European Commission

JRC SCIENCE FOR POLICY REPORT

Research and innovation in bridge maintenance, inspection and monitoring

A European perspective based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

Gkoumas, K., Marques Dos Santos, F.L., van Balen, M., Tsakalidis, A., Ortega Hortelano, A., Grosso, M., Haq, G., Pekár, F.

2019

Joint Research Centre

EUR 29650 EN

Contact information
Name: Konstantinos Gkoumas
Address: European Commission, Joint Research Centre, Vie E. Fermi 2749, I-21027, Ispra (VA) — Italy
Email: konstantinos.gkoumas@ec.europa.eu
Tel.: +39 0332 786041

EU Science Hub
https://ec.europa.eu/jrc

JRC115319

EUR 29650 EN

PDF	ISBN 978-92-79-99678-8	ISSN 1831-9424	doi:10.2760/16174
Print	ISBN 978-92-79-99679-5	ISSN 1018-5593	doi:10.2760/560211

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: Gkoumas, K., Marques Dos Santos, F.L., van Balen, M., Tsakalidis, A., Ortega Hortelano, A., Grosso, M., Haq, G., Pekár, F., *Research and innovation in bridge maintenance, inspection and monitoring - A European perspective based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)*, EUR 29650 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-99678-8, doi:10.2760/16174, JRC115319.

Contents

Abstract

Europe's aging transport infrastructure needs effective and proactive maintenance in order to continue its safe operation during the entire life cycle. This report focuses on research and innovation (R&I) in bridge maintenance, inspection and monitoring in Europe in the last quarter of a century. The assessment follows the methodology developed by the European Commission's Transport Research and Information Monitoring and Information System (TRIMIS). The report critically addresses issues and techniques, and also highlights new technological developments and future oriented approaches.

Acknowledgements

The Joint Research Centre (JRC) is in charge of the development of TRIMIS, and the work has been carried out under the supervision of the Directorate-General for Mobility and Transport (DG MOVE) and the Directorate-General for Research and Innovation (DG RTD) that are co-leading the Strategic Transport Research and Innovation Agenda (STRIA). The views expressed here are those of the authors and may not, under any circumstances, be regarded as an official position of the European Commission. Finally, Georgios Tsionis (JRC) is acknowledged for fruitful discussions that improved the content of this report and Sara Andre (JRC) is acknowledged for the graphic design of Figure 6.

Authors

Konstantinos Gkoumas, European Commission, Joint Research Centre

Fabio Luis Marques Dos Santos, European Commission, Joint Research Centre

Mitchell van Balen, European Commission, Joint Research Centre

Anastasios Tsakalidis, European Commission, Joint Research Centre

Alejandro Ortega Hortelano, European Commission, Joint Research Centre

Monica Grosso, European Commission, Joint Research Centre

Gary Haq, European Commission, Joint Research Centre

Ferenc Pekár, European Commission, Joint Research Centre

Executive summary

The present report presents a comprehensive analysis of research and innovation (R&I) in bridge maintenance, inspection and monitoring in Europe in the last quarter of a century. The report focuses on European Union (EU) funded projects from 1990 onwards. It also highlights relevant R&I initiatives in selected Member States (MS), with particular focus on Italy. The report also identifies possible emerging technologies that can help preserve the European bridge stock.

Policy context

In May 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the 'Europe on the Move' package (European Commission, 2017a), which highlights main transport R&I areas and priorities for clean, connected and competitive mobility to complement the 2015 Strategic Energy Technology Plan (European Commission, 2015). The STRIA roadmap for transport infrastructure covers R&I on physical transport networks, terminals and intermodal nodes, information systems and refuelling and electrical supply networks, which are necessary for the safe, secure operation of road, rail, civil aviation, inland waterways and shipping.

In December 2018, the European Commission has started to update the STRIA roadmap on transport infrastructure in close cooperation with the Member States and industry stakeholders. The roadmap will include an action plan for short, medium and long-term R&I initiatives.

Unlike other transport operations, transport infrastructure is either managed or actually owned by public sector organisations at Member States (MSs) or regional level. An issue concerns the growing pressure on existing transport systems, combined with regularly underfunded maintenance activity and infrastructure vulnerabilities to man-made or natural disasters. In this context, life-cycle optimisation and integrated efficient operations can lead to improvements in the existing and future infrastructure stock, regarding both safety and serviceability.

Following growing concerns about infrastructure safety in Europe, in September 2018, the European Commission published a discussion paper on infrastructure maintenance in transport, which specifically addresses bridge maintenance. The paper raises questions based on the research and suggestions regarding the role the EU could play in improving infrastructure maintenance. It also highlights the different approaches implemented in MS, focusing on the lack of investments in the last years.

Considering the above, the present report supports the STRIA infrastructure roadmap update, with a specific assessment of research carried out on bridge maintenance, inspection and monitoring, based on TRIMIS. It also provides an overview of the EU's role in research on this topic and meaningful directions for future research.

Key conclusions

— A large amount of research has been funded through European research Framework Programmes (FP), since FP2. The research addressed all areas of bridge safety (materials, loads, hazards, management, monitoring, etc.).

— There is a weak link between research (including case studies) and the wide scale adoption of technologies, with most cases happening in recent large scale bridge projects, where budget is less restricted.

— There appears to be a certain duplication of research, especially regarding sensor technology. Similar sensor technology is used in projects addressing different fields (e.g. naval, aeronautical) and different civil engineering structures (dams, tall or special buildings, bridges). This signals research spillovers, but the repetition of research also suggests that limited progress towards maturity is made.

— Research project outcomes are well documented in Europe, however these outcomes are not always accessible to stakeholders or they may not be aware of them. Furthermore, while bridge maintenance is covered by national legislation, generally no specific legislation or standards on bridge monitoring are in place beyond some recommended practices.

Main findings

The report investigates especially the evolution of European research on bridge monitoring and safety throughout FP.

Basic research on monitoring was carried out in the 90’s and in the beginning of the 2000’s, on different Framework Programmes. From FP6 and onwards funded research focused on specific structures and case studies, including bridges.

FP7 concentrates most of the research on bridge monitoring, with the number of funded projects decreasing in the Horizon 2020 Framework Programme (H2020). Very often, bridge case studies are to be found in projects addressing wider scopes, e.g. risk reduction, resilience, life cycle assessment, Internet of Things (IoT) and specific hazards, e.g. earthquakes, landslides, flooding. This reflects the change of focus on H2020 calls and an adaptation from the bridge monitoring research community.

Related and future JRC work

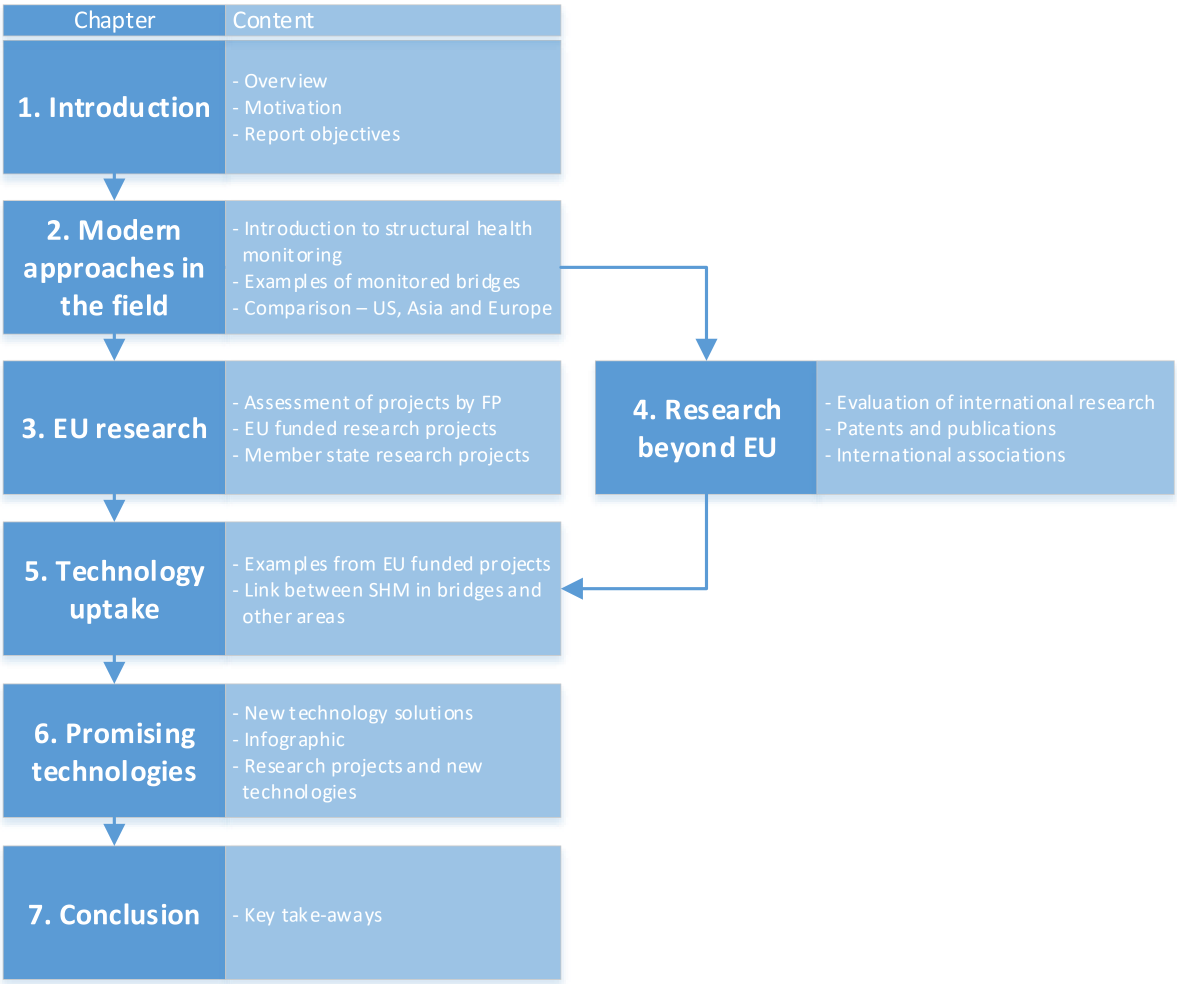
The Transport Research and Information Monitoring and Information System (TRIMIS) team is expanding the data repository to better assess R&I efforts of projects not funded by the EU or MS. As part of this effort, information will be added on technologies, patents and publications, and various other topics of interest, including on transport infrastructure.

TRIMIS will continue to provide support to STRIA and, on the basis of its research, provide recommendations to policymakers.

Quick guide

The report is structured as shown in the following figure.

Chapter 1 gives a brief introduction on the subject of bridge maintenance and its motivation. Chapter 2 presents a technical background. Chapter 3 assesses research projects funded in the EU, and Chapter 4 looks at research internationally. Chapter 5 discusses the transition of technology from research to market and Chapter 6 introduces promising future technology solutions. Finally, the conclusions of the report are provided.


Chapter
Content
1. Introduction
- Overview
- Motivation
- Report objectives
2. Modern approaches in the field
- Introduction to structural health monitoring
- Examples of monitored bridges
- Comparison – US, Asia and Europe
3. EU research
- Assessment of projects by FP
- EU funded research projects
- Member state research projects
4. Research beyond EU
- Evaluation of international research
- Patents and publications
- International associations
5. Technology uptake
- Examples from EU funded projects
- Link between SHM in bridges and other areas
6. Promising technologies
- New technology solutions
- Infographic
- Research projects and new technologies
7. Conclusion
- Key take-aways

1 Introduction

Transport infrastructure, which includes physical networks, terminals and intermodal nodes, information systems, as well as refuelling and electrical supply networks, is crucial to the European Union's (EU) economic growth and social development. Regarding the physical network, bridges are challenging structures to design and build that facilitate transport by creating crossings between countries and regions, thus, enhancing mobility. More than 1,234 kilometres of road bridges over 100 meters are spread across Europe[1]. When smaller bridges are included, this number will be significantly higher.

While acknowledging the importance of bridges, their safety has been questioned in recent periods since the existing transport infrastructure is aging and not equally well maintained. This is highly problematic as bridge failures can cause significant human and economic losses, while invoking long-lasting disruptions in transport networks.

In this context, it is important to remember that most of the transport bridge stock built after 1945 was designed with a design life of 50 – 100 years. The majority of those bridges are operational today, in some cases with a question mark about their safety performance.

The EU funded BRIME project in 2001 identified that highway bridges in three different European countries (France, Germany and the UK) present deficiencies at a rate of 39%, 30% and 37% respectively, with the main cause being the corrosion of reinforcement.

Recent publications echo such concerns, after a number of bridge failures and collapses were attributed specifically to material degradation and lack of maintenance. The quality of the European bridge stock has been heavily questioned in national and international press in the second half of 2018, after the dramatic events of the Genova Bridge collapse in Italy on August 14[(2)].

It is noteworthy that the knowledge on the probabilistic occurrence of extreme natural events (e.g. earthquake, wind loads), material properties (especially reinforced concrete) and bridge design methods, were less developed when most European bridges were built. On top of that, recurring extreme loading conditions (also attributed to climate change) contributed to the faster deterioration of the infrastructure (Nemry and Demirel, 2012).

As a consequence, the majority of EU countries must invest and address maintenance issues to ensure serviceability and safety. This includes increasing the number of inspections, investing into structural health monitoring systems and prioritising interventions for those critical structures with no sustainable retrofitting solutions.

Given the number of assets and the limited resources, it is of high importance to define strategies to monitor and critically evaluate the need for maintenance and upgrading of civil infrastructures.

In September 2018, the European Commission published a discussion paper on infrastructure maintenance in transport[3], which specifically addresses bridge maintenance. The paper raises questions based on the research and suggestions regarding the role the EU could play in improving infrastructure maintenance. It also highlights the different approaches implemented in Member States (MS), focusing on the lack of investments in the last years.

Following up on the discussion paper, this report aims to contribute with the following:

— Provide an overview of bridge safety projects financed through the different European research Framework Programmes (FP).

[1] http://www.cedr.eu/download/Publications/2018/TEN-T-Performance-report-2017.pdf
[2]https://www.nytimes.com/2018/08/21/world/europe/genoa-bridge-collapse.html
[3]http://ec.europa.eu/growth/content/ec-discussion-paper-published-maintenance-road-and-rail-infrastructures_en

— Highlight technologies and methods that have been addressed in the areas of bridge management, inspection, retrofitting and monitoring.

— Identify future oriented approaches developed or currently under study.

The assessment methodology in this report is largely based on the European Commission's Transport Research and Information Monitoring and Information System (TRIMIS) methodology (Tsakalidis *et al.*, 2018) for monitoring the progress of the Strategic Transport Research and Innovation Agenda (STRIA) roadmaps. Results are particularly useful for the STRIA infrastructure roadmap[4], undergoing an update in 2019.

The assessment focuses on projects related to highway bridges, thus, railway projects fall out of this report's scope. However, the conclusions of certain projects are relevant for railway bridges too.

[4] https://trimis.ec.europa.eu/stria-roadmaps/infrastructure

2 Modern approach to bridge maintenance and condition monitoring

Bridge maintenance requires both scheduled and unscheduled actions. For the latter, it is common to perform visual inspections. Since the 1980s, there have been attempts to "automatise" the process, implementing Bridge Management Systems (BMS) and Structural Health Monitoring (SHM). There was a speed-up in the process due to the construction of very long span bridges that incorporated SHM sensors and systems, as well as the upgrade of older bridges due to the increase of loads considered in the structural codes.

SHM usually focuses on the assessment of deformations and displacements with the use of external or embedded sensors. At a global level, SHM focuses on the assessment of the dynamic properties of the structure. This includes the vibration characteristics using special sensors (e.g. accelerometers). If the vibration characteristics of the structure change, it can be assumed that the structure is damaged.

Modern integrated SHM systems flourished in the mid-1990s in Asia for complex structural systems and long-span bridges. For such structures, environmental actions and the corresponding loads (wind, temperature, rain, earthquake, etc.) together with the live loads (railway traffic, highway traffic), have a strong influence on their dynamic response, and can significantly influence the structural behaviour and alter its geometry, thus limiting the serviceability performance even up to a partial closure (Sgambi, Gkoumas and Bontempi, 2012). In Hong Kong, the "Wind And Structural Health Monitoring System (WASHMS)" on the Tsing Ma Bridge suspension bridge was one of the first systems, conceived in 1993. Since then, numerous bridges in China were equipped with SHM systems (Li and Ou, 2016). Similar initiatives took place in bridge construction in other Asian countries[5].

In Europe, there are some notable examples of recent long-span highway bridges that were equipped with SHM sensors and other instrumentation since the construction phase. These include:

- The Rio–Antirio Bridge (officially the Charilaos Trikoupis Bridge) in Greece, one of the world's longest multi-span cable-stayed bridges, which opened in August 2004. The bridge has a "floating" deck which needs specific monitoring actions[6].
- The Millau Viaduct, a multi-span cable-stayed bridge in southern France inaugurated on in December 2004. The monitoring system was designed in parallel with the bridge design and was also used during the construction (Cachot *et al.*, 2015).

Nevertheless, the condition monitoring of ordinary bridges is a much more complex task. There are thousands of short- to medium-span bridges in Europe that would be impossible to retrofit with fixed instrumentation. Also, very few new bridges are integrated with monitoring sensors due to the high cost. Ad-hoc solutions are sometimes applied (e.g. using portable SHM systems, including instruments for non-destructive inspection).

In the last 25 years path-breaking research took place in the field. Although research in the US and Asia is strongest, Europe remained a frontrunner in Research and Innovation (R&I) activities, facilitated by the long tradition in civil engineering fields such as structural design and structural dynamics.

Another aspect worth highlighting is the specific bridge infrastructure stock in the old continent, and as a consequence, the differences in bridge research. While in the US there is a relatively high number of steel bridges, in Europe the bridge construction industry relied a lot, after World War II, on reinforced concrete, including prestressed.

---

[5] https://www.nytimes.com/2011/03/13/business/13novel.html
[6] http://www.portaledesign.com/download/fip_rion2.pdf

The latter, developed in particular in Italy, Germany and Switzerland in the 1960s and 70s, enabled spans of 50-100 meters, depending on the bridge form and type of pre-stressing, i.e. bonded or external (Muttoni, 2014).

Finally, as stated before, modern bridge research in Asia moved in parallel in the last 30 years with the design of very long span bridges in steel. Numerous long span suspension and cable-stayed have been built, for which innovative and automated maintenance plans and SHM systems were part of the design process.

3 Research on bridge maintenance and monitoring

To gain more precise understanding bridge maintenance and monitoring research, this chapter will evaluate a number of relevant projects. Since the research areas concerning bridge infrastructures are so vast and heterogeneous, it is important to divide them in relevant themes for a proper assessment. These are:

— **Maintenance & Lifecycle**: includes research, which has as driver the improvement of maintenance methods and lifecycle assessment.

— **Sensing Technology**: represents any project where sensors are researched or investigated. It does not cover usage of standard available sensors and technology.

— **Software Tools**: concerns the development of software for database creation, management and analysis of bridge and infrastructure related systems.

— **Bridge Safety**: focuses on the safety of bridges.

— **Structural Health Monitoring**: entails the development of continuous monitoring systems, which use a combination of sensors, models and prior knowledge to automatically detect deficiencies.

— **Materials & Components**: covers research on new materials and components for newly built bridges or for the retrofitting of older ones.

— **Bridge Manual Inspection**: contains projects that focus on methods and technologies for the periodically inspection of the structure.

— **Hazards**: deals with research on different natural or man-made hazards.

3.1 Technologies addressed in the projects

An important assessment is related to the identified project themes in relation to their starting year. In this way, it is possible to analyse which theme had the highest priority on certain periods.

Box 1. Framework Programmes research overview

Groundwork on vibration based SHM went on through different FP. Then in FP6, FP7 and H2020, funded research focused on specific structures, including bridges. Very often, SHM case studies are to be found in projects addressing wider scopes (e.g. risk reduction, resilience, life cycle assessment, energy harvesting, IoT) and specific hazards (e.g. earthquakes, landslides, flooding).

The breakdown of project themes with relation to the project starting years is shown in Figure 1. From the graph, it can be seen that there have been very few projects/topics addressed before 1998 (beginning of FP5).

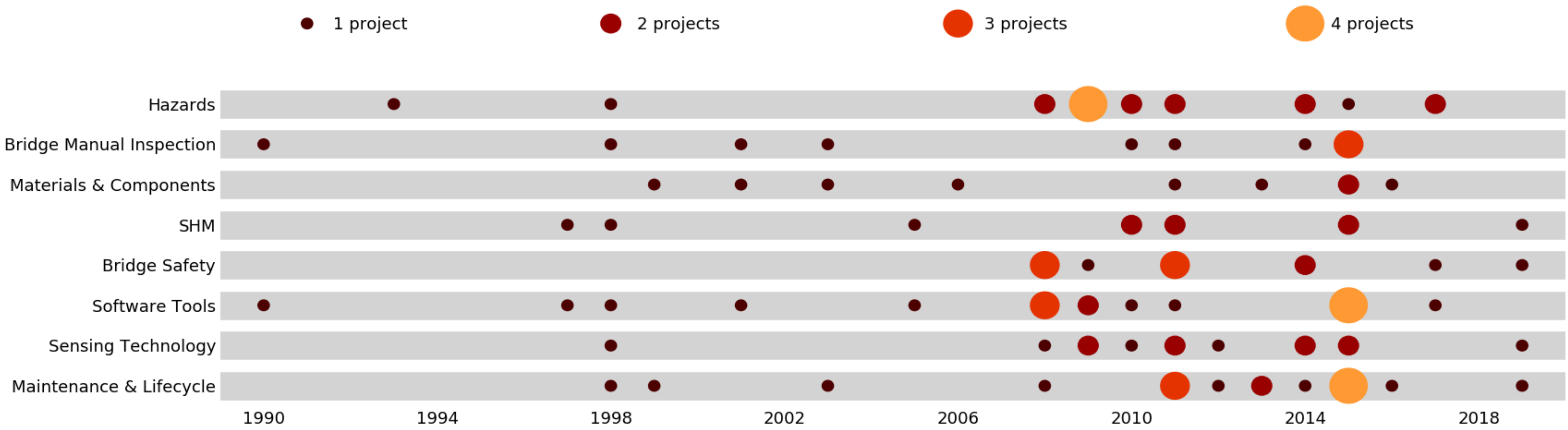
Before 2008 (FP2 - FP6), the most researched topics have been materials & components and software tools, still with a moderate number of projects. During this period, there has been very little focus on sensing technologies (1 project) and projects addressing hazards or bridge safety (2 projects).

In the period between 2008 and 2013, there has been a great increase in the number of funded research projects, with the previously least researched categories (sensing technology, hazards and bridge safety) taking up some of the highest positions, signifying a strong shift in research priorities. During FP7, specific hazards were addressed, including low probability high consequence (LPHC) events, which can cover landslides and tsunamis, and unforeseeable events, like terrorist attacks. Many of these hazards were studied in proposals related to disaster resilience, following extreme flooding events in northern Europe and catastrophic earthquakes in the southern east Europe.

Finally, from 2014 onwards covered by the Horizon 2020 Framework Programme (H2020), bridge safety and hazards projects start to decline, giving space to maintenance & lifecycle and bridge visual inspection. Overall, software tools projects have been present throughout the whole timeline. In the same period, a decline in research expenditure has been observed in general for transport infrastructure in Europe (van Balen *et al.*, 2019).

It is noted that despite efforts to be comprehensive, it still may be possible that some projects are not included.

Figure 1. Breakdown of projects and issues addressed



Source: TRIMIS

3.2 European projects

Table 1 provides the list of projects financed by various European programmes considered in this report. The projects are presented in ascending order from the project start, and cover funding programmes from FP2 to H2020. Some of the H2020 projects are still ongoing. The funding source is also indicated, together with the total project cost. The performed analysis is based on the TRIMIS projects and programmes database (European Commission, 2017b).

Table 1. Projects identified through the European FP

Project Acronym	Project name	Project duration	Source of funding	Total cost* (EUR)
2nd Framework Programme				
Total EU Contribution: NA				
(no acronym)	Assessment of performance and optimal strategies for inspection and maintenance of concrete structures using reliability based expert systems	1990-07-01 to 1993-06-30	FP2-BRITE/EURAM 1	NA
3rd Framework Programme				
Total EU Contribution: NA				
PREC8	Pre-normative Research in Support of Eurocode 8	1993-06-01 to 1996-05-31	FP3-HCM	NA
4th Framework Programme				
Total EU Contribution: EUR 0,5 million (based on available budget data)				
SIMCES	System identification to monitor civil engineering structures	1997-01-01 to 1999-04-30	FP4-BRITE/EURAM 3	NA
BRIME	Bridge Management in Europe	1998-01-01 to 1999-12-31	FP4-TRANSPORT	1 000 062
(no acronym)	Development of a specific cable with new mechanical and corrosion protection characteristics to improve maintenance and safety of suspended bridges	1999-03-01 to 2001-02-28	FP4-BRITE/EURAM 3	NA
(no acronym)	Advanced methods for assessing the seismic vulnerability of existing motorway bridges	1998-05-01 to 2001-04-30	FP4-ENV 2C	NA
MILLENNIUM	Monitoring of large civil engineering structures for improved maintenance	1998-07-01 to 2001-10-31	FP4-BRITE/EURAM 3	NA
SMART STRUCTURES	Integrated monitoring systems for durability assessment of concrete structures	1998-09-01 to 2002-02-28	FP4-BRITE/EURAM 3	NA
5th Framework Programme				
Total EU Contribution: EUR 1,7 million				
IMAC	Integrated monitoring and assessment of cables	2001-02-01 to 2004-04-30	FP5-GROWTH	3 007 677
6th Framework Programme				
Total EU Contribution: EUR 8,8 million				
SUSTAINABLE BRIDGES	Sustainable Bridges: Assessment for future traffic demands and longer lives	2003-12-01 to 2007-11-30	FP6-SUSTDEV	10 251 360
CISHM	Design of health monitoring systems optimised for civil infrastructure	2005-11-01 to 2007-10-31	FP6-MOBILITY	EUR 0* -EU contribution: EUR 80 000
ARCHES	Assessment and rehabilitation of Central European highway structures	2006-09-01 to 2009-08-31	FP6-SUSTDEV	2 942 413
7th Framework Programme				
Total EU Contribution: EUR 71,1 million				
IRIS	Integrated European Industrial Risk Reduction System	2008-10-01 to 2012-03-31	FP7-NMP	12 496 996
MEMSCON	Radio Frequency Identification Tags Linked to on Board Micro-Electro-Mechanical Systems in a Wireless, Remote and Intelligent Monitoring and Assessment System for Maintenance of CONstructed Facilities	2008-10-01 to 2012-03-31	FP7-NMP-2007-SME-1	4 976 006
SERIES	Seismic engineering research infrastructures for European synergies	2009-03-01 to 2013-07-31	FP7-INFRASTRUCTURES	10 715 218
SHARE	Seismic Hazard Harmonization in Europe	2009-06-01 to 2012-11-30	FP7-ENVIRONMENT	4 114 266

ISTIMES	Integrated System for Transport Infrastructures surveillance and Monitoring by Electromagnetic Sensing	2009-07-01 to 2012-06-30	FP7-SECURITY	4 367 950
SERON	Security of Road Transport Networks	2009-11-01 to 2012-10-31	FP7-SECURITY	2 942 113
SYNER-G	Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain	2009-11-01 to 2013-03-31	FP7-ENVIRONMENT	4 784 534
CO-PATCH	COmposite PATCH repair for marine and civil engineering infrastructure applications	2010-01-01 to 2013-04-30	FP7-TRANSPORT	5 272 148
ISMS	Internet-based Structural Health Monitoring System	2010-09-01 to 2014-08-31	FP7-PEOPLE-2009-IAPP - Marie Curie Action	484 954
NERA	Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation	2010-11-01 to 2014-10-31	FP7-INFRASTRUCTURES	12 014 028
WI-HEALTH	A wireless network with autonomously powered and active long range acoustic nodes for total structural health monitoring of bridges	2011-10-01 to 2013-09-30	FP7-SME	1 502 259
PANTURA	Flexible Processes and Improved Technologies for Urban Infrastructure Construction Sites	2011-01-01 to 2013-12-31	FP7-ENVIRONMENT	4 682 605
CROSS-IT	Smart condition monitoring and prompt NDT assessment of large concrete bridge structures	2011-11-01 to 2014-01-31	FP7-SME	1 066 928
REAKT	Strategies and tools for Real Time EArthquake RisK ReducTion	2011-09-01 to 2014-12-31	FP7-ENVIRONMENT	10 111 177
LONG LIFE BRIDGES	Long Life Bridges	2011-09-01 to 2015-08-31	FP7-PEOPLE	890 855
BRIDGEMON	Bridge Safety Monitoring	2012-12-01 to 2014-11-30	FP7-SME	1 070 967
HEALCON	Self-healing concrete to create durable and sustainable concrete structures	2013-01-01 to 2016-12-31	FP7-NMP	5 610 518
SAFELIFE-X	Safe Life Extension management of aged infrastructures networks and industrial plants	2013-09-01 to 2015-08-31	FP7-NMP	1 331 971
RAIN	Risk Analysis of Infrastructure Networks in response to extreme weather	2014-05-01 to 2017-04-30	FP7-SECURITY	4 611 933
RPB HEALTEC	Road Pavements & Bridge Deck Health Monitoring/Early Warning Using Advanced Inspection Technologies	2014-06-01 to 2016-05-31	FP7-SME	1 534 720
BRIDGE SMS	Intelligent Bridge Assessment Maintenance and Management System	2015-01-01 to 2018-12-31	FP7-PEOPLE-2013-IAPP - Marie Curie Action	1 418 821
Horizon 2020				
Total EU Contribution: EUR 28,6 million				
TRUSS	Training in Reducing Uncertainty in Structural Safety	2015-01-01 to 2018-12-31	H2020-EU.1.3.1	3 701 306
SmartPatch	Use of a cost effective smart skin sensor system for remote SHM and post event structural damage assessment	2014-07-01 to 2014-12-31	H2020-SMEINST	71 429
INFRALERT	Linear infrastructure efficiency improvement by automated learning and optimised predictive maintenance techniques	2015-05-01 to 2018-04-30	H2020-EU.3.4	3 183 243
SENSKIN	'SENsing SKIN' for Monitoring-Based Maintenance of the Transport Infrastructure	2015-06-01 to 2019-05-31	H2020-EU.3.4	3 883 041
COBRI	Ultrasound NDE tomograph. Design and construction of a portable 3D ultrasound scanner for non-destructive testing and evaluation (NDT and NDE) of concrete	2015-11-01 to 2017-12-31	H2020-EU.2.3.1	1 849 465
LoStPReCon	Long-term structural performance of pre-stressed concrete bridges	2015-11-01 to 2017-10-31	H2020-EU.1.3.2	183 454
AEROBI	AErial RObotic System for In-Depth Bridge Inspection by Contact	2015-12-01 to 2018-11-30	H2020-EU.2.1.1 INDUSTRIAL LEADERSHIP	3 584 850

FASTSCALE	Fast-Beam - Novel modular repair and newbuilding system for concrete bridges	2016-12-01 to 2017-05-31	H2020-SMEINST	71 429
SAFE-10-T	Safety of Transport Infrastructure on the TEN-T network	2017-05-01 to 2020-04-30	H2020-EU.3.4	2 997 000
SERA	Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe	2017-05-01 to 2020-04-30	H2020-EU.1.4.1.2	11 090 779
BridgeScan	Laser Scanning for Automatic Bridge Assessment	2019-01-01 to 2020-12-31	H2020-EU.1.3.2	177 598

Source: TRIMIS/CORDIS

The total EU contribution for each FP, in Table 1, shows that FP7 and H2020 have received the highest budget related to bridge research projects, with total contribution of EUR 71,1 million and EUR 28,6 million respectively. This represents a budget that is 2.5 times higher for FP7 for double the number of projects. This discrepancy can be attributed to very large projects in FP7 (e.g. IRIS, MEMSCON, SERIES, ISTIMES, CO-PATCH, NERA, PANTURA, REAKT, HEALCON, RAIN), which cover other areas besides bridge safety. Here it also should be mentioned that a single project (SERA) accounts for a large part of the mentioned H2020 budget.

The projects have been categorised according to the themes presented in the beginning of the section. Each project has been linked to at least one theme. Figure 2 shows the division by themes and their representation within each framework program.

Bridge Safety, Hazards, Sensing Technology and Maintenance & Lifecycle are themes mainly comprised within FP7 and H2020 frameworks, while Software Tools, Materials & Components, Bridge Manual Inspection and SHM represent a more homogeneous presence throughout the different research frameworks.

This can be explained as there has been a shift in research calls focusing on themes such as disaster or urban resilience and security. This is the case of projects WSAN4CIP, INSPIRE, SERSCIS, BRIDGE, RAIN, ISTIMES and SERON, funded under Security and ICT calls.

Figure 2. Coverage of research themes through the FP

Source: TRIMIS

Size indicates the number of projects

3.3 Project review

European projects considered in this report initiate in 1990 and during FP2 and go all the way to the most recent (and not completed) H2020 projects. In the following paragraphs, the projects are reviewed based on their objectives and (if available) the outcomes (project deliverables or other scientific output).

Some disclaimers are necessary.

— An effort has been made to limit the (vast) number of projects that focus on the maintenance of structures and infrastructures to those specific to bridges, or where bridges are the central subject.

— Similarly, there is a large number of SHM projects that focus on other type of structures (mainly aircraft and vessels). These methods may be relevant to bridge monitoring, but are outside the scope of this assessment.

— Structural control related projects (relevant for flexible long span bridges) are also outside the scope of this report.

3.3.1 FP2, FP3 and FP4 research

A single FP2 project was identified, running between 1990-1993. The project constitutes an early effort to bridge monitoring and inspection using "expert systems", including the development and integration of stochastic models for corrosion, inspection, maintenance and repair of concrete bridges.

One FP3 project was identified, **PREC8** (1993-1996), which deals with the Eurocode 8 (EC8), a standard related to the design of structures in seismic areas, with one of the topics being related to bridge design.

In FP4 a number of projects were witnessed. The **SIMCES** project (1997-1999) focused on vibration monitoring of civil engineering structures, aiming at evaluating its potential as a valid method of condition assessment. To this end, long-term monitoring and progressive damage tests were carried out on a real bridge in Switzerland, and additional tests were performed on three other bridges before and after repair. The project included the development of structural identification methods and Finite Element (FE) models.

The **BRIME** (Bridge Management in Europe) project (1998-1999) was undertaken by the national highway research laboratories in the United Kingdom, France, Germany, Norway, Slovenia and Spain, and aimed at the development of a framework for the management of bridges on the European road network and at identifying the steps towards implementing such system. It investigated Artificial Intelligence (AI) methods as a means of improving condition assessment, and it developed recommendations for methods to assess the load-carrying capacity of highway bridge structures. It also focused on the development of deterioration models, specifically by modelling the ingress of chlorides into concrete, which can be used to provide data for forecasting maintenance actions. Finally, a methodology for selecting the best maintenance option for a given bridge, considering safety, durability, functionality and socio-economic issues.

An additional project under the FP4 focused on the development of a specific cable with new mechanical and corrosion protection characteristics to improve maintenance and safety of suspended bridges. Aim of the research was the development and testing of prototypes of new protected cables and specific steel collars, which would lead to an easy and without traffic interruption installation.

Another project under FP4, 'Advanced methods for assessing the seismic vulnerability of existing motorway bridges' (1998-2001), analysed reliable methods for assessing the seismic vulnerability of already existing bridges, in particular large and irregular motorway bridges. Objectives included the development of in-situ testing procedures, simulation models and analysis tools.

The **MILLENNIUM** project (1998-2001) focused on the development and demonstration of an on-line strain measurement system for large civil engineering structures (and specifically bridges), using optical fibre distributed. The project included the development of appropriate software and the demonstration on a 1km long existing bridge equipped with conventional sensors.

The **SMART STRUCTURES** project (1998-2002) aimed at producing an integrated monitoring system for existing and new bridges in reinforced concrete. The development was combined with the parallel development of enhanced deterioration models and inexpensive probes for the monitoring of the corrosion in the reinforcement and other material deterioration. The consortium estimated initially the implementation of such system could help reduce operating costs by 15%.

Box 2. Main findings from FP2 - FP4 research

A lot of groundwork has been performed in these projects.

— The concept of information based bridge management has been introduced.

— Vibration-based SHM was investigated, together with structural identification and on line expert systems.

3.3.2 FP5 and FP6 research

The **IMAC** project (2001-2004) aimed to developing a non-destructive methodology for locating, assessing and finding damage in existing cables embedded in structures (in particular bridges). It also provided a method that enables quality control of external cables during construction. During the project, a high number of bridge cables were tested in field tests and laboratory conditions. Focus was given in existing cable-stayed bridges in Europe (for instance the recent Donaustadt Bridge, a 343m long cable-stayed bridge in Austria).

Finally, it is worth mentioning the **SUSTAINABLE BRIDGES** project (2003-2007) which focused at upgrading railway bridges, so they could accommodate up to 33 tonnes in freight traffic and higher speeds up to 350 km/h for passenger trains. The project also inventoried 220,000 railway bridges across the continent and identified major challenges, highlighting arched masonry bridges as a major consideration worth investigating. The project also proposed measuring techniques and wireless sensors based on fibre-optic technology.

The **CISHM** project (2005-2007) is a reintegration grant on SHM, which had as an outcome an enhanced set of tools for managing and mining the data sets and presenting information.

The **ARCHES** project (2006-2009) took a more sustainable approach for rehabilitation, and it focused on bridge monitoring, load testing of different types, dynamic impact and bridge management system development. A key aspect of the project was to monitor and prevent corrosion of existing bridge reinforcement and to develop new highly resistant materials to achieve this. For the first, it looked into the costs of cathodic protection of reinforcing steel and concluded that this (already well-developed) technique could be instrumental. On the second, the project focused also on innovative materials, and proposed the use of an Ultra High Performance Fibre Reinforced Concretes (UHPFRC) rehabilitation technique for the first time outside of Switzerland, applying it in Slovenia.

Box 3. Main findings from FP5 and FP6 research

In FP5 and FP6 projects, more specific issues have been addressed.

— The monitoring of bridge cables.

— Innovative materials for bridge identification and bridge corrosion protection.

— Railway bridge upgrading to accommodate higher loads.

3.3.3 FP7 research

The large scale **IRIS** project (2008-2012) focused on producing integrated methodologies and risk assessment strategies for industrial systems, including online monitoring with decision support systems. Within the addressed objectives, it contributed on the identification of critical threats and the subsequent warning procedure for the construction industry. It also developed a degradation model that can be applied directly in bridges. Damage assessment models using Artificial Neural Networks (ANN) for assessing the progress of the damage state were performed in bridges, while three real bridges provided the testbed for developed methodologies.

The **MEMSCON** project (2008-2012) focused on the development and integration of MEMS-based sensors (low power accelerometers and strain sensors) for monitoring concrete structures. Software for proactive rehabilitation and rehabilitation following seismic damage has been also developed.

The large scale **SERIES** project (2009-2013) focused on overcoming the extreme fragmentation of research infrastructures in the earthquake engineering community, especially that of Europe's most seismic regions, promoting cooperation, exchanging knowhow, pooling their human resources and jointly developing novel seismic testing systems and techniques. It also focused on bridges (in particular, assessing the vulnerability of old Reinforced Concrete (RC) viaduct with frame piers and the effectiveness of retrofitting an isolation system, after the 2011 Emilia earthquake earthquake). The project highlighted the impact of using base isolation and dissipation devices in bridge retrofitting.

The **SHARE** (Seismic Hazard Harmonization in Europe) project (2009-2012) focused on seismic hazard assessment, with the objective of creating a framework and computational infrastructure for seismic hazard assessment and a European assessment model, probabilistic seismic hazard assessment, with scenario based modelling tools.

The **ISTIMES** project (2009-2011) designed, assessed and developed a prototypical modular and scalable Information and communications technology (ICT) based system, exploiting distributed and local sensors, for non-destructive electromagnetic monitoring.

The **SERON** project (2009-2012) investigated the impact of possible man-made attacks on the transport network, by developing a methodology for the risk-assessment of critical road transport networks and by evaluating planned protection measures for critical road transport infrastructures.

The **SYNER-G** (Systemic Seismic Vulnerability and Risk Analysis for Buildings, Lifeline Networks and Infrastructures Safety Gain) project (2009-2013) addressed the seismic vulnerability of buildings in urban systems, with the development of a software tool capable of estimating damage in case of hazards.

The **CO-PATCH** project (2010-2013) provided a repair method for large steel structures, including bridges. The proposed repair technology involves an innovative composite patch that can substitute the traditional methods (that involve the renewal of welds, application of bolted or welded plates, or even replacement of entire panels) thus addressing fatigue and corrosion issues. The project provided also best practice guidelines and application procedures covering evaluation of damage, patch design, composite patch application and repair monitoring.

The **ISMS** project (2010-2014) addressed the commercial potential of improved damage detection and SHM technologies for large-scale civil infrastructure by developing a fully automated internet-based damage detection procedure with primarily application to bridges. The main deliverable and result of the project was a commercial software package (ARTeMIS) and its modules.

The **NERA** project (2010-2014) focused on the assessment and reduction of the vulnerability of constructions and citizens to earthquakes, towards an improved coordinated earthquake monitoring service for Europe.

The **WI-HEALTH** Small Medium Enterprise (SME) project (2011-2013) developed a SHM technology for the detection of defect growth at damage-prone areas of steel bridges, such as welded plate structures, by combining Long Range Ultrasonic (LRU) and Acoustic Emission (AE) monitoring techniques in autonomously powered nodes.

The **PANTURA** project (2011-2013) focused on the development of new strengthening and repair systems for bridges, including the use of new materials, proposing ICT tools for monitoring, planning and decision support. In doing so, a comparative analysis of best practices, benchmarking and selection of suitable sustainability indicators for bridge building and retrofitting took place. It also proposes a list of case studies on completed strengthening and repair projects in Europe, together with alternative strengthening approaches for selected bridges.

The **CROSS-IT** SME project (2011-2014) developed a new technology to inspect concrete bridge structures for dangerous levels of age-related degradation, which could consist of cracks due to water ingress and corrosion of internal steel reinforcement. The project developed two technologies based on a hybrid system of Ground Penetrating Radar (GPR) and Ultrasonic Guided Waves (UGW), implemented to detect failure due to corrosion of the internal steel reinforcement and tendons.

The **REAKT** project (2011-2013) focused on real-time earthquake risk mitigation methods (taking advantage of forecasting models, early warning and rapid alert systems) and their ability to protect people, buildings and infrastructures. Within this, the use of an Earthquake Early Warning System (EEWS) for automatically closing access to bridge has been developed, accounting also for the losses calculation. A cable stayed (Greece) and suspension bridges (Turkey) have been considered as case studies, while the development of nation-wide earthquake early warning systems were explored, in particular for Italy, very prone to earthquakes.

The **LONG LIFE BRIDGES** project (2011-2015) focused on railway bridge dynamics and life-cycle and fatigue evaluation. A damping system to minimise the effect of harmful vibrations was developed and tested in a real bridge with hangers that were susceptible to fatigue damage. A monitoring system was also tested in a different bridge focusing on the structural identification from temperature loads.

The **BRIDGEMON** SME project (2012-2014) focused on the monitor and fatigue resistance of road bridges to traffic loading, using Weigh-in-Motion (WIM) sensors for calculating the weight of every passing truck. The project was extended also to railway bridges.

The **HEALCON** project (2013-2016) had as objectives to design, develop, test, apply and evaluate self-healing methods for concrete structures, focusing on either early age cracking in structures which demand liquid tightness, or, bending cracks at concrete structural parts with a high risk of premature reinforcement corrosion. The second application is interesting in bridge design and retrofitting. It also developed non-destructive testing and monitoring techniques to characterise the effects of different self-healing mechanisms, as well as, a life-cycle assessment methodology for the developed technologies.

The **SAFELIFE-X** project (2013-2015) focused on the improvement of the ageing management for energy and transport infrastructures (including bridges), towards an improved availability and a cost effective management. It also provided input on standardisation procedures.

The **RAIN** project (2014-2017) focuses on minimising the consequences of extreme weather events to European critical infrastructures. Although the project aimed at a holistic assessment at network level, case studies addressed multiple risks (arising from e.g. extreme rainfall in the Friuli Venezia Giulia Region of North Eastern Italy) to be analysed at an individual infrastructure element (e.g. bridge level).

The **RPB HEALTEC** SME project (2014-2016) integrated three technologies, namely, GPR, InfraRed Thermography (IRT) and Air Coupled Ultrasound (ACU), in an integrated

Non-Destructive Testing (NDT) system. The project focuses on pavement defects, but extension to bridge deck condition is also possible. The system captures data at a speed of 60 km/h.

The **BRIDGE SMS** project (2015-2018) focused on the development of standardised methods for bridge scour inspection, including the development of standards for bridge assessment and management. Within the project, pilot studies have been performed in selected bridges and a bridge scour inspection module has been developed for mobile devices.

Box 4. Main findings from FP7 research

Research projects progressed into considering further methods together with the advancements in monitoring technologies. In addition, specific hazards have been addressed.

— The SERIES, REAKT and NERA projects focus on addressing earthquake action.

— A consistent number of SME projects (WI-HEALTH, BRIDGEMON, CROSS-IT, RPB HEALTEC) developed close to market technologies and software.

3.3.4 H2020 research

The **SmartPatch** SME instrument phase 1 project (2014) combines a strain gauge and a transmission system in a sandwich patch that attaches to and becomes an integral part of the structure. The sensor is able to detect damage before it reaches a critical state after a hazardous event (e.g. earthquake) and allows rapid post-event assessment.

The **TRUSS** project (2015-2018) is a training project focusing on the incorporation of emerging technologies (hi-tech monitoring and manufacturing, computing, etc.) for the structural safety of structures and infrastructures. In doing so, it develops reliable monitoring systems and structural, material and loading models. The project specifically tried to address uncertainties in bridge safety, using among else rotation measurements as a monitoring method, distributed optical fibre sensing and the use of an instrumented vehicle.

The **INFRALERT** project (2015-2019) aims to develop an expert-based information system to support and automate rail and road infrastructure management from measurement to maintenance. This includes the collection, storage and analysis of inspection data, the determination of maintenance tasks necessary to keep the performance of the infrastructure system in optimal condition, and the optimal planning of interventions.

The **SENSKIN** project (2015-2019) aims to develop a skin-like sensing solution for the structural monitoring of the transport infrastructure, including bridges. The project will develop hardware and software for the communication interface and perform field tests in real bridges. Two pilot installations have been performed, one in the Bosphorus Bridge in Turkey, a suspension bridge with a main span of 1074m, and one in the Krystallopigi Bridge (a prestressed concrete bridge), in Metsovo (Greece).

The **COBRI** SME instrument phase 2 project (2015-2017) developed, tested and validated a novel fast and high-resolution tomograph (3D-scanner) for the NDT/E (Non-Destructive Testing /Evaluation) of concrete bridges. Field tests have also been performed towards the industrialisation and the scaling-up of the project.

The **LoStPReCon** project (2015-2017) provided a risk-based monitoring framework for the life-cycle asset management of pre-stressed concrete bridges, focusing on principal issues for such structures (creep and shrinkage). Testbed for numerical validation were two long span pre-stressed bridges in Portugal (the Lezíria Bridge and the São João Bridge), for which creep and shrinkage measurements at specimen level were available.

The **AEROBI** project (2015-2018) developed a robotic system for bridge inspection, consisting in an Unmanned Aerial Vehicle (UAV) equipped with sensors that can detect, identify and measure anomalies and defects. Field tests have been performed and the reached results are comparable to manual measurements.

The **FASTSCALE** SME instrument phase 1 project (2016-2017) was developed by a Fast Beam, a SME operating in the field of bridge repair and building. It is a modular repair system for concrete bridge edges, promising over 50 % reduction in labour, over 50 % reduction in net work duration and up to 90 % reduction of non-recyclable waste during the repair works.

The **SAFE-10-T** project (2017-2020) will develop a Safety Framework for critical infrastructure such as bridges and tunnels, using remote monitoring data stored in a Building Information Modelling (BIM) model. The project will make use of advanced techniques (machine learning, AI and big data), and it aims demonstrate its methodology at critical interchanges and nodes of the Trans-European Transport Networks (TEN-T).

The **SERA** (Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe) project (2017-2020), focuses on seismology and earthquake engineering, and aims to improve the access to data, services and research infrastructures. It involves partners from previous projects that are also included in this report (NERA and SERIES).

The recently started **BridgeScan** project (2019-2020) will try to overcome visual inspection deficiencies and UAV low accuracy, using laser scanning integrated into UAV to acquire 3D topographic data points of bridges and to automatically process data for bridge assessment purpose.

Box 5. Main findings from H2020 research

The number of H2020 projects on bridge safety decreased in this FP. Many projects are still ongoing and thus their assessment is not complete.

— There have been developments in technologies and methods in the last years, and this is reflected in two projects that address the use of UAVs for bridge inspection.
— Several SME projects (WI-HEALTH, BRIDGEMON, CROSS-IT, RPB HEALTEC) developed close to market technologies and software.

3.4 Other research in Europe

There are other research initiatives that led to relevant projects to this report, notable the ERA-NET Plus Infravation and the EU Research Fund for Coal and Steel managed by the European Commission.

3.4.1 ERA-NET Plus Infravation

The ERA-NET Plus Infravation 2014 Call under FP7 began as a pooled research fund to develop transport infrastructure innovations which address the challenges identified in the European Commission's White Paper on Transport: Smart, Green and Integrated transport. Its objective is to enable a high quality infrastructure offering high service levels to the user/economy/society through solutions for both new and existing infrastructure. The ERA-NET scheme aimed to develop and strengthen the coordination of national and regional research programmes. Under the ERA-NET scheme, national and regional authorities identified research programmes they wish to coordinate or open up mutually.

Under ERA-NET Plus Infravation, three relevant to this report projects have been identified. The **FASSTbridge** (FASt and effective Solution for STeel bridges life-time extension) project focused on the assessment of the residual life of existing bridges and the fatigue strengthening process (design, execution and maintenance) using Carbon Fiber Reinforced Plastics (CFRP) strips in order to guarantee the initially expected life-time (or even more). The **SHAPE** (Safety, HAzard and Poly-harmonic Evaluation) project has developed an accelerometer based SHM solution at Technology Readiness Level (TRL) 7 to identify presence and location of damage in bridges. The developed "SHAPE box" sensor records acceleration under traffic loading on bridges and uploads to an online server. The solution was tested in a number of bridges, including the arch steel Arstabroarna Bridge in Sweden. The **SeeBridge** (Semantic Enrichment Engine for Bridges) project aimed on creating a Building Information Modelling (BIM) 3D representation of bridges, which could be used to assess if there is damage or need for repair. The project has been demonstrated at TRL 5-6.

3.4.2 The EU Research Fund for Coal and Steel

The EU Research Fund for Coal and Steel (RFCS) funding scheme[7], supports research and innovation projects in coal and steel sectors. The funding is managed by the Commission in cooperation with committees and advisory groups, such as the Coal and Steel Committee (COSCO) and the Coal and Steel Advisory Groups (CAG/SAG) and technical experts. In the period 2015-2017, three projects were financed that focused on the design and strengthening of steel bridges. These include, the **SBRIPLUS** project, focusing on the valorisation of knowledge for sustainable steel-composite bridges in the built environment by combining analyses of environmental, economic and functional qualities along the entire life-cycle of bridges. The ongoing **OUTBURST** project which focuses on the structural behaviour of curved and nonrectangular steel panels (stiffened and unstiffened), not covered by Eurocodes, in the design and life-cycle assessment (LCA) of bridges. The **PROLIFE** project focused on novel strengthening approaches for steel bridges.

RFCS funded between 2003 and 2014 around 20 projects that focused on or included bridge design, construction, pedestrian and composite bridges, welded steelwork, abutments, fatigue analysis, high strength steel. The **DETAILS** project which ran for three years (2006-2009) investigated specific aspects of new high speed railway bridges over their life-cycle.

The **SBRI** project (2009-2012) focused on the LCA of steel-composite bridges, with particular reference to fatigue, corrosion and carbonation. In the period 1994-2001, six bridge related projects were funded through SBRI.

3.4.3 Other research

In addition to these, many research entities co-fund research in different European countries. A large number of implementation projects is also based on private funding, with initial funds from the public sector (innovative start-up schemes). It is worth mentioning the European Space Agency (ESA), which promotes research in space related fields, with open calls on feasibility studies, demonstration projects and kick-start activities. **GeoSHM** was a feasibility study project with the objective of using global navigation satellite system (GNSS) and earth observation technologies, combined with typical monitoring sensors used in bridges, to improve the accuracy of the structural monitoring system.

3.5 Member States research

EU MS-financed research in this field was flourishing during the 1990s and the first decade of the current millennium. Although there are difficulties in comprehensively tracking research on bridge maintenance and monitoring, an effort is made to highlight initiatives and projects for selected MS.

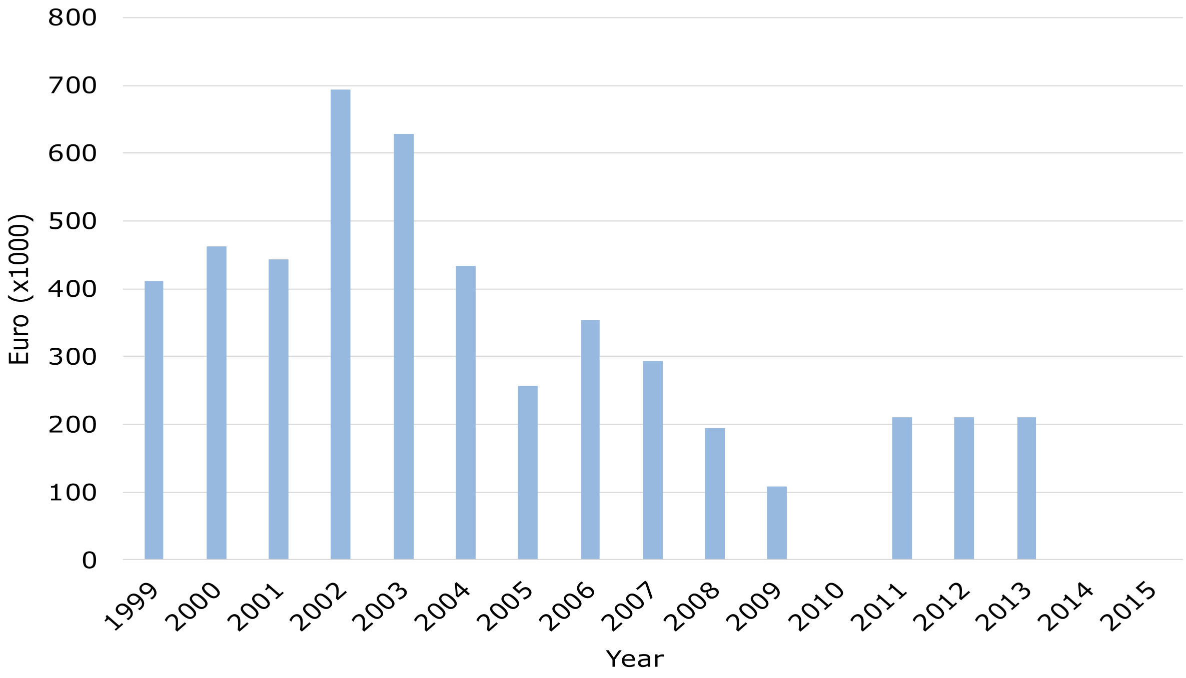
[7] https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/research-fund-coal-and-steel-rfcs_en

3.5.1 Italy

Most research in the field has been carried out inside universities. University research in Italy is funded through the Italian Ministry of Education, Universities and Research (MIUR).

MIUR announces call for proposals for funding research projects of national interest (PRIN). PRIN focus primarily on basic research. Annex 1 provides a list of 22 projects that focus on bridge maintenance, retrofitting and monitoring (in Italian). The list has been obtained after examining the 67 projects on bridge related research in the area of civil engineering and architecture from 1999 to 2015[8]. A total of EUR 5 million has been assigned to 22 projects since 1999. Figure 3 provides the total funding breakdown per year.

Figure 3. Italian bridge research project funding



Source: TRIMIS

As can be seen from the graph, most of the research has been carried out in the first decade of the new millennium. Research funding in the last years is limited (only one project financed after 2009), considering that the call for proposals nowadays takes place every three years. Some projects are linked with the high interest in that period for the design and construction of new bridges, including TEN-T priorities such as the TGV Bologna-Verona bridge over the Po river[9] and the long span bridge connecting Sicily with mainland Italy as part of the Railway axis Berlin–Verona/Milan–Bologna–Naples–Messina–Palermo[10]. This can explain also the consistent research linked to wind action, critical for long span bridges.

Most of the research is linked to research groups from the University of Rome “La Sapienza”, The University of Florence, The Politecnico di Torino and the Politecnico di Milano. Research leaders from these groups have a very high scientific and engineering curriculum both in Italy and abroad, including high ranking positions in international

[8] http://prin.miur.it
[9] https://eurocodes.jrc.ec.europa.eu/structure_high-speed-railway-bridge-over-the-po-river?id=47
[10] http://ec.europa.eu/ten/transport/priority_projects_minisite/PP01EN.pdf

bridge maintenance and SHM associations[11],[12]. Within these research, links with EU funded projects and high level international scientific collaborations can also be found (e.g. (Brownjohn *et al.*, 2011), as well as a consistent bibliography of papers in high impact factor journals (Biondini *et al.*, 2006; Malerba, 2014).

With the change to legislation on the funding of "projects of national interest", MIUR has recently introduced a new mechanism for the allocation of funds based on co-funding, group research work and peer evaluation. The main objective, at least for the next years, is the reinforcement of the national scientific foundations with a view to securing a more effective participation in the European initiatives related to the Framework Programmes[13].

3.5.2 Switzerland

National Swiss projects are funded mainly through the State Secretariat for Education and Research (SERI). Their research related to bridges concerns mainly two topics: bridge resilience to natural hazards and bridge design. The first topic originates mainly from the collapse of the two-lane street bridge Ri di Rialp in 1998, due to an avalanche. Therefore, many projects concentrate on the evaluation of the current bridge infrastructure. Additionally, many research projects concentrate on bridge materials and design, with increased resilience and lifetime as one of the main objectives.

The ARAMIS information system website[14] contains information regarding research projects and assessments that are either run or funded by the Swiss Federal Administration.

3.5.3 Austria

The Austrian Research Promotion Agency (FFG) is the national funding agency for industrial research and development in Austria. Mobility of the Future is Austria's national transport research funding program for the period 2012–2020 and it builds up on the previous mobility related research programme IV2Splus (Intelligent Transportation Systems and Services plus).

Within this programme, a number of recently funded projects focus on bridge maintenance.

The **ConDef** project focuses on the maintenance of prestressed concrete bridges and investigates the causes that lead to the development of unusual deformation. Within the project, which includes the monitoring of creep and shrinkage deformations for a case study bridge, recommendations in the form of limit values for the preservation of existing bridges as well as justified assumptions and rules for the design of new structures are derived. The project runs for 3 years (2017-2020).

TAniA focuses on a life-cycle approach for the development of a calculation procedure for a technical, condition based asset value and a replacement of road infrastructure assets, including bridges. The project considers target values of decisive performance indicators and their influencing factors for assessing maintenance requirements. The project runs for 3 years (2018-2021).

3.5.4 Germany

Research in Germany is funded mainly through the Deutsche Forschungsgemeinschaft (DFG), which is the self-governing organisation for science and research in Germany. Through this organisation, there have been multiple nationally funded projects related to

[11] http://www.iabmas.org
[12] http://www.ishmii.org
[13] https://www.researchitaly.it/en/research-projects-of-national-interest
[14] www.aramis.admin.ch

bridge structural safety and maintenance. The main areas of focus of these projects have evolved from sensor technology development in the 1990s, to life cycle assessment and lifetime prognosis in the 2000s and intelligent damage detection methods and maintenance prediction more recently.

3.5.5 France

The French National Research Agency (ANR) provides funding for project-based research in all fields of science, for both basic and applied research, to public research organisations and universities, as well as to private companies (including SMEs). A number of projects focus on the technological aspects of automated monitoring, such as sensors and data processing for automated damage detection. The main research area, however, is the aeronautics industry and more recently the wind turbine industry.

3.5.6 Portugal

Portuguese regional projects are financed mainly by the Fundação para a Ciência e a Tecnologia (FCT), a public agency under responsibility of the Ministry for Science, Technology and Higher Education in Portugal. Following the collapse of the Hintze Ribeiro Bridge in 2001, Portugal has increased investments on bridge maintenance and monitoring technology. Due to the presence of many newly built bridges, there are many research projects dedicated exclusively to the monitoring of one given bridge, usually involving partnerships between universities and the private sector.

3.5.7 Greece

ASPROGE, a research program for the Seismic Protection of Bridges funded by the General Secretariat for Research and Technology (GSRT) of the Hellenic Ministry of Development, led to the development of an integrated bridge management system (Karlaftis et al. 2006). This system was implemented by Egnatia Odos, a motorway spreading over 670 km in the north of Greece, that also participated in this joint research initiative[15]. The motorway has approximately 40 km of bridges, 177 of which are longer than 50m.

3.6 Other initiatives

It is worth highlighting some networking R&I initiatives in Europe in the last years, some of them developed in parallel to EU research.

3.6.1 SAMCO network

The European Association on Structural Assessment Monitoring and Control (SAMCO) was established in March 2006, after the end of the I-SAMCO project. Its objective was to create knowledge communities within the field of structural assessment monitoring and control, developing new technologies and methodologies in the field. The need to create an association by the end of the project came from one of the conclusions of the project, that there was still fragmentation in European research and a higher level of coordination and integration was necessary. SAMCO published in 2006 guidelines for SHM as part of its final report[16].

At the same time, SAMCO also joined the international Society for Structural Health Monitoring and Intelligent Infrastructure (ISHMII), to strengthen its international collaboration.

---

[15] http://www.egnatia.eu/page/default.asp?la=2&Id=702
[16] http://www.samco.org/network/download_area.htm

3.6.2 COST Action TU1402 – Quantifying the Value of Structural Health Monitoring

COST Action TU 1402[17] is composed of partners from 28 Member States and aims in bringing together research and engineering partners to create a network with the objective of quantifying the value of using and deploying structural health monitoring systems, and in this way improve the decision-making aspects related to design, operation, maintenance and life-cycle. The focus of the Action is the integrity management of civil structures, with a working group dedicated to case studies and bridges are one of four topics. The action started on the 13 November 2014 and will end on the 30 April 2019, and among the expected deliverables are guidelines and a library of tools and algorithms to support the quantification of the value of SHM before its implementation.

3.6.3 COST Action TU1406 –Quality specifications for roadway bridges, standardization at a European level

COST Action TU1406[18] focuses on the production of a guideline for the establishment of quality control plans for roadway bridges across Europe. It deals with recent developments on bridge safety, maintenance and management, according to a life-cycle outlook, aiming to define a standardised procedure for performance assessment as well as for the establishment of performance goals in order to accomplish a pre-specified service level.

3.6.4 Horizontal Group 'Bridges' of CEN/TC 250

The European Committee for Standardization (CEN) is an association that brings together the National Standardization Bodies of 34 European countries. The Horizontal Group 'Bridges' of the CEN Technical Committee (TC) 250 is currently reviewing the design rules of the Eurocodes on load models, fatigue and robustness of bridges[19].

[17] COST Action TU1402: Quantifying the Value of Structural Health monitoring [www page] www.cost-tu1402.eu

[18] COST Action TU1406: Quality specifications for roadway bridges, standardization at a European level [www page] https://www.tu1406.eu

[19] https://eurocodes.jrc.ec.europa.eu

4 A perspective beyond Europe

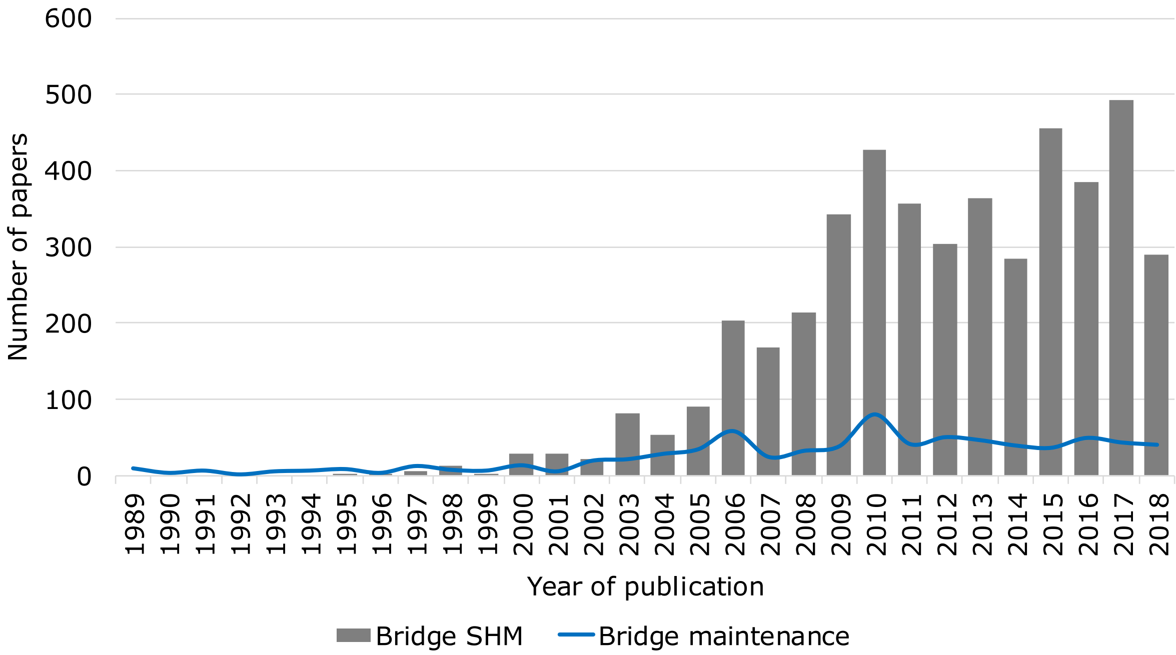
There is a vast international activity on all fronts for what regards bridge maintenance and structural health monitoring. It appears that the US and China are leaders in this field, with strong presence also from other countries (especially South Korea).

4.1 International scientific activity

The SCOPUS citation database is the reference database for scientific research[20]. The following exercise has as objective to mark the evolution of peer reviewed scientific publications in the area of bridge maintenance and SHM in the last 20 years.

Figure 4 shows the scientific production that includes the words, a. "bridge" and "SHM", and, b. "bridge maintenance". An almost linear increase in bridge SHM research between 2000 and 2010 can be observed, while in the last years the scientific production is relatively stable. Considering also a typical 1-2 year publication delay, "bridge maintenance" related research shows a constant trend in the last years, with peaks around 2005 and 2010.

Figure 4. Bridge research scientific papers



Source: Scopus, TRIMIS elaboration

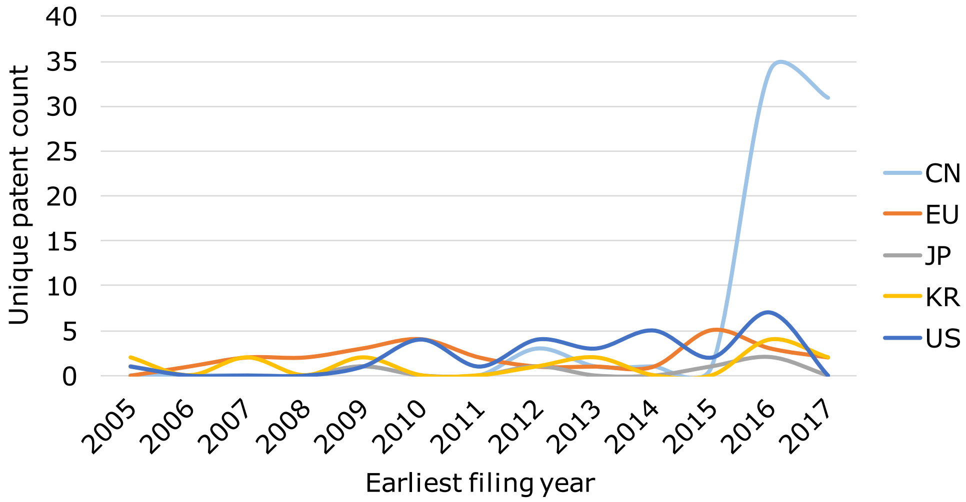
4.2 International IPR activity

A conducted exercise focuses on the Intellectual Property Rights (IPR) activity in the field of bridge SHM sector in the period 2005-2017, with 2017 results being provisory.

The PatStat database from the ESPACENET web portal[21] has been used. In particular, IP activity has been researched on the specific cooperative patent classification (CPC) code "G01M5/0008" which covers inventions on the elasticity (e.g. deflection) of bridges. The outcomes of this exercise are outlined in Figure 5.

[20] http://www.scopus.com
[21] https://worldwide.espacenet.com

Figure 5. IPR activity in bridge SHM



Source: TRIMIS
CN: China; EU: European Union; JP: Japan; KR: South Korea; US: United States

A total of 148 patent filings have been found. China leads with 72 patents, the majority of which have been filed in the last years. This leads to the necessity to further investigate the reasons of this peaking. US and Europe come a close second with 28 and 27 filings, while also Japan and Korea have a presence in the landscape. The trend in the examined period is positive in general, with some peeks in the last two years that highlight very recent developments (e.g. the use of drones). It could be useful in the future to monitor the progress and expand the search to additional IP codes.

4.3 International associations

Numerous international associations deal with research issues related to bridge safety, management and SHM, either exclusively or within other topics. A non-exhaustive list includes (see list of abbreviations for full names): AASHTO, ACI, AISC, ASCE, ESRA, FEHRL, FEMA, FIB, IABMAS, IABSE, IALCCE, IASSAR, IFIP, ISHMII, JCSS and PIARC. The California Department of Transportation (Caltrans) also performs research in the field.

In what follows a brief description of three associations focusing on bridge maintenance and SHM.

4.3.1 International Society of Structural Health Monitoring of Intelligent Infrastructure (ISHMII).

ISHMII is a society dedicated to the understanding and the application of SHM systems and related asset management methodologies for engineering infrastructures by international sharing of knowledge and experience. Among else, it promotes innovative SHM solutions as an integrated part of existing and new structures. The society is very active in international collaborations and organises a bi-annual conferences and workshops. While railways are beyond the scope of this report, it should be stated that the International Union of Railways (UIC) also performs research in the field and publishes guidelines.

4.3.2 International Association for Bridge Management and Safety (IABMAS)

This association embraces all aspects of bridge maintenance, safety, and management. Specifically, it deals with: bridge repair and rehabilitation issues; bridge management systems; needs of bridge owners; financial planning, whole life costing and investment for the future; bridge related safety and risk issues and economic and other implications. It promotes international cooperation in the fields of bridge maintenance, safety and management, and to this scope, it organises congresses, conferences, symposia, workshops, seminars, and short courses on the related topics.

4.3.3 International Association for Bridge and Structural Engineering (IABSE)

This scientific/technical association was founded in 1929 and currently comprises members in 100 countries and counts 51 National Groups worldwide. IABSE deals with all aspects of structural engineering: the science and art of planning, design, construction, operation, monitoring and inspection, maintenance, rehabilitation and preservation, demolition and dismantling of structures, taking into consideration technical, economic, environmental, aesthetic and social aspects. It promotes cooperation among all those concerned with structural engineering, including bridge engineering, and related fields by worldwide exchange of knowledge and experience. It also organises conferences and publishes a journal.

5 Technology uptake from research projects

There are many ways that research projects can contribute to the development of new technologies and their transformation into products.

Very small "one-product" companies (usually spin-offs from universities) tend to make use of research funding to further develop their product for commercialisation. Such is the case for ELOP AS, which took part in the H2020 SME instrument phase 2 project COBRI to bring their ultrasound rolling scanner close to the market.

For some companies the main goal within a project is to gather knowledge and expand their solutions portfolio through experience and use cases. For example, ROD-IS is a consultancy company which has participated in multiple EU funded projects (LONG LIFE BRIDGES, BRIDGEMON, RAIN) and with each of them extending their capabilities in bridge monitoring and maintenance (with weigh-in-motion, traffic load modelling and Risk Based Asset Management services in their portfolio).

Similarly, Vienna Consulting Engineers (VCE), a consultancy company that participated in numerous relevant FP projects (IRIS, NERA, SYNER-G, IMAC), but also national (Austrian) projects, commercialised the BRIMOS® Bridge Monitoring System which has been used extensively in case studies within the projects.

In some cases, the direct link between developed technology for bridge maintenance and monitoring is less evident. This is the case for Smartec, a European company specialised in bridge monitoring and with several real-life cases demonstrating their expertise. They are very active in research on health monitoring systems for aeronautical applications. Even though they are not frequently participating in bridge SHM projects, their involvement does indicate that innovations from other fields are applied to bridge SHM. This demonstrates the overlap between different areas, and how research in one area (e.g. aeronautics) can lead to advancements in another area (e.g. bridge safety).

Generally it is thus difficult to state the extent to which research led to market ready applications. Still, strong evidence exists on FP projects being successful in developing technologies and putting them into practice.

A final point concerns the widespread uptake of innovations. On this, Inaudi (2010) reports on applications of Smartec fibre optic sensor monitoring in 40 bridges (29 in Europe). Of these 40, 23 were commissioned by bridge owners (as opposed to 13 through research funds and 4 by engineering companies).

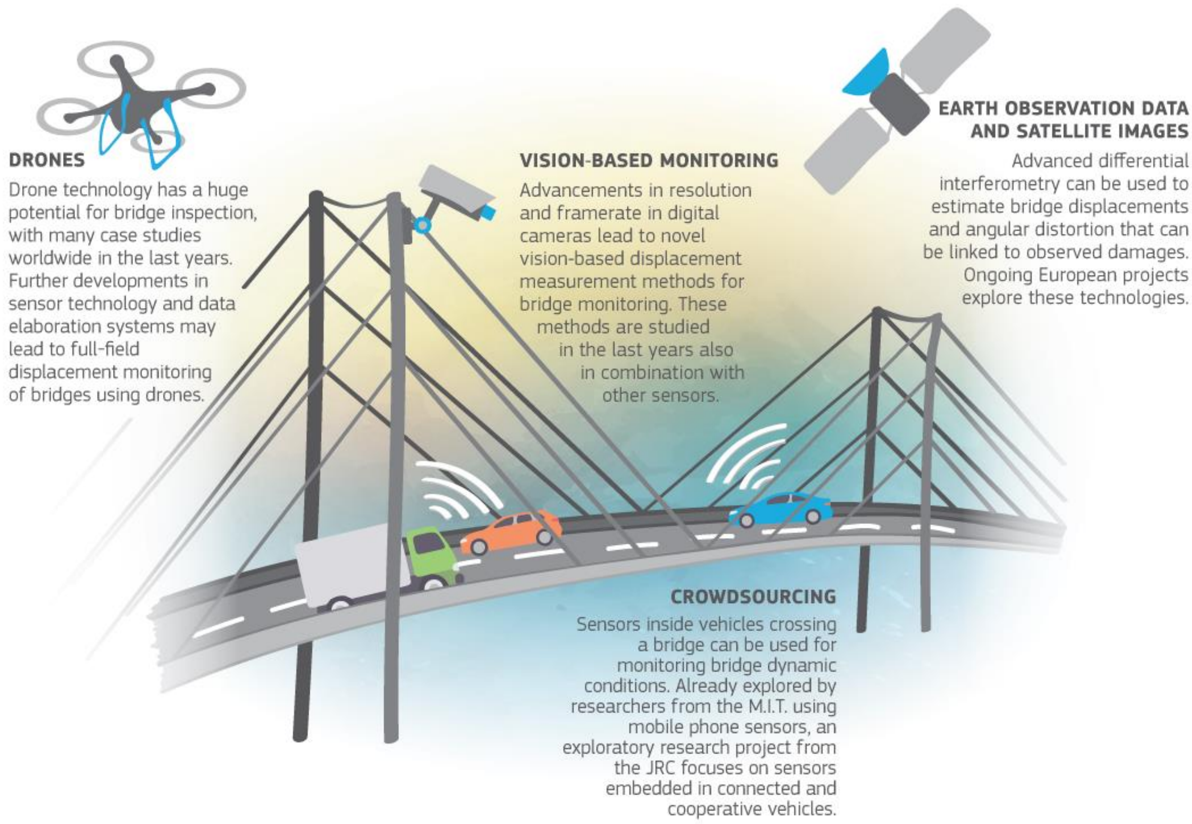
These numbers indicate that bridge SHM applications supported by EU funding go beyond case studies and include real bridge structures.

6 Promising future bridge SHM technologies

In order to provide alternatives to traditional SHM approaches, new solutions and technologies are being explored to develop low-cost, large scale and easily deployable systems that could contribute to the monitoring of the large number of civil of structures that, at present, are missing dedicated supervision.

Figure 6 provides in a graphic way some promising new methods and technologies for future bridge SHM.

Figure 6. Promising bridge SHM methods



Source: JRC/TRIMIS

Some of the emerging methods focus on novel technologies, for example use of drones (two projects already under the H2020 programme), Earth Observation data and Synthetic Aperture Radar (SAR) (I.MODI F2020 SME Instrument Phase 2 project[22]), crowdsourcing (Matarazzo *et al.*, 2018) and fast speed cameras (Park *et al.*, 2018).

A 2-year Exploratory Research project by the European Commission's Joint Research Centre (JRC), starting in 2019, will focus on bridge monitoring from sensors present in connected and cooperative vehicles that are expected to enter the roads in the future. Exploratory Research is included as a direct action in H2020 for the JRC to pursue excellence[23].

[22] http://www.imodi.info/en/home-en/
[23] https://cordis.europa.eu/programme/rcn/664511/en

Conclusions

This report provides insights into the research and innovation capacity in bridge maintenance, inspection and monitoring in Europe. It does so by assessing research and innovation projects undertaken within the framework of European and national research programmes. The main findings can be summarised as follows:

— A large amount of research has been funded through FP, since FP2. The research addressed all areas of bridge safety (materials, loads, hazards, management, monitoring etc.).

— There is a weak link between research (including case studies) and wide scale adoption of technologies. This is especially true for smaller structures, where investment in innovative materials and monitoring methods requires a budget that is not always available to bridge owners. This is different for recent large-scale projects, where a life-cycle approach has been adopted as of the initial design. For these projects, the use of state-of-the-art innovative materials and methods is common, while monitoring and management solutions are part of the design process.

— There is a lack of methods to exploit the measurements done with the various instruments/technologies and associate them to engineering performance levels within decision-making tools and processes.

— There appears to be a certain duplication of research, especially regarding sensor technology. Similar sensor technology is used in different fields (e.g. naval, aeronautical) and for various civil engineering structures (dams, tall or special buildings, bridges). This is indicative of research spill-overs, but the repetition of research also suggests that limited progress towards maturity is made.

— Regarding SHM, rich documentation is available in Europe, developed as an outcome of different research projects and other initiatives, such as SAMCO, COST Action TU1402. It is worth noting, that while many documents have been produced, not all of them are easily accessible to a broad audience.

— There appears to be a lack of a standard assessment methodology or pertinent legislation in Europe that goes beyond recommendations. This is an area to be addressed in the future, following the experience from China where a SHM code has been developed for long-span bridges (Moreu, 2018).

— There appear to be emerging SHM solutions that are worth investigating. These solutions carry a potential for reshaping the field of bridge inspection and monitoring.

References

van Balen, M., Grosso, M., Gkoumas, K., Tsakalidis, A., Haq, G., Ortega Hortelano, A. and Pekár, F., *Research and Innovation Capacity in Transport Infrastructure: An Assessment Based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)*, Publications Office of the European Union, Luxembourg, 2019 (*available soon*).

Biondini, F., Bontempi, F., Frangopol, D.M. and Malerba, P.G., "Probabilistic Service Life Assessment and Maintenance Planning of Concrete Structures", *Structural Engineering*, Vol. 132, No. 5, 2006, pp. 810–825.

Brownjohn, J.M.W., De Stefano, A., Xu, Y.-L., Wenzel, H. and Aktan, A.E., "Vibration-Based Monitoring of Civil Infrastructure: Challenges and Successes", *Journal of Civil Structural Health Monitoring*, Vol. 1, No. 3–4, December 20, 2011, pp. 79–95. http://link.springer.com/10.1007/s13349-011-0009-5.

Cachot, E., Hajar, Z., Lançon, H., Servant, C., Vayssade, T. and Virlogeux, M., "The Millau Viaduct: Ten Years of Structural Monitoring", *Structural Engineering International*, Vol. 25, No. 4, 2015, pp. 375–380.

European Commission, *Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation C/2015/6317 Final*, Brussels, 2015.

European Commission, *Towards Clean, Competitive and Connected Mobility: The Contribution of Transport Research and Innovation to the Mobility Package SWD/2017/0223 Final*, Brussels, 2017a.

European Commission, "Transport Research and Innovation Monitoring and Information System (TRIMIS) Programmes and Projects Database", *JRC109363*, 2017b. http://publications.jrc.ec.europa.eu/repository/handle/JRC109363.

Inaudi, D., "Overview of 40 Bridge Structural Health Monitoring Projects", *26th Annual International Bridge Conference (IBC) 2009: Meeting Bridge Challenges in Challenging Times: June 15–17, 2009, Pittsburgh, USA*, 2009.

Karlaftis, M., Bitsikas, T., Kepaptsoglou, K., Panetsos, P. and Lambropoulos, S., "Development of a Bridge Management System for a Freeway Authority in Greece", *Proceedings of the Third International Conference on Bridge Maintenance, Safety and Management, 16-19 July 2006, Porto, Portugal - IABMAS '06*, 2006.

Li, H. and Ou, J., "The State of the Art in Structural Health Monitoring of Cable-Stayed Bridges", *Journal of Civil Structural Health Monitoring*, Vol. 6, 2016, pp. 43–67.

Malerba, P.G., "Inspecting and Repairing Old Bridges: Experiences and Lessons", *Structure and Infrastructure Engineering*, Vol. 10, No. 4, April 3, 2014, pp. 443–470. http://www.tandfonline.com/doi/abs/10.1080/15732479.2013.769010.

Matarazzo, T.J., Santi, P., Pakzad, S.N., Carter, K., Ratti, C., Moaveni, B., Osgood, C. and Jacob, N., "Crowdsensing Framework for Monitoring Bridge Vibrations Using Moving Smartphones", *Proceedings of the IEEE*, Vol. 106, No. 4, 2018, pp. 577–593.

Moreu, F., Li, X., Li, S. and Zhang, D., "Technical Specifications of Structural Health Monitoring for Highway Bridges: New Chinese Structural Health Monitoring Code", *Frontiers in Built Environment*, Vol. 4, No. 10, 2018.

Muttoni, A., *Some Innovative Prestressed Concrete Structures in Switzerland, Keynote Lecture at the 23rd Symposium on Developments in Prestressed Concrete*, Japan Prestressed Concrete Institute, Morioka, Japan, 2014.

Nemry, F. and Demirel, H., *Impacts of Climate Change on Transport: A Focus on Road and Rail Transport Infrastructures*, Publications Office of the European Union, Luxembourg, 2012.

Park, J.-W., Moon, D.-S., Yoon, H., Gomez, F., Spencer Jr., B.F. and Kim, J.R., "Visual-Inertial Displacement Sensing Using Data Fusion of Vision-Based Displacement with Acceleration", *Structural Control and Health Monitoring*, Vol. 25, No. 3, March 2018, p. e2122. http://doi.wiley.com/10.1002/stc.2122.

Sgambi, L., Gkoumas, K. and Bontempi, F., "Genetic Algorithms for the Dependability Assurance in the Design of a Long-Span Suspension Bridge", *Computer-Aided Civil and Infrastructure Engineering*, Vol. 27, No. 9, October 2012, pp. 655–675. http://doi.wiley.com/10.1111/j.1467-8667.2012.00780.x.

Tsakalidis, A., van Balen, M., Gkoumas, K., Grosso, M., Haq, G. and Pekár, F., *Towards an Integrated Monitoring and Assessment Framework for the Strategic Transport Research and Innovation Agenda - Using TRIMIS as a Policy Support Mechanism*, EUR 29314 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-92583-2, doi:10.2760/788905, JRC112360.
[http://skp.jrc.cec.eu.int/skp/showPub?id=JRC112360].

List of abbreviations and definitions

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACU	Air Coupled Ultrasound
AE	Acoustic Emission
AISC	American Institute of Steel Construction
ANN	Artificial Neural Networks
ANR	*Agence Nationale de la Recherche* (French National Research Agency)
ASCE	American Society of Civil Engineers
BIM	Building Information Modelling
BMS	Bridge Management Systems
CAG	Coal Advisory Group
Caltrans	California Department of Transportation
CEN	European Committee for Standardisation
CFRP	Carbon Fibre Reinforced Plastics
CN	China
COSCO	Coal and Steel Committee
CPC	Cooperative Patent Classification
DFG	*Deutsche Forschungsgemeinschaft* (German Research Foundation)
ESRA	European Safety and Reliability Association
EC	European Commission
EC8	Eurocode 8
EU	European Union
FCE	*Fundação para a Ciência e a Tecnologia* (Portuguese Foundation for Science and Technology)
FEHRL	Forum of European National Highway Research Laboratories
FEM	Finite Element Method
FEMA	Federal Emergency Management Agency
FFG	Österreichische *Forschungsförderungsgesellschaft* (Austrian Research Promotion Agency)
FIB	International Federation for Structural Concrete
FP	Framework Programme
GPR	Ground Penetrating Radar
GSRT	Hellenic General Secretariat for Research and Technology
H2020	Horizon 2020
IABMAS	International Association for Bridge Management and Safety
IABSE	International Association for Bridge and Structural Engineering
IALCCE	International Association for Life-Cycle Civil Engineering

IASSAR	International Association for Structural Safety and Reliability
IFIP	International Federation for Information Processing
IoT	Internet of Things
IPR	Intellectual Property Rights
IRT	InfraRed Thermography
ISHMII	International Society of Structural Health Monitoring of Intelligent Infrastructure
JCSS	Joint Committee on Structural Safety
JP	Japan
JRC	Joint Research Centre
KR	Korea
LCA	Life Cycle Assessment
LRU	Long Range Ultrasonic
LPHC	Low Probability High Consequence
MEMS	Micro-Electro-Mechanical Systems
MIUR	*Ministero dell'Istruzione dell'Università e della Ricerca* (Italian Ministry of Education, Universities and Research)
NDT	Non-Destructive Testing
NDE	Non-Destructive Evaluation
PIARC	Permanent International Association of Road Congresses
PRIN	*Progetti di Ricerca di Interesse Nazionale* (Italian research projects of national interest).
RFCS	Research Fund for Coal and Steel
SAG	Steel Advisory Group
SAMCO	European Association on Structural Assessment Monitoring and Control
SAR	Synthetic Aperture Radar
SERI	(Swiss) State Secretariat for Education, Research and Innovation
SHM	Structural Health Monitoring
SME	Small Medium Enterprise
STRIA	Strategic Transport Research and Innovation Agenda
TC	Technical Committee
TEN-T	Trans-European Transport Networks
TGV	*Train à Grande Vitesse* (high speed train)
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UGW	Ultrasonic Guided Waves
UIC	International Union of Railways
US	United States

List of boxes

List of figures

List of tables

Annex. Italian basic research projects (PRIN)

Year	Scientific coordinator	University*	Research title (in Italian)	Total budget	Co-financing	Duration (m)
1999	Claudio Borri	UNIFI	*Analisi, controllo e riduzione del rischio eolico sulle costruzioni e sull' ambiente urbano*	369 267	182 309	24
1999	Mauro Dolce	UNIBASILICATA	*Le leghe metalliche a memoria di forma per lo smorzamento delle vibrazioni nelle grandi strutture*	167 848	78 501	24
1999	Fabrizio Vestroni	UNIROMA1	*Risposta dinamica di strutture flessibili sotto l'azione di forze naturali e artificiali*	286 117	127 048	24
2000	Paolo Emilio Pinto	UNIROMA1	*Metodi per la riduzione del rischio sismico di ponti e di sistemi stradali*	102 775	88 314	24
2001	Claudio Borri	UNIFI	*WINDERFUL: Dominare il rischio eolico ed assicurare il funzionamento di impianti ed infrastrutture*	361 520	164233	24
2001	Fabrizio Vestroni	UNIROMA1	*Comportamento dinamico delle strutture: analisi e sperimentazione*	299 545	151 322	24
2001	Luigi Gambarotta	UNIGENOVA	*Sicurezza e controllo di ponti in muratura*	123 950	93 995	24
2002	Pier Giorgio Malerba	POLIMI	*Identificazione, modellazione, analisi e controllo delle incertezze nel progetto dei ponti di grande luce.*	190 000	101 500	24
2002	Paolo Emilio Pinto	UNIROMA1	*Aspetti innovativi nella progettazione antisismica dei ponti*	135 000	95 700	24
2002	Enrico Spacone	UNICHIETI-PESCARA	*Opere in cemento armato per l'edilizia e le infrastrutture: diagnostica, modellazione e riabilitazione*	277 000	140 000	24

Year	Scientific coordinator	University*	Research title (in Italian)	Total budget	Co-financing	Duration (m)
2003	Luigi Gambarotta	UNIGENOVA	*Sicurezza, conservazione e gestione dei ponti in muratura*	150 000	117 100	24
2003	Claudio Borri	UNIFI	*Prestazioni per l'intera vita, innovazione e criteri di progettazione di strutture ed infrastrutture a fronte dell'azione eolica e di altri eventi naturali*	293 000	171 800	24
2003	Fabrizio Vestroni	UNIROMA1	*Modelli e Fenomeni nella Dinamica di Sistemi Strutturali Complessi: analisi, sperimentazione e controllo*	211 000	121 200	24
2004	Pier Giorgio Malerba	POLIMI	*Affidabilita' nel tempo delle strutture di ponti e viadotti*	214 000	141 000	24
2005	Fabrizio Vestroni	UNIROMA1	*Modellazione e sperimentazione del comportamento dinamico di strutture flessibili*	207 000	122 400	24
2005	Domenico Capuani	UNIFERRARA	*Diagnostica e salvaguardia di opere in calcestruzzo armato per le infrastrutture con degrado ambientale.*	91 000	48 900	24
2006	Claudio Borri	UNIFI	*Fenomeni aeroelastici ed altre interazioni dinamiche in ponti e passerelle non convenzionali*	234 000	145 200	24
2006	Alessandro De Stefano	POLITO	*Linee guida per la sorveglianza e la gestione delle strutture e infrastrutture storiche con il supporto di tecniche innovative per il monitoraggio strumentale.*	177 000	126 000	24

Year	Scientific coordinator	University*	Research title (in Italian)	Total budget	Co-financing	Duration (m)
2007	Paolo Emilio Pinto	UNIROMA1	*Valutazione probabilistica in tempo reale della transitabilità post-sisma di opere da ponte*\\\\	175 000	139 300	24
2008	Camillo Nuti	UNIFI	*Effetto del non sincronismo inclusa la risposta sismica locale sulla sicurezza dei ponti*	80 325	52 500	24
2008	Giuseppe Mancini	POLITO	*Modellazione chimico-fisico-meccanica della durabilità nelle strutture in C.A. e C.A.P.*	135 350	98 300	24
2011	Angelo Luongo	UNILAQUILA	*Dinamica, stabilità e controllo di strutture flessibili*	630 000	349 466	36

*UNIFI: Università degli studi di Firenze, POLITO: Politecnico di Torino, UNIBASILICATA: Università degli Studi della Basilicata, UNICHIETI-PESCARA: Università degli Studi "Gabriele d'Annunzio", UNIFERRARA: Università degli Studi di Ferrara, UNIGENOVA: Università degli Studi di Genova, UNILAQUILA: Università degli Studi di L'Aquila, UNIROMA1: Università degli Studi di Roma "La Sapienza"

Source: MIUR[24], TRIMIS elaboration.

[24] http://prin.miur.it

KJ-NA-29650-EN-N

The European Commission’s science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre’s mission is to support EU policies with independent evidence throughout the whole policy cycle.

doi:10.2760/16174

ISBN 978-92-79-99678-8