DTADD Systematic Review Protocol

Project Number: 101066739

Project Acronym: DTADD

Project Title: Digital Twin Anomaly Detection Decision-Making for Bridge Management

Experienced Researcher: Dr. Alejandro Jiménez Rios

Main Supervisor: Prof. Vagelis Plevris

Secondment Supervisor: Prof. Maria Nogal

Funded by
the European Union

Table of Contents

List of tables

List of figures

No table of figures entries found.

1 Preferred Reporting Items for Systematic Review (PRISMA) 2020

1.1 Introduction

A transparent systematic review should present completely and accurately why it has been done, what has been done and what was found. The benefits of a systematic review are:

- They allow to identify future research priorities based on the synthesis of state-of-the-art knowledge in a certain field.
- Questions that cannot be addressed by individual studies can be answered by systematic reviews.
- Give a hint to future studies to rectify aspects of primary research identified on them.
- Provide answers to how and why a particular phenomenon occur based on the generation and/or evaluation of theories.
- They can generate or evaluate theories about how or why phenomena occur.

The PRISMA 2020 [1] methodology, although mainly developed and used in the medical and clinical sciences, could be also applied in engineering, as it provides guidance in methodologies to identify, select, appraise and synthesize the available literature. This document presents the protocol adopted to perform a systematic review for the DTADD project following the checklist provided by PRISMA and guidelines of the PRISMA-P Explanation and Elaboration [2].

1.2 Protocol

The recommended items to address in a systematic review protocol according to the PRISMA methodology are presented in Table 1, Table 2 and Table 3.

Table 1. Administrative information

Title:		
	Identification	DTADD Systematic Review
	Update	-
Registration:		In accordance with the guidelines, our systematic review protocol was registered in the Open Science Framework (OSF) Registries on November 30, 2022, registration number sh9b2, DOI: https://osf.io/sh9b2
Authors:		
	Contact	**Corresponding author:** Alejandro Jiménez Rios; alejand@oslomet.no Structural Engineering Research Group (SERG), Department of Built Environment (DBE), Faculty of Technology, Art and Design (TKD), Oslo Metropolitan University, Rebel Building, 7th floor, Universitetsgata 2, 0164, Oslo, Norway. Vagelis Plevris; vplevris@qu.edu.qa Department of Civil and Architectural Engineering, Qatar University, Doha P.O. Box 2713, Qatar. Maria Nogal; m.nogal@tudelft.nl Materials, Mechanics, Management & Design Department, Delft University of Technology, 2628 CN Delft, The Netherlands.
	Contributions	Alejandro Jiménez Rios is the guarantor, he drafted the manuscript and provided expertise in Cultural Heritage Conservation. Vagelis Plevris provided expertise in Digital Twins and Artificial Intelligence. Maria Nogal provided expertise in Reliability-Based Bridge Management Approach and Assets Managements. All authors read, provided feedback and approved the final manuscript.
	Amendments	In the event of protocol amendments, the date of each amendment will be accompanied by a description of the change and the rationale. See Annex A.

Support:	
Sources	This systematic review has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 101066739.
Sponsor	The European Union funded this research.
Role of sponsor/funder	The European Union is funding this research. The funder is not involved in any other aspect of the project and will have no input on the interpretation or publication of the study results.

Table 2. Introduction.

Rationale:	In 2018 the Morandi bridge collapsed in Genova, Italy, killing 43 people, forcing the displacement of 200 families living below the bridge, causing damages of EUR 422 million and yearly losses of EUR 784 million to the industry sector in the region. More recently, other bridges have collapsed only a few months after being inspected and/or repaired. After these disasters, several European countries reported the poor state of their aging bridge infrastructure and highlighted the need of urgent investments to guarantee user safety and adequate functioning of their transport networks. Most **bridges** in Europe were built after 1945, designed with a 50–100-year design life, have already started to deteriorate. In fact, it is estimated that 10% of those bridges are structurally deficient. From another point of view, many old European bridges are considered to have a **cultural heritage** (CH) value. Seven European bridges have been inscribed on the UNESCO World Heritage List thanks to their outstanding universal cultural value. In addition to the human and economic losses, the damage or collapse of a historical bridge also entails the painful loss of a cultural asset. The problem of **damage detection** in bridge monitoring may seem like a simple classification problem, i.e., identifying whether there is or isn't any damage in the bridge. Several researchers have applied well-known machine learning and classification algorithms to try to identify damage in bridges. Chalouhi *et al*. implemented a two-stage artificial neural network (ANN) process for damage detection in railway bridges. Pan *et al*. implemented a support vector machine to try to identify damage in cable-stayed bridges. More recently, Tran-Ngoc *et al*. presented a modified ANN cuckoo search algorithm that was tested on a steel truss bridge. However, the individual and highly complex nature of bridges may result in different dynamic responses and thus add to the complexity of this task. According to Mehrotra *et al*. these classification approaches are rarely successful due to the important imbalance between normal and anomalous cases, and thus result in too many false negatives. An excessive number of false negatives may hinder the detection of actual damages or substantial decay, ultimately affecting the performance of a bridge and, in critical cases, leading to its collapse. Conversely, many false positives would lead to unnecessary spending of resources. By contrast, an acceptable number of false positives may be even desirable for damage detection on CH bridges which could be obtained with the application of a fine-tuned **anomaly detection algorithm** (ADA). ADAs have been specifically developed to deal with complex damage detection situations and could effectively detect changes in the data collected during a bridge health monitoring process. A **digital twin** (DT) is a virtual replica of a real-world bridge (asset, process or system). The 3D geometry of the bridge can be created through a **bridge information modelling** (BrIM) approach, whereas that a mechanical twin can be constructed in a **finite element** (FE) software. Sensors installed during a **bridge health monitoring** process can provide data about the environmental conditions, loads and response of the structure to those loads, either at local-element or global bridge scale. A series of damage and decay scenarios can be simulated directly on the DT model, which will reproduce the structural response of its physical counterpart through a series of FE models. This digital approach allows testing the bridge and generate the required data under several '*normal*' and '*damaged*' scenarios.
Objectives:	The aim of this systematic review is to collect and synthesis state-of-the-art knowledge and information about how bridge information modelling, finite elements and bridge health monitoring are combined and used on the creation of digital twins of bridges and how these models could generate damage scenarios to be used by anomaly detection algorithms for damage detection on bridges (specially in those bridges with cultural heritage). To this end, the proposed systematic review will answer the following questions: 1. What are the most efficient ways to build bridge digital twins based on bridge information modelling, finite elements and bridge health monitoring? 2. What are the best anomaly detection algorithms that could be used on the damage detection of conventional and cultural heritage bridges?

Table 3. Methods.

Eligibility criteria:	Peer reviewed papers (as well as reviews and book chapters), published both in journals or in conferences, in the field of engineering, from 2017 up to 2022, in English and containing the following keywords (and similar terms, namely: bridge and bridges, etc.) of interest will be eligible: • Bridge. • Digital twin. • Bridge information modelling. • Finite elements. • Bridge health monitoring. • Anomaly detection algorithm. • Cultural heritage.
Information sources:	The information source to be used will be Scopus which is the main source of online trustworthy scientific material in the field of engineering.
Search strategy:	See PRISMA-S checklist [3].
Study records:	
Data management	See PRISMA-S checklist.
Selection process	See PRISMA-S checklist.
Data items:	Qualitative data will be extracted from the bridge information modelling, finite elements and bridge health monitoring available tools for the creation of digital twins. Furthermore, quantitative data in terms of anomaly detection algorithm effectiveness, i.e., precision, recall and rank power parameters, would also be extracted if available. A quantitative bibliometric analysis will as well be performed based on keywords co-occurrence and co-authorships.
Outcomes and prioritization:	The primary outcomes of the review will be the software used to build the 3D geometry of the bridge information models, the finite element models and their characteristics. Regarding the bridge health monitoring, the primary outcomes will be the kind of hardware and software used during the collection and processing of the data. Of special interest will be the extraction of primary outcomes related to the anomaly detection algorithms, the programming language they have been implemented on and whether there are any open-source tools available that may fit within the digital twin methodology. Secondary outcomes will be the information related to study cases, bridge characteristics and methodology implemented, as well as the bibliometric outputs.
Risk of bias in individual studies:	The risk of bias and quality of individual studies will be assessed based on the prior experience and background knowledge of the authors of the review working on similar reviews on the past.
Data synthesis:	No meta-analysis is envisaged for the proposed systematic review.
Meta-bias(es):	No meta-bias assessment is planned for the proposed systematic review.
Confidence in cumulative evidence:	No confidence assessment plan will be used for the proposed systematic review. This is based in the fact that no universally accepted methodology is available for the grading of reviewing in the engineering field.

References

1. Page, M.J., et al., *The PRISMA 2020 statement: an updated guideline for reporting systematic reviews.* BMJ, 2021. **372**: p. n71.
2. Page, M.J., et al., *PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews.* BMJ, 2021. **372**: p. n160.
3. Rethlefsen, M.L., et al., *PRISMA-S: an extension to the PRISMA Statement for Reporting Literature Searches in Systematic Reviews.* Systematic Reviews, 2021. **10**(1): p. 39.

Annex A

Table 4. History of changes.

Version	Publication date	Change
1.0	05/12/2022	Initial version.
2.0	10/12/2022	Reduce the search databases to only Scopus and reduced the publication years to only 2017-2022 to make the review more focused in latest developments.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 101066739.