Lecture Notes in Civil Engineering

Tung Nguyen-Xuan ·
Thanh Nguyen-Viet · Thanh Bui-Tien ·
Tuan Nguyen-Quang ·
Guido De Roeck *Editors*

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Preface

The construction industry has experienced fundamental changes in facilitating environmental-friendly infrastructure toward the sustainable development goals (SDGs) in recent years. Since the 1973 oil crisis, the green structures have ever improved and gained momentum across all industries. Green construction has become a popular norm in many new construction projects. Promoting green building principles in infrastructure is globally challenging for all stakeholders.

Green building is still in its infancy and constantly evolving. There are numerous principles applied to green projects: efficiency of structural design, energy distribution, water supply, material selection, waste, pollutant reduction, and so forth. Nowadays, the combination of economic development and advanced environmental management technology has paved the way for a sustainable built environment. At the country level, construction projects should be built to meet the green building standards, focusing on a priority for customers and communities.

The 4th International Conference on Sustainability in Civil Engineering—ICSCE 2022 was successfully held on November 25–27, 2022, in Hanoi, Vietnam. The local organizing committee (LOC) would like to greatly appreciate to all of you. Your participation contributes not only to the success of the conference itself but also to the innovation in green technologies. The ICSCE 2022 received 262 abstracts and 167 full papers from 15 countries and regions, including Algeria, Australia, Belgium, Brazil, Bulgaria, China, France, Japan, South Korea, Portugal, Russia, Taiwan, Myanmar, Cambodia, and Vietnam. The International Scientific Committee selected 81 papers for this proceedings, which is divided into eleven parts. These papers were presented at the conference and played an important role in promoting sustainable civil engineering infrastructures toward a green future.

The LOC would like to sincerely thank the International Scientific Committee, keynote speakers, session chairs, and reviewers for your support and cooperation for the success of the ICSCE 2022. We also gratefully acknowledge the sponsors for their valuable time and support.

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Geotechnical Engineering

About the Editors

Dr. Tung Nguyen-Xuan has been working at Civil Engineering Faculty, University of Transport and Communications (UTC), Vietnam, since 2008. He got Bachelor's and Master's degrees at UTC and Ph.D. degree at Tokyo Metropolitan University, Japan, with his main research topic about corrosion monitoring on steel truss bridges. Dr. Tung's research interests are concrete structure including concrete using recycled aggregates, structure engineering, advanced material, and structural health monitoring. Dr. Tung has published 20 scientific papers (in national and international journals) and 4 scientific books and is a principle investigator for 3 research projects.

Dr. Thanh Nguyen-Viet obtained his engineering and master's degrees from the National University of Civil Engineering (Vietnam) in 2001 and 2006 and his Ph.D. degree from Hohai University (China) in 2012, respectively. He joined the University of Transport and Communications in 2005 as a lecturer and is now a vice dean and an associate professor in the Faculty of Civil Engineering at the University of Transport and Communications, Hanoi, Vietnam. Dr. Viet Thanh Nguyen is a specialist working in the field of the harbor, coastal, and offshore engineering. Practical knowledge and experience help a lot in his research as well as inspire students and researchers. Dr. Nguyen's research areas are hydrodynamics, sediment transport, port, coastal and offshore engineering, and inland waterways. He has 26 publications in Web of Science and Scopus. He has obtained an Outstanding Ph.D. Candidate Award at Hohai University in 2013.

Assoc. Prof. Dr. Thanh Bui-Tien is an expert in Civil Engineering, specializing in structural health monitoring, AI, digital twin, intelligent transportation, and structural damage diagnosis of bridges. He is currently the dean of the Faculty in Civil Engineering at the University of Transport and Communications in Vietnam. He obtained his Bachelor of Engineering degree in Bridge Engineering from the University of Transport and Communications (UTC) in Vietnam in 2000 and his Ph.D. in Civil Engineering from the University of New South Wales (UNSW), Australia, in 2007. He has held academic positions at various institutions, including lecturing at UNSW and UTC and postdoctoral research at Université de Liège and KU Leuven. Assoc.

Prof. Dr. Bui Tien Thanh has published numerous papers in peer-reviewed prestigious journals and has contributed to many conferences and seminars around the world. He has a citation count of 1048, an h-index of 18, and an i10-index of 26. His current work involves developing new methods based on optimization and AI for structural health monitoring and structural damage detection.

Assoc. Prof. Tuan Nguyen-Quang is currently the vice dean of Faculty at Civil Engineering, University of Transport and Communications in Vietnam. His research domain is on the behavior of materials and structures, new materials, and technologies in construction. He graduated from University of Transport and Communications, Vietnam, in 2006. Then, he received a master's degree in 2007 and a Ph.D. in 2011 from Ecole Nationale des Travaux Publics de l'Etat (ENTPE) in France. Until now, he has more than 10 years of research in the field of materials in transport construction, especially asphalt materials. He is a member of the editorial board of Road Materials and Pavement Design Journal since 2016. He has published 60 scientific papers (in national and international journal) and 2 scientific books. His total number of citations is 750 (according to Google scholar). His h-index is 13 (according to Google scholar) and is 10 (according to Scopus). He chaired and participated in more than 10 ministerial and state-level projects in Vietnam as well as participated in the international RILEM project (RILEM TC 237 SIB, Testing and characterization of sustainable innovative bituminous materials and systems).

Emeritus Prof. Dr. Guido De Roeck is a highly respected figure in the field of civil engineering, with a distinguished career spanning several decades. He is currently affiliated with the Department of Civil Engineering, Section Structural Mechanics at Katholieke Universiteit Leuven (KU Leuven), Belgium. With expertise in fuzzy finite element method, dynamic analysis, soil mechanics, and fracture mechanics of composite materials, he has contributed extensively to research in these areas. Professor De Roeck obtained his Bachelor of Engineering Science in 1968, followed by his Master of Science in Civil Engineering in 1971, both from KU Leuven. He earned his Ph.D. in Structural Mechanics from the same institution in 1975 and his Doctor of Science degree in 1981. As a top professor at KU Leuven, Prof. De Roeck has published thousands of international articles, with a citation count of 22609, an h-index of 74, and an i10-index of 220. His notable achievements include being a senior specialist in the field of structural health monitoring with the output-only method of determining damage from vibration measurement. Professor De Roeck leads multiple research activities, covering a broad spectrum of domains such as static and dynamic analysis of mechanical structures, damage detection by vibration monitoring, dynamic system identification, soil-structure interaction, non-linear constitutive soil models, fracture mechanics of composite materials, fuzzy finite element method, and so on.

Keynotes

The Use of New Tools and Technologies for the Management of Existing Infrastructures. Worldwide Perspective

José C. Matos, Ngoc-Son Dang, Mário Coelho, and Sérgio Fernandes

Abstract The development of modern society heavily relies on existing infrastructures. In particular, transport infrastructures are crucial to moving people and goods around the world, thus materializing globalization. In recent years, awareness has been raised on the necessity to maintain the existing infrastructures and aspects such as sustainability are nowadays the top priorities of infrastructures' stakeholders. Accordingly, the future infrastructures will be those already existing and properly maintained rather than new ones to be built to replace them. The success of this huge compromise on maintaining existing infrastructure depends on the development of more accurate, efficient, cost-effective and sustainable tools and technologies to support all the lifecycle management. The present work provides an overview of some relevant efforts that are being conducted worldwide in this regard, highlighting the current trends of technological development, identifying some existing opportunities, and anticipating some of the most relevant tools that will be used in the near future to support transport infrastructures' management.

Keywords Transport infrastructures · Management · Technology

1 Introduction

During the last decades of the twentieth century and the start of the twenty-first century, significant investments were made in the transport industry in most developed nations. In the past, the main emphasis was on finding a design that would result in the lowest investment cost for various assets, including bridges, viaducts, and highways, while merely considering the functional requirements. This strategy

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produced an infrastructure design with high maintenance costs. An innovative life-cycle cost analysis (LCCA) method was developed to buck this tendency and seek the best balance between maintenance and investment [1].

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 [2]. 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 the adoption of predictive maintenance [3, 4]. 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 [5, 6].

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 the needs of various clients and to 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 USA [7]. 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 entire 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 [8]. 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 in a flexible manner, is the geometric representation of each structural member. In this context, several types of bridge structures have lately been widely launched using the bridge digital information model (BIM method) [9–14]. 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. Collaboration between multiple project stakeholders and stages is made possible by the design platform's interoperability.

2 Methodology and Framework

Managing the existing infrastructure is challenging regarding interoperability among different BIM solutions, different BIM uses, or difficulties in integrating other BIM models. Therefore, the prototyping methodology and case study are strongly recommended. This method includes the prototype creation, application and curating to a specific infrastructure asset, then reworking when needed until an acceptable prototype is achieved. It allows engineers to deal with any project when the requirements come from multiple disciplines and aspects, a crucial challenge that needs to be overcome.

During the prototyping research, the expertise and methods from different disciplines will be integrated into pursuing objectives. According to the management purposes for existing infrastructure, the following concept and framework works can be introduced:

2.1 Risk and 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 extreme natural hazards, such as floods and fires, on people and local and global economies.

The main actions and deliverables following the proposed framework can be considered as follows:

- Risk-based predictive model (algorithm) for transportation infrastructures (includes climate change effects on the impact and return period of extreme events).
- Relational database with risk mitigation measures for transportation infrastructures, their effects, and costs.
- 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 that influence these three risk components and defining 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).

Fig. 1 Configuration for the risk and resilience-based decision-making framework

2.2 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 2—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:

- Development of a new web-based platform, modular, and scalable that can be continuously upgraded with new features and modules.
- Development of an intelligent interface platform to be used in the field by the in situ inspectors' team.
- 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.
- Development of mixed reality tools to manage bridges information with visual analytics and augmented reality techniques.

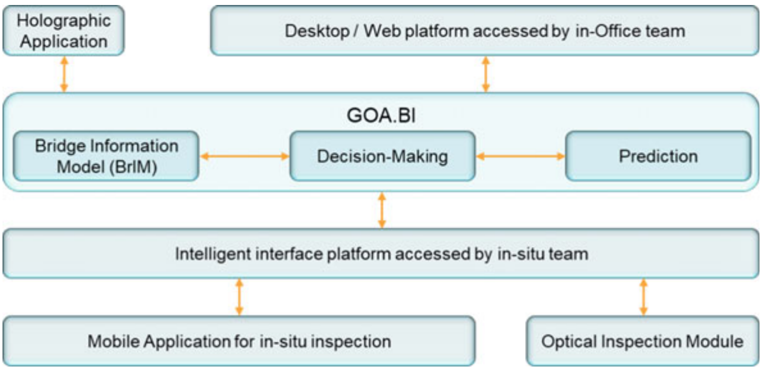

Fig. 2 Flowchart of the new BIM-based bridge management system architecture

- Development of algorithms to be used in information exchange between new inspecting equipment sensors and BrIM models.
- Development of digital image correlation algorithms to post-process inspection measurements.
- Development of a predictive maintenance management module, which will help in defining priorities for maintenance works.
- Development of a decision-making module will help define the type of intervention to be taken, considering the associated cost–benefit ratio.

3 Case Study 1: Strengthening Infrastructure Risk Management (SIRMA)

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 Fig. 3). The technical WPs are listed: WP4—Climate change and natural hazards in Atlantic Area; WP5—Instrumenting transportation infrastructure for extreme natural hazards; Wp6—Risk and resilience-based decision-making procedure for transportation infrastructure; WP7—Testbed.

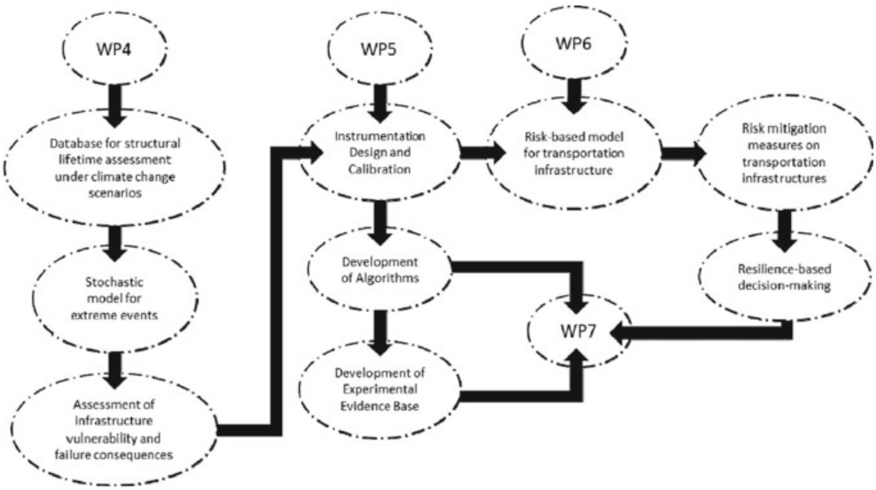

Fig. 3 Interaction graph between WPs