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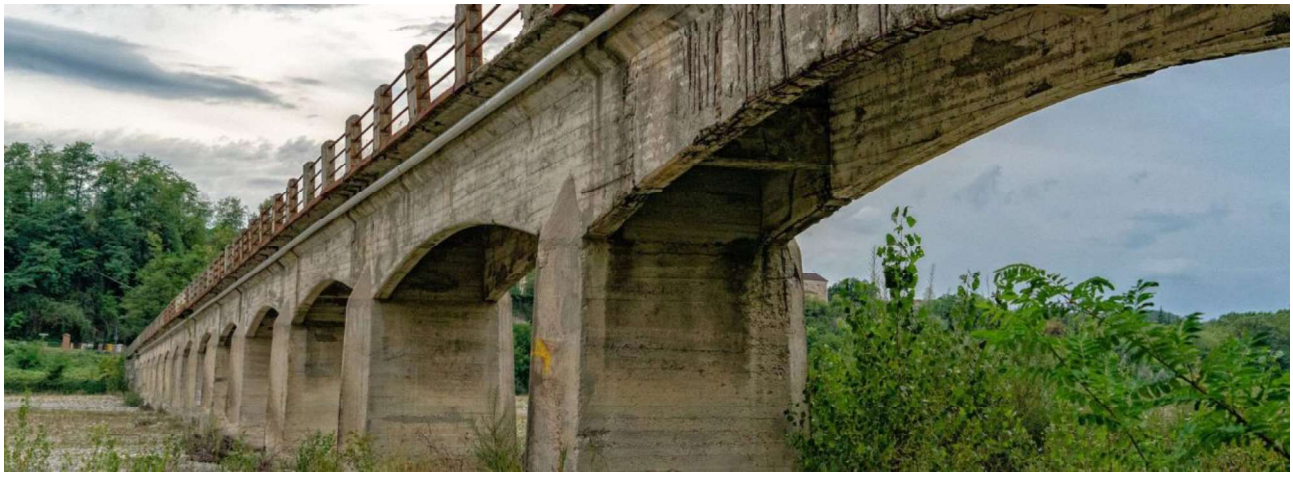
BIM4CE

Scalable Low-Cost Digital Monitoring Solution for European Bridges



BIM4CE SOLUTION OUTLOOK

Introduction

Bridge owners across Europe face growing challenges related to ageing infrastructure, limited maintenance budgets, and increasing operational demands. Existing monitoring systems are often expensive, complex, and difficult to implement on a larger scale, while traditional inspections provide only periodic information about bridge condition. As a result, infrastructure managers often lack real-time data needed for timely decision-making and effective maintenance planning. Additional challenges include increasing traffic loads, environmental impacts, and moisture infiltration — one of the main causes of deterioration in reinforced concrete structures. Many monitoring technologies also remain fragmented and poorly integrated, leading to reactive maintenance that addresses damage only after deterioration has progressed. The BIM4CE project addresses these issues through a simplified, scalable, and affordable digital monitoring solution that supports continuous condition assessment, early warning detection, and more efficient infrastructure management.

Smarter Approach to Bridge Monitoring

The integrated digital bridge monitoring system combines low-cost sensor technologies, real-time data transfer, cloud-based data collection, digital twin visualisation, and predictive maintenance support into one unified and easy-to-deploy approach. The system enables bridge owners and infrastructure authorities to continuously monitor bridge behaviour and detect early signs of deterioration without relying solely on periodic manual inspections. The solution has been designed as a modular, scalable, and cost-efficient approach that can be easily replicated and adapted to different bridge types (as well as other critical infrastructure) and operational environments, making it suitable for both regional and national infrastructure authorities across Europe.

A Transferable Bridge Monitoring System

The BIM4CE project developed a scalable and transferable digital bridge monitoring solution that helps bridge owners, public authorities, and other stakeholders monitor infrastructure, reduce maintenance costs, and improve long-term safety. The system combines affordable sensors, real-time data transfer, cloud-based monitoring, and digital twin technology into one modular solution adaptable to different bridge types, operational conditions, and other critical infrastructure across Europe.

Unlike traditional inspection approaches based on periodic manual inspections and fragmented monitoring systems, BIM4CE enables continuous, data-driven maintenance planning. The system provides early warnings of structural deterioration, moisture infiltration, abnormal vibrations, and excessive traffic loading before visible damage becomes critical. The solution was successfully validated on various pilot bridges demonstrating reliable operation under different environmental, climatic, and traffic conditions. Its modular design allows authorities and infrastructure owners to deploy only the components they need, making the system financially accessible for both large infrastructure operators and smaller regional authorities.

Who Can Use the Monitoring system?

The BIM4CE monitoring system is designed for a wide range of organisations responsible for the management, maintenance, and long-term safety of bridge infrastructure

- National road authorities
- Regional infrastructure agencies
- Municipal bridge owners
- Transport ministries
- Infrastructure maintenance operators
- Engineering and maintenance companies
- Public infrastructure asset managers

The solution has been designed as a flexible digital monitoring system that can be tailored to different bridge types, operational environments, and monitoring requirements. Beyond bridge infrastructure, the concept also offers strong transferability potential to other areas of critical infrastructure, including tunnels, transport corridors, industrial facilities, public buildings, and other structures where continuous condition monitoring and preventive maintenance are essential.

How it works?

The BIM4CE system combines several interoperable components into **one unified monitoring platform.** The system combines **adaptable sensors, cloud-based data transfer, and digital twin visualisation** into one integrated platform that helps bridge owners better understand the condition of their infrastructure and react before serious damage occurs.

1. Sensors

The monitoring system uses a combination of cost-efficient and high-performance sensors that can be adapted to the specific needs of each bridge type. One of the key innovations developed within the project is a novel leakage sensor foil created by TU Dresden. These flexible thin-film sensors are installed at critical bridge locations such as expansion joints, deck surfaces, bearings, and structural connections, where moisture infiltration most commonly occurs. By detecting water ingress at a very early stage, the sensors help prevent structural deterioration before visible damage appears. The technology is energy efficient, easy to install, adaptable to complex bridge geometries, and suitable for long-term outdoor use, making it highly appropriate for large-scale and cost-effective deployment. Because the solution is modular, owners and stakeholders can start with a basic monitoring setup and expand the system later if needed.

Key benefits: low energy consumption, easy installation, adaptability to complex bridge geometries, suitability for outdoor conditions, affordable large-scale deployment.

Additional Options
The system can also integrate additional monitoring technologies, including:

Sensor Type	Purpose
Accelerometers	Detect abnormal vibrations and structural behaviour
Bridge Weigh-in-Motion (B-WiM) systems	Monitor traffic loads and axle weights
Environmental sensors	Measure temperature and environmental conditions
Leakage sensors	Detect moisture and water ingress at critical points in bridge structures (e.g. expansion joints, deck surfaces, bearing areas, etc.)

2. Data Transfer and Cloud-based monitoring platform

The collected sensor data is automatically transferred in real time to a secure cloud-based monitoring platform. This enables bridge owners, maintenance teams, and infrastructure authorities to remotely monitor bridge conditions without the need for extensive on-site IT infrastructure. Through a centralised digital environment, users can access live monitoring information, receive automated alerts, analyse trends, and manage multiple bridges simultaneously. The cloud-based approach significantly reduces operational complexity while improving access to reliable and up-to-date data. The solution also supports remote access, enabling maintenance teams and authorities to review bridge conditions from any location.

The cloud-based platform enables: remote monitoring of bridge condition, centralised data storage, real-time alerts, historical trend analysis, multi-bridge management, access for different stakeholders.

3. Digital Twin

To further simplify interpretation and decision-making, each monitored bridge can also be represented through a digital twin model — a virtual bridge model connected directly to real-time monitoring data. The digital twin provides a clear visual overview of bridge condition, helping users quickly identify critical areas, better understand structural behaviour, and plan maintenance activities more efficiently. By transforming complex engineering data into accessible visual information, the BIM4CE solution improves communication between technical experts, infrastructure managers, public authorities, and other stakeholders.

The digital twin enables: live visualisation of bridge condition, identification of critical structural areas, faster interpretation of monitoring data, improved maintenance planning, better communication between technical and non-technical stakeholders.

Together, these interconnected components create a scalable, cost efficient and user-friendly digital monitoring ecosystem that supports preventive maintenance, reduces infrastructure risks, and enables smarter long-term management of bridges and other critical infrastructure assets.

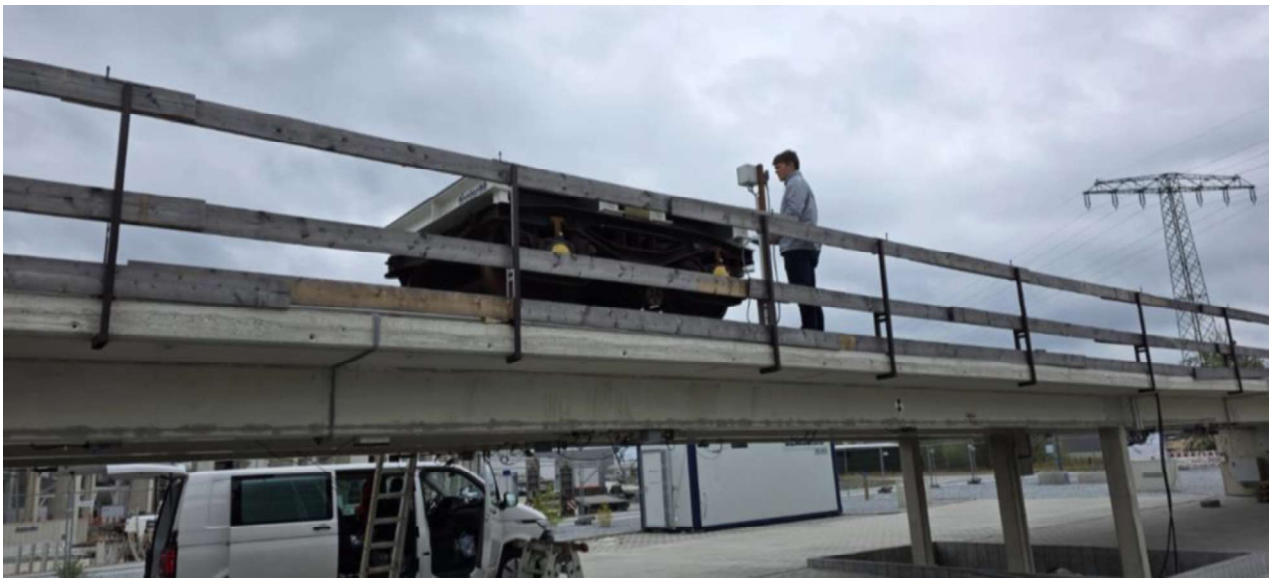
Why the BIM4CE Solution is Different

Traditional bridge monitoring systems are often expensive, technically complex, and difficult to implement across large infrastructure networks. Maintenance still mainly relies on periodic inspections, meaning problems are often detected only after deterioration has progressed. Existing systems also require significant investments, operate as isolated solutions, and provide technical data that can be difficult for non-specialists to interpret. The BIM4CE solution addresses these limitations through a simpler, more flexible, and accessible monitoring approach. Its modular and scalable system can be gradually implemented according to the needs and budgets of infrastructure owners. By combining real-time monitoring, cloud-based data management, intelligent sensors, and digital twin visualisation into one integrated platform, the solution enables continuous condition monitoring and early detection of potential problems before visible damage occurs. This supports preventive and condition-based maintenance instead of reactive interventions. An important advantage of the BIM4CE approach is its ability to transform complex technical data into clear visual insights that support faster and better-informed decision-making. The system also allows flexible integration of different sensor technologies and monitoring parameters, making it adaptable to various bridge types, operational environments, and other critical infrastructure

Validation Across Three European Pilot Sites

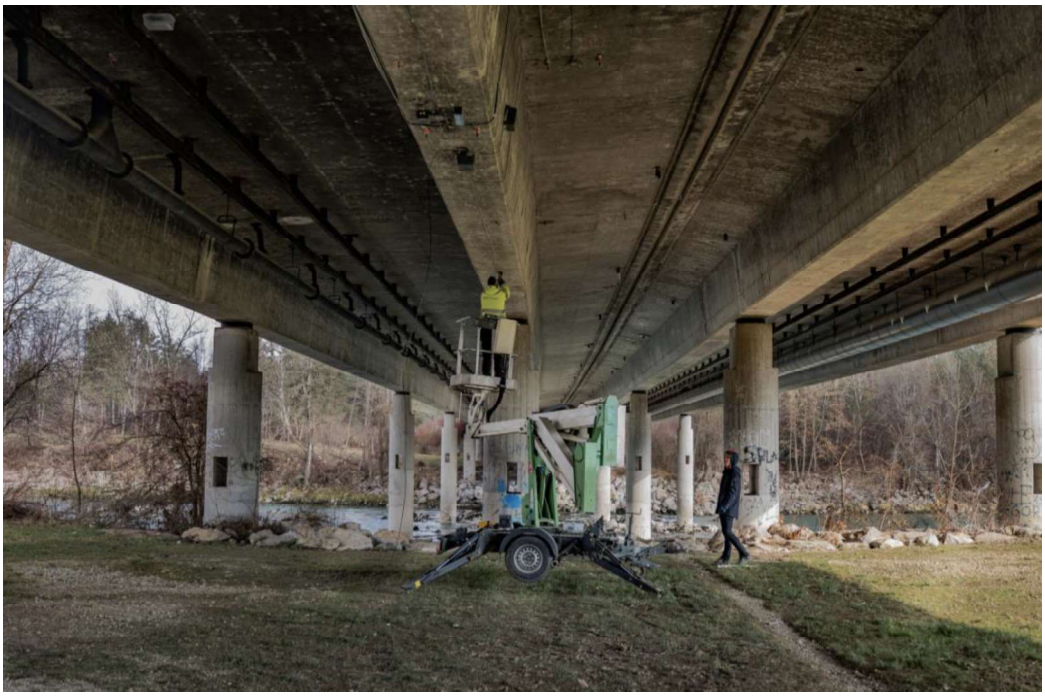
The BIM4CE solution was validated at three pilot bridge sites in Central Europe.

Germany – IDA-KI Bridge
The IDA-KI is an openLab bridge in Bautzen that serves as a research and validation site for testing sensor technologies, data transfer systems, and digital twin integration. The bridge represents a typical Central European Road bridge subject to heavy traffic and seasonal moisture exposure.



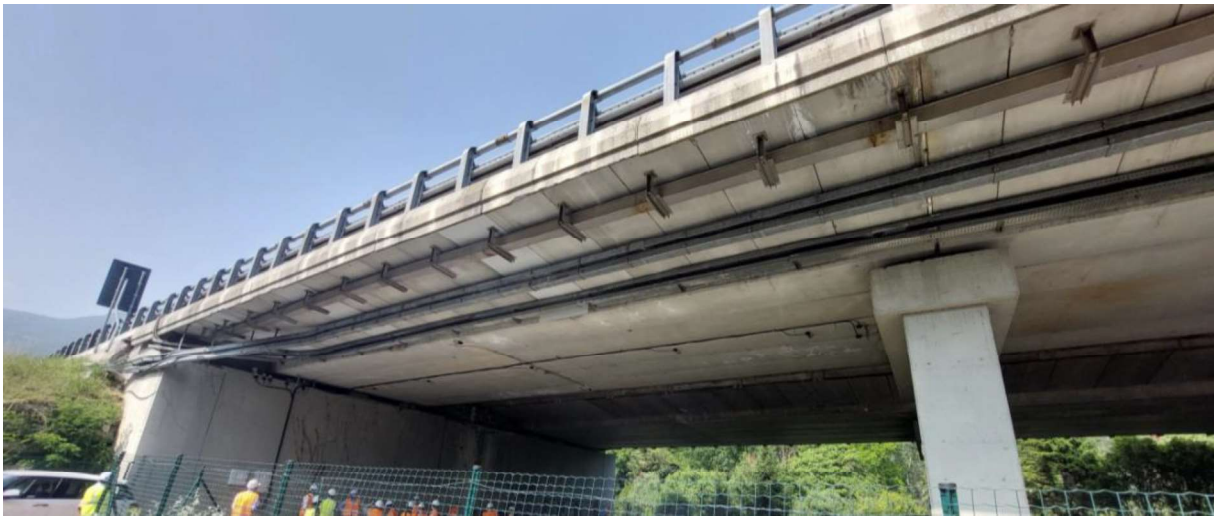
Slovenia – Tomačevo Bridge

The Tomačevo bridge in Ljubljana demonstrated the applicability of the solution under Alpine environmental and traffic conditions. The Tomačevo Bridge is a two-lane bridge spanning over the Sava River and is one of the main thoroughfares connecting the capital of Slovenia with its northern suburbs.



Italy – Sant'Ambrogio Bridge

The Sant'Ambrogio bridge in Italy represents the southernmost pilot site, providing data under specific climate conditions - moderately continental with Mediterranean influences. Its inclusion ensures the solution's applicability across diverse environmental contexts within Central Europe.



Scalability and Transferability

One of the main strengths of the BIM4CE solution is its modular and scalable design, allowing gradual implementation according to budgets, technical requirements, and infrastructure priorities. Bridge owners can introduce digital monitoring step by step without large upfront investments or complex technical systems.

Users can deploy different monitoring levels — from low-cost moisture detection to vibration monitoring, multi-sensor systems, or full digital twin integration. This makes the solution suitable for both small municipalities and large national infrastructure operators. The system can be applied to concrete and prestressed concrete bridges, urban bridges, regional roads, and heavily trafficked transport corridors, while its interoperable digital architecture supports expansion from individual bridges to bridge networks.

The BIM4CE approach also has strong transferability potential. It was designed to be reusable across different countries, infrastructure systems, and organisational environments without depending on a single bridge type, technology provider, or national framework. Its flexible monitoring architecture, scalable cloud infrastructure, adaptable digital twin functionality, and integration of various sensor technologies can be customised to local needs. By combining commercially available technologies with cost-efficient sensors, the solution can be implemented by other European regions without highly specialised infrastructure. Beyond bridge monitoring, it is also suitable for broader smart infrastructure initiatives and other critical infrastructure requiring continuous monitoring and preventive maintenance.

Environmental, Social, and Economic Impacts

The BIM4CE digital bridge monitoring solution **delivers important environmental, social, and economic benefits** by supporting smarter and more preventive infrastructure management. Continuous monitoring and early detection of deterioration help extend bridge service life, reduce unnecessary reconstruction works, and optimise maintenance resources, contributing to more sustainable use of public infrastructure and investment budgets.

Environmentally, the solution reduces the need for large emergency repairs, extends the lifespan of existing bridges, and improves climate resilience through better condition assessment and preventive maintenance. **Socially**, it supports safer and more reliable transport infrastructure by reducing the risk of unexpected failures, bridge closures, and traffic disruptions that affect regional mobility and economic activity. **Economically**, the system enables more strategic and data-driven maintenance planning, helping authorities reduce repair costs, minimise infrastructure downtime, and gradually implement monitoring according to available budgets and operational needs.

Conclusion

The BIM4CE project partners developed a practical, scalable, and transferable digital bridge monitoring solution that simplifies infrastructure maintenance through affordable sensors, cloud-based monitoring, and digital twin technology integrated into one modular system. The solution enables continuous and preventive monitoring while allowing gradual deployment according to operational needs, budgets, and infrastructure priorities. Its flexible design also supports replication across different regions, bridge types, and infrastructure

systems. Successful pilot implementations in Germany, Slovenia, and Italy confirmed that the system can operate under different environmental and operational conditions and can be adapted to diverse infrastructure contexts across Europe. The BIM4CE approach therefore provides a strong foundation for future European bridge monitoring strategies and supports smarter, more sustainable, and more resilient infrastructure management based on digitalisation, preventive maintenance, scalability, and cross-regional transferability.

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Further information on partners available at https://www.interreg-central.eu/projects/bim4ce/

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