From case study to worldwide perspective for the management of existing infrastructures.

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Abstract

Infrastructures already in place are crucial to the development of modern society. The transportation system, in particular, is essential for moving people and products internationally and bringing globalization to life. Infrastructure stakeholders today place a high priority on issues like sustainability as a result of increased awareness in recent years of the need to maintain existing infrastructures. As a result, rather than being replaced by new infrastructures that must be developed, the future infrastructures will be those already in existence and well maintained. Creating more precise, effective, affordable, and sustainable tools and technologies to enable entire lifecycle management is crucial to preserving existing infrastructure. The current work gives a broad overview of some pertinent initiatives that are being made in this area on a global scale, highlighting the latest technological trends, pointing out some opportunities that already exist, and speculating on some of the essential tools that will be employed shortly to support the management of transportation infrastructure.

Keywords: *transport infrastructures, management, technology.*

1. INTRODUCTION

The fact that a portion of Portugal's transportation system traverses several geological and environmental concerns enhances its sensitivity to climatic risks. Due to their crucial role in socioeconomic growth, one of the difficulties for transport decision-makers is ensuring the transportation networks' resilience to extreme events and climate change (Demirel, 2012). The Strengthening Infrastructure Risk Management in the Atlantic Area (SIRMA) project was suggested to create, validate, and implement a comprehensive framework for effectively managing and mitigating natural hazards in terrestrial transportation modes. According to the Transport White Paper (2011), SIRMA significantly increases the resilience of transportation infrastructure. The SIRMA idea, which uses multiplatform remote sensing and crowdsourcing to monitor big data, is at the forefront of adopting predictive maintenance (Campo et al., 2006; Sy et al., 2019). The primary goals of SIRMA are to lower maintenance and retrofitting costs through long-term recovery and risk mitigation. To achieve this goal, existing deterministic models of infrastructure resilience under the current climate will be modified to incorporate probabilistic models that take into account the uncertainties of future climate and change on land use and how it affects the impact of hazards on specific mode components (Alderson et al., 2015; Bar-ber, 2015).

On the other hand, recently, the Bridge Management System (BMS, hereafter used by the acronym GOA - Gestão de Obras de Arte in Portuguese) has evolved to meet various clients' needs and reflect the features of their bridges. GOA has been modified into a product owned by Betar, Lda. Betar discovered a void in the domestic market and began developing the first Portuguese bridge management system in 1997, 29 years after establishing the first bridge management system in the United States (Costa et al., 2019). Estradas de Portugal, a public transportation company, was also acquired and used the GOA system in 2004. By establishing GOA as a national standard, these facts helped private and public transportation agencies in Portugal and practically all bridge owners create a consistent language and framework. Continuous advancements in GOA have been made possible by more than 20 years of research and experience. It led to expansion outside the Portuguese market, specifically in Mozambique and China. More recently, opportunities to implement it in other countries have also arisen. The specification of the fundamental modules that allow storing various data types has mostly undergone revisions during the past few years (IABSE Symposium Report 91). In this sense, GOA.BI is a project built on modern technology and digital trends that focuses its efforts on addressing the issues with the highway and railroad infrastructures that were previously mentioned. Due to the large number of assets involved, this project seeks to develop a smart interface to assist stakeholders (owners, transportation authorities, and inspectors, among others) in the lifecycle management of complex systems, such as transportation infrastructures (bridges, viaducts, tunnels, acoustic barriers, buildings, retaining walls, slopes, pavements, rail tracks, telematics equipment, sign gan-tries, high mast columns, among others). The first step is to create an integrated asset management system framework based on the Bridge Management System (BMS), which offers flexibility to apply and extrapolate its concepts for different types of infrastructure.

Building information modelling (BIM), which can cover integrated management of asset networks like motorways, railways, or bridges, has recently assumed a crucial position in the infrastructure sector. The state of the art of BIM implementation in this field, including an overview of the BIM domains, BIM applications, data schemas, and BIM uses, has been presented through the thorough review and critical analysis of 198 publications in the field of building information modelling for transportation infrastructure (Costin et al., 2018). For transportation infrastructure in general, and particularly for highways and bridges, it demonstrates better BIM research and application development. Additionally, it draws attention to the state of research at the moment, how emerging technologies are being used, and the considerable research gaps that still need to be filled.

Depending on the originator's source, the 3D geometrical model for an existing infrastructure can be generated in various ways. The IFC model, which aims to link the geometric representations with the semantic objects flexibly, is the geometric representation of each structural member. In this context, several bridge structures have been widely launched using the bridge digital information model (BIM method) (Dang & Shim, 2020b, 2020a, 2018). An improved version of the alignment-based object-oriented design philosophy appears to be the key to building a bridge information model. The entire bridge model can be delivered without discontinuity using a set of parameter definitions and suitable algorithms. Because of the flexibility afforded by the parametric design idea, the model's creator can alter any input variables to satisfy the desired objectives. The digital bridge model greatly aids the engineer in effectively controlling the flow of information for various goals throughout the project's lifecycle. The design platform's interoperability makes collaboration between multiple project stakeholders and stag-es possible.

2. CASE STUDY 1: STRENGTHENING INFRASTRUCTURE RISK MANAGEMENT (SIRMA)

3.1. Framework for a Risk & Resilience-Based Decision Making

Extreme natural occurrences and the robust corrosion processes brought on by closeness to the water directly impact how well railway and transportation infrastructure performs in the service, particularly in the Atlantic Area. To increase the resilience of transportation infrastructure, a robust framework for managing and mitigating extreme natural occurrences must be developed and put into place. Figure 1 suggests a framework for risk- and resilience-based decision-making intended to lessen the effects of severe natural hazards, such as floods and fires, on people and local and global economies.

Figure 1. Configuration for the risk & resilience-based decision-making framework.

The main actions and deliverables following the proposed framework can be considered as follows: (1) Risk-based predictive model (algorithm) for transportation infrastructures (includes climate change effects on the impact and return period of extreme events). (2) Relational database with risk mitigation measures for transportation infrastructures, their effects and costs. (3) Framework (user-friendly software) for multi-criteria decision-making, i.e., by maximizing resilience and minimizing the risk mitigation costs.

Noteworthy, the risk definition here is associated with the consequences of an asset's failure in case of a hazard's occurrence. While a holistic methodology was defined, its implementation was only done for specific parameters. Risk management involves monitoring the factors influencing these three risk components and determining mitigation actions to keep the network risk within acceptable levels. This framework enables forecasting transportation infrastructure performance to multiple hazards, comprising the likelihood of such extreme events and their impact on the infrastructures. Moreover, it is expected to create the premise for the creation of a database with the most relevant risk mitigation measures, including their description, when they should be used, and with what time frequency, effects and costs (direct and indirect).

3.2. Work packages and Results

To achieve the project's aims, the distribution of different Work Packages (WPs) was proposed and subdivided into specific actions that interact with each other (see figure 2). The technical WPs are listed: WP4 - Climate change & natural hazards in Atlantic Area; WP5 - Instrumenting transportation infrastructure for extreme natural hazards; Wp6 - Risk & resilience-based decision-making procedure for transportation infrastructure; WP7 - Testbed.

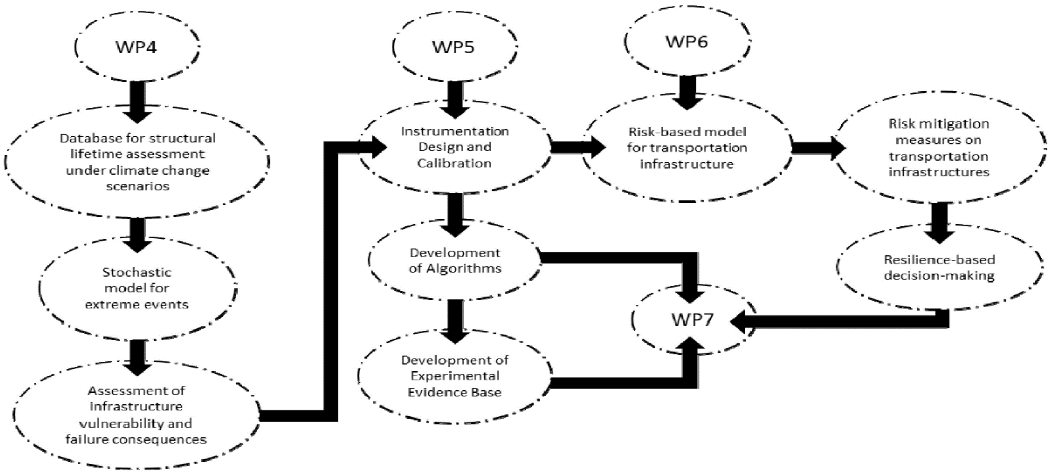

Figure 2. Work packages for the SIRMA project implementation.

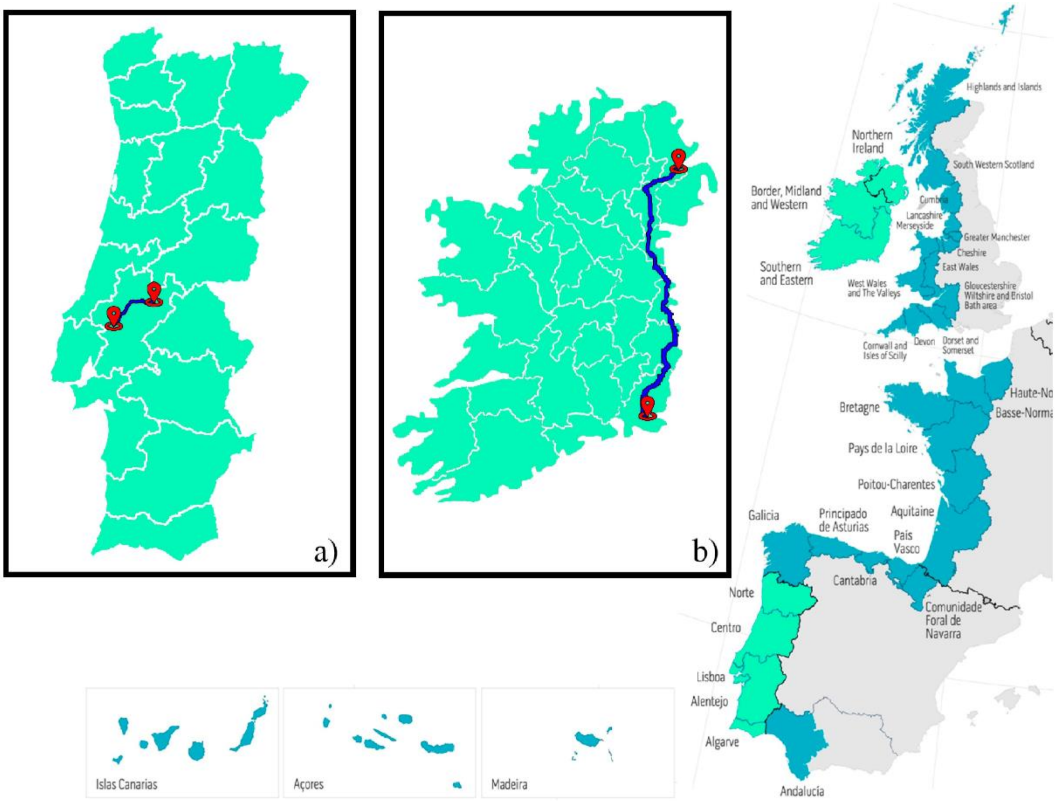

Figure 3. Tentative test bed location. a) Portugal. b) Northern Ireland.

The primary goal will be to deploy the SIRMA risk assessment system and decision-making in two multimodal case studies affected by climate change events, one in Portugal and the other in Ireland/Northern Ireland, to test and validate it (transborder). A portion of National Road 6 (EN6) and the Cascais Train Line will serve as the Portuguese test bed (Figure 3a). There are parts of both infrastructures that practically sit atop the Atlantic Ocean. Every winter, the water surges over the road due to floods alone or with sea storms, resulting in significant traffic accidents and protracted blockages. The primary rail line (Figure 3b) between Ireland and Northern Ireland (UK) will also serve as the test bed. More than 200 train crossings will be employed for a chosen 10-kilometre length of track to evaluate the track's state, the strength of its bridges, and the capability to spot water damage to the road's pavement. The two case studies will test the sensoring system created by WP5. From that system, a list of indicators about the performance of the infrastructure will be incorporated into the risk-based model and later into the decision-making framework created by WP6. Additionally, the risk-based model will include WP4 research on the effects of climate change. As a result, WP7 will calibrate this model and test the decision-making algorithm to determine the best course of action for risk minimization.

3. CASE STUDY 2: GOA BRIDGE MANAGEMENT SYSTEM – BRIDGE INTELLIGENCE (GOA.BI)

3.1. Framework for a BIM-based Bridge Management System

A desktop web-based and intelligent interface platform should be available and supported by the new bridge management system (GOA.BI). The earlier system is a full version with all its modules because it is designed for the central management team. In-situ inspectors will use this GOA.BI, which they will access through mobile devices. There should be a lighter version with less functionality in fewer modules.

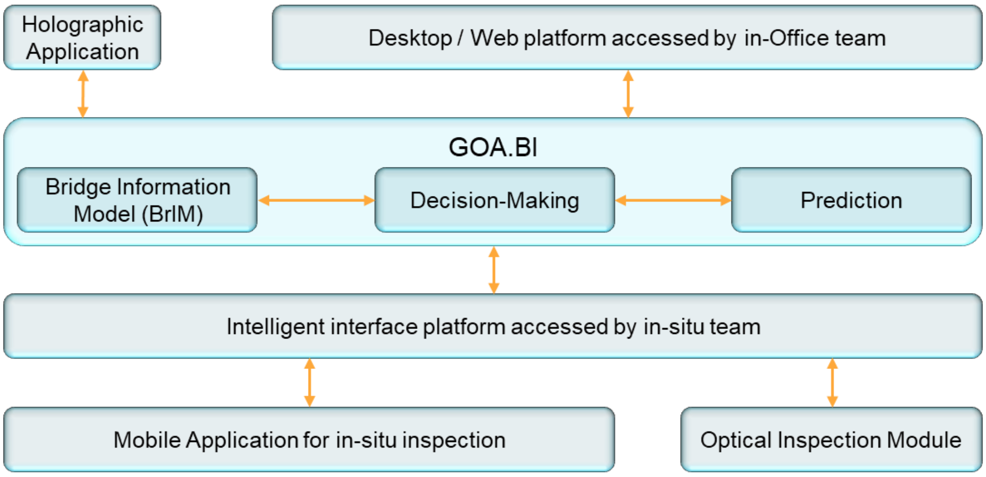

Figure 4. Flowchart of the new BIM-based Bridge Management System architecture.

Figure 4 – Flowchart of the new system architecture summarizes the new system architecture. On top and bottom extremities are represented the two main ways to access the new system referred to before. In the middle, the significant modules to be developed are shown. They are beginning with the system's core, GOA.BI module will be essentially based on the existing GOA system, which will be upgraded considering the interoperability between the current system and the new modules. Remark that this is the central module through which all other modules communicate.

Besides the objectives directly related to developing a new bridge management system, other important goals are associated with the recent acquisition tools and the exchange of information between all modules. The following list summarizes all the main objectives of the project: (1) Development of a new web-based platform, modular and scalable that can be continuously upgraded with new features and modules; (2) Development of an intelligent interface platform to be used in the field by the in-situ inspectors' team; (3) Development of new inspecting equipment taking advantage of existing commercial tools (e.g. commercial drones, cameras, etc.) and algorithms/methods in the computer vision and deep learning field; (4) Development of mixed reality tools to manage bridges information with Visual Analytics and Augmented Reality techniques; (5) Development of algorithms to be used in information exchange between new inspecting equipment sensors and BrIM models; (6) Development of digital image correlation algorithms to post-process inspection measurements; (7) Development of a predictive maintenance management module, which will help in defining priorities for maintenance works; (8) Development of a decision-making module will help define the type of intervention to be taken, considering the associated cost-benefit ratio.

3.2. Prototype development

The process of parsing data in existing IFC from the current GOA platform can be introduced in figure 5. IfcOpenShell is an open-source (LGPL) software library that helps users and software developers to work with the IFC file format. The IFC file format can describe building and construction data, and the form is commonly used for BIM/BrIM. IfcOpenShell helps engineers build digital platforms and tools for the built environment. Read, write and modify BrIM using IFC, a diverse digital language from design to construction and beyond.

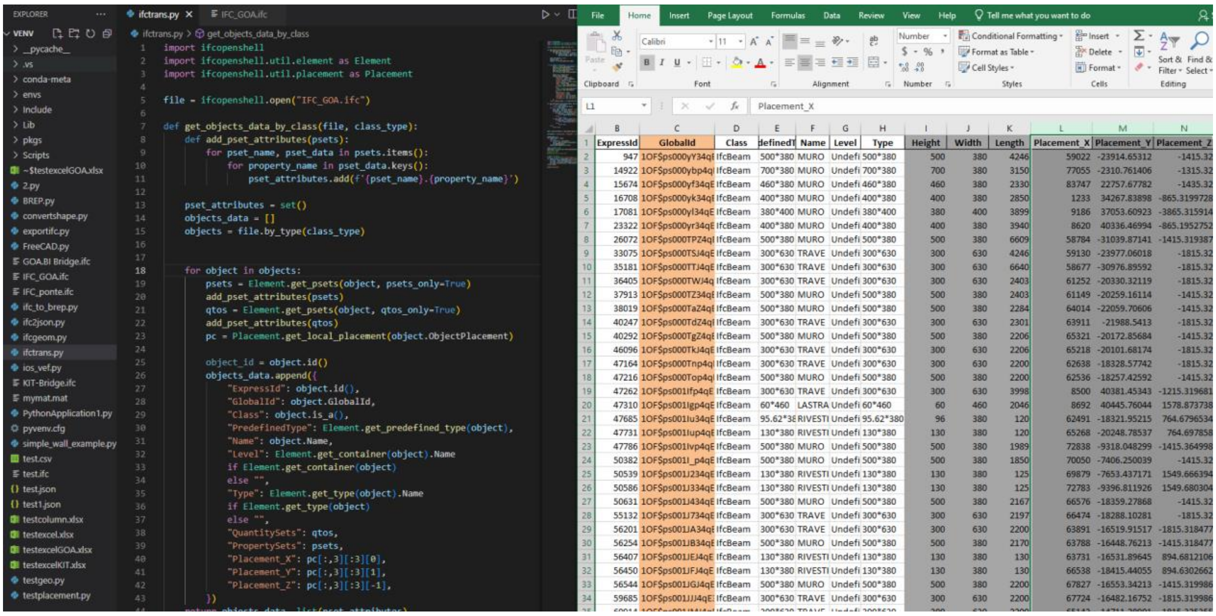

Figure 5. Parsing IFC data from existing GOA system by IfcOpenShell-python.

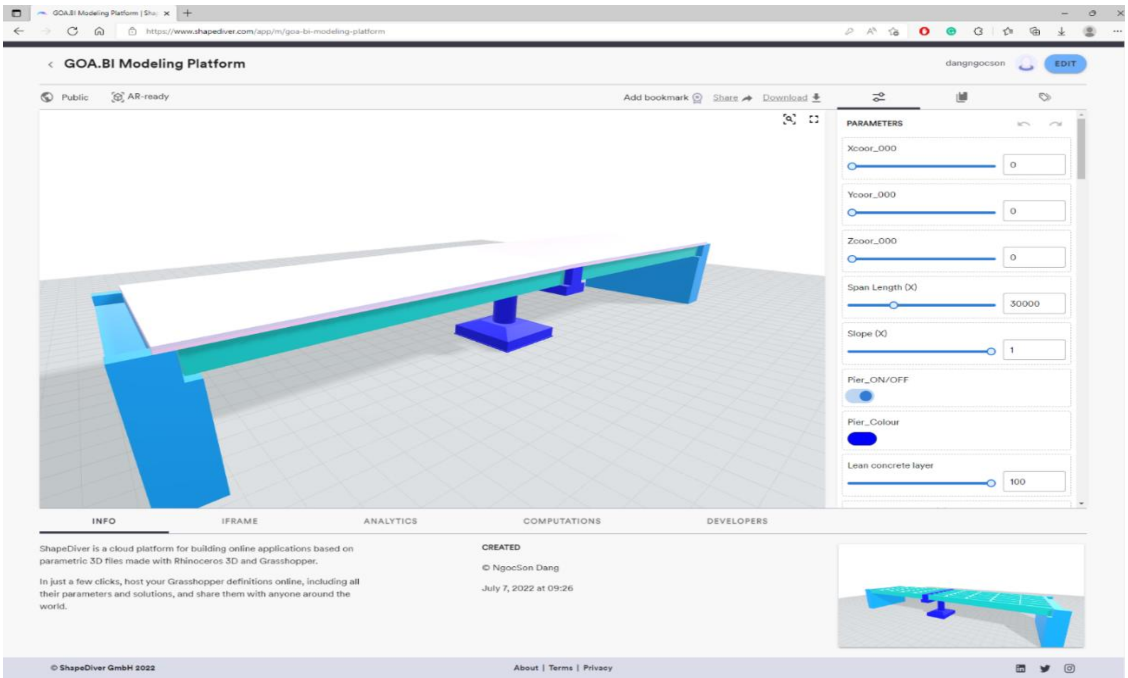

Figure 6. Cloud applications for the GOA.BI modelling platform.

The algorithm-based coding in algorithmic tools is mainly used to create the BrIM module. The coordinates and size of the primary structural members served as the basis for producing a 3D geometric model. The reference coordinates data, dimension table data and modelling algorithm data can be embedded into a web-based modelling platform by an open-source cloud application scripting tool or even some commercial ones (figure 6). The BIM users can join with the originator to modify any parameters and algorithm. The model can be flexibly changed according to different BIM uses. Along with that, the users also can export the 3D model to a neutral format.

The android application's primary focus is to allow it to be easy to use and for the recording of anomalies and views during inspection to be done. It is necessary for the application to have an internet connection, not only for the user authentication part but also to access data from previous inspections so that the recorded inspection information is stored and accessible to all system users. For the development of the augmented reality application, the objective is to use a 3D model of the bridge in question. During the visualization of the holographic model of the bridge, the user must also be able to manipulate certain aspects that facilitate the visualization, such as zooming, rotating and positioning the model in any position in space. Finally, the Desktop/Web application will include most of the features of the mobile application, such as accessing and editing data already existing in the system. The advantage of this module is that it allows for an easier way, using a physical keyboard, to add denser written content, which will help clarify certain aspects that were not detailed in the field. It will also allow for to improvement of specific parts of the information that may not have been explained during the inspection with the mobile application.

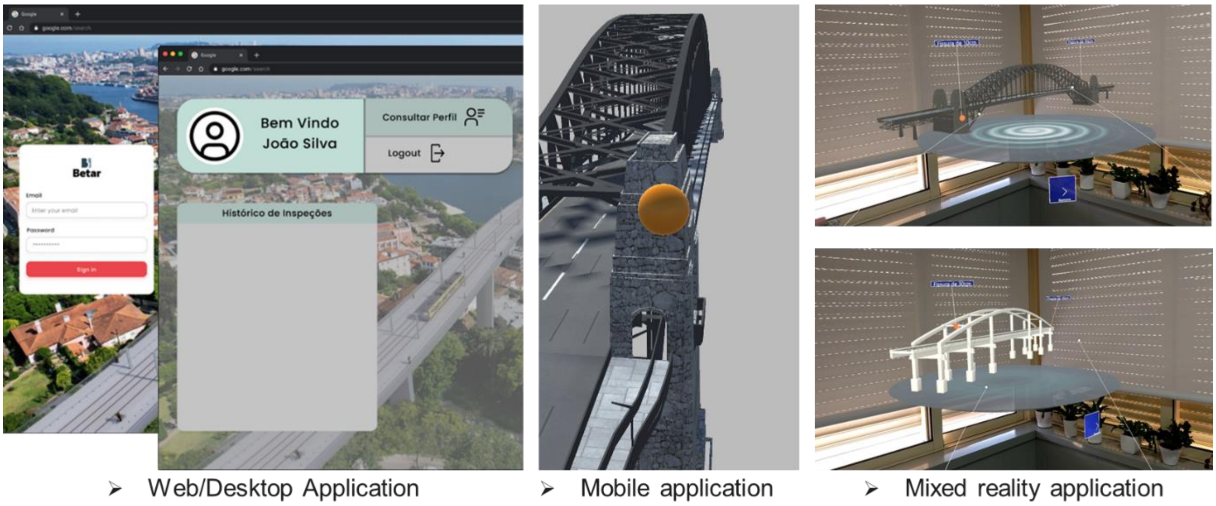

Figure 7. Applications for GOA.BI platform.

4. RESULTS AND DISCUSSION

A successful framework to increase resilience in the most critical transportation infrastructure in the Atlantic Area is anticipated following the development of the SIRMA project, taking into account the database gathered from the implemented monitoring and the impact of extreme events under the effects of climate change. This project's long-term benefits will include decreasing the risk of severe natural calamities, including floods and fires, on transportation infrastructure and improving population readiness for such hazards. Two public operators will test and use the proposed framework and make it available to other public and commercial operators in and outside the Atlantic Area. These organizations will ensure such effects by assisting partners (such as the government, municipalities, etc.). The scientific outcomes from this initiative will also be integrated with academic institutions, with some of the findings used in current or future courses (e.g. asset management, risk analysis, etc.).

Concerning the GOA.BI project, the digital revolution, has led to the design and management of numerous new and existing transportation infrastructures utilizing what is known as bridge information models (BrIM). Although BrIM models are primarily used in the design phase, they are a beneficial tool for infrastructure management during the operational stages. Therefore, it's critical to reconsider how maintenance has been carried out and how it should change to meet today's difficulties and prepare for the future. Due to this, two significant changes will be made to the current project. The first has to do with the required maintenance paradigm. A predictive maintenance paradigm will be used instead of the current preventive maintenance paradigm, which calls for several maintenance inspections and preventative treatments. The objective is to allocate resources more effectively while also being able to predict how the infrastructure's conditions will change over time. The second change concerns the new maintenance management tools' incorporation of digital elements. This modification will change two things: first, the management platform will be developed to be completely compatible with BrIM standards. On the other hand, modern inspection tools will be improved in terms of the inspector's equipment (such as a mobile tablet), the equipment utilized for the inspection (such as drones), and the features of both (e.g. digital image correlation). Mixed reality tools for information analysis and visualization will also be created to support the maintenance process.

After completing those projects, the largest Portuguese transportation infrastructure owner, the project's partner (Infraestruturas de Portugal), will offer actual data for the new web-based platform's testing.

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