estimation of specific variables or parameters that give new insights
Description of the applicable solution	Tokbo is a smart IoT solution designed for monitoring bolted joints in real-time, detecting anomalies such as stress, temperature, vibration, and inclination. The solution provides predictive maintenance insights for enhanced safety and efficiency in infrastructure and industrial machinery.
Input raw data	Stress state of the joint, temperature, vibrations, inclinometer data, accelerations, tension and elongation
Other necessary/recommended digital objects	Cloud-based platform, gateway for sensor connectivity
Enabler of other possible applicable solutions	Maintenance optimization, data-driven decision-making for infrastructure management, environmental monitoring systems
Output results	Real-time monitoring of joint status, alerts for anomaly detection, predictive maintenance schedules, data analysis reports
Benefits expected in operation, especially emphasizing circular economy principles	Optimizes resource use by preventing unnecessary maintenance, enhances equipment lifespan by monitoring conditions and addressing issues promptly, improves safety and efficiency
Necessary human resources for installing and operating	Engineers for sensor installation, maintenance technicians for monitoring, IT specialists for platform setup and integration
Possible pitfalls and problems	Possible complex installation for existing structures, sensor calibration may be sensitive to environmental conditions, potential network connectivity issues
Technology readiness level (TRL)	TRL 7
For TRL>4, where it has been already applied	Transportation infrastructure (roads, railways, airports, ports), Industrial machinery for production systems
For TRL>1, who is the technology developer	Tokbo was developed through a joint venture between Gruppo Agrati (a leader in fastening

	solutions) and E-novia (a deep-tech solutions provider)

Table 144 PAS W-11

Possible applicable solution W-12	
Name	bGrid
Solution category (from the Existing knowledge)	b.ii.3. Explicit decision support
Description of the applicable solution	bGrid has implemented a network of sensors connected to the Internet of Things (IoT) within the NEXT Delft building. This system serves as a digital backbone, enabling the building to sense, collect, position, control, and learn from various data points, thereby providing actionable insights for building owners, operators, and occupants.
Input raw data	Utilization of meeting rooms and workspaces: Air quality parameters, Temperature, Light levels, Other environmental factors
Other necessary/recommended digital objects	Heating, Ventilation, and Air Conditioning (HVAC) systems, Lighting management systems, Building management dashboards, User interfacing applications for controlling climate and lighting, as well as booking meeting rooms.
Enabler of other possible applicable solutions	Adaptation to evolving user and operator needs. Integration with third-party applications; Facilitation of machine learning algorithms to benchmark comfort and identify improvement opportunities.
Output results	Valuable data insights into space utilization and environmental conditions; User-specific comfort settings; Optimized cleaning schedules based on actual usage; Enhanced operational efficiency.
Benefits expected in operation, especially emphasizing circular economy principles	Create a healthy and comfortable state-of-the-art building; Enhance sustainability by optimizing resource usage; Reduce energy consumption through efficient system management; Support adaptability to future technological advancements.

Necessary human resources for installing and operating	Technical asset managers, Facility managers, IT professionals for system integration and maintenance, Data analysts to interpret insights
Possible pitfalls and problems	Ensuring seamless integration with existing building systems, maintaining data privacy and security, keeping the system updated with evolving technologies, managing user adaptation to new technologies.
Technology readiness level (TRL)	The technology is at TRL 9, indicating it is fully operational and has been proven in real-world applications.
For TRL>4, where it has been already applied	bGrid's smart building technology has been installed in more than 50 buildings across Europe, the United Kingdom, and the other parts of the world
For TRL>1, who is the technology developer	The technology has been developed by bGrid, a PropTech company specializing in smart building solutions. (https://bgrid.com/blog/realising-tu-delfts-latest-smart-building/)

Table 145 PAS W-12

Possible applicable solution W-13	
Name	Madaster
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	Madaster serves as an online registry that documents all materials and products incorporated into a building, offering insights into their circularity, environmental impact, and residual value. This enables stakeholders to make informed decisions regarding sustainable construction and material reuse.
Input raw data	Building Information Models (BIM) in IFC format. Excel documents detailing material specifications. Data from verified Environmental Product Declaration (EPD) databases.

Other necessary/recommended digital objects	Material passports providing detailed information on materials and products; Integration with external databases for enriched data; Compliance reports aligned with industry standards such as EU Taxonomy, BREEAM, and DGNB.
Enabler of other possible applicable solutions	Circular design and construction practices, Sustainable asset management, Regulatory compliance, Environmental impact assessments.
Output results	Comprehensive material passports; Insights into circularity and environmental impact; Residual value assessments; Compliance documentation.
Benefits expected in operation, especially emphasizing circular economy principles	Enhanced transparency of material usage; Facilitation of material reuse and recycling; Reduction of waste; Optimization of resource efficiency; Support for sustainable construction practices.
Necessary human resources for installing and operating	Data managers for input and maintenance, sustainability consultants for analysis, facility managers for implementation, IT professionals for system integration.
Possible pitfalls and problems	Ensuring data accuracy and completeness; Maintaining up-to-date information; Integrating with existing systems; User training and adoption.
Technology readiness level (TRL)	TRL 9; the platform is fully operational and has been applied in various real-world projects.
For TRL>4, where it has been already applied	Madaster has been utilized in multiple projects, including the Looppark project, where it played a pivotal role in calculating the project's demountability index and ensuring material traceability.
For TRL>1, who is the technology developer	Madaster was developed by Madaster Services BV in the Netherlands, a company dedicated to promoting circular construction and material reuse. (https://madaster.com/platform/)

Table 146 PAS W-13

Possible applicable solution W-14	
Name	Maeconomy

Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	MAECONOMY.org introduces an innovative system that combines circular economy principles with financial instruments. The system creates a digital twin for buildings to inventory and certify materials, allowing them to serve as collateral for financial instruments. This approach facilitates transparency, material reuse, and the creation of a secondary market for construction materials, integrating these materials back into the circular economy.
Input raw data	Material data collected from existing buildings (type, quality, quantity); Building Information Models (BIM) or manual inventory data; Environmental impact data (CO_2 emissions, lifecycle analysis).
Other necessary/recommended digital objects	Digital twins of materials and buildings; Certification reports for material traceability; External data from environmental databases (e.g., CO_2 emission databases).
Enabler of other possible applicable solutions	Supports the reuse and recycling of materials in new construction projects; Enables creation of a transparent financial market for construction materials; Facilitates the creation of new circular-driven digital assets.
Output results	Comprehensive material passports with dynamic market value assessments; Financial instruments linked to certified materials, tradable in secondary markets; Reduced material waste and enhanced material lifecycle tracking.
Benefits expected in operation, especially emphasizing circular economy principles	Narrow the Loop: Reduces the need for new raw materials by promoting reuse; Slow the Loop: Extends the lifecycle of materials through incentives for prolonged usage; Close the Loop: Ensures materials re-enter the economy at the end of their lifecycle, maintaining high-value reuse; Lowers CO_2 emissions and operational costs for building owners; Encourages sustainable practices across the construction and demolition sectors.

Necessary human resources for installing and operating	Certified inspectors for material inventories; Data managers for updating and maintaining digital twins; Sustainability consultants to evaluate environmental impacts; Developers and IT specialists for platform integration and management.
Possible pitfalls and problems	High upfront costs for material inventory and certification; Reliance on accurate and up-to-date data for market trust; Resistance from stakeholders unfamiliar with circular economy principles; Risk of low adoption without clear financial incentives.
Technology readiness level (TRL)	The platform is fully operational and has been applied in various real-world projects.
For TRL>4, where it has been already applied	Maeconomy is in R&D stage of implementation and soon will be realised as a real-world pilot project in the municipality of Heerlen in The Netherlands.
For TRL>1, who is the technology developer	Developed and implemented by Stichting MAECONOMY.org, a non-profit organization based in Heerlen, Netherlands.

Table 147 PAS W-14

Possible applicable solution W-15	
Name	ActivePlan
Solution category (from the Existing knowledge)	a.iii. Data structuring and techniques for ensuring data quality, accessibility and interoperability
Description of the applicable solution	ActivePlan offers a suite of applications designed to create and manage machine-readable data throughout the entire building lifecycle, enhancing asset information management and supporting compliance with building safety regulations.
Input raw data	Building Information Models (BIM), CAD drawings, Schedules, Operation and Maintenance (O&M) manuals, COBie (Construction Operations Building Information Exchange) files, Product data from manufacturers.
Other necessary/recommended digital objects	Data templates for facilities, spaces, systems, and assets; Standardized data libraries; Digital records of installations, including 360° photos; Compliance documents.

Enabler of other possible applicable solutions	ActivePlan's platform supports: Integration with various asset management applications; Collaboration among stakeholders through shared data standards; Automation of data validation processes; Creation of interactive digital twins for risk assessment and compliance.
Output results	Coordinated 3D BIM models; Validated COBie asset data; Comprehensive digital records and O&M manuals; Automated compliance reports.
Benefits expected in operation, especially emphasizing circular economy principles	Improved data accuracy and consistency; Enhanced operational efficiency through automation; Facilitation of material reuse and recycling by providing detailed asset information; Support for sustainable building management practices.
Necessary human resources for installing and operating	Data managers for overseeing data input and maintenance; IT professionals for system integration and support; Facility managers for utilizing asset information; Compliance officers to ensure adherence to regulations.
Possible pitfalls and problems	Challenges in integrating with existing legacy systems; Ensuring data quality and completeness; User adoption and training requirements; Maintaining up-to-date information amidst ongoing changes.
Technology readiness level (TRL)	ActivePlan's solutions are fully operational and have been applied in various real-world projects, indicating a high TRL. (TRL 9)
For TRL>4, where it has been already applied	The platform has been utilized in sectors such as healthcare, residential, education, and commercial projects, including collaborations with organizations like Sodexo and Tower Hamlets in the United Kingdom.
For TRL>1, who is the technology developer	The technology has been developed by ActivePlan, a UK company specializing in asset information management solutions.

Table 148 PAS W-15

Possible applicable solution W-16	
Name	Bandora Systems

Solution category (from the Existing knowledge)	d. On-line data processing for autonomous operation
Description of the applicable solution	Bandora Systems offers a cloud-based Operations Manager that utilizes Artificial Intelligence (AI) and Machine Learning (ML) to optimize building energy management systems (EMS) in real-time. This solution is designed to enhance operational efficiency and occupant comfort in commercial buildings. .
Input raw data	Data from existing BMS and IoT devices within the building; Occupant feedback regarding comfort levels, gathered through a mobile application.
Other necessary/recommended digital objects	Mobile application for occupants to provide feedback on comfort; Integration with weather forecasting services to anticipate and adjust for external conditions.
Enabler of other possible applicable solutions	Bandora's AI-driven platform supports: Predictive maintenance by forecasting potential malfunctions; Energy consumption forecasting to optimize resource usage; Occupancy prediction to adjust systems based on building usage patterns.
Output results	Real-time adjustments to HVAC and lighting systems; Alerts for detected anomalies in energy consumption; Reports on energy usage and occupant comfort levels.
Benefits expected in operation, especially emphasizing circular economy principles	Reduction in energy consumption, leading to lower operational costs; Enhanced occupant comfort through continuous monitoring and adjustment; Extension of equipment lifespan due to optimized operation; Contribution to sustainability goals by minimizing energy waste.
Necessary human resources for installing and operating	IT professionals for integration with existing BMS and IoT devices; Facility managers to oversee system operations and respond to alerts; Data analysts to interpret system reports and optimize performance.
Possible pitfalls and problems	Challenges in integrating with diverse BMS and IoT devices from different manufacturers; Ensuring data privacy and security, especially with occupant

	feedback; Dependence on the accuracy of AI predictions for optimal performance.
Technology readiness level (TRL)	Bandora's solution is operational and has been deployed in real-world settings, indicating a TRL of 8 or 9.
For TRL>4, where it has been already applied	The platform has been implemented in various commercial buildings, including fast-food chains, where it has optimized HVAC systems and reduced energy consumption.
For TRL>1, who is the technology developer	Bandora Systems, founded in 2017 and based in Porto, Portugal

Table 149 PAS W-16

Possible applicable solution W-17	
Name	Smart concrete sensors
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Smart IoT sensors built in concrete that collect data from poured concrete through mobile apps. After concrete pouring, installed on-site sensors are automatically activated to immediately analyse the concrete, ensure quality, and create efficiency. Sensors continually collect data, reporting on performance and alerting contractors of issues before they happen.
Input raw data	Important physical parameters of poured concrete: temperature and strength
Other necessary/recommended digital objects	Data processing to enable smart management of the construction site
Enabler of other possible applicable solutions	Management of the construction site
Output results	Digitalized properties of poured concrete
Benefits expected in operation, especially emphasizing circular economy principles	More efficient operations on the construction site, with informed decision making

Necessary human resources for installing and operating	Sensors are integrated in concrete; construction engineers need to follow the measurements obtained from poured concrete
Possible pitfalls and problems	Interpretation of data requires skilled construction engineers
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Western Yards, a 49-storey residential building in Central London
For TRL>1, who is the technology developer	Converge, London; Cemex, Mexico

Table 150 PAS W-17

Possible applicable solution W-18	
Name	Virtual Reality Based Construction Services
Solution category (from the Existing knowledge)	c. Expert software for analysis
Description of the applicable solution	VR incorporated with BIM to enable construction professionals to have a preview of the construction project. Through this project visualization, construction companies, project managers, and teams will be able to develop solutions, reduce costs, and eliminate repetitions.
Input raw data	Construction project in BIM
Other necessary/recommended digital objects	Construction site management software
Enabler of other possible applicable solutions	Training for the construction site operations
Output results	Figures/videos of the site displayed to the users in the planning phase

Benefits expected in operation, especially emphasizing circular economy principles	Better communication among different project teams; Accelerated design and construction-process-related decisions; Scheduling ideal work plans and cost budgeting that aims at identifying design flaws and fixing them; Identification of potential problems that may arise in construction projects in order to obtain improved construction planning; Panoramic view of the construction sites to get a full view of all the areas of the construction sites; Risk-free environment for decision-making.
Necessary human resources for installing and operating	Construction engineers use the software to make informed decisions
Possible pitfalls and problems	Engineers that need to adapt to a different workflow
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Banner Health Center, Arizona
For TRL>1, who is the technology developer	Pinnacle Infotech

Table 151 PAS W-18

Possible applicable solution W-19	
Name	Construction Safety Sensors for workers
Solution category (from the Existing knowledge)	a.i. Sensing technologies
Description of the applicable solution	Construction site safety sensors are specialized tools that use cutting-edge technology to detect, gauge, and react to a range of safety-related data.
Input raw data	Construction site scenario
Other necessary/recommended digital objects	Construction site management software
Enabler of other possible applicable solutions	Intensified cooperation of robots and humans on the construction site, with workers safety preserved
Output results	Measurements and warnings related to following quantities: Proximity and Presence, Motion & Movement, Temperature and Environmental

	Conditions, Detection of Gases and Chemicals, Structural Integrity
Benefits expected in operation, especially emphasizing circular economy principles	Increased efficiency with reduced injury risk
Necessary human resources for installing and operating	None
Possible pitfalls and problems	Cost; Arrangement and Compatibility; Management of Data and Privacy; Training and Acceptance of Users; Calibration and False Alarms
Technology readiness level (TRL)	9
For TRL>4, where it has been already applied	Many sites, e.g. Merdeka 118 skyscraper, Kuala Lumpur, Malaysia
For TRL>1, who is the technology developer	Spacebands, Samsung C&T

Table 152 PAS W-19