Innovative UHPFRC Trackform System for the Coventry Very Light Rail Program

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Abstract

The Coventry Very Light Rail (VLR) program, a collaborative research and development initiative, to date supported by $30 million in UK government funding, aims to create a low-capital expenditure (CAPEX), low-carbon, rail-based public transportation system for Coventry and other cities. This ambitious project, involving partners from academia and industry, primarily focuses on developing an innovative trackform system in conjunction with a bespoke vehicle design.
Conventional rail trackform systems typically necessitate deep foundation layers, increasing risk, duration, complexity, and costs, particularly in urban scenarios. The primary objective of this project is to engineer a shallow yet resilient trackform that can be installed on diverse substructures commonly found under existing road systems, which vary greatly in material, construction, and bearing capacity. This approach minimizes the need for deep excavation, substantially reducing project risks, duration, complexity, and costs.
The 4-year R&D program has produced a patent-pending track system incorporating a concrete slab design whose stringent performance requirements were only feasibly met using Ultra-High Performance Fibre Reinforced Concrete (UHPFRC). Following prototype manufacture and two successful pilot installations of the system, the program has secured an additional $42 million in funding to construct a 1.6 km (1 mile) requirement-validation demonstrator route, requiring the provision of approximately 1,100 UHPC slabs (about 800 m^3 or (1,046 yd^3)). If successful, this city-centre demonstrator route will pave the way for a full network expansion in Coventry and other cities, necessitating the production of thousands of UHPC slabs annually.

Keywords: Coventry Very Light Rail, CVLR, UHPC Track Slab, Structural health monitoring

1. Introduction; the Coventry VLR programme

The Coventry Very Light Rail (VLR) programme, initiated in 2017, is a major effort to develop a novel, low-capital expenditure (CAPEX), low-carbon, rail-based public transport system for operation within Coventry (Coventry City Council). The program aims to deliver an affordable rail-based public transport system with on- and off-street running capabilities, using lightweight, self-propelled, emission-free vehicles, providing a "turn up and go" service to encourage the public to shift away from cars.
Currently in an advanced R&D stage, the programme has two main workstreams led by the primary innovation partner, WMG, University of Warwick:

- **Vehicle**: Design and construction of a lightweight, battery-propelled, rail-guided vehicle.
- **Track**: Comprehensive development of an innovative, shallow trackform, minimally disruptive to underground utilities when installed into roads.

The track development workstream aims to deliver a detailed, tested, and verified design specification for an innovative trackform with the aim of enabling significant reduction in the

typical urban light-rail construction costs. The success of this workstream is crucial for achieving the overall program's target cost savings, making it technically viable and affordable.
The average urban light rail project in the UK has a CAPEX of over £30 million/km. Most trackform systems used can be supplied and installed for a direct cost of £3-4 million/km of double track; however, when including all necessary enabling works, they typically account for 65-80% of a project's CAPEX, as illustrated in Figure 1.

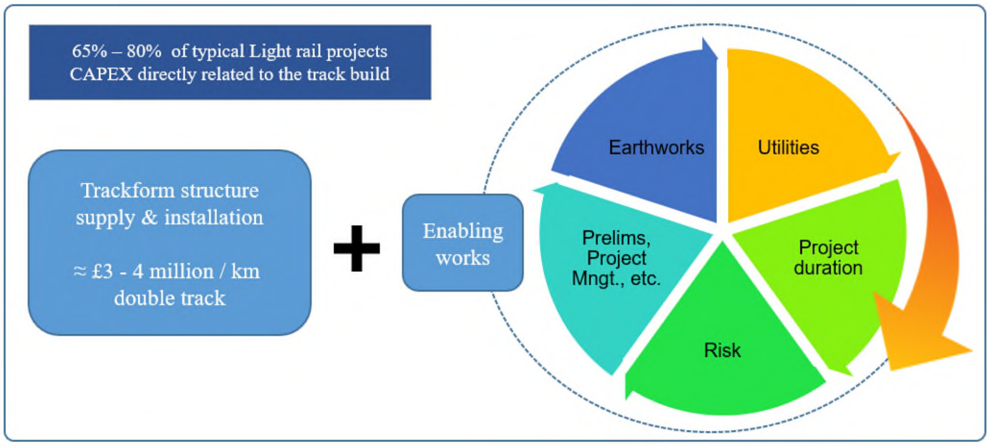

Figure 1: The central strategy of the CVLR Track system focuses on investing in a holistic design approach of the trackform structure, intended to facilitate a substantial reduction in the costs of enabling works, which typically far exceed the trackform system expenses, especially in complex urban scenarios.

The key strategic elements of the novel trackform system identified as being essential for achieving the cost reductions, include (but are not limited to):

- A shallow trackform located within the top structure of existing roads.
- Minimization of utility relocation; significant reduction of excavation and earthwork costs and associated project risks.
- Simple installation and rapid removal methodology for the track, reducing disruption during implementation as well as securing buy-in from buried utility owners.
- Substantial reduction in the time needed to deliver a light rail scheme in a real-city scenario.
- Utilization of state-of-the-art BIM and digitization tools to identify potential civil engineering issues before construction.

Additionally, the design of the track system was based on two key enabling assumptions:

- No catenary systems and related limitation of underground stray currents hence requiring a vehicle with on-board propulsion energy source.
- CVLR vehicle with low axle loading (5 kN (225 lbf) dynamic axle loading).

2. CVLR Track System Requirements Development

The single technical system requirement that differentiates the CVLR track from most existing rail track specifications is the total system height, which has a maximum dig depth target of 300 mm (12 in). Figure 2 illustrates that most trackform systems have a minimum overall system height of 700 mm (27.5 in), though this can be optimized to about 550 mm for light rail applications. A common element of this total height is a 300 mm (12 in) layer of hydraulically bound material. A primary aim of this project is to develop a trackform superstructure that does not require this high-bearing-capacity supporting layer and instead relies on the existing, highly varied road substructure. This would necessitate a track superstructure with sufficient flexural stiffness to ensure its integrity and reduce stress concentrations transferred into the subgrade.

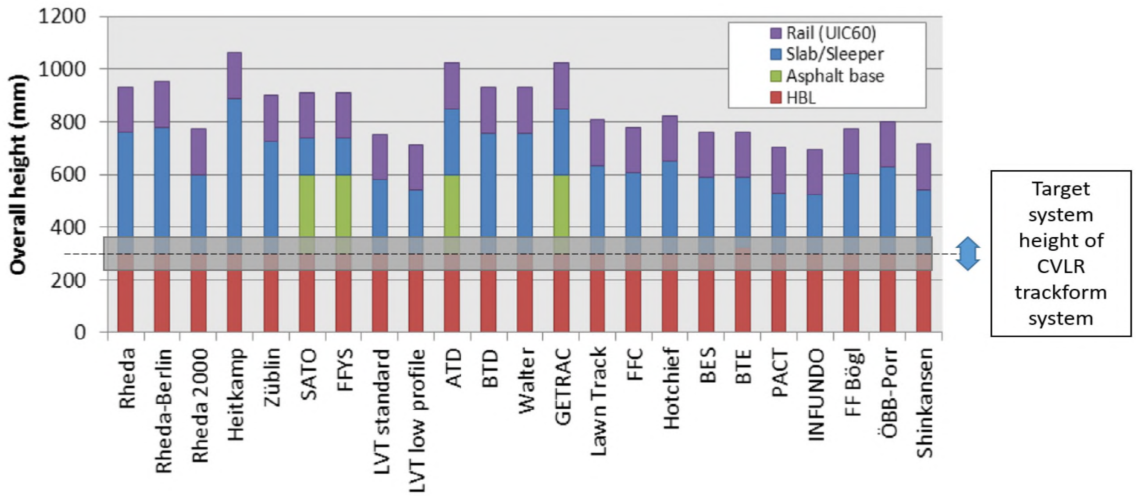

Figure 2: Overall height of existing slab track systems. Source: (International Union of Railways, UIC)

Figure 3 summarizes the other main system design requirements and their direct implications on the CVLR Track system configuration and design. In addition to the shallow depth of the system, requirements for compliance with access to surface and buried equipment and utilities posed severe challenges and restrictions to the design process.

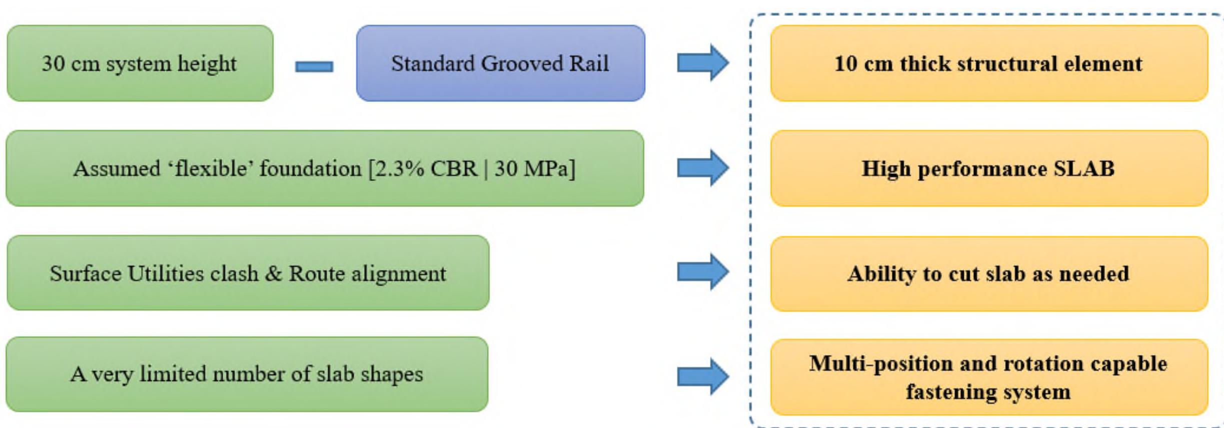

Figure 3: Summary of the fundamental design requirements that the CVLR track system was developed against. UHPC is possibly the only feasible material that offers the performance required by this application.

3. The CVLR Track System

The resulting CVLR Track system is fully defined in a pending patent (Micallef and Manage, *Rail Support Arrangement*) and illustrated in Figure 4. The CVLR track system successfully meets all the strategic requirements previously defined. It features a net height of 26 cm (10.2 in), enabling a real-world dig depth target of 30 cm (12 in). A high-performance slab is crucial to allow installation on subgrade conditions expected to be found at a 30 cm depth for 99% of Coventry roads.

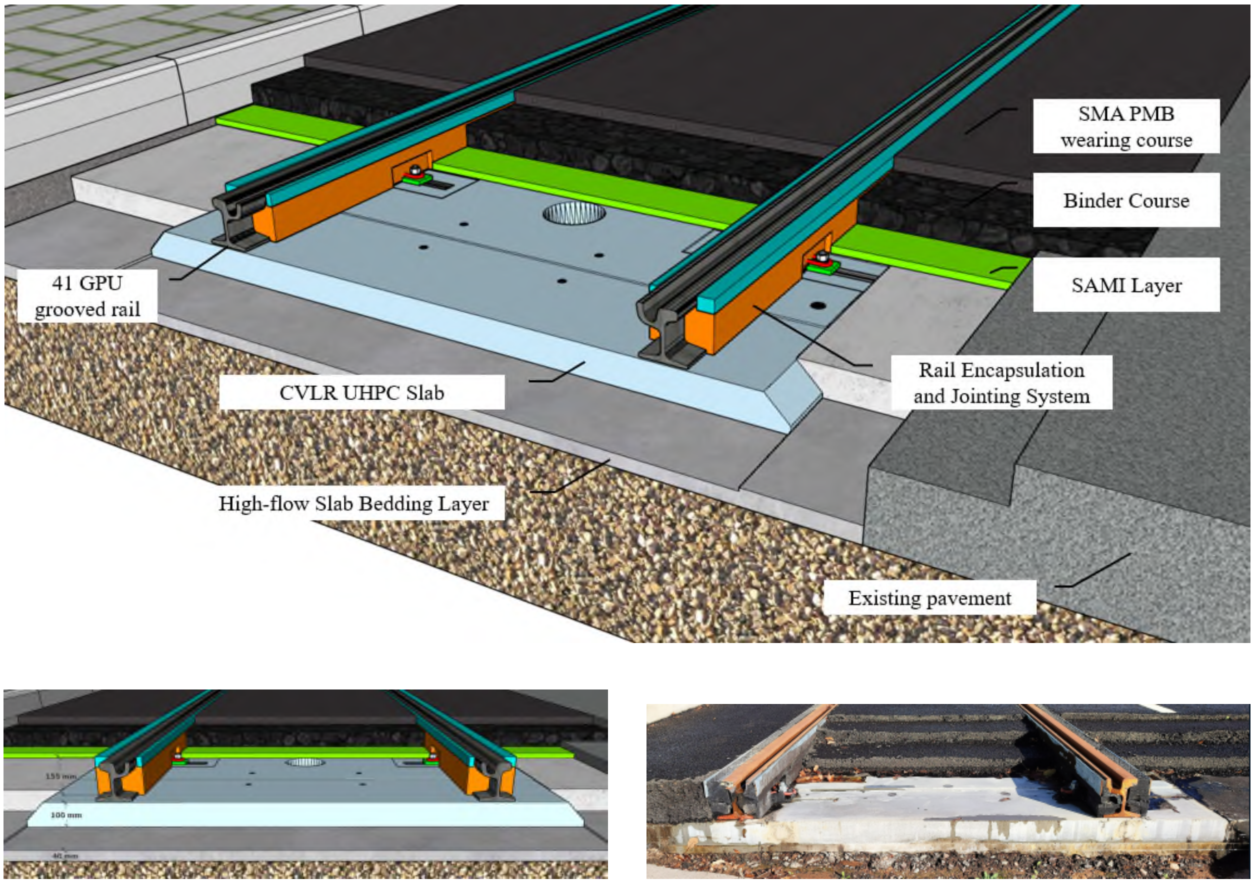

Figure 4: The CVLR track system has been designed to sit just 30 cm (12 in) into an existing pavement structure requiring the supporting subgrade to have a minimum bearing capacity of just 2.3% CBR.

4. The CLVR UHPFRC Slab

The key structural and function sub-system of the CVLR trackform is the CVLR UHPC slab illustrated in Figure 5. Some of the salient features of the slab include:

- The slab has a thickness of just 105 mm (4.13 in.) enabled through the utilisation of UHPC.
- Integrated cast-in channels providing a flexible-location fastening system, enabling any route alignment to be delivered using the same standard slab, as shown in Figure 6.
- The CVLR Track system employs a positive mechanical rail fixation system, not relying on the encapsulation and embedment of the rail for safe rail vehicle operation.
- The fibre-reinforced slab allows for cutting to accommodate route alignment and fitting with utility access holes, as depicted in Figure 7.
- Only one slab shape needs to be stocked for repair and maintenance, which is critically important to comply with the requirements imposed by a buried utility emergency repair scenario.
- The UHPFRC slab will retain structural integrity and safety in an overload scenario, such as an abnormal-load vehicle trespass or limited localized subsidence of the subgrade layer.

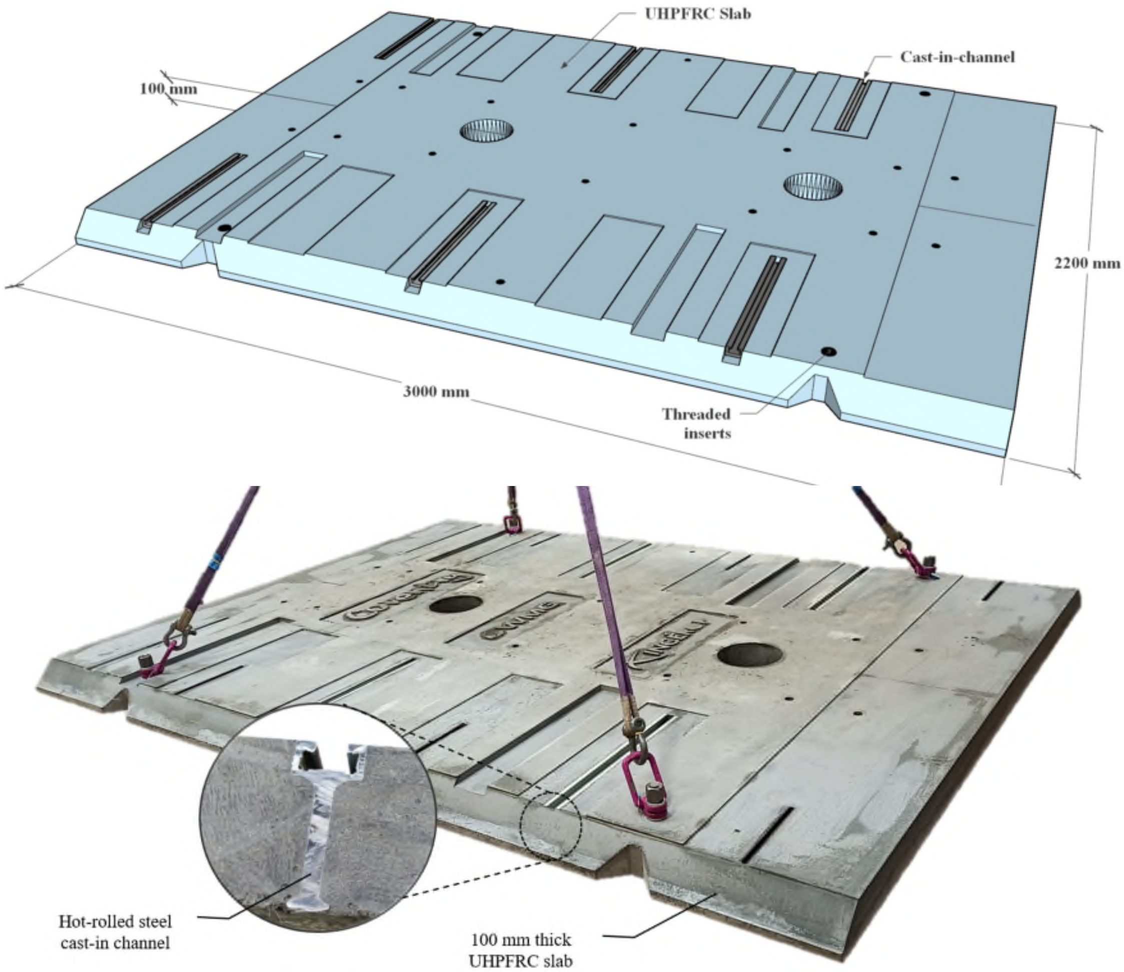

Figure 5: The CVLR slab is 3 m x 2.2 m x 0.1 m thick UHPC slab, weighing approximately 1700 kg (3750 lb)

Figure 6: **The integrated cast-in channels within the UHPC slab allow for rails to have any curved alignment without the need for a bespoke slab to be cast for each uniquely shaped section of the route.**

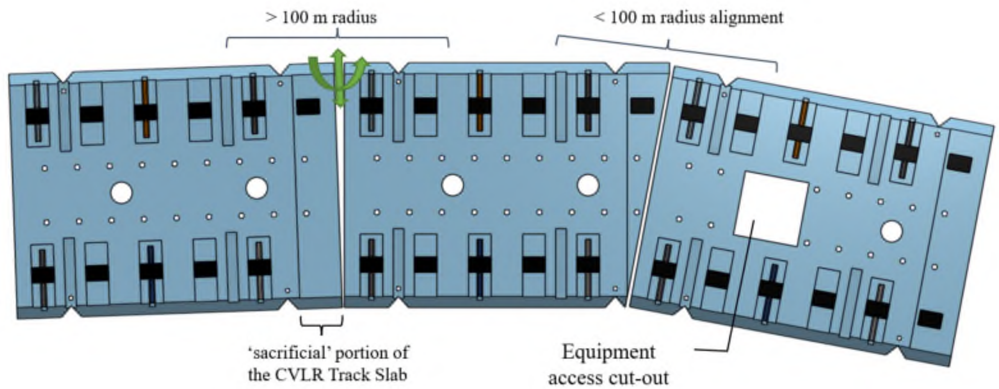

Figure 7: The same-shape casting tool can be utilized to manufacture all the slabs required for any route alignment at volume, which is especially advantageous in urban environments where significant portions of curvature are typically encountered.

5. System testing and technical verification

The CVLR track program is currently in its technical verification testing phase, which comprises two main elements: installation methodology and structural integrity testing.
The proposed installation methodology for the system is documented in a pending patent (Micallef and Manage, *Method of Installing a Rail Support Arrangement*). While not a primary requirement, the inherent design features of the slab resulted in an exceptionally efficient installation process, demonstrated during successful pilot installations of the system. This included a 36 m (118 ft) single track integrating a 4% vertical inclination with a straight horizontal alignment transitioning into a 25 m (82 ft) radius curvature, as illustrated in Figure 8. This installation was completed in less than 8 single-shift days.

Figure 8: A 36 m (118 ft) pilot installation of the CVLR Track system was completed in 8 single-shift days

The secondary aim of the pilot installation is to investigate the system's structural performance. The pilot installation is equipped with a state-of-the-art structural health monitoring system that integrates strain gauges within the slabs, rail, and asphalt pavement, along with various sets of accelerometers, relative movement sensors, and pressure load cells. The system's response will be automatically labelled against the specific axle loading and vehicle speed recorded by a weigh-in-motion sensor integrated with the SHM system as depicted in Figure 9.

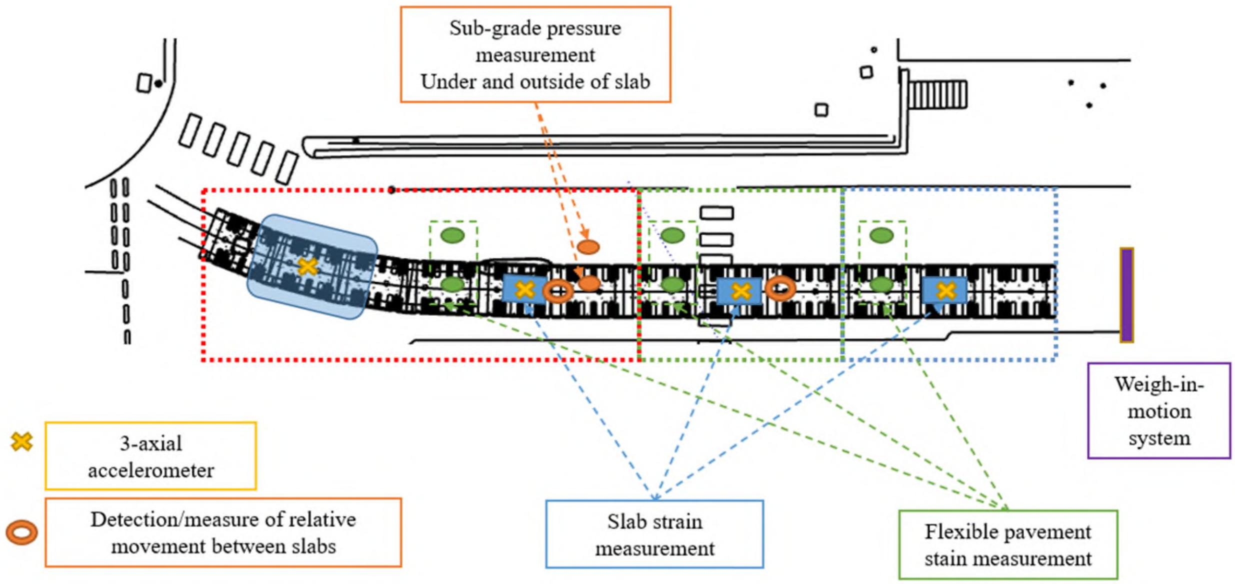

Figure 9:, integrated with a structural health monitoring system that will provide real-world measurement of the strains the UHPC slabs will need to resist during operation.

The data will be used to setup a CVLR track digital twin (DT), as illustrated in Figure 10.

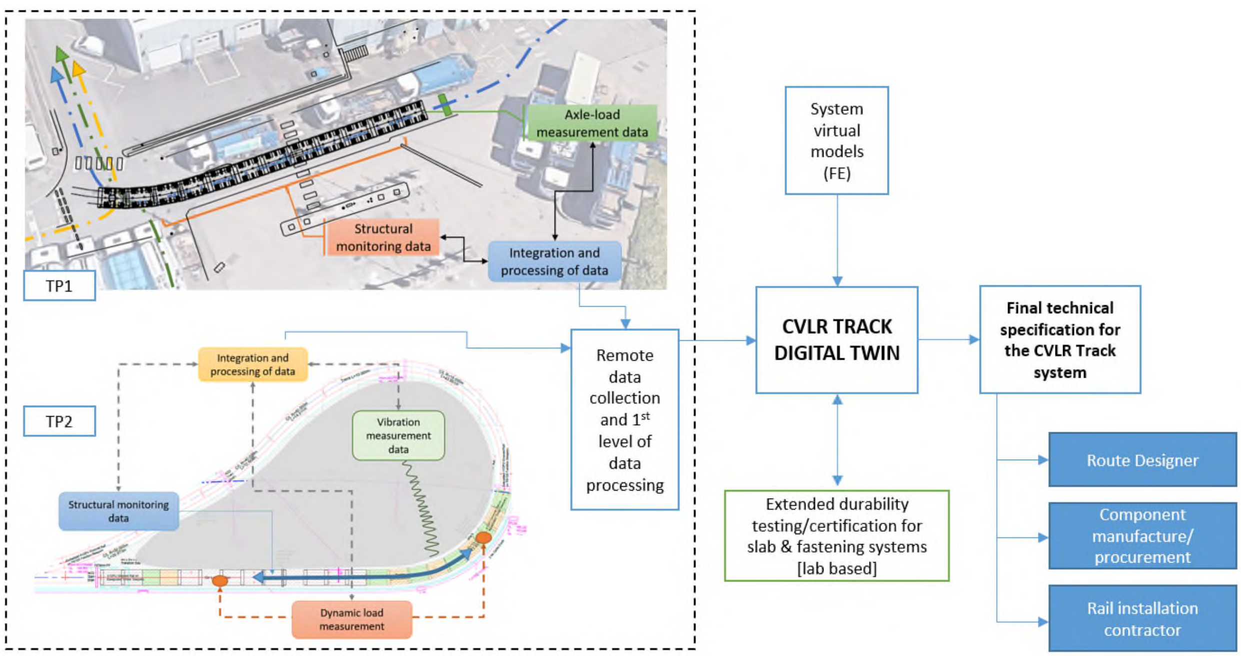

Figure 10: The main system-level technical-verification testing phase of the project consists of two pilot installations (TP1 and TP2). These installations are intended to test various elements of the system's constructability and assess the impact of loading imposed by both road-going vehicles (TP1) and rail vehicles (TP2). Data collected from both projects will help update the virtual models of the system, on which the complete CVLR Track system specification will be based.

The DT model will be utilized to forecast the system's long-term performance and inform decisions on which specific aspects of the system require further investigation. Ultimately, it will support the issuance of the final CVLR Track system specification, which will be utilized by UHPC slab precasters, route alignment designers, and infrastructure installation contractors to deliver the transport system to Coventry and beyond.

6. Conclusion

The Coventry Very Light Rail (VLR) program has made significant strides in developing an innovative and cost-effective trackform system that addresses the critical challenges associated with traditional rail-based public transportation systems in urban environments. Enabled by the use of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC), the CVLR track system offers a shallow and resilient trackform that can be installed on diverse substructures commonly found under existing road systems, greatly reducing the need for deep excavation and minimizing project risks, duration, complexity, and costs.

The UHPFRC slab, a crucial structural component of the CVLR track system, has been meticulously designed to meet stringent performance requirements such as flexural strength and adaptability to various route alignments. The system is undergoing extensive testing and technical verification, including pilot installations and a state-of-the-art structural health monitoring system, validating its effectiveness and efficiency in real-world scenarios.

The CVLR track system holds immense potential for expanding rail-based public transportation networks in Coventry and beyond, contributing to the adoption of sustainable and low-carbon transport solutions. The project's success has not only highlighted the possibilities of UHPFRC as a material for urban infrastructure but also provided invaluable insights and lessons for future transportation innovations. As research and development efforts continue, along with the application of digital twin technology, further refinement of the CVLR track system will support its widespread implementation in urban settings, revolutionizing public transportation infrastructure.

7. Acknowledgements

This program has been funded by the Council of the City of Coventry. All the intellectual property generated throughout this program is the sole property of CCC.

8. References

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