

LIAISON

Final Innovation Handbook

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The project

LIAISON is a Horizon Europe Research and Innovation project running from May 2023 to August 2026, bringing together fifteen partners from six European countries under the coordination of TECNALIA. Its mission is to make European transport infrastructure — the roads and railways that extend across some 136,700 km and 234,000 km respectively — climate-neutral, sustainable and circular across the whole of their life cycle, from procurement and design through construction, operation and maintenance to decommissioning.

To achieve this, the project combines three complementary elements: a governance methodology, a set of supporting digital tools, and a portfolio of close-to-market technological solutions. It seeks to minimise lifecycle costs and optimise energy management by embedding the industrialisation of construction, circular-economy principles and digitalisation at every stage of the infrastructure life cycle, while also building capacity, enabling knowledge transfer and cultivating new circular business models to drive market adoption.



SECTOR 1 OF 5
FRAMEWORK

New Governance framework for Transport Infrastructure

A SMARTER, MORE CIRCULAR WAY
TO MANAGE AND MAINTAIN EUROPE'S
TRANSPORT SYSTEMS

SECTOR 1 of 5
FRAMEWORK



Europe's transport networks are essential for open trade and commerce throughout the Union. However, the cost of their maintenance is not only economic. Transport infrastructure construction and maintenance has significant carbon / sustainability costs. The uptake in circular approaches in this space to date has been unsatisfactory.

To meet the EU Green Deal and digital transition goals, infrastructure governance must evolve. The LIAISON project is developing the Dynamic Multi-Infrastructure Governance Framework (DMIGF) – a practical model that helps authorities, operators, and service providers manage interconnected transport systems based on the principles of circularity.

The DMIGF provides a structured, cooperative approach to planning, operating, and maintaining Europe's multimodal transport infrastructure. The framework incorporates Multi Life-Cycle Assessment in order to quantify KPIs relating to the five main arms of circularity – risk, sustainability, material use, social impact and cost.

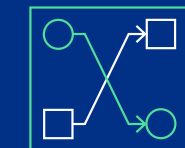
At its core, the DMIGF integrates digital twins, shared data platforms, and collaborative decision-support tools. These components make it possible to perform quantitative circularity assessment of the innovative transport solutions developed in LIAISON:

- smart and sustainable beams,
- smart rigid road pavements,
- improved railway track ballast,
- bioasphalts and automated pavement damage detection system,
- intelligent tunnel control system and photovoltaic guardrails.

Indicator-based tools help stakeholders anticipate barriers, evaluate trade-offs, and align investment priorities. The framework also includes guidance on governance processes, data standards, and roles to ensure transparent cooperation among sectors and governance levels.

This evidence-based and adaptive approach enables more resilient, efficient, and sustainable management of Europe's transport ecosystems.

BENEFITS FOR TRANSPORT INFRASTRUCTURE OWNERS



FACILITATES COORDINATION OF
MAINTENANCE ACROSS TRANSPORT MODES

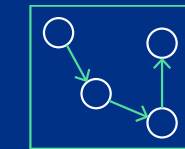


REDUCES COSTS THROUGH
INNOVATION

BENEFITS FOR PUBLIC AUTHORITIES AND POLICY MAKERS



ENHANCES THE CIRCULARITY OF
MAINTENANCE SCHEMES



ENHANCES STRATEGIC
PLANNING



SUPPORTS CROSS-SECTOR
COLLABORATION



STRENGTHENS RESILIENCE
TO CLIMATE AND DIGITAL RISKS

ROADMAP TO IMPLEMENTATION

DMIGF helps assess and rank design and operation options for transport

It scores each option and provides a confidence level for results

It builds on EU and national policies, evolving during the project

Demo cases and stakeholder input will guide its final development

The goal is a scalable tool for owners and managers across projects

It supports circularity, cuts emissions, and informs future policies



SECTOR 2 OF 5
SUSTAINABLE ELEMENTS

Structural elements for sustainable TI

Smart precast geopolymer solution

FASTER REPAIRS, LOWER-CARBON MATERIALS, AND LONGER-LASTING ROAD PERFORMANCE

SECTOR 2 of 5
SUSTAINABLE ELEMENTS



Keeping road networks safe and reliable often comes down to one persistent challenge: how to repair damaged pavement quickly, without long closures, repeat interventions, or heavy environmental impacts. Traditional rigid pavement repairs can be slow, disruptive, and material-intensive. At the same time, conventional cement-based solutions carry a significant carbon footprint.

KER 5 addresses these issues with a smart precast rigid pavement solution made using geopolymer-based materials and designed for rapid slab replacement. The approach combines the speed and precision of precast concrete slabs with the sustainability potential of cement-free geopolymer binders, using industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash (FA) as key ingredients.

What makes this solution especially practical is its focus on the real-world mechanics of repair. Precast slabs allow a damaged section of pavement to be removed and replaced individually, rather than reconstructing larger areas. This can reduce traffic disruption and deliver a more predictable, high-quality surface. To make installation and alignment easier on site, the concept includes a lifting and levelling

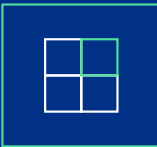
insert that helps teams position slabs accurately and adjust final levels to achieve a consistent riding surface.

Another important innovation is the slab-to-slab connection design. In many existing replacement approaches, large mortar-filled areas around dowels can become weak points, leading to cracking, water infiltration, and higher maintenance needs. KER 5 proposes a more robust detail by minimising dowel cavity size and applying a controlled grout injection method (inspired by bridge post-tensioning duct grouting). This supports better confinement around the dowel using the slab's reinforcement mesh, improving long-term performance.

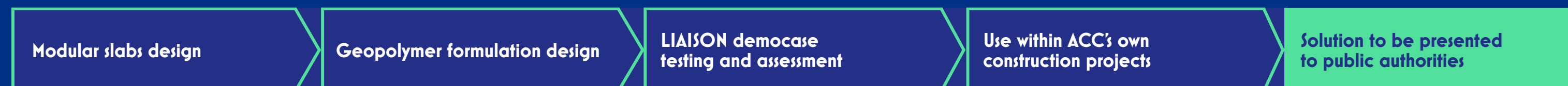
To ensure that the material is fit for purpose, geopolymer concrete mixtures are being developed to meet the structural requirements of rigid pavements, without the need for thermal curing, through a structured programme of testing different formulations, including durability assessments (such as water penetration and chloride exposure tests).

Overall, KER 5 demonstrates how low-carbon materials and smarter precast design can work together to deliver faster, cleaner, and more durable rigid pavement maintenance—with clear potential for scaling across road networks where uptime, safety, and sustainability all matter.

BENEFITS

-  MODULAR DESIGN FOR QUICK AND EASY INSTALLATION WITH MINIMAL LABOUR
-  FASTER PAVEMENT REPAIRS VIA INDIVIDUAL PRECAST SLAB REPLACEMENT
-  LOWER-CARBON MATERIALS USING GEOPOLYMER BINDERS (SLAG/FLY ASH)
-  LONG-TERM DURABILITY THROUGH IMPROVED DOWEL/GROUT CONNECTION DETAILS
-  MORE PRECISE INSTALLATION WITH LIFTING AND LEVELLING INSERTS
-  REDUCED TRAFFIC DISRUPTION AND MORE PREDICTABLE MAINTENANCE OUTCOMES

ROADMAP TO IMPLEMENTATION



Road construction and maintenance are among the most material- and carbon-intensive activities in transport infrastructure. Conventional asphalt relies heavily on oil-based bitumen, contributing significantly to greenhouse gas emissions. To meet Europe’s climate and circular economy goals, road materials must evolve toward lower-carbon, resource-efficient alternatives.

KER 3 addresses this challenge by developing and validating innovative bio-asphalts, in which conventional bitumen is partially or fully replaced with bio-based binders derived from renewable and residual resources. Developed within the LIAISON project by the University of Cantabria, the solution explores how bio-asphalts can deliver comparable — or even superior — performance while significantly reducing environmental impact.

Two bio-binder solutions are being assessed. The first replaces up to 30% of conventional bitumen with lignin, a by-product of the paper industry. The second fully replaces oil-based bitumen using a combination of natural bitumen and a bio-based oil rejuvenator derived from cashew nutshells, a residue from the food industry. Both approaches reduce reliance on virgin fossil materials while promoting circular use of industrial by-products. Extensive laboratory testing has been carried out

to evaluate the physical, rheological, thermal, and mechanical performance of the bio-binders and resulting asphalt mixtures. Bio-asphalts were tested under standard European procedures and compared directly with conventional asphalt mixtures. Bio-asphalts were tested under standard European procedures and compared directly with conventional asphalt mixtures. Results show that both bio-asphalts comply with Spanish technical specifications, with the fully bio-based solution even outperforming traditional asphalt in key mechanical indicators.

Recyclability is a core aspect of the innovation. Artificial aging tests assess whether bio-asphalts can be reused at similar rates to conventional mixtures, ensuring compatibility with existing asphalt recycling practices. Long-term performance is further evaluated using a Circular Road Simulator, replicating traffic loading conditions in a controlled environment.

The solution will be validated at full scale on a pilot road section in Cantabria, where production, laying, and compaction are monitored to identify upscaling barriers. Environmental, social, and economic impacts will be assessed through Life Cycle Assessment and Life Cycle Costing, aligned with the LIAISON Dynamic Multi-Infrastructure Governance Framework (DMIGF). KER 3 demonstrates how bio-based materials can enable durable, recyclable, and climate-positive road pavements, supporting the transition to low-carbon transport infrastructure.

BENEFITS

-  LOWER CARBON FOOTPRINT BY REDUCING OR ELIMINATING OIL-BASED BITUMEN
-  USE OF BIO-BASED AND RESIDUAL MATERIALS (LIGNIN, CASHEW NUTSHELL DERIVATIVES)
-  COMPARABLE OR IMPROVED MECHANICAL PERFORMANCE VS CONVENTIONAL ASPHALT
-  COMPATIBILITY WITH ASPHALT RECYCLING PRACTICES
-  VALIDATED THROUGH LABORATORY, SIMULATOR, AND REAL-ROAD TESTING
-  SUPPORTS EU CIRCULAR ECONOMY AND CLIMATE GOALS

ROADMAP TO IMPLEMENTATION



Concrete beams are fundamental components of bridges, footbridges, and many transport structures. Yet conventional cast-in-situ construction methods remain labour-intensive, waste-generating, and imprecise, often leading to over-design and unnecessary material use. In a sector facing skills shortages and growing pressure to decarbonise, new approaches are urgently needed.

The Sustainable Smart Beams solution introduces a digitally driven solution for the design and fabrication of sustainable “smart” reinforced concrete beams, developed within the LIAISON project by École Nationale des Ponts et Chaussées (ENPC) together with industrial partners. The innovation combines structural optimisation, robotic fabrication, advanced formwork technologies, and embedded monitoring, enabling beams that are lighter, more accurate, and digitally traceable throughout their life cycle.

At the heart of the solution is a performance-based, generative design process compliant with Eurocode 2. Instead of conventional prismatic beams, the smart beams integrate internal cavities and optimised geometries, reducing concrete use by up to 40% while maintaining structural safety. This reduction directly lowers embodied carbon

and material consumption. Fabrication takes place in a robotic construction cell, where the entire workflow — from reinforcement measurement to formwork production — is digitally controlled. The actual reinforcement cage is first measured using laser-tracking technology to create an accurate as-built digital twin. This data is then used to design and manufacture customised formworks, including complex internal cavity moulds produced through 3D printing.

Multiple formwork strategies are explored, including reusable and recyclable thermoplastic moulds and printed mortar formworks, balancing material efficiency, reuse potential, and industrial feasibility. Sensors are embedded into selected beams, enabling structural health monitoring (SHM) and continuous performance tracking once installed. The solution will be validated through the construction of full-scale 7-metre beams, including mechanical testing and real use in a footbridge installation. Data from embedded sensors will be transmitted to the cloud, supporting long-term monitoring, maintenance planning, and future retrofitting decisions.

By combining digital fabrication, structural optimisation, and smart monitoring, KER 4.1 demonstrates how concrete infrastructure can become lighter, cleaner, more precise, and digitally manageable, supporting the transition to sustainable, Industry 4.0 transport construction.

BENEFITS



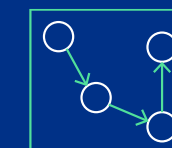
UP TO 40% REDUCTION IN CONCRETE USE THROUGH STRUCTURAL OPTIMISATION



LOWER CARBON FOOTPRINT AND REDUCED MATERIAL WASTE



HIGH PRECISION AND QUALITY CONTROL VIA DIGITAL FABRICATION



REDUCED CONSTRUCTION WASTE COMPARED TO CAST-IN-SITU METHODS



EMBEDDED MONITORING FOR LIFETIME PERFORMANCE TRACKING



EUROCODE-COMPLIANT AND MARKET-READY DESIGN APPROACH

ROADMAP TO IMPLEMENTATION

Digitise cavity positioning
(augmented reality glasses
for operators)

Improve the moulding
methodology to obtain two
clean surfaces

Use AI-assisted photogrammetry
methods for simpler
measurement of cages

Industrial pilot demonstrator
enabling manufacture of finalised
and competitive components

Apply to other typologies,
slabs, piles

Structural elements for sustainable TI

Low Noise & Low Vibration Ballasted Railway Track

CIRCULAR SOLUTIONS FOR QUIETER,
MORE DURABLE AND SUSTAINABLE
RAIL INFRASTRUCTURE

SECTOR 2 of 5
SUSTAINABLE ELEMENTS



Railways are already one of the most sustainable modes of transport, yet maintenance still requires large quantities of natural resources. One of the most critical components of a railway track is the ballast layer, which ensures load distribution, drainage, and track stability. Over time, ballast degrades due to particle breakage, abrasion, and contamination, which reduces track performance, increases noise and vibration levels, and leads to more frequent maintenance.

An innovative circular solution combines reused or low-quality ballast aggregates with scrap rubber derived from recycled waste tyres. These materials are integrated with shoulder elements and a geosynthetic reinforcement layer that provides lateral confinement to the ballast. Rubber particles act as a resilient interface between ballast grains, helping to absorb energy, reduce grain breakage, and dampen vibrations generated by passing trains.

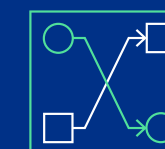
At the same time, the shoulder elements are mechanically connected by a planar geosynthetic reinforcement layer that acts as a tensile tie, increasing grain confinement and limiting permanent movement and rotation of the ballast grains without interfering with standard railway maintenance operations. This enhanced ballast system

also delivers performance improvements. By slowing ballast degradation, it helps maintain track geometry over longer periods and reduces the frequency of maintenance and associated costs. The elastic properties of recycled rubber reduce noise and vibration emissions, while the shoulder elements can also serve as a foundation for additional low-height noise barriers located close to the source. Together, these improvements enhance passenger comfort and reduce disturbance to nearby communities.

A comprehensive assessment programme and laboratory testing evaluates mechanical behaviour, abrasion resistance, stiffness, and friction properties of the modified ballast. Additional testing addresses critical safety and environmental aspects, including fire behaviour, combustibility, and the potential leaching of pollutants or microplastics. Large-scale physical models and numerical simulations are used to further optimise the design before final field validation.

By upgrading reused materials instead of discarding them, the solution transforms ballast from a waste stream into a high-performance resource. It demonstrates how circular materials, geosynthetics, and smart engineering can work together to deliver quieter, more durable, and more sustainable railway infrastructure.

BENEFITS



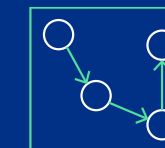
REDUCED NOISE AND VIBRATION THROUGH RUBBER-ENHANCED BALLAST BEHAVIOUR



EXTENDED BALLAST SERVICE LIFE BY REDUCING ABRASION AND GRAIN BREAKAGE



REUSE OF DEGRADED BALLAST, REDUCING DEMAND FOR VIRGIN AGGREGATES



IMPROVED TRACK STABILITY VIA LATERAL CONFINEMENT



LOWER MAINTENANCE REQUIREMENTS AND COSTS



ALIGNMENT WITH CIRCULAR ECONOMY PRINCIPLES AND SUSTAINABILITY GOALS

ROADMAP TO IMPLEMENTATION

Analyse sections to identify locations that could benefit from the installation

Define and communicate technical requirements for rubber aggregates

Present and promote the benefits of the solution to railway authorities

Adapt existing technical specifications for ballasted railway tracks

Support standardization and ensure interoperability with existing infrastructure

Demonstrate replicability across diverse environments and locations



SECTOR 3 OF 5

ENERGY EFFICIENCY

Energy Efficiency & Generating infrastructure Adaptive Tunnel Ventilation Control System

SMARTER, SAFER AND MORE
SUSTAINABLE AIRFLOW MANAGEMENT
FOR EUROPE'S TUNNELS

SECTOR 3 of 5
ENERGY EFFICIENCY

Ventilation is one of the most energy-intensive and safety-critical components of any road tunnel. Traditionally, tunnel fans operate in a simple on/off mode, running at full speed even when demand is low. While effective in emergencies, this approach wastes significant energy, increases noise and vibration, and accelerates equipment wear — all of which translate into higher costs and reduced reliability.

ZITRÓN is developing an Adaptive Control System for Tunnel Ventilation that redefines how fans operate in both normal and emergency conditions. The system introduces Variable Frequency Drives combined with sine-wave filters, enabling precise fan speed control and dramatically improving energy efficiency. Early measurements confirm up to 40% energy savings thanks to optimized airspeed control and reduced power consumption.

Beyond efficiency, fan speed regulation brings a series of operational and environmental benefits. Lower speeds reduce mechanical stress, decreasing vibration and noise levels — a major advantage for tunnels located in urban or residential areas. Reduced vibration also extends equipment lifetime and lowers maintenance needs, contributing to safer long-term operation. In fire scenarios, lower background

noise allows emergency announcements and alarms to be heard more clearly, improving evacuation and response conditions. Central to the innovation is ZITRÓN's ZJET electronic card, installed directly on each fan. It gathers signals from accelerometers, temperature sensors, heaters, and other components, enabling real-time health monitoring. Integrated vibration spectrum analysis helps detect anomalies early, supporting predictive maintenance and reducing the risk of unexpected failures. The cards also simplify installation by arriving fully wired from the factory.

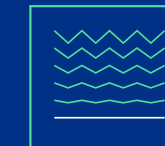
The system is managed through ZVM control software, which streams data to the cloud, where ZCARE performs advanced diagnostics and analyses environmental sensor inputs such as airflow and smoke behaviour. Together, these tools allow operators to continuously optimise airflow, improve energy performance, and test fire-control strategies under different scenarios.

The adaptive ventilation system is being validated in Spain's Mamariga Tunnel, where upgraded control cabinets, ZJET units, and monitoring software are now operating across both tunnel tubes. Performance will continue to be assessed through 2026, delivering real-world evidence of energy savings, safety improvements, and circularity benefits.

BENEFITS



UP TO 40% ENERGY SAVINGS THROUGH PRECISE, VARIABLE-SPEED FAN CONTROL



LESS NOISE AND VIBRATION, IMPROVING USER COMFORT, EXTENDING EQUIPMENT LIFESPAN



LOWER MAINTENANCE AND OPERATIONAL COSTS THANKS TO LESS MECHANICAL STRESS



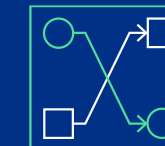
ENHANCED SAFETY WITH CLEARER EMERGENCY COMMUNICATION



SMART, REAL-TIME MONITORING VIA ZJET SENSORS AND CLOUD-BASED DIAGNOSTICS



MORE RELIABLE TUNNEL OPERATION THROUGH ADAPTIVE AIRFLOW MANAGEMENT



EASY INTEGRATION WITH PREWIRED UNITS AND UPGRADED CONTROL SYSTEMS

ROADMAP TO IMPLEMENTATION

Definition of adaptive tunnel ventilation system, identifying inefficiencies

Development of smart components, control software and cloud integration

Deployment, commissioning in a real tunnel, with system calibration and training

Monitoring & validation of energy savings, safety, performance

Optimisation of performance, development of guidelines for replication

Deployment across EU infrastructures, integrating with other smart systems

Energy Efficiency & Generating infrastructure Intelligent Tunnel Lighting System

AI-ENHANCED OPTIMISATION FOR
SAFER, CLEANER AND
MORE ENERGY-EFFICIENT TUNNELS

SECTOR 3 of 5
ENERGY EFFICIENCY



Every day, thousands of drivers enter tunnels experiencing the so-called “black hole effect” — a momentary loss of visibility caused by the contrast between bright daylight and the darker tunnel entrance. This phenomenon can compromise safety, especially in high-traffic tunnels. To address this, international standards such as CIE 88:2004 define precise lighting levels for each tunnel section, ensuring visibility and comfort for all users. Yet current lighting systems often rely on static configurations or simple expert rules that cannot adapt to changing outdoor conditions or optimise energy consumption.

The Intelligent Tunnel Lighting System, developed by TECNALIA within the LIAISON project, introduces an intelligent tunnel lighting control system designed to meet safety requirements while drastically reducing energy use. The system continuously adjusts light levels based on real-time luminance measurements (L20 readings) and traffic conditions, ensuring compliance with the CIE curve while avoiding the unnecessary over-lighting that increases electricity demand and CO₂ emissions. The goal: a 30% reduction in electricity use for tunnel lighting. At the heart of the tunnel lighting system is a meta-heuristic optimisation algorithm. Unlike traditional Expert Rule Systems, this AI-

driven approach evaluates live tunnel conditions, identifies the most suitable luminance profile, and calculates energy-cost implications using electricity price data from the Spanish grid (ESIOS). A dynamic cost function guides the system toward the optimal balance between safety and efficiency.

The solution is being validated in the Mamariga Tunnel on Spain’s N-644 road — a 320-metre twin-tube tunnel linking the A-8 motorway to the Port of Bilbao. Its diverse traffic patterns and geometry provide an ideal testbed to demonstrate energy savings, reliability, and visibility improvements under real operational conditions.

Aligned with the LIAISON Dynamic Multi-Infrastructure Governance Framework (DMIGF), The intelligent tunnel lighting system contributes to technical, environmental, circularity, and social KPIs, including reduced energy demand, lower emissions, optimised resource use, and enhanced driver safety.

By combining advanced optimisation, LED and DALI technologies, and dynamic control, the intelligent tunnel lighting system forms a cornerstone of smart tunnel infrastructure — and offers strong bundling potential with Adaptive Ventilation for integrated, energy-efficient traffic tunnels.

BENEFITS



UP TO 30% ENERGY SAVINGS, LESS ELECTRICITY CONSUMPTION AND OPERATIONAL COSTS



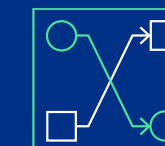
IMPROVED SAFETY AND VISIBILITY COMPLIANT WITH CIE TUNNEL LIGHTING STANDARDS



LOWER CO₂ EMISSIONS THANKS TO REDUCED ENERGY DEMAND



EXTENDED EQUIPMENT LIFETIME DUE TO OPTIMISED, DEMAND-BASED LIGHTING LEVELS



AI-BASED OPTIMISATION BRINGS INTELLIGENCE AND ADAPTABILITY TO PUBLIC INFRASTRUCTURE

ROADMAP TO IMPLEMENTATION

Define lighting system addressing inefficiencies, ensuring safety standards

AI-based optimisation, validate performance through simulations

Deploy in real tunnel, install hardware, calibrate controls, train operators

Monitor performance, energy savings, ensure safety and environmental benefits

Refine for scalability, standardisation, economic viability across use cases

Scale to market, integrate with smart infrastructure, improve via data insights

Guardrails are essential elements of road safety, designed to protect drivers and motorcyclists by reducing the severity of roadside accidents. Traditionally, they have served a single purpose: impact protection. The Photovoltaic (PV) Guardrail concept developed within the LIAISON project transforms guardrails into dual-function infrastructure that improves safety while generating renewable energy.

The core idea is simple yet innovative: integrate photovoltaic modules into standard guardrail structures so they can harvest solar energy throughout the day. This allows roads to contribute directly to sustainability goals without requiring additional land or altering the road layout. The PV guardrail becomes a compact, efficient solar installation embedded in existing transport networks.

Assessing how the PV guardrail performs in real operational conditions includes evaluating its energy generation capacity, analysing how different orientations (north, south, east, west) affect performance, and studying the guardrail's durability and safety behaviour through virtual impact tests and structural monitoring. Continuous data collection—covering sunlight intensity, temperature, rainfall, shading patterns, and performance ratio—helps build a complete picture of how the

system behaves across seasons and weather conditions.

Beyond energy production, the solution enhances safety by enabling powered safety functions. Electricity generated by the guardrail can feed roadside LED lighting for improved night visibility or support sensors for hazard detection, fog monitoring, or emergency alerts. These features can help reduce accident risk and increase driver awareness, especially in challenging environments.

Feedback from road authorities, users, maintenance personnel, and local communities helps assess acceptance and identify potential barriers to deployment. Cost and environmental analyses further examine the long-term value of PV guardrails, including their recyclability and potential for reducing carbon emissions.

The demonstration on VITA premises, alongside real-world testing, will provide insights into scalability and replicability and will inform guidelines for future installations, supporting wider adoption across Europe.

The Photovoltaic Guardrail represents a new generation of multifunctional infrastructure combining road safety, renewable energy, and sustainable design into one innovative solution.

BENEFITS



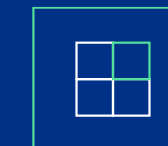
MORE ROAD SAFETY, IMPROVED IMPACT PERFORMANCE, POWER LIGHTING/SENSORS



CLEAN ENERGY PRODUCTION INTEGRATED DIRECTLY INTO EXISTING GUARDRAILS



TURNING EXISTING SAFETY INFRASTRUCTURE BECOME DUAL-PURPOSE SOLAR ASSET



SCALABLE AND ADAPTABLE TO DIFFERENT ROAD TYPES, CLIMATES, AND ORIENTATIONS



DATA-DRIVEN PERFORMANCE WITH ENERGY AND ENVIRONMENT MONITORING



LOWER IMPACT THROUGH RENEWABLE GENERATION AND RECYCLABLE MATERIALS



REDUCED ENERGY COSTS AND POTENTIAL ACCIDENT-RELATED COST SAVINGS

ROADMAP TO IMPLEMENTATION

Demonstration in VITA premises: energy and performance

Durability and safety behavior through virtual impact tests and monitoring

Demonstration in real-world testing site (Italian Highway)

Stakeholders engagement: authorities, users, communities, maintenance personnel

Key inputs for market scalability: PV provider agreement

Market Uptake: standardization

Transport infrastructure is expected to do more than provide structural support. Alongside durability and safety, modern assets must enable monitoring, digitalisation, and energy efficiency, often in locations where grid access is limited. At the same time, the construction sector faces growing pressure to reduce resource consumption and environmental impacts by adopting circular and low-carbon materials.

Within the LIAISON project, an innovative thermoelectric concrete transforms conventional cement-based materials into functional, energy-harvesting infrastructure elements capable of converting naturally occurring temperature differences into electrical energy through the Seebeck effect, enabling concrete components to act as passive power sources for embedded monitoring and sensing systems.

The approach builds on circular economy principles by enhancing thermoelectric performance using secondary raw materials and industrial by-products. Materials such as red mud, copper slag, mine residues, and recycled graphite are incorporated into the cement matrix to increase electrical conductivity and thermoelectric response while preserving the inherently low thermal conductivity of cementitious materials. In this way, waste-derived

materials are reused and re-activated with new energy-related functionalities. Extensive laboratory testing has demonstrated that selected mixtures can achieve order-of-magnitude improvements in thermoelectric properties compared to conventional cement pastes, while maintaining mechanical performance. Rather than targeting high-efficiency power generation, the solution is designed for distributed, low-power energy harvesting, where robustness, durability, and large surface areas are key advantages.

Based on these results, optimised mixtures incorporating graphite and red mud have been selected for field validation in Slovenia. Thermoelectric concrete elements are integrated into secondary-raw-material-based infrastructure components and equipped with electrodes and monitoring systems to assess voltage output and thermal response under real operating conditions.

By enabling self-powered monitoring systems and reducing dependence on external energy supply, thermoelectric concrete opens new possibilities for smart, low-maintenance transport infrastructure.

BENEFITS



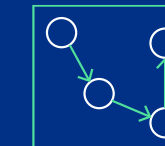
ENERGY FROM WASTE HEAT, ENABLING SELF-POWERED SENSORS AND MONITORING



CIRCULAR ECONOMY INTEGRATION THROUGH USE OF INDUSTRIAL BY-PRODUCTS



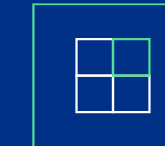
LOW-CARBON SOLUTION WITH MINIMAL OPERATIONAL ENERGY FOOTPRINT



IMPROVED INFRASTRUCTURE AUTONOMY, LESS CABLING AND MAINTENANCE NEEDS



STRONG INTEGRATION POTENTIAL WITH SMART MONITORING AND DIGITAL SYSTEMS



TRANSFERABLE CONCEPT FOR RAIL, ROAD, INFRASTRUCTURE, FAÇADES, AND PAVEMENTS

ROADMAP TO IMPLEMENTATION

Pilot validation: demo in Slovenia to validate usability and energy harvesting performance in real conditions

Gradual market outreach: expand across EU, starting with rail, then road and urban sectors

Licensing and integration: partners will license the technology and support industrial adaptation

Support and knowledge transfer: guidance on material formulation, installation, and monitoring



SECTOR 4 OF 5
DIGITAL TOOLS

Digitalisation, Monitoring, Predictive Maintenance

Pavement management system

AI-POWERED MONITORING TO
ENABLE SAFER, SMARTER AND MORE
SUSTAINABLE ROAD MAINTENANCE

SECTOR 4 of 5
DIGITAL TOOLS



Roads are essential to economic activity and social well-being, but their performance depends on timely and effective maintenance. When surface distresses such as cracks or potholes are not detected early, they can compromise traffic safety, increase vehicle operating costs, and shorten pavement lifespan. Traditional road condition monitoring relies heavily on manual visual inspections, which are time-consuming, costly, subjective, and potentially dangerous for inspectors.

An Intelligent Pavement Distress Detection System has been developed to support a shift toward data-driven and preventive road maintenance. The solution combines low-cost image acquisition, artificial intelligence, and a web-based management platform to automatically detect, classify, and assess pavement distresses in a fast, reliable, and scalable way.

The system uses a vehicle-mounted camera setup based on a stabilised drone camera adapted for road operation. It captures high-quality pavement images at normal traffic speeds and associates them with precise GPS locations. This enables large volumes of data to be collected efficiently without disrupting traffic or requiring specialised inspection vehicles.

Advanced deep learning models analyse the images to identify a wide range of pavement distresses, including cracks, potholes, surface defects, and drainage elements. To overcome common data limitations, the system integrates generative AI techniques, which create synthetic images of underrepresented distress types. This improves model robustness and detection accuracy across diverse pavement conditions.

A key innovation is the development of an automated Pavement Condition Index, derived from AI-based detection and pixel-level segmentation of defects. Unlike conventional indices, it provides objective, repeatable assessments of defect type, severity, and extent, supporting transparent maintenance prioritisation. All results are visualised through a user-friendly web platform, where road authorities can upload inspection videos, view detected defects on an interactive map, analyse trends, and filter results by distress type. The cloud-based, containerised architecture ensures scalability, flexibility, and secure data management.

The system is being prepared for validation in collaboration with road authorities, with the aim of integrating it into existing maintenance workflows. By enabling early detection and targeted interventions, the solution supports preventive maintenance strategies, reducing long-term costs and environmental impacts.

BENEFITS



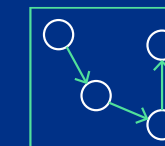
AUTOMATED DETECTION OF MULTIPLE PAVEMENT DISTRESSES USING AI



LOW-COST DATA ACQUISITION WITHOUT SPECIALISED INSPECTION VEHICLES



OBJECTIVE PAVEMENT CONDITION ASSESSMENT THROUGH AN AI-BASED INDEX



IMPROVED MAINTENANCE PLANNING AND PRIORITISATION



ENHANCED ROAD SAFETY THROUGH EARLY DEFECT DETECTION



LOWER LONG-TERM COSTS AND ENVIRONMENTAL IMPACT

ROADMAP TO IMPLEMENTATION

Definition of standard low-cost equipment (kit) for data acquisition

Enhancement of system robustness: ensure resilience against different scenarios

Pilot deployment by end user: monitoring of fully real operational conditions

Normalization, standardization of metrics for pavement condition index

Dissemination of system capabilities to potential users

Integration into the existing road-maintenance ecosystem

Digitalisation, Monitoring, Predictive Maintenance

Weigh-In-Motion System using Optical Fiber Sensor

REAL-TIME TRAFFIC LOAD MONITORING
FOR SMARTER, SAFER AND MORE
SUSTAINABLE ROAD PAVEMENTS

SECTOR 4 of 5
DIGITAL TOOLS



Heavy vehicle overloading is a major challenge for road infrastructure across Europe. Excessive axle loads accelerate pavement deterioration, increase maintenance costs, and raise safety risks, while enforcement is often limited by the disruption caused by traditional control methods. Weigh-In-Motion (WIM) systems offer a way to monitor vehicle loads in real time without stopping traffic, but conventional technologies can be costly, difficult to install, and sensitive to environmental conditions.

An innovative WIM system based on optical fiber sensors is being developed and integrated into precast concrete pavement slabs. The solution combines advanced sensing technology with modular, low-carbon construction to enable continuous, accurate monitoring of traffic loads while supporting more sustainable pavement design and maintenance. At the core of the system are Fiber Bragg Grating optical sensors that are highly sensitive to strain, immune to electromagnetic interference, lightweight, and capable of multiplexing multiple measurements along a single optical fiber. Unlike conventional electronic sensors, they are electrically passive, durable, and suitable for long-term operation in harsh road environments. To ensure reliability during concrete casting and service life, the sensors are

housed in a specially designed protective casing. This casing has been optimised through finite element modelling and validated through laboratory compression tests to amplify sensor sensitivity while protecting it during installation. A temperature decoupling mechanism further improves accuracy by separating mechanical strain from thermal effects.

The WIM-enabled slabs are manufactured using industry-friendly geopolymers concrete, significantly reducing the carbon footprint compared to conventional Portland cement concrete. The modular slab design allows rapid installation, easy replacement of damaged elements, and minimal disruption during maintenance works. A 30-metre demonstration section will validate the system under real traffic conditions.

Data collected by the sensors are transmitted to a digital platform where AI-based algorithms process the information in real time. A dedicated graphical interface allows infrastructure operators to visualise loads, track trends, and set alerts when threshold values are exceeded. This supports proactive maintenance strategies, enforcement planning, and asset management decisions. By combining low-carbon materials, optical fiber sensing, and digital monitoring, the solution enables longer pavement service life, reduced maintenance costs, and improved road safety.

BENEFITS



ACCURATE REAL-TIME VEHICLE LOAD MONITORING WITHOUT TRAFFIC DISRUPTION



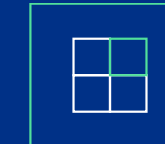
HIGH DURABILITY AND RELIABILITY THROUGH OPTICAL FIBER SENSING TECHNOLOGY



REDUCED PAVEMENT DAMAGE CAUSED BY OVERLOADED VEHICLES



LOWER MAINTENANCE COSTS AND EXTENDED SERVICE LIFE



EASY INTEGRATION INTO MODULAR PRECAST PAVEMENTS



SUPPORTS ENFORCEMENT, ASSET MANAGEMENT, AND SUSTAINABILITY GOALS

ROADMAP TO IMPLEMENTATION

WIM System Design

WIM Prototype Build

WIM Lab Validation

WIM Slab Integration

WIM Field Deployment

WIM Dashboard Setup



SECTOR 5 OF 5
GOVERNANCE

Modern transport infrastructure is built to last — but over time, roads, bridges, and railways still need repair, renewal, or even replacement. Today, many of these works are carried out without a full picture of the materials on-site, their condition, or how they could be recovered and reused. This lack of information makes planning difficult, increases waste, and limits circular economy opportunities.

BIM4INFRA, developed within the LIAISON project brings Building Information Modelling (BIM) — widely used in buildings — into the world of linear infrastructure, where digital tools have historically been scarce.

This solution combines BIM with practical waste management and planning tools, enabling infrastructure owners and contractors to model sites, estimate materials, and plan selective dismantling and reuse.

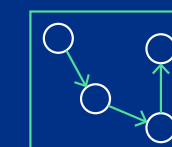
The tool enables engineers and maintenance teams to digitally map transport assets, from a highway section to a railway segment. Using 2D plans, images, or simple model inputs, BIM4INFRA builds a detailed overview of the infrastructure's components and materials. From there, it automatically estimates waste streams, identifies reusable elements, and calculates environmental and economic impacts.

Rather than relying on rough approximations, planners gain a clear and evidence-based view of what a maintenance or deconstruction project will involve. This makes it easier to plan selective dismantling, reduce unnecessary waste, and prioritise reuse and recycling — core goals of the EU's shift toward circular construction.

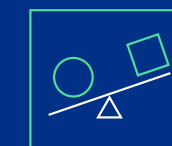
By improving knowledge upfront, BIM4INFRA can help reduce inefficiencies in maintenance works by 15%, cut landfill disposal of construction and demolition waste from 30% to just 5%, and lower life-cycle costs by up to 30%. It turns waste into a resource and data into better decisions.

BIM4INFRA also makes sustainability performance visible. The tool quantifies CO₂ emissions, energy use, time requirements, and cost impacts linked to different demolition or renovation strategies. A built-in Gantt schedule supports the organisation of tasks across crews, machinery, and timelines, helping teams deliver projects more efficiently from start to finish.

BENEFITS



IMPROVED PLANNING
AND DECISION-MAKING



REDUCTION OF CONSTRUCTION
AND DEMOLITION WASTE



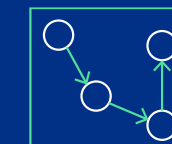
LOWER ENVIRONMENTAL
IMPACT



COST AND EFFICIENCY
SAVINGS



ENHANCED CIRCULAR ECONOMY
OPPORTUNITIES



BETTER PROJECT COORDINATION
AND MANAGEMENT



INCREASED TRANSPARENCY
AND TRACEABILITY

ROADMAP TO IMPLEMENTATION

Prototype and final optimization: Validate core algorithms and workflow to obtain a Minimum Viable Product (MVP)

Pilot testing and validation in operational environments to collect feedback from clients in real scenarios

Commercial ready product and certification: Version 1.0 ready for market

Commercialisation and market scaling: Launch the tool and establish market presence with First clients onboarded

Transport infrastructure — roads, railways, bridges, tunnels — is built to serve generations. Yet information about what they are made of, how they perform, what waste they generate, or how materials can be reused is often scattered or incomplete. As a result, valuable resources are lost, maintenance becomes less efficient, and achieving circular economy goals becomes harder.

The Digital Logbook for Transport Infrastructure, developed within the LIAISON project, provides a solution. It acts as a centralised digital record of an infrastructure asset's materials, components, and circularity performance throughout its life cycle — from construction and operation to renovation and end-of-life processes.

The Logbook builds on and expands CinderOSS, a digital platform originally created for circular construction processes. In LIAISON, the platform is transformed into a dedicated tool for transport infrastructure, capable of storing, organising, and visualising the data needed to support Green Public Procurement (GPP), circular business models, and decision-making based on real evidence rather than assumptions.

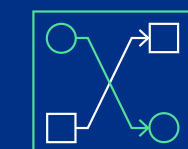
As data flows in from the BIM4INFRA tool and from on-site processes, the Logbook becomes a living asset passport,

providing insight into material quantities, environmental impacts, treatment options, and opportunities for reuse. It also connects to the TRACETOKEN blockchain system to ensure that secondary raw materials and reusable components are tracked transparently and securely.

More than a storage space, the Logbook is a digital ecosystem. It includes tools and services that help public authorities, contractors, and businesses identify new circular opportunities. Through its database of materials, regulations, circular business models, and demonstration cases, it helps users understand how waste can become a resource — and how circularity can be embedded in everyday infrastructure decisions.

The integrated marketplace function also enables organisations to offer or source secondary materials, supported by data on quantities, characteristics, availability, and environmental impact. This creates the conditions for real circular value chains in transport infrastructure, moving from theory into practice.

BENEFITS



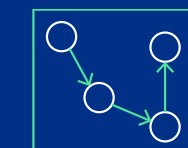
MATERIAL INVENTORY
ACROSS THE LIFE CYCLE



DOCUMENTS
AND MODELS REPOSITORY



OPERATIONAL
PERFORMANCE



MONITORING
DATA



CIRCULARITY
METRICS



ENVIRONMENTAL
AND SUSTAINABILITY ANALYSIS



ECONOMIC
DATA

ROADMAP TO IMPLEMENTATION

**Set foundations for material passports and asset life-cycle tracking.
Implement GIS + BIM integration**

**Validation with stakeholders
to align functionalities with GPP
and EU taxonomy requirements**

**Standardisation and interoperability with
digital construction standards.
Develop links with BIM platforms**

**Commercialisation and market scaling:
first paying clients
and demonstration portfolio**



LIAISON

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