Digital Roads Prosperity Partnership

Annual Review 2023

Foreword

Prof Andy Neely

Pro-Vice-Chancellor for Enterprise and Business Relations, University of Cambridge

It is always a pleasure to support success, and the Digital Roads Prosperity Partnership is just that. A synergy of industry and academia that aims to improve the way our national infrastructure supports the public through innovation and practical implementation.

There has been a strong, long-standing strategic relationship between the University of Cambridge, National Highways and Costain, culminating in the setting up of the Digital Roads of the Future (DRF) Initiative, a research group made up of the EPSRC co-funded Digital Roads Prosperity Partnership and the MSCA Future Roads fellowship programme. The DRF initiative brings together the multidisciplinary themes of digital twins, smart materials, data science, automation and robotics and sustainability with an international highly skilled research team supported by invested industry experts.

The DRF Initiative is generating opportunity, through their research, either directly or through tangential themes, to experiment and implement trials and exemplars of within the strategic road network. The Roads Research Alliance, of which Cambridge are the leading academic partner, are a fertile ground for these seeds of research innovation to bring industry together and turn research into practice.

This report is just the beginning, detailing the achievements of the first year of research. We have strong ambition and drive for the coming years, with the skills and talent to get us to deliver on our vision.

Nick Harris

Chief Executive, National Highways

I am pleased to celebrate the Roads Research Alliance's first anniversary. In just 12 months we have established a leading research programme for the highways sector and secured strong support from our industry and academic partners.

The Digital Roads Research programme was founded by members of the Alliance: National Highways, Costain and Cambridge University with support from the Engineering and Physical Sciences Research Council. It is part of a pioneering initiative called Prosperity Partnerships and is a first for our sector. I'm proud that the Alliance can class itself among other research-focused organisations such as Microsoft, Siemens, Thalis, Jaguar Land Rover and Rolls Royce. It also gives me great pleasure to see our industry working together to advance capability and talent in the sector.

The Digital Roads Research programme sits alongside the Marie Skłodowska Curie Action Future Roads fellowship programme, and we are working in partnership to set research challenges. Through this Alliance we are able to address some of the biggest challenges we're facing in the transport sector today. However, research alone is not enough, we must accelerate innovation into operation – delivering solutions that will improve strategic outcomes at scale.

This report captures progress and achievements of the project to date. Thank you to those who have worked hard to get us to this point. I'm excited about what we can achieve in the coming year.

"Research alone is not enough; we must accelerate innovation into operation - delivering solutions that will support strategic outcomes at scale."

Digital Roads Prosperity

The Challenge

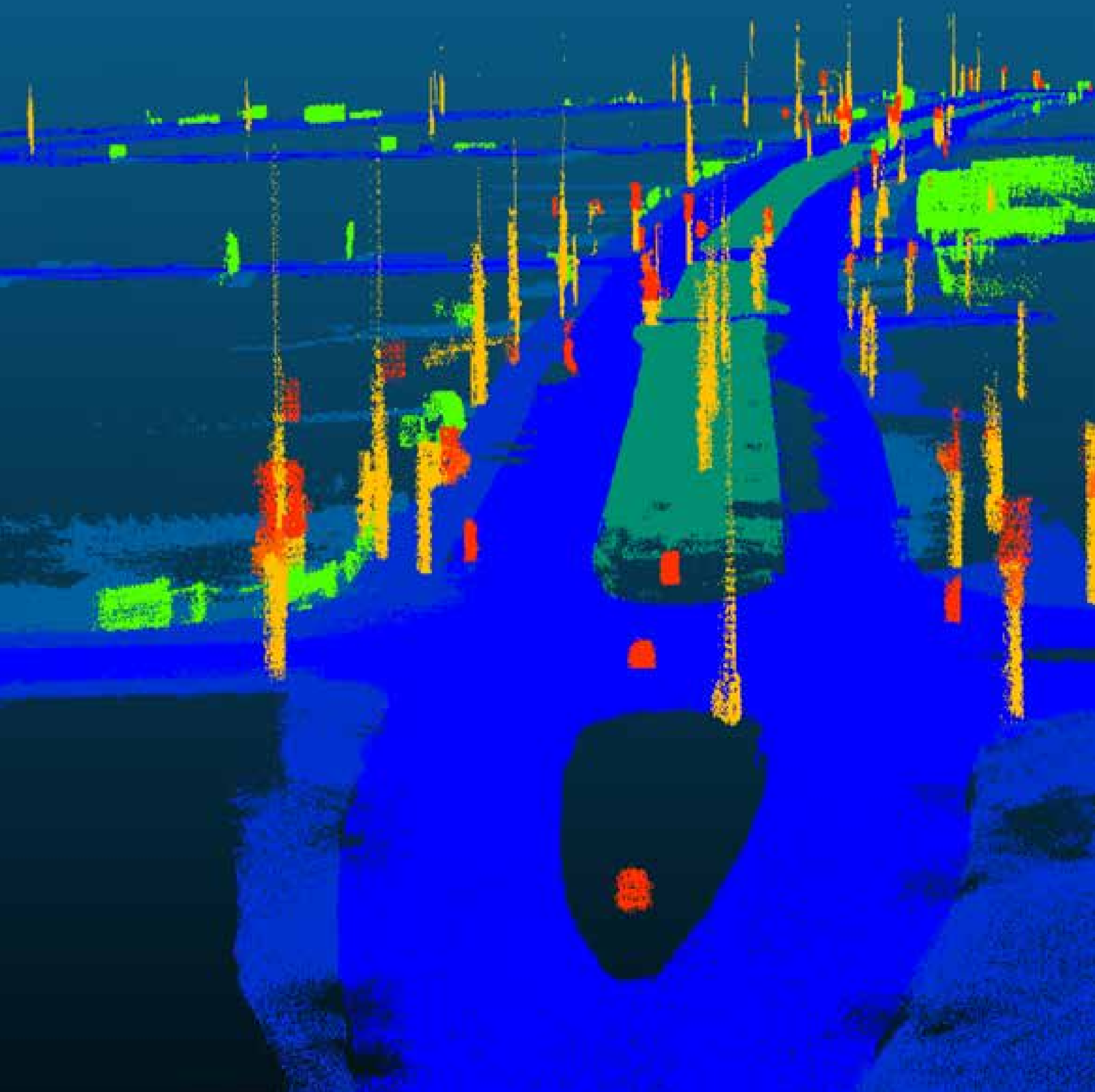
Roads are cost-effective to build and expand (£10 to £50M/mile)1 when compared to rail (£50 to £400+M/mile). Over time, this has led to an enormous 246,700 miles of motorways and A roads in the UK carrying over 83% (328 billion vehicle miles) of all passenger miles travelled and 79% of all domestic freight. Roads are responsible for 69% of all transport Greenhouse Gas Emissions (GHG), the highest of all UK industries.

Roads are increasingly safer, but still responsible for 1,784 deaths and 25,511 serious injuries just in 2019. Motorways and A roads are only 13% of the road network's total length but carry 66% of the total road traffic on a shoestring budget, receiving only 15% of the total public expenditure on all transport modes. This lack of investment is a leading cause of steady annual traffic delay increases, with the average delay estimated at 47.3 seconds/vehicle/mile in 2018. This means that 4.3 billion labour hrs/year are wasted in traffic.

These numbers highlight the need for efficient road network expansion, maintenance, and repair. Interventions that are carried out before they are really needed or after they could have been easily corrected can waste resources and unnecessarily increase GHG and accident rates. Unfortunately, this is too often the case, with 3% of all 'A' roads, 6% of 'B' and 'C' roads, and 16% of unclassified roads categorised as needing substantial maintenance,

repair/maintenance road closures alone costing the UK £26.2 m/year, and the annual carriageway maintenance budget shortfall per authority ballooning to £4.1 million in 2018/19. Years of under-funding within both revenue and capital budgets has led to insufficient cyclical maintenance of roads that, along with the climate change impact and increased traffic volumes particularly on the minor road network, has accelerated further structural decline.

Partnership



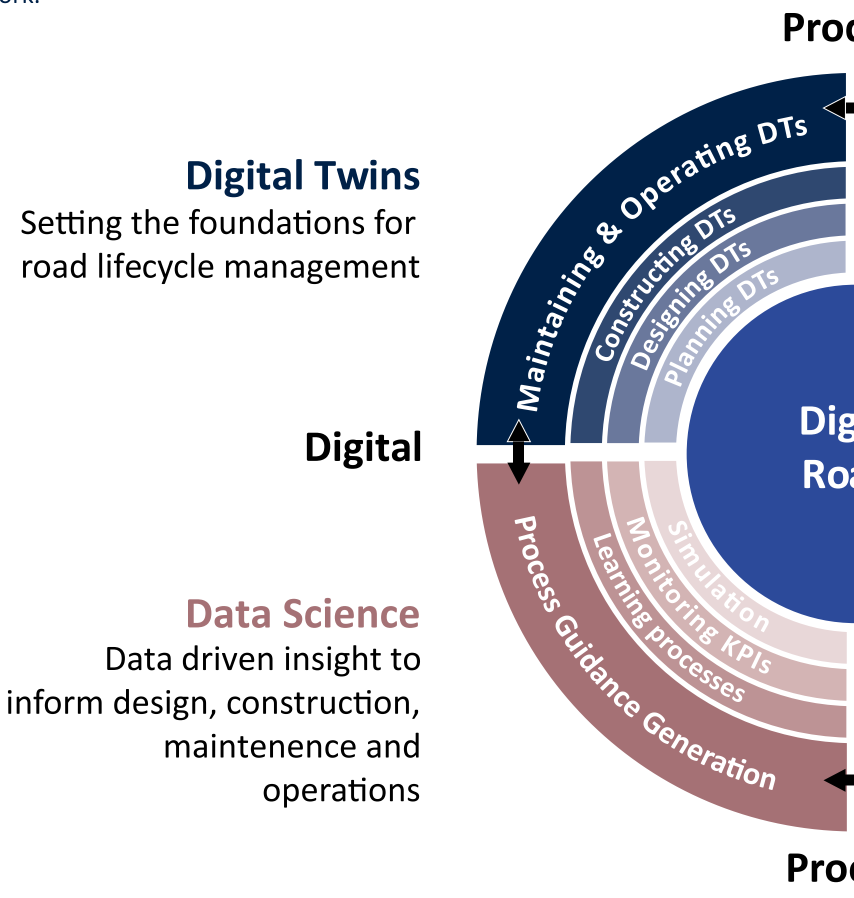
Vision, Ambition and Partnership

We envision a future where roads are documented in up-to-date digital twins and made of smart materials that are aware of their state and properties, while the road network lifecycle processes are data science driven and efficiently executed via automation and robotics.

Our ambition is to realise this 20-year vision to make a step change in terms of cost, time, quality, safety, sustainability, and resilience, for both the roads network and its associated design, construction, maintenance and operation processes.

The Digital Roads Prosperity Partnership was formed in April 2022 and is an industry led partnership between Costain Group, University of Cambridge and National Highways, supported by the Engineering and Physical Sciences Research Council (EPSRC), part of UK Research and Innovation (UKRI).

Our scientific ambition is to rethink roads as the integrated set of digital and physical products and processes, deployed through a product-led approach that offers value-adding choice to client stakeholders yet provides unprecedented life cycle KPIs performance and can scale across the whole road network.

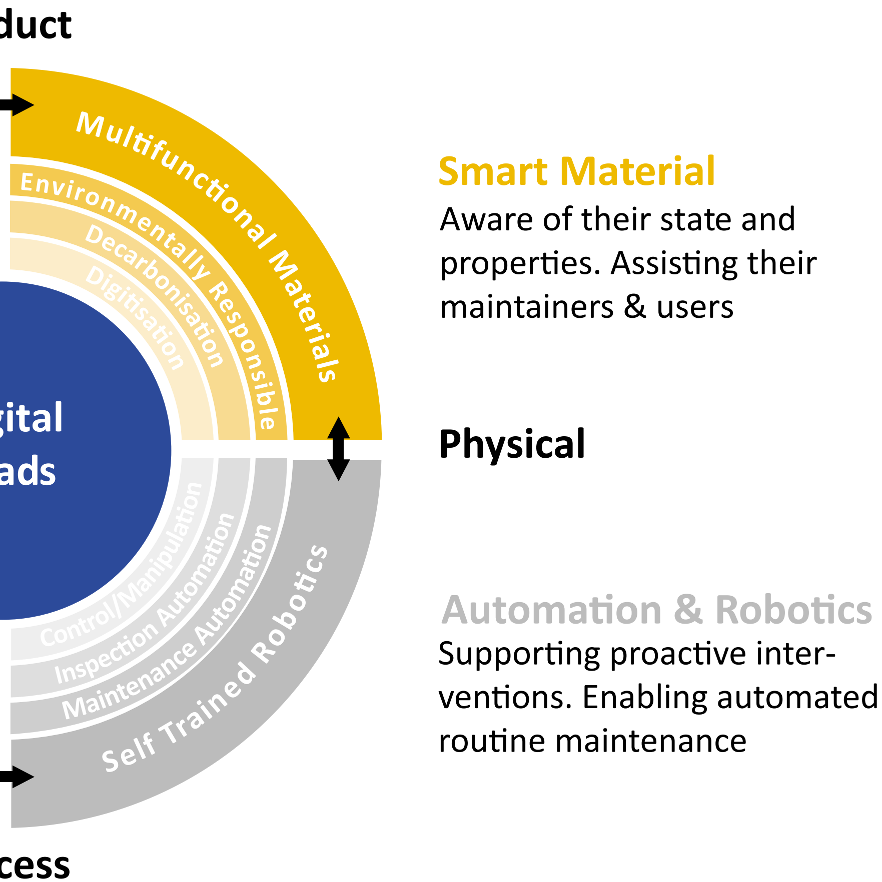


Research Integration and outputs

The figure below illustrates how Digital Roads will bring together a novel synthesis of digital twins, smart materials, data science, and automation and robotics can work together to create an interconnected physical and digital product and associated processes. Each of the four quadrants represents a theme to be addressed. Focus will be given on the arrows, where each theme will leverage the rest and provide data/information.

Digital Roads will provide multi-disciplinary, integrated datasets that can be used to further improve the outcomes or devise exemplar data structures, cloud architectures, algorithms, smart materials and robotic solutions that can underpin a vast array of add-on solutions or solutions for other lifecycle processes; and fundamental methods to generate, update, integrate, verify and curate infrastructure data, use it to measure performance and make decisions, and to drive the decisions to the asset.

These outcomes will be detailed in conference and journal papers, online publications in magazines and popular media, and potential patents.

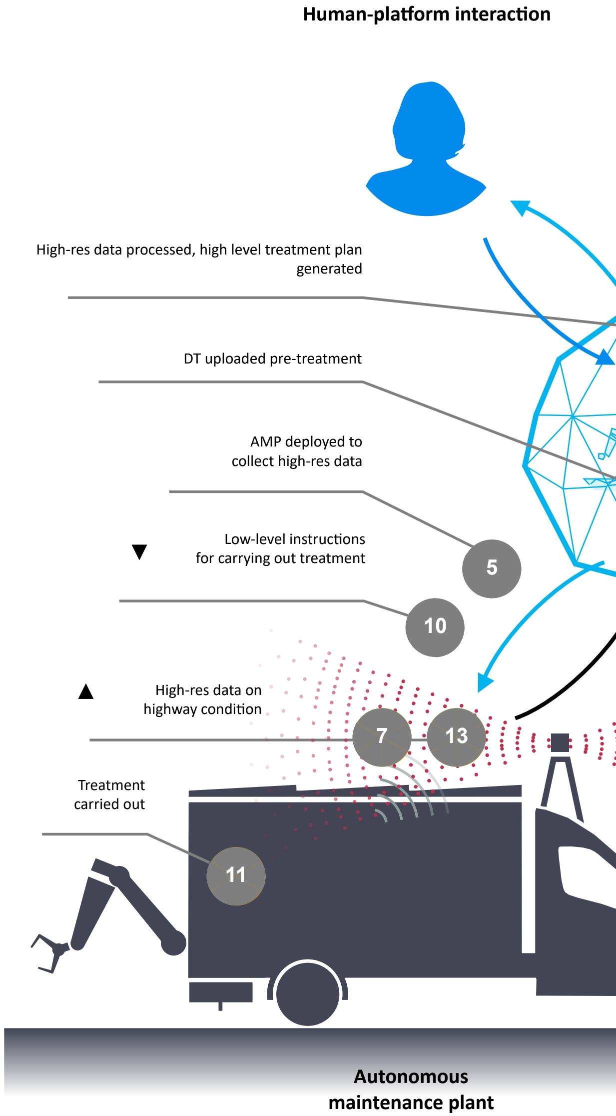


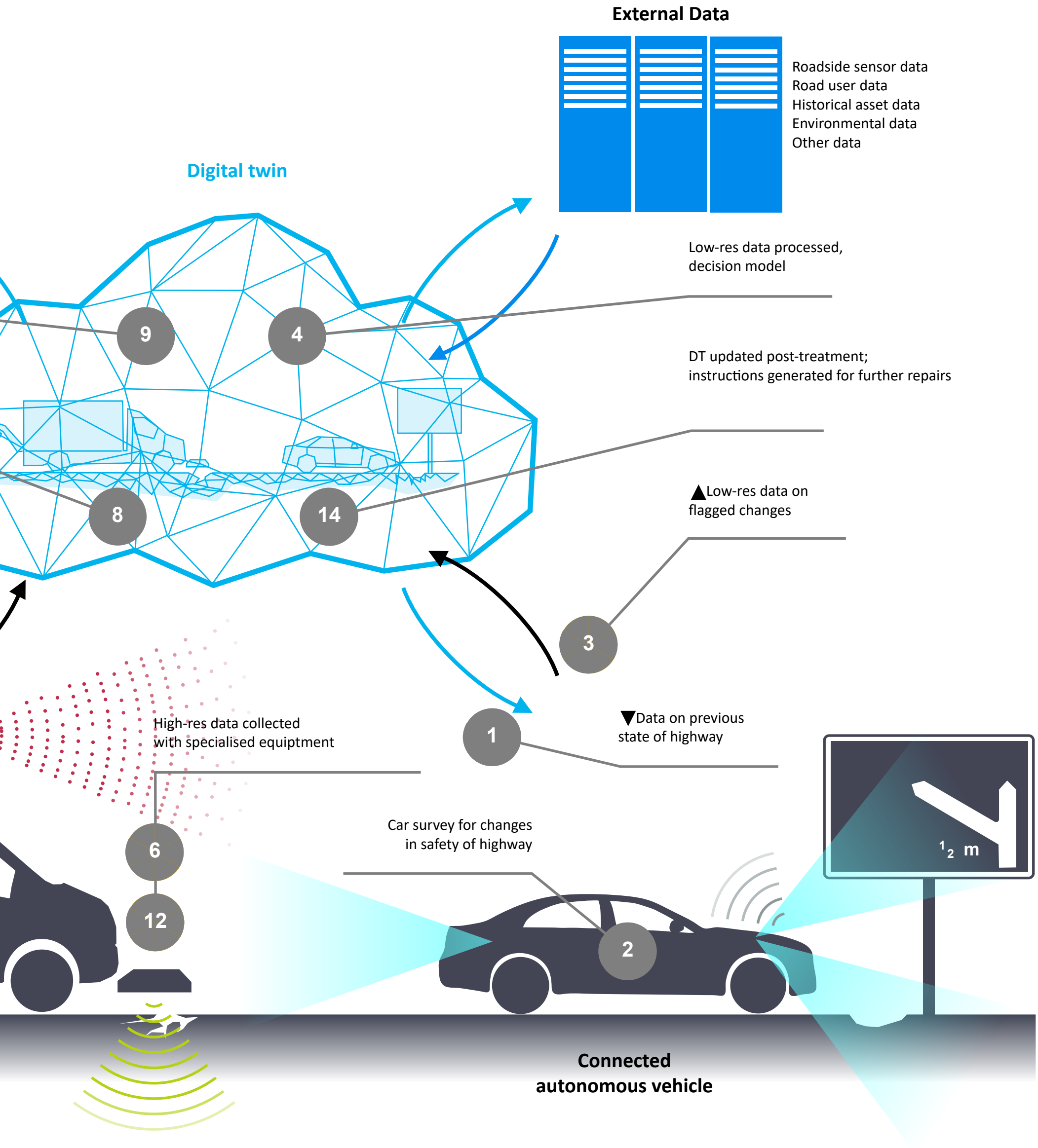
The Digital Roads Platform

As our Strategic Road Network begins to age, we must find a way to better manage the maintenance and repair of our key national asset in a less disruptive way: both for the road user and the environment. The Digital Roads cyber-physical platform addresses this challenge. The DR Platform can be broken down into three components:

1. Twin Systems of the SRN for and by Connected Autonomous Vehicles: Drive Digitally before Driving Physically
2. Twin Systems of the SRN
3. Twin Systems of the SRN for and by Autonomous Maintenance Plants: Repair Digitally before Repairing Physically

Positioning papers are being written to address the challenges that each of these components resolve. The following are abstracts for each of these papers:




External Data
Roadside sensor data
Road user data
Historical asset data
Environmental data
Other data
Digital twin
Low-res data processed,
decision model
9
4
DT updated post-treatment;
instructions generated for further repairs
8
14
▲Low-res data on
flagged changes
3
▼Data on previous
state of highway
1
High-res data collected
with specialised equiptment
6
12
Car survey for changes
in safety of highway
2
1 2 m
Connected
autonomous vehicle

Twin Systems for the Strategic Road Network for and by Connected Autonomous Vehicles

Drive Digitally, before driving Physically

Abstract

Highways are critical for any country's daily life and economy. Highways condition is directly connected with users' comfort and safety. Thus, transport authorities monitor highways condition and apply maintenance when needed. Current monitoring practices followed by authorities are either manual and subjective or semi-automated and cost ineffective. Hence, researchers and car manufacturers try to enhance highways monitoring by collecting data utilising sensors embedded on Connected Autonomous Vehicles (CAV), and processing data via computer vision and machine learning techniques. However, certain important questions remain partially unanswered.

What data do they need to be collected?

What is the optimal combination of embedded sensors to collect data?

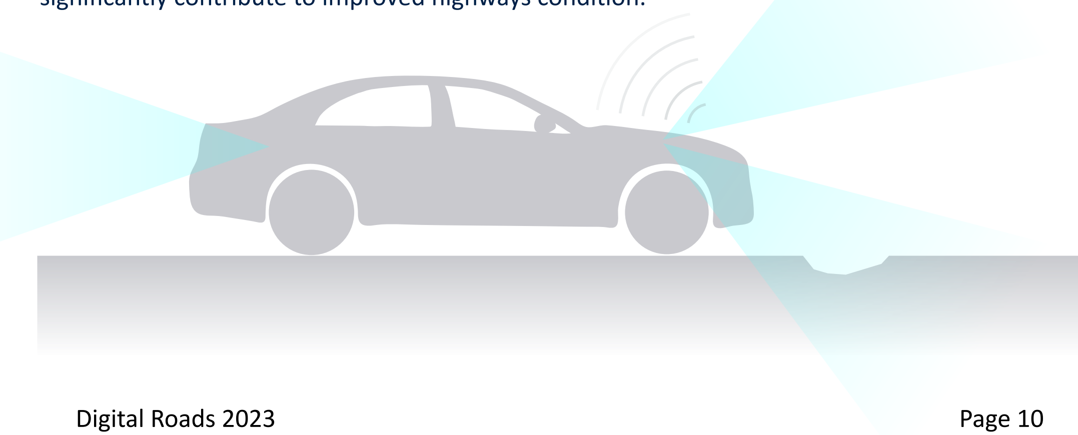
Where is data stored and processed?

Which are the appropriate data science techniques and algorithms to process the data?

What extracted information is useful and what is dropped?

How is crowdsourcing addressed?

Presented in the positioning paper is a framework designed to address these challenges. The framework is divided into three main stages. Firstly, CAV download data on the previous condition of a highway section as it is saved on a Digital Twin (DT). Secondly, CAV check for changes in the geometry and condition of the examined highway section. Thirdly, CAV upload data on the detected changes to the DT. Hence, highways will be constantly monitored, with any change in existence or deterioration of related assets being flagged and used for updating the DT. The framework offers comprehensive low-resolution monitoring, which will facilitate decisions on applying high resolution monitoring and predictive maintenance. This will significantly contribute to improved highways condition.



Towards a Framework for the Twin Systems of the Strategic Road Network

Abstract

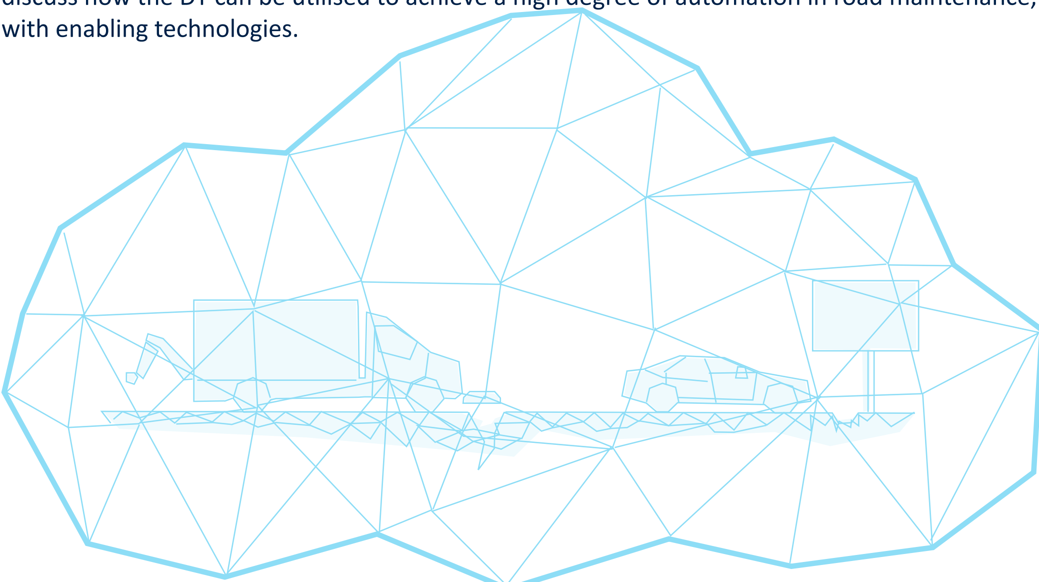
Efficient road network expansion, maintenance and repair are necessary to reduce annual traffic delays and avoid waste of resources. For the current practice,

- the management of assets,
- the decision-making processes, and
- the execution of road inspection and maintenance,

rely heavily on relevant staff of the highway operation authorities, utilising disjoint systems built for different purposes.

This poses significant challenges to efficiency in road maintenance and repair, leading to increased maintenance costs and traffic delays. To this end, building a Digital Twin (DT) for the Strategic Road Network (SRN) would greatly improve the monitoring and analysis of road assets. In addition, with the help of artificial intelligence (AI) and other enabling technologies, the decision making on road maintenance can be optimised, boosting the efficiency of inspection and repair.

In the positioning paper, we review the current state of practice for the maintenance of SRN, identify the need for the DT of SRN, identify the main components of such DT and discuss how they shall be designed and developed, presenting a research roadmap for the DT of the SRN and discuss how the DT can be utilised to achieve a high degree of automation in road maintenance, with enabling technologies.



Towards a fully robust highway pavement system

A perspective of Autonomous Maintenance Plants (AMP)

Abstract

The importance of maintaining a good condition of highway pavement for daily road users has been widely acknowledged as it directly impacts the local economy. For a long time, countries commonly suffering from highway pavement damage issues normally rely on the highway operation authorities to routinely inspect and repair the pavement using a site crew. This repair process is time-consuming and without proper prediction and control over material usage and maintenance time.

The intention of automating pavement maintenance using robotics has appeared back to the 1990s. Lots of research efforts have been made up to now, leading to the semi-automation state-of-art in some developed regions, which to a large extent refers to the automatic pavement geometry inspection thanks to the development of digital technologies (e.g. terrestrial laser scanning, etc.) and Artificial Intelligence.

However, site workers are still required to manipulate special maintenance vehicles and equipment to implement the physical repair operations, reflecting a clear gap to fully autonomous maintenance.

This positioning paper reviews the current progress in the highway pavement maintenance automation involving different machines and tasks, followed by a summary of the key challenges ahead. Based on these, a framework of Autonomous Maintenance Plants (AMP) is established, which consists of five modules:

- data acquisition module,
- material storage module,
- material handling and placement module,
- power supply module , and
- mobile platform.

This AMP concept is part of a Cyber-Physical Platform of the Strategic Road Network. The vision is that the AMP receives instructions from the highway Digital Twin that uses low-resolution pavement geometry data collected from Connect Autonomous Vehicles for decision-making and it moves to the site to conduct high-resolution geometry data collection and physical repair operations with continuous communication with the Digital Twin. This process is unmanned and autonomous with an expectation to create a fully robust highway pavement system.

From Research to Practice

Digital Roads researchers helped to develop the first 3D-printed piece of concrete infrastructure to be used on a live National Highways project. This has been achieved in collaboration with the three Digital Roads parters, Costain, University of Cambridge and National Highways, and Future Roads Partners Versarien and Jacobs.

The wall will provide real-time information on temperature, strain and pressure, using sensors embedded in its structure and could help spot and correct faults before they occur. The 2.3-tonne curved headwall is constructed using an alkali-activated cementitious material and a 3D printer.

Professor Abir Al-Tabbaa, Professor of Civil & Environmental Engineering, University of Cambridge, added: “I am delighted that my team and I are part of this highly innovative project and that our sensors, both developed in-house and commercially hand-picked systems, have successfully been implemented within the wall structure during the manufacturing phase and will continue to monitor the performance for longer-term performance under field stresses.”

Members of the team included Costain’s Head of Materials Bhavika Ramrakhyani, and Ben Harries, Architectural Innovation Lead at Versarien along side Digital Roads Researchers Dr Damian Palin, Dr Hussameldin Taha, Dr N’zebo Richard Anvo and Dr Lilia Potseluyko Amobi; as well as University of Cambridge Researchers Dr Sripriya Rengaraju, Dr Christos Vlachakis, Dr Yen-Fang Su.

“We’re committed to exploring sustainable and innovative ways of constructing and maintaining our roads and this marks a significant first step as part of the work carried out by the Roads Research Alliance.”

Joanna White,
Roads Development Director, National Highways

Project progress

2022-2023

Digital Twins

Information Delivery Manual (IDM)

The IDM)aims to provide the integrated refence for process and data required by the DT system for the Strategic Road Network (SRN) by identifying the discrete processes undertaken within inspection and maintenance of the SRN, the information required for their execution and the results of that activity. It will specify:

- Where a process fits and why it is relevant
- Who are the actors creating, consuming and benefitting from the information
- What is the information created and consumed
- How the information should be supported by the Digital Twin System

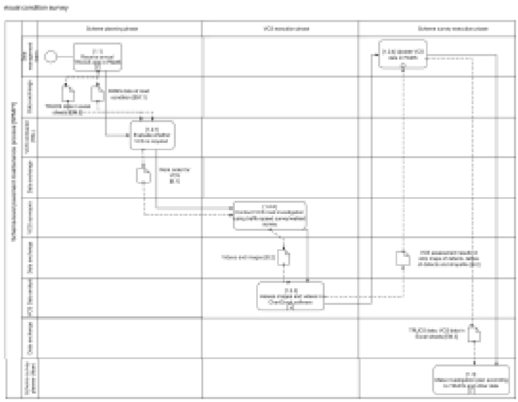
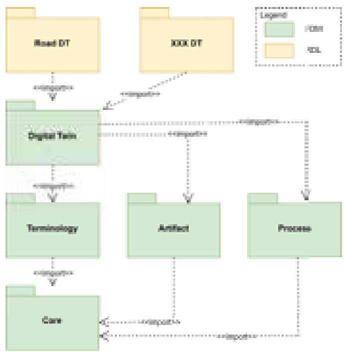


Fig. 1 Process modelling for pavement inspection and repair using the Business Process Model and Notation (BPMN) to capture process steps, data to be exchanged, and stakeholders involved.

Heterogenous Models for Digital Twin

Conceptual DT Models to promote Extensibility, Modularity and Interoperablity

Based on the IDM, the Foundation Data Model (FDM)is derived, which contains common entities and relationships for DTs across domains. Based on the FDM, a Reference Data Library (RDL) for the road DT is derived.



User model visualisation

Fig,2b. Upon visualisation, the DT Platform: a) convert user requirement into queries and execute them; b) return FDM/RDL model elements (with links to mesh, texture, etc.); c) denerate 3D objects and user interfaces automatically; d) present the users with rendered 3D environment where different textures can be selected based on user's needs.

Smart Materials

Smart Automated Repair

In collaboration with the Automation and Robotics team, we are developing smart materials for their automated application on the UK road network.[1] In consultation with industry representatives, we have identified eight promising commercial materials to make smart (Fig. 1a). We have also developed a suit of laboratory tests to evaluate the performance of developed smart materials (Fig. 1b,c).

Fig. 1a) Eight selected commercial repair materials. b,c) Mechanical tests (b) Slant shear test and (c) flexural test.

Low-resolution Sensing

With the Data Science team, we are developing a mobile computer vison-based road pre-damage detection system. Building on digital image correlation (DIC) work initiated in the RM4L programme, we are employing advanced image processing techniques, including autorectifying images taken at angles (Fig. 2a,b); formeasurements for road materials (Fig. 2c,d).

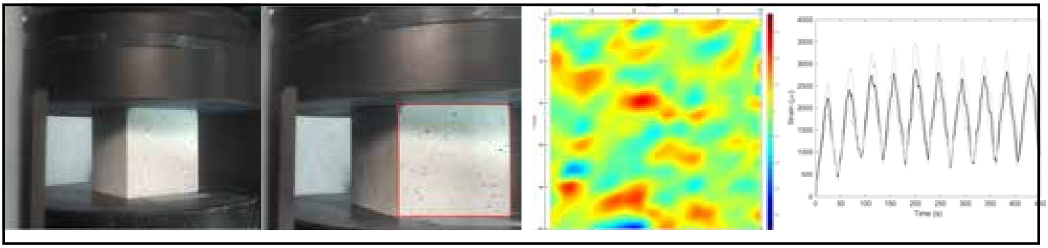


Fig. 2.a,b) Images taken before (a) and after auto rectification (b). c) Strain contour plot and (d) strain plot generated from auto rectified images.

Historical Assets and Roadside Sensors

With the Automation and Robotics and Digital Twin teams, we are working with historical data sets, developing in-house sensor systems and investigating commercial sensor. The team has registered historical GPR data with point cloud data (Fig. 3a,b). We have also instrumented a 3D printed headwall with in-house and commercial sensors (Fig. 3c,d).

Fig. 3. a) CloudCompare to register GPR with point cloud data. b) In-house PZT sensor system and (c) Instrumented 3D printed headwall.

Data Science

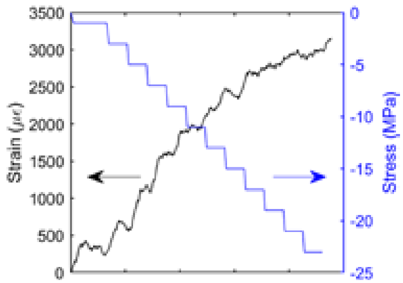
Low-Resolution Monitoring

On the move road pre-damage detection

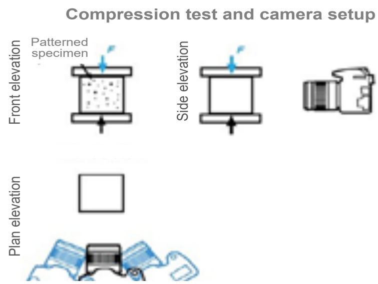
- Connected Autonomous Vehicles collect and process data using their embedded sensors to monitor highways condition on the move.
- Measurement of material strain (1.a), which can be an early indication of pavement failure, is done using Digital Image Correlation and orthorectification of images taken from various angles (1.b).

Enhancing defect clasification using augmentation techniques

1.a



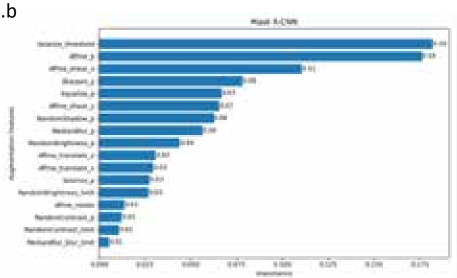
1.b



- Data augmentation techniques (2.a) allow the enlargement of the size and the improvement of quality of existing datasets.
- Identification of the impact (2.b) of combinations of augmentation techniques to enhance the performance of a set of defect detection algorithms.
- Impact of various data augmentation techniques for a state-of-the-art pothole detection algorithm (2.b)

2.a

2.b

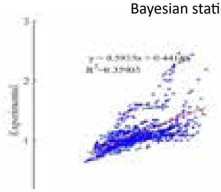


Predictive Modelling

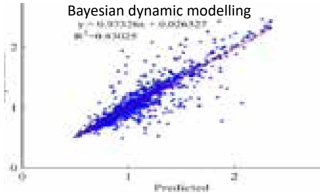
Improving the fit and performance of predictive Bayesian models.

- Reducing the computational cost and adapting to time-varying characteristics of pavement performance by introducing a moving window strategy to static Bayesian models.
- The dynamic Bayesian models (3.b) exhibit higher predictive performance than the static ones (3.a).

Bayesian static modelling



Bayesian dynamic modelling



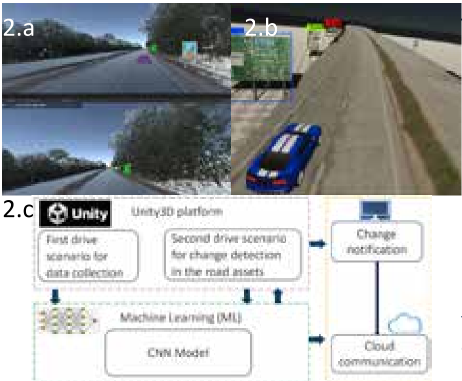
Automation & Robotics

Low-cost readily-deployable sensing

This work provides a low-cost low-resolution sensing method using a car-mounted integrated stereo camera for supporting road maintenance decision-making. The outcome of sensing is a Structure from Motion (SfM) reconstructed 3D digital model of the road pavement that highlights the degradation of the pavement and the need for attention by the maintenance team.

Fig. 1 a) Car equipped with a ZED 2i stereo camera; b) An uneven pavement surface; c) Pavement SfM 3D model showing the potholes and cracks; and d) Road roughness evaluation using IMU.

Simulation for fault detection & communication



This work provides a simulation of A12 using a high-resolution data set based on Unity 3D. The developed simulation refers to a true representation of the road assets embodying roadside signs, barriers, etc., underpinning machine learning-based fault (change) detection, localization and communication (to the cloud-based decision-making centre) on these assets.

Fig. 2 a) A12 road asset simulation in Unity 3D; b) Demonstration of fault detection and localization; and c) Road asset change detection and communication process.

Robotic pavement repair

Two pieces of work are presented here:

- A method for simulating the crack sealing fluid material with varying viscosity and the robotic repair process based on Unity 3D, validated by the side-by-side physical experiment.
- A method of haptics-based human-robot cooperation mechanism for tele-operated robotic construction and maintenance of future roads.

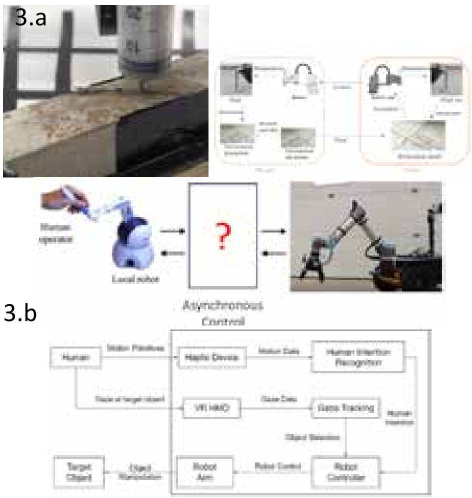


Fig. 3 a) Calibrated position-based viscous sealing fluid and robotic repair simulation with physical experiment validation; and b) Haptics-based human-robot cooperation mechanism for road construction.

Delivering Impact - Digital Roads dataset

National Highways provided a dataset of mobile mapping data collected by KOREC using a Trimble MX9, GPR and Thermal data for 42.8km of Strategic Road Network from the A11, A12 and A14.

Data preparation

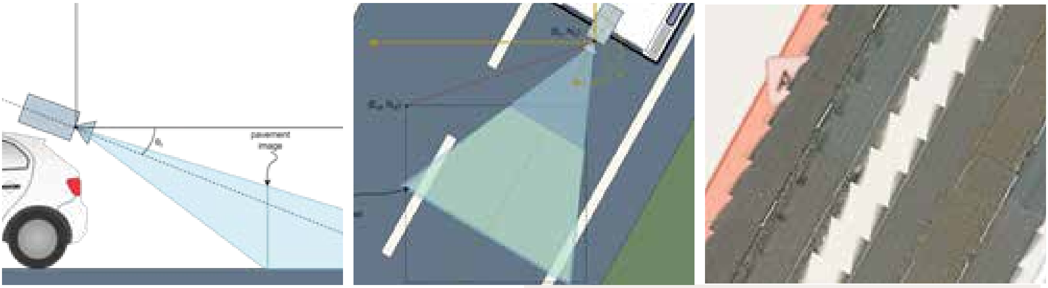
The raw data was then prepared to

- build a Digital Twin, a 3D environment of the roads surveyed where every asset and defect is labelled.
- develop a framework for automating the building of the Digital Twin.

The following work was undertaken;

Creating the mesh/ Creating 3D objects

- the pavement mesh
- road furniture meshes
- vegetation



Creating the textures

- Building a pavement orthomosaic from pavement images
- Georeferencing the textures onto the mesh

Labelling

- Pointcloud labelling
- Defect detection

Integration

- Unreal Engine
- Unity

Storage & Dissemination

The dataset is available at www.drf.eng.cam.ac.uk/research/digital-roads-dataset

Research papers

Published papers

Autonomous detection and sorting of litter using deep learning and soft robotic grippers

Almanzor, Elijah; Anvo, Nzebo Richard; Thuruthel, Thomas George; Iida, Fumiya. *Autonomous detection and sorting of litter using deep learning and soft robotic grippers, published in Frontier In Robotics and AI.* https://doi.org/10.3389/frobt.2022.1064853

Autonomous Litter detection, sorting and clearing. A deep learning-based algorithm is used for automatic detection, classification and 3D localization of roadside garbage. Control framework is independent from the deep network making it easily transferrable to crack detection

On the performance of pothole detection algorithms enhanced via data augmentation

Bunker, Hadjidemetriou, Marie d'Avigneau, Girolami, *On the performance of pothole detection algorithms enhanced via data augmentation.* https://doi.org/10.17863/CAM.99748

Paper will be presented by Georgios Hadjidemetriou at Euro Working Group in Transportation, Sept. 2023, Santander, Spain.

Automated detection of distressed areas is often challenged by an insufficient amount of training data or uneven class balance within datasets. Data augmentation techniques offer the opportunity to enlarge the size and quality of existing datasets. This paper investigates how various augmentation techniques impact the performance of a set of representative detection algorithms applied to detecting highway potholes. The results suggest that: firstly, no specific augmentation seems to be more beneficial than the others in this domain; and second, using a moderate amount of augmentation techniques can provide performance gains. This work forms the basis for performance improvement of multiple detection algorithms, used for transport infrastructure management, and it consequently contributes to enhanced transport systems simulation and monitoring.

Automated 3D mapping, localisation and pavement inspection with low cost RGB-D cameras an IMUs

Anvo, Nzebo Richard; Iida, Fumiya A*utomated 3D mapping, localisation and pavement inspection with low cost RGB-D cameras an IMUs.*

Paper will be presented at 24th TOWARDS AUTONOMOUS ROBOTIC SYSTEMS (TAROS) Conference, 12 September 2023.

This study aims to bring low-cost technology to help road inspection to be more efficient and accurate. To this end, a fast real-time condition monitoring approach is proposed for road pavements using an RGB (Zed 2i) stereo camera with IMUs mounted on a car. The algorithm used for road pavement reconstruction is based on Structure from Motion (SfM) and requires no calibration of the sensor data. The experiment uses two types of roads to compare the pavement reconstruction and IMU data.

Papers in preparation

Vision-based multi-perspective road pre-damage detection

Vlachakis, Hadjidemetriou, Palin, Marie d'Avigneau, Taha, Rengaraju, Anvo, Girolami and Al-Tabbaa

Proposed for Transport Research Arena 2024 (TRA 2024), Dublin, 15 April 2024

Roads are essential for transportation and economic prosperity. Concrete roads are highly durable, providing near maintenance-free service for many years. Even when concrete roads are approaching the end of their service life, authorities can extend their longevity by repairing cracks and damage.1 However, road repairs themselves can be susceptible to damage, particularly when exposed to seasonal weather changes and heavy loads,2 yet there is limited understanding of the durability of concrete road repair materials particularly exposed to freeze-thaw cycles and dynamic loading.

To address this gap, we propose to evaluate a series of commercial road repair materials designed for the repair of concrete roads. First, we will damage cementitious mortar specimens and repair the specimens with the repair materials. We will then subject the repaired specimens to freeze-thaw cycles and measure the dynamic flexural and slant shear strength of repaired specimens. Additionally, we will evaluate the strain in the repaired materials using digital image correlation. Preliminary crack-filling experiments show that a belitic calcium sulfoaluminate cement (BCSC) repair material cannot penetrate cracks <4 mm wide, whereas a polyurethane-based material can penetrate cracks ~1 mm. Additionally, we tested the flexural and slant shear strength of mortar specimens repaired with both repair materials. The specimens repaired with both repair materials have flexural strengths of ~4 MPa, 40% lower than the undamaged mortar specimens. The BCSC repaired specimens have a slant shear strength of ~18 MPa, and the polyurethane material has one of ~5 MPa, which are ~50% and 85% lower than the undamaged cementitious mortar specimens, respectively.

The next phase of this research will investigate the dynamic flexural and slant shear strength of repaired specimens following freeze-thaw cycles. This research will make recommendations for more durable concrete road repair exposed to extreme weather conditions and heavy traffic loads. Well-executed road repairs will extend road life, reducing disruptions and increasing road users' productivity and safety. This work is part of a broader effort for developing smart automated road repair materials for better-performing, longer-lasting roads.

Assessing road repair via digital image correlation

Palin, Taha, Vlachakis, Rengaraju, Hadjidemetriou, Marie d'Avigneau, Anvo, Girolami and Al-Tabbaa

Proposed for Transport Research Arena 2024 (TRA 2024), Dublin, 15 April 2024

Road networks are critical for social development and prosperity by facilitating mobility of people and goods. However, road pavements are subject to constant deterioration over their lifetime, which can be accelerated by heavy traffic, weather conditions or inadequate maintenance. This deterioration can lead to failures that pose threats to users' safety, isolate areas from the main network and reduce society's productivity. Transport authorities expend significant effort to monitor and maintain the networks to decrease the possibility of failures and ensure that road networks continue to serve the needs of society. Road pavement monitoring consists of detecting and classifying defects, as well as evaluating defects' severity and extent. Pavement monitoring has been traditionally manual, subjective and time-consuming. Thus, there has been tremendous interest from academia and industry in automating pavement monitoring using artificial intelligence.

Digital image correlation (DIC), which is a photogrammetry-based metrology technique, has the potential to be used for early detection of road pavement failures. DIC involves pixel correlation between images, used for measuring the displacement of structural elements subjected to stress. Road pavement videos and frames are collected via cameras and laser scanners on vehicles moving at highway speeds and from angles. However, frames collected at different angles prevent the implementation of DIC for detecting strain and distress in road pavements. This work aims to overcome this challenge and develop a method for detecting strain or damage using images taken at different angles. The use of a wider range of images would allow for more accurate and robust method of road assessment. Understanding where deterioration is about to happen will allow predictive maintenance, increase road safety, and reduce disruption and associated CO2 emissions.

In this work, 100 mm concrete cubes are tested under compression. The specimens are sprayed with white paint, over which black speckles are sputtered in a random pattern. The samples are then loaded and imaged with a camera positioned firstly normal to the specimen face (standard setup) and secondly at various angles to the specimen face (non-standard setup), simulating images taken at angles from a moving vehicle. To calibrate the effect of image orientation, a built-in inertia measurement unit (IMU) is used to estimate the extrinsic camera parameters during the image-capturing process. The images taken at different angles are pre-processed via computer vision techniques, such as orthorectification and image stitching, to reconstruct the surface of the specimen. Then both sets of images are processed using DIC software to measure the strain in the specimens. The images taken normal to the specimen's face act as the ground truth. The primary contribution to science and practice is the ability to measure material strain using frames captured at angles, which is a real-world requirement of predictive road maintenance. The proposed research will mark a step change in infrastructure monitoring and predictive maintenance, improving safety and allowing significant cost savings and efficiency gains.

Robotic Maintenance and Repair of Roads: A Systematic Review,

Schaefer, Palin, Hadjidemetriou, Abdalgadir, Marie d'Avigneau, Anvo, Ambrose (NH), Al-Tabbaa, Iida and Thuruthel

Suggested publication route: Automation in Construction

In preparation

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