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Laing O'Rourke Centre

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Book of Abstracts

Foreword

The Laing O'Rourke Centre for Construction Engineering and Technology has made significant progress in the last decade in establishing world leading expertise in the intersection of civil and information engineering. Over 65 million GBP in active grants are funding over 70 staff and students in the areas of Planning, Designing, Constructing, Maintaining and Operating Digital Twin Systems of the Built Environment, supported by automation tools for on- and off-site construction.

In planning and designing Digital Twin Systems, the Centre is engaged in groundbreaking work on understanding and measuring the scope, feasibility, and costs of digital twins at the planning phase. It is also setting the foundations for establishing the foundation data models, reference data libraries, and integration architectures consistent with the Information Management Framework proposed by the Centre for Digital Built Britain and the National Digital Twin Programme for the case of the strategic road network.

In constructing and maintaining Digital Twin Systems, the Centre has from its beginning pioneered several patented and/or highly cited methods for multi-modal (XYZ, RGB, NIR, T, GPR, GNSS, etc.) mobile scanning solutions able to capture raw data registered in space and time and estimate error in real-time for guiding its user. It has also been at the forefront of converting the raw data to information via detecting objects and their condition properties and enriching them with relationships into rich geometry models with very little manual support.

In operating Digital Twin Systems, the Centre has a history of Augmented and Virtual Reality solutions for enabling better user immersion to the Digital Twins, and more recently in text and information mining tools with the help of natural language processing and large language models. This is

supported by strong data science foundations that enable the modelling of processes and forensics and forecasting tools that bring out the value of digital twinning.

In collaboration with other colleagues, the Centre is also active in pioneering smart materials, automation, and robotics solutions that complement the above into enabling the digital transformation of the construction sector.

The abstracts below offer a glimpse of the current activity in this space. I invite you to read them and contact us for more information.

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Our partners

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Table of Abstracts

A survey exploring the value of digital twins in highway maintenance

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Highway authorities have difficulties in gathering and merging real-time road condition data because of the extensive scale of the roadway networks. This is a challenge in coordinating timely maintenance actions aimed at preventing accidents and prolonging the lifespan of equipment. A digital twin (DT) offers the ability to address this issue by providing a systematic way to digitising information for road infrastructure systems. Presently, there is a lack of clarity on the application of the DT concept in highway maintenance and its benefits for stakeholders. This research presents the findings of a survey that investigates the possible improvements in highway maintenance by using a road DT. The first phase entails conducting interviews with 20 highway professionals to obtain insights into the existing repair procedures and inefficiencies. A questionnaire was created and sent worldwide to get information from industry professionals regarding the critical phases, functional characteristics, applications, and use cases for the future development of digital transformation. A total of 183 replies were collected from industry professionals. The findings demonstrate that the primary challenge in the current practice lies in the arduous task of determining optimal decisions while adhering to limitations such as financial resources and potential hazards. DTs are mostly utilised for asset degradation prediction, routine maintenance planning, and maintenance scheme creation. The results of this research lay essential foundations for the future development of DTs for highway maintenance.

A graph-based approach for road digital twin

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The major problem to be addressed in the project is how to design road digital twins. This problem will be addressed by achieving the following four objectives: (1) Objective 1: Identifying the specific information requirements for road digital twin (2) objective-2: Developing a graph-based reference data library for road assets; (3) objective-3: Developing an extensible, future-proof, and scalable road integration cloud architecture; and (4) objective-4: Validating the proposed approach for road digital twinning. These objectives are identified and scheduled logically, and, to achieve these objectives, the standard procedure specified in an international standard, ISO19650 organization and digitalization of information about buildings and civil engineering works, will be referenced. To be specific, the following methods will be used: (1) Objective 1: Relevant literature will be reviewed and interviews/questionnaires with stakeholders, such as Jacobs and National Highways, will be conducted to learn the specific information requirements for future road management and define the road Foundation Data Model. (2) Objective-2: Graph-based technologies, such as Resource Description Framework (RDF) and labelled property graph (LPG), will be compared to select the proper graph technology for implementing the graph reference data library that is developed based on information requirements identified in Objective-1. (3) Objective 3: An extensible, future-proof, and scalable road integration cloud architecture will be developed by working with stakeholders, taking data fusion and data interoperability into consideration. (4) Objective 4: Real project data will be used to validate the effectiveness of the proposed approach for road digital twinning.

Automating Digital Twinning Processes to Streamline Road Infrastructure Operations

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Road infrastructure Operation & Maintenance (O&M) activities account on average for 70% of total investments in infrastructure. Inefficiencies in these O&M activities contribute for 30% to 50% of expenditure losses. Although promising, the assimilation of digital technologies (i.e., Digital Twins (DT)) in this domain still faces complex challenges: absence of uniform standards and processes; the O&M phase lacks comprehensive and descriptive methodologies; bespoke manual digital twinning processes are fraught with inefficiencies.

The broad objective of this research is to introduce a knowledge graph-based DT concept and prototypes implementation backed by a microservice system architecture. The system enables seamless and automatic damage-related information updating and retrieval during on-site road infrastructure O&M activities. It leverages Augmented Reality (AR) and Natural Language Processing (NLP) as real-time bi-directional communication mediums between the virtual and the physical components of the DT.

The proposed approach encompasses four work packages that involves the development and implementation of: (i) a real-time Digital Twin platform based on Semantic Web technologies to manage large-scale networks and their heterogeneous data (including Building Information Modelling (BIM), images, point clouds, and so on); (ii) a seamless and marker-less high accuracy AR registration method and application for road inspection and maintenance on-site activities; (iii) an automatic image-based Damage Information Modelling (DIM) system that identifies and maps damages alongside their properties onto the BIM model using image segmentation and Semantic Web technologies; (iv) an NLP-based DT querying assistant system that supports operators in querying the database without the need of knowing the database query language.

The research resulted in a knowledge graph-based Digital Twin web platform that can integrate real-time microservices. Specifically, an AR service has been developed to stream BIM models from the platform to the AR device (i.e., HoloLens2). The seamless inside-out and marker-less high accuracy AR registration method were tested on HoloLens2 within a Facility Management use case. Results showed centimetre-level accuracy in both device localization and holograms registration. On top of that, an automatic image-to-OpenBIM registration method has been also defined. Furthermore, the capabilities of the NLP-based querying assistant were successfully tested through verbal interactions and via the enclosed chat box.

In conclusion, the research findings highlight the potentialities of the proposed system to bridge some of the gaps related to the lack of automation in digital twinning processes. The Digital Twin web platform has proven to be robust against large-scale assets. The developed high-accuracy AR technology and NLP-based querying assistant have a practical way of setting efficient and user-friendly bi-directional communication between the physical and virtual entities of a DT. The potentialities of the AR registration method make it possible to use these technologies even in unprepared environments (e.g., not surveyed areas), which gives scalability and applicability to the system. Although the proposed image-to-OpenBIM method is promising, further practical testing is required. More work has to be done in relation to the DIM microservice. Finally, the use of the proposed system in O&M processes would streamline on-site inspection and maintenance activities on road infrastructure by significantly reducing the time required for manual information updating, processing, and retrieval.

A review of trustworthy requirements for road digital twins

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Digital Twins (DT)have been recognised as a powerful tool for whole-life management of road infrastructure in an intelligent, sustainable, and resilient manner. On the way forward, however, the road infrastructure stakeholders are still faced with the challenge of how to ensure the DTs work trustily. An untrustworthy DT would produce inaccurate information and decision-making, resulting in high financial costs, inefficient road management, and safety concerns. To address this challenge, this research analyses the current state of the DT paradigm and classifies the potential factors that will impact the trustworthiness of DTs. The analysis and classification take into consideration the functionality layers of DTs and the operational requirements in road infrastructure management. Accordingly, the practical approaches that can be adopted to resolve the identified trustworthiness issues are thoroughly reviewed and systematically integrated into a framework designed to ensure the appropriate and trustworthy use of a road DT. Specifically, the developed trustworthy framework is underpinned by three key pillars: precision, transparency, and cybersecurity. Precision is highlighted as a primary concern, with the study illustrating the importance of accurate data collection, synchronisation, and the application of machine learning for enhancing model accuracy. Transparency is underscored through the need for explainable Artificial Intelligence (AI) and Machine Learning (ML) models, ensuring that decisions are understandable to users, thereby building trust. Cybersecurity is identified as a critical aspect, with the study addressing the vulnerabilities inherent in cloud-based systems and the necessity of safeguarding against data tampering and unauthorised access. Together, these elements form a robust framework aimed at enhancing the trustworthiness of road DTs, ultimately contributing to more effective and reliable infrastructure management. It is strongly envisioned that this developed framework will serve as valuable guidance for the design and construction of robust and trustworthy digital twins, helping mitigate risks and enhance the overall effectiveness of road infrastructure management.

Conceptual framework for advanced digital planning and building permits through road digital twins

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In times of resource scarcity, maximising the utilisation of existing resources becomes crucial, particularly in sectors facing shortages of skilled workers or materials. This necessity extends beyond traditional perspectives, prompting a focus on leveraging road digital twins (RDTs) to enhance efficiency in planning and building permit (PBP) processes. PBP processes are vital for ensuring compliance and safety in the architecture, engineering, and construction (AEC) industry but are often manual and time-consuming, leading to project delays. While there's increasing interest in automating code compliance, there's a recognised need for more holistic research. Digitalisation holds promise for improving PBP processes, yet its implementation faces challenges, including stakeholder involvement and sector complexity. Despite the potential of digital twins to streamline processes, research on their application in PBPs remains limited, with little exploration of efficiency gains through adjacent data sources like real-time data.

The research concept proposed aims to explore the integration of RDTs into PBP processes through a structured approach. This concept consists of four main steps. Step 1 involves identifying and developing information packages (IPs) by gathering relevant data that links RDTs and PBPs. Examples of IPs include site development assurance, accessibility of land, and regulatory compliance. Step 2 focuses on knowledge management, organising the gathered information into a structured system such as an ontology. Step 3 conducts an uncertainty analysis, examining uncertainties in PBP processes and building a robust decision model. Step 4 evaluates the business case, aiming to generate value for stakeholders by offering services like automated querying of required information for building permits.

The research anticipates uncovering insights that could revolutionise PBP processes by integrating RDTs effectively. By addressing questions regarding use cases, management elements, and risk mitigation, the study seeks to enhance decision-making, efficiency, and transparency throughout the building lifecycle. The research expects to provide valuable solutions, such as reducing time delays, increasing certainty in construction management, and facilitating accurate decision-making for stakeholders involved in PBP processes. These findings are poised to have significant implications for both research and practice, potentially transforming how PBP procedures are conducted and benefiting various stakeholders in the AEC sector.

In conclusion, the research concept offers a promising avenue to bridge the gap between PBP processes and RDTs, aiming to improving the efficiency and transparency of PBP processes and to enhance decision-making processes. By systematically exploring the integration of RDTs into PBPs, the study seeks to break down information silos between different domains, while acknowledging potential limitations such as data restrictions and international perspectives, this research endeavour holds the potential to offer innovative solutions that could reshape how PBP processes are conducted, benefiting both stakeholders and society as a whole.

Evaluation and Auto-Generation of Digital Twins for Roads

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In Industry 4.0, Digital Twins (DTs) offer promise for improving road management's efficiency, safety, and sustainability. However, navigating the complex DT landscape requires effective evaluation methods to identify optimal solutions and mitigate risks, aiding decision-makers in maximising project benefits. Despite the availability of various DT models, there is a lack of focus on their evaluation, potentially leading to inefficient resource use and increased costs. Additionally, manual DT creation is impractical due to the extensive and evolving road lifecycle data, underscoring the need for automated, optimal DT solution generation within existing frameworks. To tackle the challenge, firstly the research will collaborate with local and national stakeholders to gather road Digital Twins (DTs) user requirements, categorising them based on global and stage needs for evaluation criteria. This involves literature reviews, interviews, and surveys to understand their needs comprehensively. Weights will be assigned to each criterion using various methods like subject assessment, Analytic Network Process (ANP), and regression analysis. Next a sensitivity analysis will be conducted to refine the evaluation matrix and finally the resulted performance metrics will be validated by experts. Based on the results, a framework for auto-generating DTs will be designed, covering micro to macro scales and resolutions, various property groups, and information from design to maintenance phases. This comprehensive framework aims to auto-generate DTs to meet detailed requirements, using metamodels (Ontology) to describe the DT framework.

Secondly models will be generated to populate DT assets corresponding to Physical Twin (PT) assets based on the mentioned metamodels. A knowledge-and-data-driven method will be employed for automatic optimal DT model generation. The auto-generated DT model will be tested on existing and virtual road cases for specific scenarios. Performance metrics from automated and manual DT models will be compared quantitatively to evaluate DT model performance effectively.

The expected outcomes are the development of quantified evaluation metrics and an automated framework for DT generation tailored to road infrastructure. These outcomes will highlight the potential for significant time and cost savings by reducing manual efforts in DT creation and emphasise the importance of user requirements and stakeholder input in developing reliable and efficient DT solutions, while enhancing the management and sustainability of road infrastructure in the digital age.

Advancements in Traffic Sign Inspection Using a Digital Twin Approach for 3D Model Reconstruction

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While BIM models are valuable tools for construction and facility management, using them as a digital twin for roads can pose certain challenges. Firstly, many road construction models are created in CAD formats containing road alignments and coordinates of point assets and lack comprehensive 3D representation. Secondly, BIM models are typically designed for the pre-construction and planning phases. Updating them in real-time to reflect changes in the physical environment might not be feasible due to model parsing and asset referencing issues. BIM Models commonly do not have support for texture mapping and no parameters available to reflect damage and changes with the road assets.

Currently, the most efficient and cost-effective method for acquiring road assets data is traffic speed surveys collecting multi-modal from LiDAR mobile mapping equipment, RGB, Thermal, and NIR cameras, GPR system.

We used mobile point cloud data (PCD) as a starting point for reconstructing 3D virtual representations of road segments. PCD datasets can be massive, requiring substantial storage capacity and computational power for processing and analysis. At the same time, compared to static scanning, mobile PCD, collected at traffic speed, can commonly lack resolution and detail and have gaps due to occlusions on the road. PCDs significantly reduce frame rate when visualised in VR, making the experience near to impossible except in cases when visualised in very small sections. PCD lack detailed color information, especially when compared to textured models. Limited color data can affect visual realism and interpretation. Overall, PCD stat-of-the-art research is in the stage of investigating the best methods for object detection, feature extraction, and fitting in simple BIM Objects(Scan to BIM).

Textured Mesh generated directly from mobile PCD in Software like Metashape or ContextCapture commonly has gaps, patched from countless elements, and hence is not feasible for updating and incorporating new data from road physical assets in real-time. It is also difficult to edit for the creation of synthetic defect data.

To summarise the above challenges, we aim to develop a Digital Twin 3D Model containing fused data from images, PCD, and historical data from databases or BIM. The model should be lightweight in triangle count, but contain the necessary level of detail in areas of cracks and potholes. The point asset objects(e.g., signs) will need to have sufficient resolution to reflect object deformation or tilt. The workflow will entail extracting necessary parameters from images and point clouds using machine learning algorithms and developing a foundation data model generating dynamic asset objects. The process of extracting and applying image textures to the existing model should be uniform and feasible to automate. Through parametrisation or procedural workflows, the asset models will be capable of generating synthetic data for defect detection simulation. Finally, each asset object, or linear asset segment, should represent a separate entity in the digital twin, quarriable through the user interface and connected to external databases.

In this paper, we explore geometry scripting for application for application in Infrastructure DTs through the generation of detailed, high-precision traffic signs mesh from point clouds.

Geometry Scripting is a blueprints-node-based scripting system that allows users to automate tasks, create procedural content, and implement custom logic for construction design within Unreal Engine. Geometry Scripting has similarities with parametric modelling in BIM software like Revit or scripting systems like Dynamo or Grasshopper. The distinctive feature of geometry scripting is the ability to manipulate image texture mapping on a 3D model and work in communications with other plugins and systems in the engine.

To conclude the above, the research will respond to the industry challenges in creating an optimised, data-rich DT model capable of reflecting changes in the physical world. Although the paper covers traffic signs only as one of the road assets,

we are applying similar approaches with other assets and aim to describe this strategy in subsequent research papers.

Construct and maintain a highway digital twin from multi-modal data

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Highways serve as fundamental infrastructure within the transportation network, with road freight accounting for 79% of domestic movement in the UK in 2018 and cars, vans, and taxis representing 88% of passenger kilometres in 2021. Emerging from the manufacturing sector, digital twins have gained prominence in the infrastructure domain, particularly within the Architecture, Engineering, and Construction (AEC) sector. A digital twin is universally acknowledged as a representation linking an asset or system, offering transformative potential for enhancing lifecycle processes of transportation infrastructure, such as highways, railways, and bridges. Despite the promise, challenges persist in efficiently constructing useful digital twins from diverse data sources due to manual reconstruction efforts, disjointed data linkage, and insufficient data structure design.

This project aims to automate digital twin construction and maintenance using Artificial Intelligence (AI) methods applied to multi-modal data, encompassing laser-scanned point clouds, RGB images, thermal images, and ground-penetrating radar data. Leveraging the capabilities of deep learning in processing point cloud and image data, the project has amassed a substantial annotated dataset suitable for training models, necessitating high-performance computing resources.

The anticipated outcomes of this research encompass: a) contributing a registered and annotated multi-modal dataset and trained deep learning models to the research community; b) introducing an automated approach to developing highway digital twins, mitigating costs and human involvement; and c) facilitating industry advancements through the integration of digital twins in real-world applications, enhancing maintenance procedures, optimising planning and construction processes, and monitoring asset conditions.

Benchmarking a Road Digital Twin Using Multi-modal Data

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The evolution of remote sensing and multi-sensor technologies has led to the generation of multi-modal data, facilitating diverse representations of a singular scene. Ground Penetrating Radar (GPR) employs electromagnetic pulses to probe the subsurface of road pavements. Light Detection and Ranging (LiDAR) captures 3-dimensional (3D) data along with the intensity of road assets. RGB cameras provide insights into colour, texture, and edge details. Thermal cameras detect infrared radiation emissions from roads. The fusion of GPS and Inertial Measurement Unit (IMU) compensates for individual biases, offering precise platform and sensor orientations. Integrating these data modalities yields a holistic understanding of scenes and objects.

Despite the potential benefits of multi-modal data fusion, challenges arise from the inherent differences in coordinate systems across sensors. The co-registration of diverse data modalities, both for offline and online applications, remains a pivotal concern. While the LiDAR-camera registration has garnered attention from several researchers, achieving engineering-level geometric accuracy has not been the primary focus for many. Furthermore, addressing registration issues for other modalities, especially road data due to its irregular shape and dynamic 3D changes, remains under-explored. The reliability of a digital twin, inherently dependent on its data, hinges on the quality of data and the resultant information from its analyses.

This research project aims to emphasise data quality control and co-registration across modalities using learning-based and photogrammetry methods. Beyond registration precision, a multi-faceted analysis of data quality will be undertaken, considering data application, expected detail levels, and storage and processing capabilities. The visual fidelity of data, crucial for data visualisation, particularly for products resulting from the fusion of 2-dimensional (2D) and 3D data, will be assessed for a virtual road twin. Additionally, Augmented Reality (AR) dimensions will be explored in evaluating the virtual twin's quality, encompassing the aforementioned challenges.

It is anticipated that the established quality metrics for digital twin assessment will ascertain its trustworthiness, leveraging the diverse data modalities and their fusion. With a clear understanding of a digital twin's reliability, the extracted insights and subsequent decision-making processes gain significance. This, in turn, enables the qualification of Key Performance Indicators (KPIs) and analyses rooted in the digital twin, facilitating ongoing progress tracking and insights evolution. Ultimately, by comprehending how to measure and enhance the quality of outputs, including knowledge and processes, the overall quality of outputs can be consistently improved.

Dense 3D Reconstruction of Building Scenes Only Using a Low-cost LiDAR

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Scanning plays a vital role in civil engineering, automation construction, and remote sensing, which is the basis for high-level tasks like Building Information ModelingModelling (BIM) and construction quality control. However, static scanning requires a significant amount of manual laborlabour and time. Mobile scanning has reduced the time and post-processing work compared to traditional static scanning. However, the point cloud density in mobile scanning is often lower than that of static scanning.

To address this challenge, we propose a novel approach that relies only on a cheaplow-cost Light Detection and Ranging (LiDAR), Velodyne VLP-16, an old version of LiDAR with 16 beams, around $4,000 in 2022, to enhance scanning resolution. The Velodyne company was acquired by Ouster Company in 2022. Now, the price of the new version of LiDAR, Ouster OS1 with 32 beams is around $8,000, Ouster OS1 with 64 beams is around $12,000, and Ouster OS1-128 beams is around $18,000. Some famous mobile scanners are more expensive: LEICA BLK2GO is priced at around $53,000; the price of FARO Orbis is around $56,000; the cost of ZEB Go is around $33,200. Our approach employs explicit LiDAR odometry for odometry estimation and Artificial Intelligence (AI)-based implicit 3-Dimensional (3D) dense mapping. The approach combines the high-precision registration of current explicit LiDAR odometry with the strategy of jointly optimizsing global temporal information through neural implicit representations.

The experiment was conducted on recorded data in a meeting room. As a result, we achieve high accuracy in localiszation and high density in mapping. In particular, the proposed method can get dense depth estimation even with sparse point clouds from the cheapLiDAR. Furthermore, one significant advantage of using NeRFthe proposed method can get dense depth estimation even with sparse point clouds from low-cost cheap LiDAR. Furthermore, one significant advantage of asusing the back end is the ability to construct point cloud maps with varying levels of density once the scene is well-trained. By adjusting the resolution of the redarning, we can render point clouds with different levels of densitiesy. This is attributed to the global fitting capability of the neural map, a capability that previous methods of 3D scanning and reconstruction cannot achieve. Our case studies on building scenes demonstrate that our method significantly improves the point cloud density of original scans.

In a conclusion, we applied the AI-based implicit map representation to reconstruct 3D building scenes and proposed combing the explicit LiDAR odometry with the implicit global map representation. Finally, we achieved dense 3D reconstruction of building scenes using only low-cost LiDAR. This technology holds the potential to significantly reduce the construction costs of digital twin.

Scanning is pivotal in civil engineering, automation construction, and remote sensing, serving as the foundation for advanced tasks such as Building Information Modelling (BIM) and construction quality control. While traditional static scanning demands considerable manual effort and time, mobile scanning has streamlined these processes. Nonetheless, mobile scanning often suffers from reduced point cloud density compared to its static counterpart.

In this research, we introduce an innovative approach leveraging cost-effective Light Detection and Ranging (LiDAR) technology to augment scanning resolution. Our methodology integrates explicit LiDAR odometry for precise odometry estimation with Artificial Intelligence (AI)-driven implicit 3-Dimensional (3D) dense mapping. This approach synergises the accurate registration capabilities of explicit LiDAR odometry with a neural implicit representation strategy for optimising global temporal information.

Our approach yields superior localisation accuracy and enhanced mapping density. Notably, our method achieves dense depth estimation even when operating with sparse point clouds from inexpensive LiDAR devices. An inherent advantage of our approach lies in its adaptability to construct point cloud maps with varying density levels post training, enabled by the neural map's global fitting capability—a feature unattainable by prior 3D scanning and reconstruction methodologies. Empirical evaluations on building scenes corroborate that our technique substantially enhances the point cloud density of initial scans.

In conclusion, we employ AI-driven implicit map representation for 3D building scene reconstruction and advocate for the fusion of explicit LiDAR odometry with implicit global map representation. Ultimately, we achieve dense 3D reconstruction of building scenes using budget-friendly LiDAR technology. This advancement harbours the potential to markedly curtail the expenses associated with digital twin construction.

Advanced Multi-Sensor 3D Mobile Scanner for Asset Inspection

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Efficient asset management is contingent upon regular inspections, ensuring the integrity and functionality of infrastructure, buildings, and various assets. However, traditional scanning methods often pose challenges, including high costs, time-consuming processes, and limited accessibility. Mobile scanning technology offers a promising solution, but accuracy constraints have limited its efficacy in comprehensive defect inspections. Addressing this critical gap, we present PointPix, a pioneering multi-sensor mobile 3D scanner designed to revolutionise asset inspection across diverse industries. Conventional asset inspection methods, such as terrestrial scanners, are burdened by high costs and lengthy scan times, hindering widespread adoption. Mobile scanners offer mobility and flexibility but often lack the precision required for thorough defect inspection. This limitation presents a significant challenge in industries where accurate asset assessment is paramount, such as construction, infrastructure maintenance, and urban planning.

In response to the shortcomings of existing scanning solutions, we developed PointPix, a multi-sensor mobile 3D scanner engineered for adaptability and affordability. Leveraging mapping and computer vision techniques, PointPix enhances the accuracy and efficiency of asset inspection processes. By carefully selecting hardware components, including LiDAR, high-resolution colour and near-infrared cameras, and an inertial measurement unit, PointPix achieves optimal functionality while minimising costs. PointPix represents a significant advancement in asset inspection technology, offering robust capabilities in various applications. PointPix has demonstrated its ability to capture reliable 3D data in construction monitoring, facilitating progress monitoring. Moreover, in road asset inspection—a historically challenging and costly endeavour—PointPix promises to revolutionise maintenance practices by significantly reducing inspection costs while ensuring comprehensive defect detection. The strategic hardware selection of PointPix, focusing on minimalist yet high-performance components, underscores our commitment to affordability without compromising functionality. While acknowledging slightly lower resolution than competitors, PointPix's cost-effectiveness and practical functionality position it as a transformative tool for many users and industries. By democratising advanced scanning technology, PointPix empowers users to conduct thorough asset inspections efficiently and cost-effectively.

PointPix represents a paradigm shift in asset inspection technology, offering a harmonious balance between performance, affordability, and accessibility. With synchronised data recording and processing capabilities, PointPix facilitates streamlined surveying, mapping, and inspection workflows, empowering users to make informed decisions and optimise asset management practices. As we refine and expand PointPix's capabilities, we envision a future where advanced scanning technology is readily accessible and beneficial across diverse industries, ushering in a new era of efficiency and effectiveness in asset inspection and management.

Artificial intelligence assistant autonomous-vehicle-mounted sensors-based road surface condition monitoring system

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Road transportation is an important component of transportation. Numerous roads to be monitored are a challenge for the management by the authorities. Untimely road maintenance endangers the safety of drivers and vehicles. Low-cost and high-efficiency Road Surface Monitoring (RSM) becomes an important target for future roads. Conventional RSM systems have the disadvantages of high costs and difficulty to be improved.

Automated driving shows potential for future road transportation. Will autonomous vehicles mounted with non-conventional sensors monitoring roads be a future RSM solution? This research will develop a low-cost RSM system mainly based on autonomous-vehicle-mounted Inertial Measurement Units (IMUs) sensors. The onset of aquaplaning is a key research point and is expected to be monitored by the RSM system. Information processing in complex road environments is a major difficulty in this research. Data fusion methods and artificial intelligence will be developed for the RSM system.

This research mainly consists of three stages. The first stage is to study the scenarios where there is a high risk of aquaplaning for vehicles. The second stage is to develop the RSM system for these scenarios and to study the signal acquisition of the onset of aquaplaning in the laboratory. The third stage is to conduct a field study in multiple real-life scenarios in Cambridge.

This research will develop a low-cost vehicle-mounted-sensor mobile RSM system which is helpful to improve the driving safety of drivers and vehicles and improve road maintenance efficiency.

Constructing and Maintaining Geometric Digital Twins of Road Conditions

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Motorways provide essential connectivity between major locations. Today's road maintenance practice however requires intensive human input, which hinders the society's demand for drastic improvements in meeting future traffic demands, attaining carbon net zero and safeguarding zero harm on roads. To address the societal need to maintain undisturbed connectivity while achieving step-change advancements, digitisation provides a promising avenue. The current digitisation process however relies heavily on manual effort.

Hence, the research proposed here aims to enhance automation in creating a geometric Digital Twin (gDT) capturing the conditions of roads. The prospects of gDT for road conditions first hinge on ways to improve efficiency and reduce human effort in preparing and annotating real-life visual datasets. With a curated and annotated visual dataset, development proceeds to identify defects in pavement and off-road assets discoverable from the prepared data and construct detectors to detect such defects. A fully functional gDT should also include the ability to update the conditions of identified assets and output conditions in a tractable manner for further visualisation. The research has primarily advanced in the area of image annotation. This research proposes improvements to reduce human effort and maintain quality when annotating pavement image datasets, which are large, noisy and domain specific.

The proposed annotation pipeline in this research reduces human effort in creating and reviewing labels by selecting the most informative images for review, leveraging unlabelled images and mimicking past manual corrections. The improved annotation pipeline builds on an existing two-stage instance segmentation architecture, Mask R-CNN, and includes three additional components. The first component on consistency regularisation calculates the loss between predictions on the input image and its horizontally flipped augmentation and improves the accuracy of the classifier. The second component, the active learning scoring module, predicts the Bounding Box (bbox) and mask loss on unlabelled images and prioritises informative images for manual review. The third module captures corrections done manually and automatically reproduces the correction on similar pseudolabels. Combining the three modules with Mask R-CNN yields approximately 25% savings of manual mouse clicks from fully manual labelling. The prediction performance also gains by an average of 40% in average precision and recall by using the three modules compared with using the vanilla Mask R-CNN.

The overall annotation pipeline increases automation and reduces manual labour in annotating images, as well as addressing needs in creating and correcting pseudolabels. Despite the room for further improvements in labelling domain-specific datasets with advances in large language models and open-set annotation, the annotation pipeline already helps label more and better visual data with limited manpower. The expedited data annotation alleviates the burden of preparing data for creating a gDT and the overall digitisation process.

Automated Geometric Digital Twin Construction for Existing Buildings

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This research addresses the challenge of automating the construction of geometric Digital Twins (gDTs) for existing buildings from Point Cloud Datasets (PCDs) to minimise costs and manual labour. Many existing buildings lack reliable geometric information as they were constructed prior to the adoption of DTs for building construction, complicating their management and maintenance. DTs are crucial for enhancing operational efficiency by dynamically using real-time data to manage buildings. However, the current process of generating these models from PCDs is labour-intensive and costly. Hence, this study aims to develop methods that significantly reduce the manual effort and expense involved in constructing gDTs, thereby maximising their operational and economic benefits during the maintenance phase of the buildings' lifecycle.

This research develops a framework to automate the digitisaation of gDTs of existing buildings by focusing on spaces, objects, and their topological relations. The framework integrates model-driven and data-driven approaches to handle varying complexities and variabilities within building structures. Model-driven methods are applied where object geometries are consistent and simple, such as in detecting spaces through empty volume analysis and structural elements like walls and doors. Conversely, data-driven methods are utilised to handle high variability scenarios such as identifying object relationships and non-standard geometries. Key steps in the methodology include; (1) Space Detection: Utilizes empty blob detection to identify potential space volumes within a PCD, facilitating the detection of doors and walls by examining the boundaries of these volumes; (2) Object Detection: Employs neural networks to generate heatmaps identifying potential locations for structural objects, followed by model-driven methods to confirm presence and shape, enhancing accuracy in object representation; and (3) Relation Detection: Detects low-level geometric features and infers topological relations through a combination of clustering, region-growing, and neural network classification to establish compositional and adjacency relations between objects and spaces. This hybrid approach is designed to efficiently process internal PCDs of buildings, assuming no prior knowledge from existing models, thus making the framework applicable to a wide range of existing buildings without digital blueprints. It also enables more accurate space, object, and relation detection within complex building structures. The outcome is a robust set of gDTs that reflect the true geometric and topological nature of building structures. The resulting cost reduction can increase DT adoption for existing building operation that leads to enhancing operational efficiency and proactive building management. These advancements contribute to the management of sustainable built environments, highlighting the framework's potential relevance to and facility management.

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Maintaining Geometric Building Digital Twins from Spatial and Visual Datasets

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One of the greatest challenges faced by the Architecture, Engineering, and Construction (AEC) industry is poor project performance due to the lack of timely progress monitoring and quality control during the construction stage. A Digital Twin (DT) can serve as an information repository for storing and sharing an asset's properties over time with all AEC stakeholders for managing a building project throughout its lifecycle. Keeping the geometric DT dynamic by detecting, segmenting, and recording the as-built geometry data of building object instances from the on-site collected Spatial and Visual Data (SVD) with the help of the Design Intent (DI) is a core step in automating and standardising progress monitoring and quality control. However, there is no state-of-practice solution that can automatically keep geometric DT updated based on the DI during the construction stage. Four core knowledge gaps are: 1) Top frequent building object classes are unknown. 2) The lack of method to update DT geometry with high-resolution in the environment with significant occlusions and clutter. 3) The lack of method to update DT geometry when there are distinct deviations in terms of position, orientation, and scale between the DI and the as-built object instances. 4) The lack of method to update DT geometry for object instances with various shape complexities.

This research aims to achieve the automatic process of geometric DT maintenance from the SVD of top frequent object classes in complex environments reflecting to the knowledge gaps. We proposed a geometric DT updating framework based on Machine Learning (ML) that can tackle various top frequent object classes with primitive and irregular shapes. Specifically, as for structural instances, an enlarged bounding box is generated to crop the entire Point Cloud Data (PCD) into small clusters. Then, a method based on shape fitting and unsupervised clustering algorithms is developed to extract final instance point clusters. As for Mechanical, Electrical, and Plumbing (MEP) objects, photogrammetry and deep learning are combined to locate instances in PCD before applying spatial feature extraction and matching algorithms. Finally, the incomplete PCD is reconstructed into meshes by adding artificial points to fill gaps and holes. The final as-built model is assigned into as-designed IFC model as updated information for geometric DT maintenance. The experimental data is collected by authors using a Faro terrestrial laser scanner. Other public datasets including IFC model and as-built PCD are also used in the experiments.

The experiment results on detecting, segmenting, and tessellating as-is geometry data of top frequent object instances, including planar and curved walls, columns, pipes, elbows, and heating terminals, show that the proposed solution can handle the geometric DT updating of object classes with various shapes in different complex environments. The solution is robust on instance matching with high resolutions when there are occlusions, clutter, and deviations between DI and as-built status.

Overall, the updated geometric building DT can significantly reduce manual checking time, leading to faster project progress monitoring and quality control at the construction stage. As the proposed solution can be implemented at different timestamps during the building's construction, the discrepancies between DI and as-built status can be detected and reported timely. It can help avoid costly rectifications in the later stages of construction.

Generate Operation Phase Geometrical Digital Twin Models for Digitising Old Buildings

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Currently, an increasing number of buildings and infrastructure are undergoing repairs or retrofitting. Many older buildings were constructed before the advent of digital technologies and documentation, resulting in most existing structures lacking both as-built and as-designed digital models. Laser scanning technology offers a more efficient and precise means of capturing the geometric information of these existing building structures. Nevertheless, reconstructing buildings from the collected laser scanning point cloud data remains a time-consuming and labour-intensive process.

Previous research has developed methods for the 3-dimensional (3D) reconstruction of buildings, primarily focusing on indoor structural elements like walls, ceilings, and floors. However, there have been limited studies on detecting other objects such as hidden objects and building envelopes, which are crucial for building retrofitting analysis. Additionally, these reconstruction methods often produce building elements in the form of point clusters or meshes, with few studies concentrating on generating data formats that are compatible with other digital twin tools. Consequently, this research aims to address these gaps and streamline the creation of geometric digital twin models during the operational phase of buildings.

To address the above challenge, this research will develop data-driven approaches based on machine learning and Artificial Intelligence (AI) techniques to automatically detect building objects with acceptable accuracy by extending the research to detect a broader range of objects, including hidden objects and building envelopes, as well as their relationships. This approach also includes the process of converting the generated dataset to the Industry Foundation Class (IFC) format that could be directly used for building retrofitting analysis. Finally, the proposed approach will be validated using real-world cases.

The outcomes could be directly applied to other applications requiring geometry and spatial information of old buildings, such as building retrofitting and energy simulation. Furthermore, this research will generate a point cloud dataset of the Civil Engineering Building, along with associated IFC models. The labelled point cloud dataset can serve as a benchmark for testing and validating semantic segmentation algorithms. Additionally, the dataset will include the as-designed and as-built IFC models of the building, which can be used for evaluating other algorithms, such as point cloud registration and building quality check algorithms.

A graph-based approach for road digital twin

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The major problem to be addressed in the project is how to design road digital twins. This problem will be addressed by achieving the following four objectives: (1) objective-1: Identifying the specific information requirements for road digital twin (2) objective-2: Developing a graph-based reference data library for road assets, (3) objective-3: Developing an extensible, future proof and scalable road integration cloud architecture, and (4) objective-4: Validating the proposed approach for road digital twining. These objectives are identified and scheduled in a logical manner, and, to achieve these objectives, the standard procedure specified in an international standard, ISO19650 organization and digitalization of information about buildings and civil engineering works, will be referenced. To be specific, the following methods will be used. (1) Objective-1: Relevant literature will be reviewed and interviews/questionnaires with stakeholders, such as Jacobs and National Highways, will be conducted to learn the specific information requirements for future roads management and define road Foundation Data Model. (2) Objective-2: Graph-based technologies, such as Resource Description Framework (RDF) and labelled property graph (LPG), will be compared to select the proper graph technology for implementing the graph reference data library that is developed based on information requirements identified in Objective-1. (3) Objective-3: An extensible, future proof and scalable road integration cloud architecture will be developed by working with stakeholders, taking data fusion and data interoperability into consideration. (4) Objective-4: Real project data will be used to validate the effectiveness of the proposed approach for road digital twinning.

Geometric Digital Twin Construction and Inference from the Point Cloud Data Powered by AI and Linked Data Technologies

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The research focuses on the automated generation of geometric Digital Twins (gDTs) of buildings using scanned point cloud data from pre-existing structures. Digital Twins (DTs) act as virtual replicas of tangible assets, systems, or processes, providing stakeholders with advanced capabilities to visualise, monitor, and analyse projects with unmatched precision. Specifically, gDTs emphasize the static aspects of the model, capturing both the geometric intricacies and key attribute data of building components.

Despite the advancements, the prevailing automatic scan-to-gDT methodology encounters challenges such as varied construction techniques across different objects and the difficulty in reconstructing hidden or unscannable building segments. To address these issues, this research commences with a comprehensive review of existing practices, aiming to amalgamate current knowledge on gDT construction techniques towards a cohesive solution. The study highlights the importance of adopting both a bottom-up, data-centric approach and a top-down construction methodology, enriched by pre-established architectural insights.

The primary objective of this research is to formulate a comprehensive knowledge framework encompassing the construction and inference mechanisms inherent to gDTs. This framework aims to facilitate the development of more cohesive and precise digital representations of physical structures, bridging the gap between digital and physical realms.

Digital Twin Enabled Contrauction Progress Monitoring

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Digital twin technology has revolutionised overseeing newly built structures. This study suggests employing digital twin-based automatic progress monitoring on construction sites, comparing 3D point clouds with their Building Information Modelling to track progress and predict completion. It highlights integrating semi-continuous monitoring with a building's digital twin for efficient construction management. Leveraging precise data enhances understanding and identifies schedule deviations, enabling timely actions. Demonstrated through real-world construction data, visualised Gantt charts showcase its effi- cacy, offering insights into task status, schedule deviations, and projected completion dates. This underscores digital twin technology's potential to transform construction oversight.

Deriving Handcrafted Road Asset Condition Forecasting and Forensic Maintenance Processes

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There is a new need for better controlling and monitoring processes for existing road maintenance techniques, measuring their performance to address budgetary constraints and to bring existing systems to a higher standard. By focusing on data science methods that monitor Key Performance Indicators (KPI's) such as money, safety, sustainability, time and quality, the efficiency of current and future methods can be strengthened to run within existing constraints. Processes from product information in the digital twin can also be derived to enable direct control of robotic maintenance and repair operations.

This project focuses on data science and machine learning methodology essential in synthesizing a digital twin with new materials, and measurement techniques for road assets, along with providing the means of control for robotic monitoring and communication, exploiting data rich feedback and new materials. This involves investigating state-of-the-art processes for highway maintenance treatments, summarising current capabilities and their implementation into the digital twin. Spatial modelling can then be performed for distributions of defects and repairs, identifying, and fitting spatial models to a constructed dataset, and investigating how the strategic road network can be broken down spatially into several sites, identifying the explanatory variables for each of these locations.

The data acquired in these stages will then be used to predict forecasting failures. State-of-the-art deterioration curves will be explored for pavement performance measures. They'll also be studied for individual defects and their systems, noting how diseases can be inferred from them and how the causes of these diseases can also be pinpointed from these deterioration curves. Decision models are then investigated and developed along with the application of the five KPIs into the digital twin, leading to a prototype implemented into the existing systems. This is in conjunction with a list of guidelines for data collection and monitoring, identifying data requirements for digital twin maintenance for various road assets and how these can be fulfilled using efficient modern tools.

The findings from this stage of the project will then lead to further optimisation algorithms on the existing KPIs and decision models, generating detailed maintenance treatment schedules with required resources and assets. Once a design automation prototype is created, optimal maintenance processes can be automatically derived into high level human readable instructions and low-level, machine-readable instructions.

Establishing Digital Twins Information Requirements for Highway Asset Maintenance

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Highway digital twins have emerged as powerful tools for asset maintenance, allowing for real-time monitoring and predictive analysis of infrastructure conditions. However, establishing the information requirements to implement these digital twins effectively remains a critical challenge. This research addresses this gap by identifying and delineating the essential information requirements to optimise highway digital twins for asset maintenance. By doing so, it aims to enhance the efficiency and efficacy of infrastructure management practices, thereby ensuring the longevity and safety of highway systems.

The methodology employed in this research involves a comprehensive approach that combines both quantitative and qualitative techniques. Initially, a thorough review of existing literature on highway digital twins and asset maintenance was conducted to identify standard practices and emerging trends. Subsequently, interviews and surveys were conducted with relevant stakeholders, including highway authorities, engineers, and technology experts, to gather insights into their information needs and preferences regarding digital twins. Data analysis techniques such as content analysis and thematic coding were then employed to distil critical findings and identify recurring themes.

Several essential information requirements for highway digital twins emerged through synthesising literature review findings and stakeholder input. The study found that fulfilling this unique set of requirements could help the industry realise the importance of digital twin technology for its quick and widescale adoption. The findings of this research underscore the critical role of information requirements in optimising highway digital twins for asset maintenance.

By delineating these requirements, highway authorities and infrastructure managers can better harness the potential of digital twins to improve maintenance practices, enhance operational efficiency, and ultimately prolong the lifespan of highway assets. Moreover, the emphasis on interoperability and data standardisation highlights the need for collaborative efforts and industry-wide standards to ensure the seamless integration of digital twin technologies into existing infrastructure management frameworks. Further research and development in this area are essential to address evolving challenges and capitalise on emerging opportunities in intelligent infrastructure management.

Digital Twin and Knowledge Graph-based Road Maintenance Decision-making

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Roads serve as the primary mode of transportation for individuals, and their maintenance is adversely affected by a shortage of skilled professionals, including manual and professional roles such as civil engineers. This skills shortage has raised concerns among industry professionals regarding its impact on budgets, project viability, and delays in maintenance, leading to further deterioration of road assets. The current road maintenance processes heavily rely on expert knowledge, making them susceptible to skill shortages.

Hence, this research proposes the integration of digital twins and knowledge graphs to address skills shortages in road maintenance preparation and operation processes. Leveraging Large Language Models (LLM) for information extraction, constructing knowledge graphs using Neo4j, performing knowledge fusion, data matching through similarity calculations, and providing candidate treatment recommendations through knowledge graph reasoning, this study aims to develop reliable and automated decision-making methods for road maintenance.

By utilizing knowledge graph-based approaches, this research seeks to mitigate skills shortages, reduce dependence on expert knowledge, and enhance the efficiency and effectiveness of road maintenance activities.

Using Class Descriptions to Classify Inspection Texts with Minimal Training Data

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Modern Large Language Models (LLMs) are pretrained over a large corpus of texts, allowing to acquire a basic understanding of the semantic structures of natural language. Further fine-tuning is often required to adapt the generalized models to a specific task, such as classification with a custom dataset. However, as with most deep neural networks, a large amount of training data is required for the models to attain acceptable levels of performance. Road management creates a vast amount of unannotated textual data, which would be infeasible to manually annotate for every natural language processing (NLP) task. This limits the application of recent advances in NLP in extracting information from road textual sources.

Inspired by few-shot learning methods, where models take advantage of only a few training data, a description-based classification technique is proposed for texts. The description of classes acts as inherent information, or priors, for the classes, which can be used to guide the classification of texts. This alleviates the need for a large quality of labelled data. Class descriptions can be manually generated by experts, or can be extracted from annotation guidance for human operators. These descriptions would be matched with input texts to output similarity scores, which are used to classify the inputs.

Experiments are ongoing. However, early results indicate that significant improvements are brought by utilizing class descriptions in classification. Compared to traditional classification techniques, improvements can be as much as 50% with only 30 training data per class. Experiments are underway to determine optimal training conditions, in addition to how the amount of training data would affect model performances in this setting.

This project has the potential to unlock LLMs for use in road management in a scalable and flexible fashion, as there is a low requirement on training data. In addition, class descriptions can be used as a means of incorporating human expertise in classification, as they can be generated by domain experts.

Defect Initiation Modelling for Predictive Maintenance via Spatial Smoothing

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Highways are critical to the economy of a country and their condition is directly connected with the safety and comfort of its users. Currently, transport authorities rely on routine visual inspection by a site crew, which is usually infrequent, expensive, time-consuming and without proper prediction and control over material usage and maintenance time. Repairs to roads are large scale disruptive processes that can close roads for extended periods delaying traffic and contributing to pollution. There is a pressing need for innovative road pavement maintenance designs that can streamline the data collection, the decision-making processes, and execution of maintenance processes while minimising disruptions and costs, ultimately contributing to more efficient infrastructure management.

Digital Twins (DTs) provide a platform to integrate vast amounts of relevant, real-time data. One approach to streamlining the maintenance process through efficient DT-driven methods is through predictive and proactive maintenance. Leveraging the data available in a DT of the highway, we perform spatial modelling with the aim of predicting the probability of various defects arising under different circumstances. A dataset is built incorporating defect counts in sites spatially partitioning National Highway's Strategic Road Network, as well as explanatory variables such as easting, northing, pavement age, surface material, length, traffic flow, and weather. Then, spatial smoothing is applied to the data, so that spatial correlation in the occurrence of defects and explanatory variables is taken into account.

The resulting model is integrated into the DT and adapted to be modular so as to inform decisions pertaining to specific time periods, locations, and defect types. It is a significant step towards implementing predictive and proactive maintenance, which majorly reduces associated costs, inefficiencies, and risks associated with the widely employed reactive maintenance. This model is also to be used in KPI and decision modelling in order to assess and quantify these improvements.

Project RESTOR: Integrating Digital Twin Technologies for the Reuse of Structural Steel

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The construction industry, a significant consumer of structural steel, faces urgent sustainability challenges due to the steel industry's substantial greenhouse gas (GHG) emissions. This research targets these challenges by pioneering digital twin technologies and processes that promote the sustainable, efficient, and low-energy reuse of structural steel, thereby facilitating reductions in GHG emissions, waste, and costs while supporting low-carbon and net-zero objectives. It introduces a suite of digital twin products designed to revolutionize the construction sector. The development begins with the creation of a web-based digital twin design tool. This tool is engineered to utilize machine learning algorithms and deep generative models (DGMs) to facilitate the generative design of new structures using repurposed steel. It integrates advanced mathematical models that characterize the material properties of used steel, considering varying grades and damage states. These properties are derived from non-destructive testing (NDT) data and are essential for assessing the structural integrity and potential reuse of materials.

The processes involved in this transition are structured around four main steps: utilizing NDT and experimental tests to develop and validate mathematical models that define the physical and mechanical properties of used steel members; conducting experimental studies and developing nonlinear finite element models to verify the structural performance of repurposed steel; implementing a novel, machine learning-based optimization process, including evolutionary algorithms, to design structural elements that minimize embodied energy while maximizing structural capacity; and enabling the automatic generation of optimized building configurations through the digital twin tool. This not only streamlines design processes but also enhances the precision and efficiency of building with repurposed materials.

This research proposes an advanced methodology for the sustainable reuse of structural steel through digital twin technologies, addressing environmental, economic, and technological challenges in the construction industry. By focusing on the development of digital twin products and processes, the study underscores the importance of transitioning from traditional construction practices to innovative, technology-driven solutions, fostering a sustainable construction culture and enhancing industry standards for environmental responsibility and economic viability.

Digital Twin-driven Structural Health Monitoring of Roads

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Road infrastructures play a critical role in facilitating mobility, supporting economic activities, and promoting social development. Hence, it is important to maintain the high performance of roads by conducting timely maintenance and rehabilitation activities. In order to formulate accurate maintenance and rehabilitation strategies, a digital twin of roads can be used to identify the latest condition of roads in service. In this process, an essential step is to obtain the structural health information of existing roads, which will be addressed in this study. At first, a physics-based model which can simulate a Non-Destructive Testing (NDT) method of roads will be developed by using a semi-analytical approach. Then, the developed model will be used to generate a database which contains the structural parameters and corresponding predicted NDT results of roads. At last, the generated database will be used to develop a data science-based technique which can identify structural parameters of roads based on NDT results, and the identified structural parameters will be used to evaluate the structural health and predict the remaining life of existing roads. The digital twin of roads with the latest structural health information can help formulate the most suitable maintenance and rehabilitation strategies, which further help maintain the service performance of roads and improve the quality of life.

Innovative Approach to Sustainable Reuse of Structural Steel in Construction Based on Generative Digital Twin Design Tool

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The significant contribution of the steel industry to greenhouse gas (GHG) emissions and the heavy reliance of the construction sector on steel structures pose a pressing challenge for sustainability. This research endeavours to address this challenge by developing innovative technical solutions that maximise the sustainable, efficient, and low-energy reuse of structural steel. By doing so, it aims to reduce GHG emissions, achieve low carbon and net-zero targets, lower waste streams and costs, and provide digital technology opportunities to diversify the construction industry. This research proposes a multifaceted approach, integrating advanced non-destructive testing (NDT), machine learning optimisation, deep generative models (DGMs), and digital twins (DTs) techniques. This approach enables the reuse of structural steel in construction (RESTOR) while delivering economic and societal benefits.

This research comprises four main steps, including material characterisation, performance of used steel members, machine learning-based optimisation, and generative design tool. Mathematical models will be developed to characterise the material properties of used steel members based on NDT measurements, considering various steel grades and pre-existing damage conditions. Experimental tests and NDT measurements will validate these models. The structural performance of used steel members will be verified through experimental studies, and advanced nonlinear finite element models will be developed and validated. These results will inform the optimised design process. A novel optimisation method will be developed to repurpose and structurally design used steel members, considering member residual life, damaged material properties, and smart repurposing strategies. Machine learning-based optimisation techniques, such as evolutionary algorithms, will minimise embodied energy and maximise structural capacity utilisation. A web-based generative DT design tool will be developed to facilitate the generative design of new buildings using used steel members. This tool will integrate mathematical models, structural performance data, and optimisation methods, enabling the automatic generation of optimised building configurations.

In conclusion, this study presents an approach to advance the sustainable reuse of structural steel within the construction sector. Its innovative methodology not only tackles pressing environmental concerns but also unveils promising economic avenues and technological advancements for the industry. This research contributes significantly to the overarching goal of creating more environmentally friendly and economically viable construction practices by emphasising the importance of recycling and repurposing steel materials. Through the strategic implementation of the proposed solutions, a culture of sustainability can be fostered while simultaneously harnessing the economic benefits and technological innovations associated with steel reuse in construction projects.

OMICRON: Advancing Road Maintenance through Digital Twin and Decision Support System

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Maintaining, renewing, and upgrading road infrastructure efficiently is crucial for ensuring safety and sustainability. However, traditional methods often lack precision and timeliness, which can lead to suboptimal outcomes. To address this challenge, the OMICRON project is developing a comprehensive Road Digital Twin (DT) and Decision Support System (DSS) to enhance infrastructure management. The project involves designing and integrating a Road DT that uses data from digital inspections and other sources. The methodology includes analysing technical requirements, defining DT architectures, and managing diverse data types through advanced integration techniques. The integration of OMICRON's intelligent platform tools further improves decision-making processes for infrastructure managers.

The project has achieved several outcomes, which include the creation of a strong Road DT architecture, effective data management strategies, and the implementation of an intelligent DSS. These advancements enable precise asset representation, comprehensive data integration, and informed decision-making for maintenance planning and resource optimisation.

"OMICRON" is a new technology that revolutionizes road infrastructure management by providing a comprehensive solution for maintenance and decision-making. The project uses advanced DT technology and intelligent platforms to develop proactive maintenance strategies that improve road network safety, reliability, and sustainability.

ChatTwin: Enabling LLM-Based Natural Language Interactions with Infrastructure Digital Twins

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Infrastructure management, particularly of road systems, faces significant challenges such as data inaccessibility, leading to increased costs, sustainability concerns, and safety hazards. Despite substantial investments in the United Kingdom (UK) and elsewhere, efficient management of such systems remains challenging, primarily due to the complexities of integrating and analysing large amounts of data from diverse data sources for informed decision-making. Digital twins have been developed as unified platforms for such data integration and analysis. However, the human interfaces of these digital twins present another layer of complexity, particularly for infrastructure professionals with limited expertise in computer systems. This situation shows the urgent need for more accessible and user-friendly interfaces with digital twins to support effective infrastructure management. This research addresses this gap by proposing an integration of Large Language Models (LLMs) with infrastructure digital twins, aiming to improve the accessibility and interpretability of the complex data within infrastructure digital twins, thereby facilitating better decision-making processes.

This study introduces an innovative system, referred to as ChatTwin, which leverages LLMs to enhance interactions between human operators and infrastructure digital twins. Focused on road systems, the system is designed to perform five primary tasks: data visualisation, data summarisation, digital twin modification, model visualisation, and work schedule inquiries. The system employs natural language prompts for user interactions, which are then categorised and processed to retrieve relevant data from the digital twin. This information, combined with the initial prompts, is fed into an LLM to generate outputs that include Python-based commands, natural language summaries and/or visual representations. A prototype digital twin of a road system, incorporating various data types such as geometry data, time-series sensor data, and defect information, was developed to validate the approach.

The integration of LLMs with digital twins enabled effective natural language interactions, thereby bridging the gap between complex domain knowledge/data and intuitive user interfaces. The system demonstrated proficiency in accurately categorising tasks, processing and visualising data, summarising information, and executing digital twin modifications within simulated scenarios. The findings highlight the system's capacity to enhance user-centricity in the lifecycle management of infrastructure, streamlining decision-making and interactions across different stages, with a particular emphasis on operations and maintenance.

The study presents a significant advancement in infrastructure management through the novel integration of LLMs with digital twins. This approach not only improves data accessibility and interpretability but also has the potential to streamline and transform decision-making processes in infrastructure management. The results demonstrate the utility of LLMs in bridging existing gaps in digital twin interactions, suggesting further research directions such as refining user feedback mechanisms, expanding task capabilities, and integrating multi-turn interactions to better address the complexities inherent in infrastructure management.

Data Science and Advanced Technologies for Carbon Management in Highway Projects

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Sustainability is the continued protection of human health and the environment while fostering economic prosperity and societal well-being. Specially, one of the most intriguing problems in sustainability is carbon measurement and analysis in infrastructure projects to meet the net-zero 2050 target. For future roads, carbon reduction is an inevitable theme to be addressed. This project will investigate data-informed sustainability decision-making in future roads, focusing on carbon management. It aims to develop a standardised carbon data model for the precise carbon management of highway projects and study what advanced technologies/techniques could be utilised to improve data availability, operability, consistency, and reliability.

To fulfil this aim, the project will develop a standardised data model that can be employed for consistent carbon calculation, assessment, and optimisation by future road developers. A mixed research method with interviews, organisational archival analysis, and ontology modelling is used. Four research objectives are outlined: (1) to review existing carbon management theories and practices, attainable advanced technologies for carbon sensing and monitoring, data analysing, sharing, and visualisation; (2) to develop a standardised data model for carbon management; (3) to develop a set of interoperable protocols for data collection, storage, analysis, sharing, and visualisation; and (4) to prepare the data model in a way that is adaptable to the foreseeable adoption of new technologies in the next five years. A carbon data trustworthy framework and an intelligent carbon data management system architecture are developed.

Comfort in motion: Assessing cyclist experience across infrastructure

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The reliance on cars contributes significantly to environmental pollution, traffic congestion, and sedentary lifestyles. Encouraging cycling presents a viable solution to mitigate these challenges and foster sustainable urban environments. However, achieving greater inclusivity and enhancing the quality of cycling infrastructure are imperative steps toward realising this vision. While policies advocating for improved dedicated cycling facilities and shared spaces aim to address equity, diversity, and inclusion (EDI) for cyclists, there remains a lack of research assessing cyclist comfort and associated EDI issues across diverse cycling infrastructures.

In response, this research endeavours to quantify the cycling experience across both non-motorised (dedicated cycling infrastructure) and motorised facilities (shared lanes with vehicles), with a specific focus on EDI issues and underrepresented groups. The study aims to observe interactions between cyclists and road users in various facilities, utilising online surveys to capture users' perceived comfort across different scenarios. Multiple scenarios will be recorded to evaluate users' concerns comprehensively.

Utilising state-of-the-art discrete choice models, the collected data will undergo analysis. This analysis will elucidate how different user groups, such as women and older adults, perceive comfort across various types of cycling infrastructure and identify factors contributing to their discomfort in different settings. Subsequently, a series of experiments will be conducted to assess the effectiveness of policy interventions aimed at improving users' perceptions of comfort, particularly among women and older adults.

The findings of this research offer valuable insights to planners and policymakers with respect to how EDI issues manifest in the use of transport infrastructure. It provides concrete evidence on how diverse user groups, based on demographics and travel histories, experience comfort in different cycling infrastructures. This will, in turn, inform the adoption of targeted policy interventions to address EDI issues within transport infrastructure. Ultimately, this project aims to enhance the overall cycling experience and promote its widespread adoption as a sustainable mode of transportation.

The Climate Change Resilience of Road Network in London and its Vicinity Areas

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Climate change alters global precipitation and temperature patterns, affecting the frequency and intensity of extreme weather events such as floods, rainstorms, hurricanes, and blizzards. Assessing and improving the resilience of the Road Infrastructure Network (RIN) to climate change is crucial, which improves its capacity to endure, adapt to, and recover from extreme weather conditions.

This study will explore: (1) Climatic events' direct effects on the RIN, examining impacts on capacity, speed, and travel times. (2) Travellers' reroute behaviours will be revealed, and the traffic load redistribution model will be developed to reveal the cascading failure process . (3) The indicator for measuring the RIN performance will be developed, and the resilience of RIN to a climatic event will be measured through the performance reduction during the climatic events affection period. The RIN states during normal operation and climatic scenarios will be generated for accessing the resilience of RIN from a time-spatial perspective. (4) From the perspective of "pre-event maintenance" and "after-event restoration", the critical nodes/links with high risks will be identified and their maintenance will be optimised, and the restoration under climatic events will also be optimised, to effectively enhance the RIN' resilience to climate change. The research contributes to building a reliable, resilient, and sustainable transport system, enhancing the reliability, efficiency, and safety of our daily travel.

The RIN in London and its vicinity, notably comprising highways vulnerable to flooding, is selected as a research area. We have acquired and processed essential data for assessing flood impacts, including flood risk and surface water depths for flood events with 1-in-30-year, 1-in-100-year, and 1-in-1000-year probabilities, light detection and ranging composite digital terrain/surface model with 2m resolution, vehicle count data at nodes from 2010 to 2022, and attributes of links/nodes within the RIN, et al. An analysis is conducted on the direct effects of floods on vehicle speed, capacity, and trip times on the RIN. Subsequently, our efforts will focus on developing a model to understand the cascading failures and the diffusion impact on the RIN.

We observe a gradual increase in traffic flow on the research areas, which follows a linear trend over time. Even flooding events with 1-in-30-year probability result in the closure of numerous road segments and a high road capacity reduction. Therefore, it can be anticipated that rainstorms exceeding the intensity of once-in-30-year events will cause widespread cascading failures, preventing most travellers from moving and substantially increasing trip time.

Climate Resilience of Highway Network

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Resilience emerges as a promising pathway to climate change adaptation that tackles the challenges in risk management. The uncertainty of changing climate may massively increase the size of risk profile and challenge established countermeasures. Besides, the threat of cascading impacts is hard to anticipate due to increasing complexity in infrastructures. To address these, resilience studies are under high priority to understand the interconnectedness and interdependency in Critical National Infrastructures (CNIs). By incorporating a system thinking, resilience science advances the doctrine from the prevention and fail-safe mechanism to a safe-to-fail system design and recoverability, which embraces the inevitability of disruptions. The proposed project aims to develop a system approach to quantify highway resilience in face of extreme weather events, with integrating geospatial analysis, risk assessment, and complex network analysis and evaluating potential cascading failure associated. This is being achieved in three steps.

We are currently working on the step one, which integrates existing data from research and surveys, which aims to create a complex network model of highways and a profile of highway assets in terms of failure probability in specific hazards and their connectivity. Cascading failure within highway network will be examined though simulating overload propagation.

Step two involves developing hazard scenarios using spatially autocorrelated random sampling techniques. Extensive scenario simulations will delineate the potential performance distribution of the highway network, enabling the derivation of resilience metrics. Future climate change impacts will be assessed by comparing current resilience levels with historical data and future projections. Additionally, traffic or logistics demand data will be incorporated to weigh resilience assessments, reflecting the system's service provision capacity during adverse events.

Step three will expand the network model to include infrastructures that are closely related to highways. The investigation focuses on the power grid and communication networks, assessing interdependencies through geospatial risk identification or documented connections from relevant agencies based on data availability. This research underscores the importance of a holistic approach to resilience assessment, offering insights into enhancing the robustness of infrastructure systems and fostering intersectoral collaboration to mitigate cascading failures.

Zero Waste Geopolymer Pavements

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The expansion of highway construction poses significant challenges to the global supply of natural resources exacerbated by substantial mineral waste generation from construction activities. Despite efforts via initiatives like warm mix asphalt and waste prevention and recycling, there remains a pressing need to explore innovative solutions to minimize waste and reduce reliance on new aggregates. This study explores the feasibility of transitioning towards zero waste and carbon neutrality in pavement construction by revisiting conventional methods and embracing underexplored alternatives like in-situ recycling and low-carbon binders. The proposed approach involves a comprehensive strategy aimed at achieving zero-waste pavements through the recycling of reclaimed asphalt pavements (RAP) and crushed concrete aggregates (CCA) into rigid pavements with the aid of geopolymer cement. The methodology is structured around several key work packages: initial stakeholder engagement for project parameter determination, such as available resources, waste streams, and potential trial sites; geopolymer binder exploration compatible with RAP and RCA using mineral waste, clay and excavation soils; laboratory-based feasibility assessments including statistical modelling, and performance comparison with prevailing technologies. Subsequently, geopolymer-based cement, incorporating waste minerals and clay, will replace conventional concrete in rigid pavement production, utilizing RAP and CCA to achieve zero waste. Large-scale and field trials will validate the final product, culminating in a comprehensive life-cycle analysis. In conclusion, this research offers a structured methodology to address waste reduction and carbon neutrality challenges in pavement construction. Prioritising zero waste and carbon emissions is paramount for sustainable resource management. By collaborating with industry stakeholders, conducting rigorous testing, and exploring innovative geopolymers, this study aspires to establish a pathway towards environmentally conscious pavements. Continuous monitoring and analysis are envisaged to refine designs, optimize performance, and foster a sustainable infrastructure paradigm.

Evaluating and Benchmarking Data-driven Performance Forecasting Techniques for Pavement Asset Management

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Accurately forecasting pavement performance is vital for effective pavement asset management, and various techniques are available in engineering practices. With the ever-increasing amount of data available to engineers, data-driven techniques have been increasingly employed for predictive modelling. In such applications, historical pavement data is often utilised to train machine learning models and forecast pavement performance. However, while the choice of the machine learning predictive model is important, the strategy to preprocess the data for machine learning implementations also plays a pivotal role in ensuring forecast accuracy and reliability. This aspect is particularly important because historical pavement data may contain various types of information. For example, environmental data, such as temperature and precipitation data, typically follow a time series format, while material properties, such as the stiffness parameter of concrete materials, are often independent of time. Therefore, incorporating such information that are not necessarily in a compatible format may require additional efforts during the data preprocessing stage. However, studies that systematically summarise and compare data preprocessing schemes for data-driven pavement performance forecasting are limited, resulting in insufficient knowledge and guidelines that engineers can tap into for pavement asset management.

In this study, four categories of data-driven pavement performance forecasting models with varying strategies to preprocess pavement data for training machine-learning-based forecasting models are proposed. The long-term pavement performance (LTPP) dataset is then employed in a comprehensive benchmarking comparison of these categories of models. Employing random forest as the machine learning algorithm, the comparative study examines the impact of data preprocessing strategies, the volume of historical pavement data, and forecast horizon on the accuracy and reliability of pavement performance forecasts. The strengths and limitations associated with each implementation strategy are summarised. Based on these findings, some recommendations are provided: (i) accurately forecasting pavement performance necessitates a comparable volume of historical data spanning the same duration as the forecast horizon itself, (ii) forecasting beyond a three-year horizon may not be advisable, and (iii) the simultaneous consideration of explanatory variables and historical pavement performance data provides a more effective strategy for yielding improved forecasting accuracy and reliability. The relevance of these findings for forecasting the international roughness index (IRI) and the length of longitudinal and transverse cracks is also discussed. The present study contributes to providing pavement engineers with engineering knowledge and guidelines for forecasting pavement performance using data-driven techniques.

An Integrated Road Health Monitoring System Supported by Probabilistic Models and Artificial Intelligence

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Effective utilisation of information is critical for road asset management. National Highways (NH) highlights the importance of data-driven proactive asset management. Despite the advancement of technologies like embedded sensors, smart cars, and Artificial Intelligence (AI) for data interpretation, NH has not fully capitalised on these innovations. Data from diverse sources often remain underutilised, indicating a lack of efficient integration tools for comprehensive understanding and decision-making in road asset management, both reactively and proactively.

This research aims to examine emerging technologies, integrating their data to improve our understanding of road asset performance, now and in the future. A shift from deterministic to probabilistic analysis is important. Given that every technology encompasses uncertainties that cannot be fully eliminated, it is essential to quantify these uncertainties and incorporate the data alongside its uncertainties. This integration can be accomplished via various probabilistic models such as Bayesian network, as well as AI methods such as ensemble learning.

Moreover, as technologies continuously evolve, there will be a persistent necessity to identify, comprehend, and incorporate new advancements. Accordingly, this research will also establish a structured and future-proof system to integrate technologies dynamically for road monitoring. The system remains relevant, adaptable, and updated in the face of future developments. The proposed system will undergo validation through both laboratory and on-site experiments. Furthermore, we will provide a comprehensive user manual to facilitate NH in effectively implementing the proposed changes, both in the present and in the future.

Net Zero Emissions from Road Infrastructure: A Critical Review on Carbon Offsetting Strategies for Their Practical Positioning and Thrust Areas

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The construction and upkeep of road infrastructure, encompassing the procurement of raw materials to the operation of construction equipment, gives rise to a carbon footprint that accounts for 24% of global energy-related emissions and 74% of the transportation sector. In light of the pressing climate crisis and the global commitment to achieve net zero emissions, it is imperative to identify and address the sources of carbon emissions stemming from road infrastructure. This entails identifying the emission pipeline and prioritising strategies for mitigating their environmental impact. This research provides a review of existing and ongoing research in the construction industry to mitigate significant emissions from their respective sub-sectors, with a focus on road infrastructure.

The strategies for achieving net zero emissions that are examined in the rstudy are closely tied to the three primary materials employed in road infrastructure - concrete, steel, and asphalt. These materials together represent the primary source of emissions from road infrastructure, during their production and transportation. The carbon reduction methodologies include the utilisation of low carbon cements, alternative supplementary cementitious materials, the incorporation of recycled aggregates, the transition to low carbon intensive warm-mix asphalts and bio-binders, and the exploration of sustainable steel alternatives. Furthermore, a section of the review also examines ongoing research on carbon capture and storage, with a particular focus on the potential for carbon storage in construction materials through various modes of cement, mineral, and aggregate-based carbonation.

The strategies reviewed are thoroughly examined in relation to the practical application of real-world road infrastructure, considering various factors such as codal restrictions, technological and market readiness, and user acceptance. This analysis highlights the need for further development of certain strategies, particularly those with high potential for carbon reduction but that are currently in the early stages of readiness for implementation. The research also discusses on the carbon offsetting of these technologies, considering their reliance on non-renewable energy sources and the lack of life cycle assessment studies to substantiate their environmental impact.

The study delineates that a timeline-oriented methodology for net zero emissions from any infrastructure ought to encompass two primary components: firstly, a reduction in the quantity of CO2 emitted, and secondly, the capture or offsetting of the emitted CO2. It underscores the necessity of carbon capture within infrastructure, in tandem with emission reduction strategies, in order to achieve net-zero emissions. The study further highlights the paucity of practical and scalable techniques for capturing or removing emissions directly from road infrastructure. It emphasizes the necessity of developing diverse absorbents based on hybrid materials that can surpass the limitations of current carbon absorbers. It also recommends a comprehensive and multi-faceted strategy that includes a life-cycle assessment for net zero emission approaches. This would require identifying hybrid strategies that incorporate complementary techniques to mitigate the limitations of each other.

With several promising road schemes and projects aimed at creating a sustainable road network across UK, the systematic review presented in the study, which critically evaluates the merits and drawbacks of each technology, can assist in selecting the most effective blends of net zero emission strategies, by combining the advantages of each and surpassing the standalone processes.

Roads Fit for a Changing Climate: Reviewing the Climate Adaptation of UK pavements

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Climate change is projected to cause increased mean temperatures, wetter winters and drier summers in the UK. Highway infrastructure, including pavements, is anticipated to be poorly affected by these changes, with increased pavement rutting and cracking expected if design and maintenance practices remain unchanged. Roads support 88% of all passenger miles and 79% of freight miles in England and so ensuring that our highway infrastructure is well adapted to climate change is paramount.

To explore opportunities and barriers in improving climate adaptation of pavements, existing academic literature and the international standards of Australia, India, US and UK were reviewed. Furthermore, 15 semi-structured interviews were conducted with industry representatives to gather insight from various perspectives. Opportunities for improving climate adaptation of UK roads included: utilising temperature inputs to allow UK design methodologies to be better suited to the rising air temperature; broadening understanding of the relationship between climate adaptation and mitigation; and exploiting any benefits that climate change may bring such as increased suitability of roadworks in winter. The two main barriers identified were a resistance to change and a lack of climate adaptation focus within the role of an engineer.

Automatic Virtual Fluid Calibration through Behaviour-mapping for Robotic Pavement Crack Sealing Simulation

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Accurate robotic crack sealing (previse deposition of sealants) has been challenging due to the complex fluid flow behaviours in a random crack geometry. Recent advances in robotic fluid manipulation paves the way to tackling such problem through computationally cheap and fast yet approximate simulations such as the position-based fluid (PBF) method, a particle-based fluid model. As the simulated (artificial) material properties have no direct mapping from the real-world physical parameters (e.g., viscosities, etc.), the simulator normally needs to undertake an exhaustive searching process (of the simulated material parameters) to reach a satisfactory simulation (most closely mimicking the physical material). This is time-consuming and impair the feasibility of the PBF method for informing real-time robot operations.

This study aims to explore handy virtual fluid calibration methods utilising a Bayesian optimisation algorithm to automatically map the flow behaviour of PBF sealants to real-world dynamics for parameters identification. Three different existing physical fluidity characterisation methods, including a flow cup test, a vertical surface slump test, and a slop test, are selected for the fluid calibration, followed by a crack sealing test using the calibrated sealant simulation to validate the calibration process. The results from different fluid calibration methods are analysed and compared, showing their adaptability to fluids with different flow behaviours. It is proven that automatic behaviour-mapping-based virtual fluid calibration provides a low-cost prerequisite to underpin the efficient and effective implementation of fast robotic pavement crack sealing simulation, and it has the extensibility to general robotic fluid manipulation.

Control and Implications of Mixed Autonomous Vehicle-Infrastructure in a Heterogeneous Multi-agent System Framework

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Connected autonomous vehicles (CAVs) will be prevalent given the technology maturity and government promotion. Transportation system administrators and constructors should be prepared to leverage the controllability and potential of CAVs when they gradually permeate the roads in the near future. Current studies for CAVs usually consider either the control of a single CAV with human-driven vehicles (HVs), or collectively control among CAVs only. Moreover, their interactions with intelligent road infrastructure are investigated separately, which oversimplifies the heterogeneity among CAVs, HVs, and intelligent road infrastructure in the near future transportation system. Numerous challenges of heterogeneous multi-agent transportation systems, such as their interactions, partial controllability, and implications, are not addressed.

This project will study the control and implications of a heterogeneous multi-agent transportation system mixed with CAVs, HVs, dynamic reversible lanes, and intelligent traffic lights. First, with awareness of the high spatial-temporal resolution and real-time characteristics of transportation systems, an efficient heterogeneous data fusion and multi-agent modelling framework will be developed. Second, optimal control policies for the heterogeneous multi-agent transportation system satisfying the safety requirements will be developed. Third, the opportunities and barriers to practical implementation and the implications for society and governance will be analysed. Through this project, we will push forward the technologies and insights of CAVs at dynamic reversible lanes and intelligent intersections and move towards a safer and more efficient system whereby CAVs can be highly leveraged.

Highway Intelligent Traffic Control System Based on Vehicle-road Coordination and Multi-agent Technology

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The escalating global issue of traffic congestion is leading to longer travel times, more fuel use, and pollution. This study explores how self-driving car technology could improve traffic management on highways. We propose the development of an integrated system leveraging multiple intelligent techniques, including experiential learning, to optimise traffic directives and route planning. We will examine scenarios involving exclusively autonomous vehicles and those where they share the road with regular cars. Anticipated outcomes suggest that our system can mitigate traffic congestion, reduce travel durations, and streamline traffic management. It will also exhibit proficiency in diverse traffic conditions, facilitates intelligent routing decisions, and will optimise electric vehicle charging station utilisation. Additionally, we will demonstrate how our system can support energy-saving by allowing cars to interact with the electricity grid. By including smart charging for electric cars and careful placement of charging stations, our system fights traffic congestion and supports a cleaner environment and energy savings. These findings are essential for the future of intelligent transport systems, showing ways to benefit society, the economy, and the planet.

A Multi-Agent System for Heavy Machine Operation through Context-Aware Sensor Fusion

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Construction sites in the UK are quite dangerous, causing over 20% of worker deaths. Not only do these accidents take lives, but they also cost companies a lot due to damaged equipment and as compensation for the losses. A big reason for these accidents is that heavy machine operators are often not fully aware of everything happening around them. Hence, it is time to make use of the concepts in Computer Science, Robotics and Automation to enhance safety in construction environments where automation is challenged due to the complexity of environment dynamics.

The project will be implemented in three stages. First, to figure out what type of safety construction workers require and what dangers they face, and then to create a digital interface that they can use to monitor their surroundings. Next, is to develop a smart algorithm to help the system better explore and understand the construction site as work happens. Finally, embed features such as visual and sound alerts to make the system even more effective on a busy construction site. The idea will be tested on real sites to fine-tune it. Although robots have been deployed in the manufacturing of equipment in industries, it has hardly been used in the construction field. If successful, this technology could make construction sites much safer, benefiting society and showcasing how different fields can work together to solve big problems. This research implements a digital interface between workers and machines which comprises robots and algorithms that can effectively handle complex, dynamic environments and ensure safe, cooperative behaviour among multiple agents. For instance, once implemented, when a machine operator wants to get a picture of a blind spot or a faraway region, they can request a robot to go closer towards the area of interest and provide a better overview of the scenario. The specialty of this idea is that it is modular, and the users will be able to fix it in a different work environment and monitor that environment if required. The research is currently creating algorithms to ensure efficient communication among machines, enabling them to share information promptly. To put it simply, this will be a bunch of 'talking machines' in the field. For the information flowing across the system, concepts underlying reinforcement learning, self-organisation and embodiment will be used.

Although the outcome of the entire research has not been accomplished yet, it was found that automated agents such as robots and drones could effectively be used to enhance the sensory inputs to a digital interface covering a construction environment. However, human requirements covering the operator and worker perspectives are underexplored at present. Grounding these aspects will help implement successful digital interfaces in the context.

Pavement Maintenance Vehicle Design for Efficient Infrastructure Management

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Highways are critical to the economy of a country and their condition is directly connected with the safety and comfort of its users. Currently, transport authorities rely on routine visual inspection by a site crew, which is usually infrequent, expensive, time-consuming and without proper prediction and control over material usage and maintenance time. Repairs to roads are large scale disruptive processes that can close roads for extended periods delaying traffic and contributing to pollution. There is a pressing need for innovative road pavement maintenance designs that can streamline the data collection, the decision-making processes, and execution of maintenance processes while minimizing disruptions and costs, ultimately contributing to more efficient infrastructure management.

The research employs a multidisciplinary approach, integrating principles from mechanical engineering, materials science, and transportation engineering. Data collection involves the use of advanced sensing technologies mounted on maintenance vehicles, including Light Detection and Ranging (LiDAR), infrared cameras, Inertial Measurement Unit (IMU), temperature sensors, and ground-penetrating radar. These sensors gather detailed information about pavement conditions, including surface defects, subsurface damage, and material properties. Analysis techniques include data processing algorithms, statistical modelling, and simulation studies to assess pavement conditions and prioritise maintenance activities. Additionally, the methodology incorporates principles of vehicle dynamics and control to optimise vehicle performance and manoeuvrability during maintenance operations.

The research yields significant insights into the development of road pavement maintenance vehicles optimised for efficient infrastructure management. Findings indicate that the integration of advanced sensing technologies enables more accurate and timely assessment of pavement conditions, facilitating proactive maintenance interventions. Moreover, leveraging data-driven decision-making processes allows for the prioritisation of maintenance activities based on the severity and anticipated future deterioration of pavement defects. The research also highlights the importance of vehicle design considerations, such as payload capacity, mobility, and energy efficiency, in ensuring the effectiveness and sustainability of maintenance operations.

In conclusion, the development of road pavement maintenance vehicles tailored for efficient infrastructure management represents a crucial step forward in addressing the challenges of maintaining transportation networks. By leveraging advanced sensing technologies and data-driven decision-making processes, these vehicles can optimise maintenance strategies, minimise disruptions to traffic flow, and reduce the overall lifecycle costs of pavement assets. Moreover, the integration of sustainable design principles ensures that maintenance operations are conducted in an environmentally responsible manner. The implications of these findings extend beyond road pavement maintenance, serving as a model for the integration of technology and innovation in infrastructure management practices, ultimately enhancing the resilience and sustainability of transportation systems.

The Pavement Repair Robot as an Embodied Predictive Simulator

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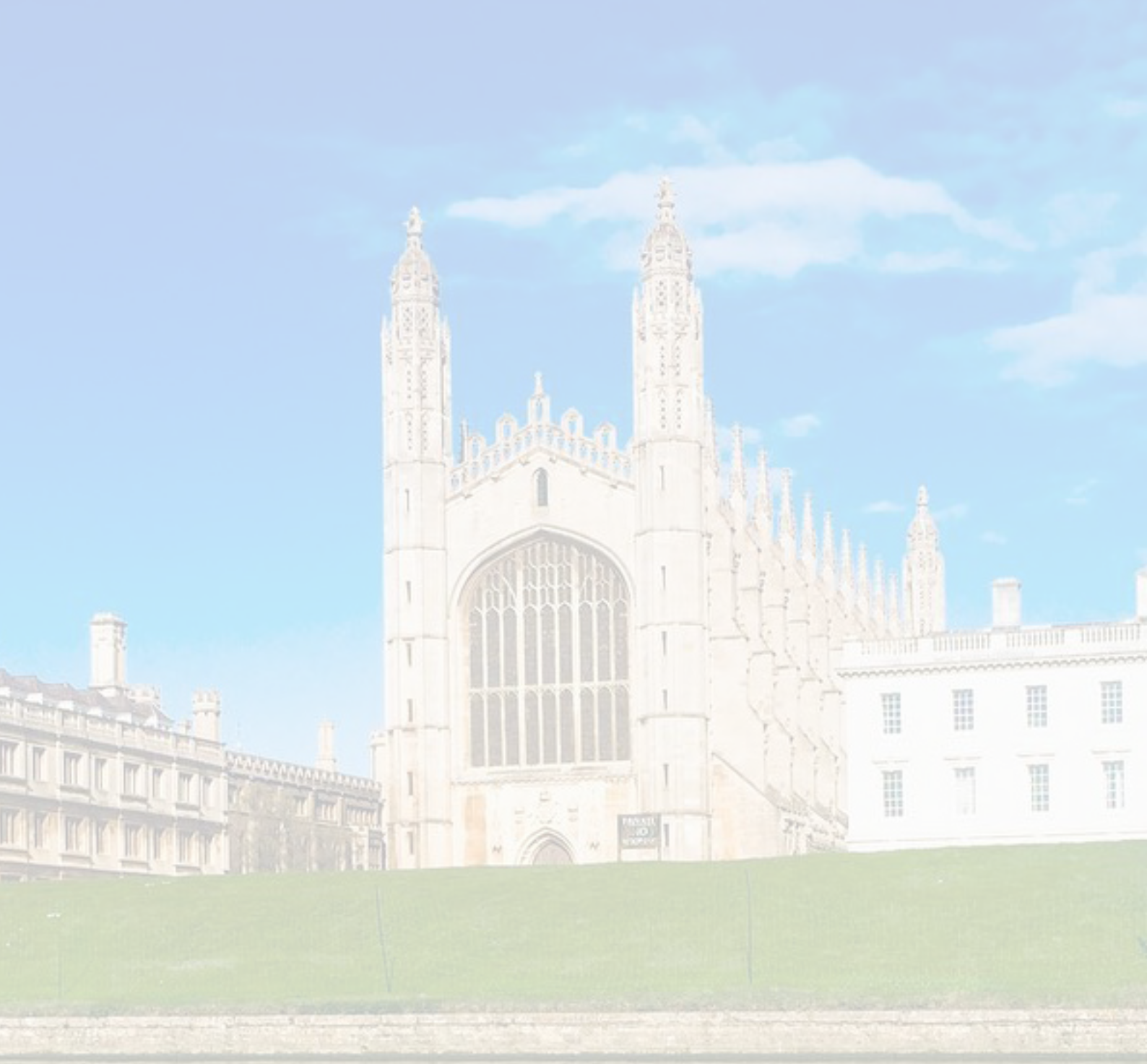
Robotic manipulation faces significant challenges in adapting to novel materials and tasks, contrasting with humans' intuitive understanding and ability to internalise new scenarios. Current data-driven control mechanisms lack a comprehensive understanding of action policies, hindering adaptation to unfamiliar situations. In contrast, humans utilise analogies from previously encountered phenomena, demonstrating the importance of a deep understanding of the world's dynamics for robust interaction. This research draws inspiration from the active participation and mental modelling observed in natural organisms. The proposed embodied predictive simulation diverges from traditional disembodied simulators by prioritising mechanical stability, real-time feedback, computational speed, and adaptability. While deep neural networks offer learnable models with potential for improvement, they exhibit limitations in adapting to unseen scenarios. Conversely, Newtonian mechanics is adaptable but lacks incremental learnability. In the specific context of highway maintenance, this study employs position-based dynamics for crack filling simulations, operating at approximately half real-time speed. Coupled with optimisation algorithms, this approach facilitates rapid discovery of automated crack sealing methods without physical experimentation. The simulation's ability to visualise hidden sub-surface material flows enables anticipation and understanding of new material effects. This intuitive physics-based workflow proves adaptable to diverse liquid manipulation tasks, paving the way for future research on robotics in highway maintenance.



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