AUTOMATED MANUFACTURING OF SMART TUNNEL SEGMENTS

Author: **Tresor Tshimbombo,** PhD Student

University of Strathclyde, Department of Civil and Environmental Engineering

1. Project aims and Objectives

The project aims to demonstrate a robotic process for installing wireless sensors into precast tunnel segments for the Lower Thames Crossing (LTC) road tunnel.

The project objectives are:

- Proof-of-concept of robotic installation of wireless sensors into and onto precast concrete elements;
- Assessments of performance and robustness of smart elements during accelerated ageing;
- Demonstrations of ad-hoc wireless networks between multiple smart elements;
- Business case and impacts reports with pathways towards commercial implementation.

2. Design methodology & implementation

Standard tunnel segment from LTC road tunnel has been downsized With a 1/5 scale and fabricated with a fibre reinforced concrete.

Using a 6-axis robotic arm UR-10, we picked and placed (PnP) the Standalone wireless node hosting a vibrating wire strain gauge (VWSG) on the metallic formwork before casting concrete. The box housing the node is covered with a set of Neodymium magnets.

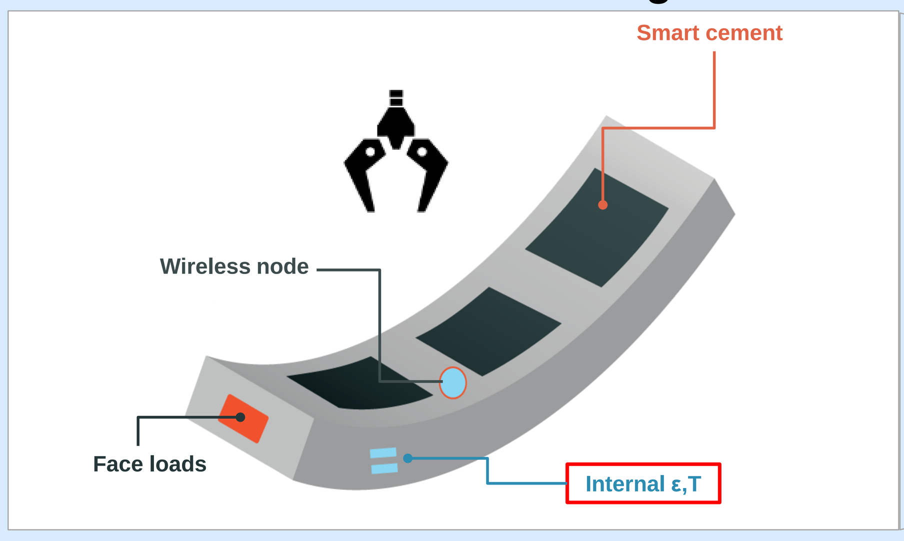
At the same time, we designed a performance assessment framework Combining most recent findings in the literature ([1],[2]).

The smart segment left to cure for 28 days before submitting it to cyclical loadings. Two segments are casted, one instrumented (containing box and VWSG) and the other left plain. The latter is tested up to failure both in flexion and compression. 40-50% of the failure load is then used as maximum load for instrumented segments.

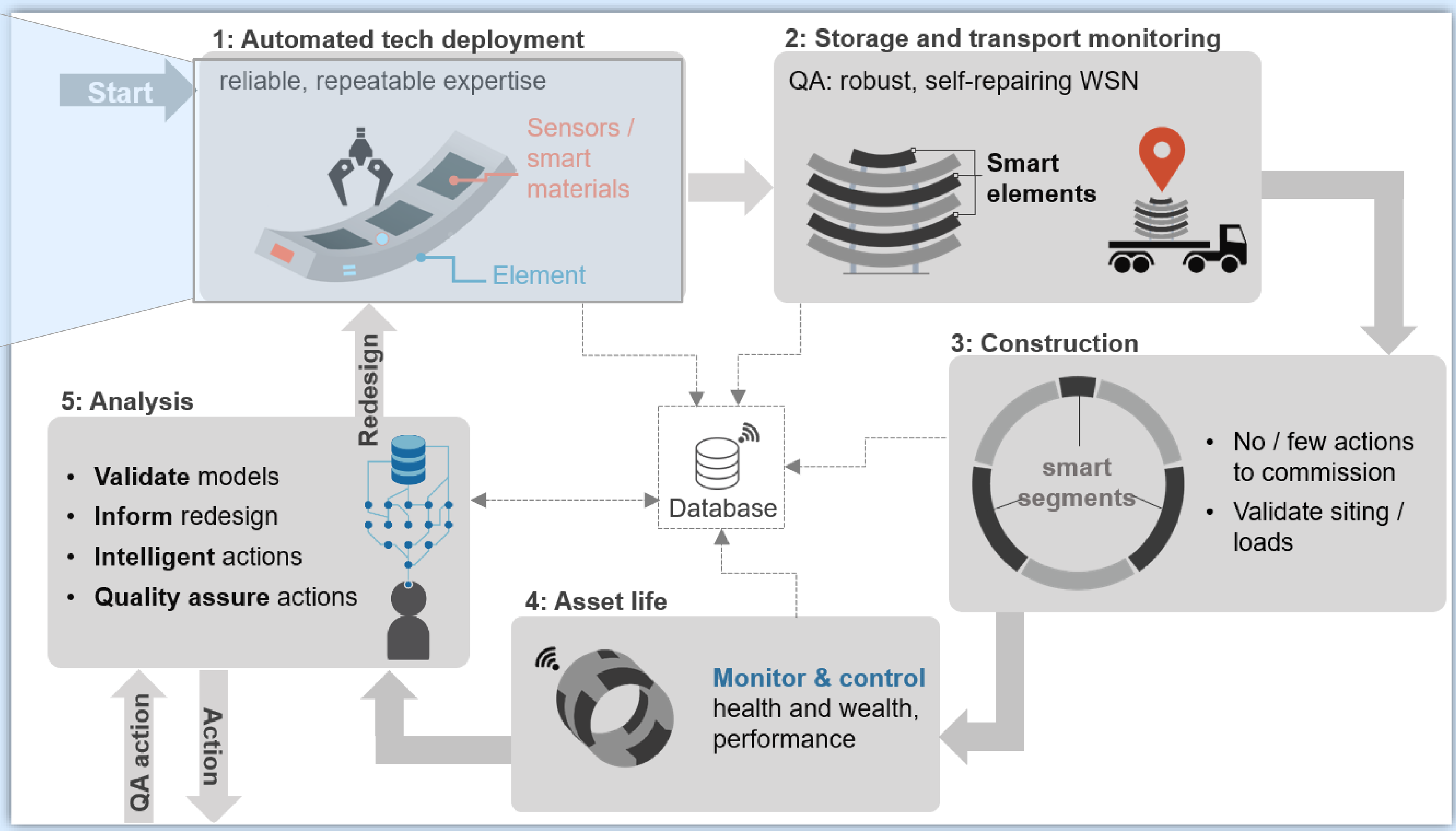
Concept of automated manufacture of smart segment

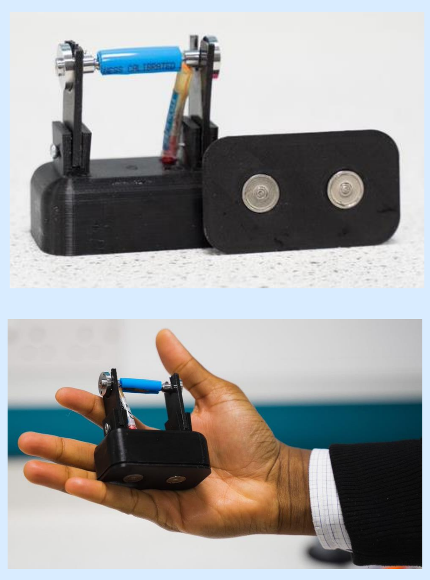
Sensors in smart segment make it possible to track location, physical and structural parameters during the whole lifecycle (See smart segment vision).

The standalone wireless node hosting a small sized VWSG* (see below) can robotically deployed before casting concrete

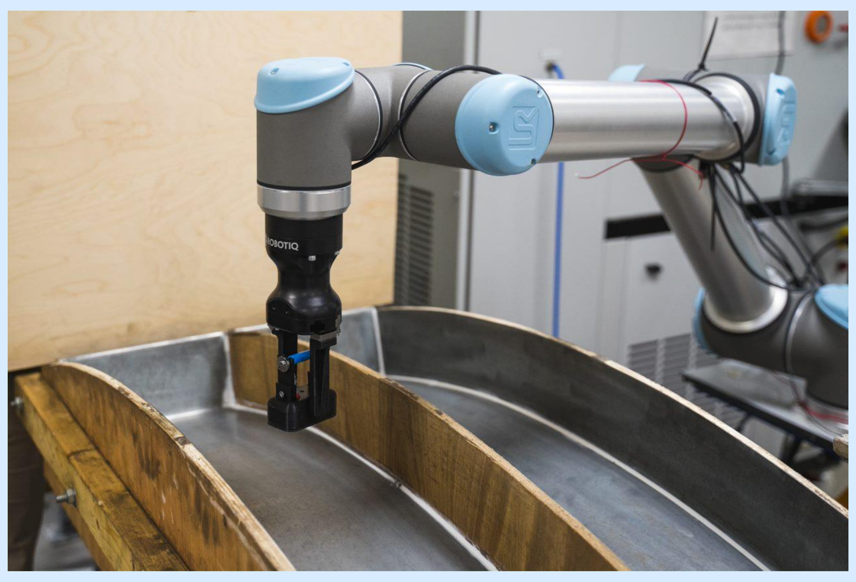


Smart segment vision





Magnetic box to host VWSG and wireless node



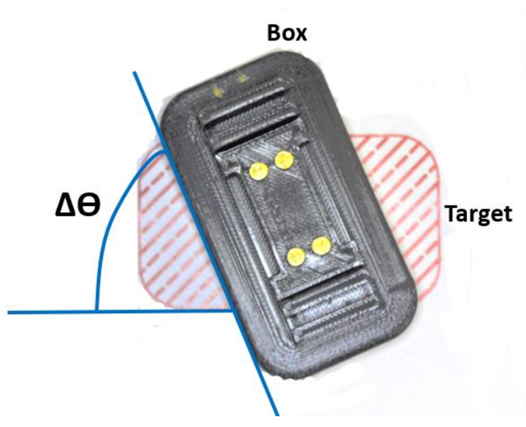
Pick-and-place of magnetic box using 6-axis collaborative robot before casting.

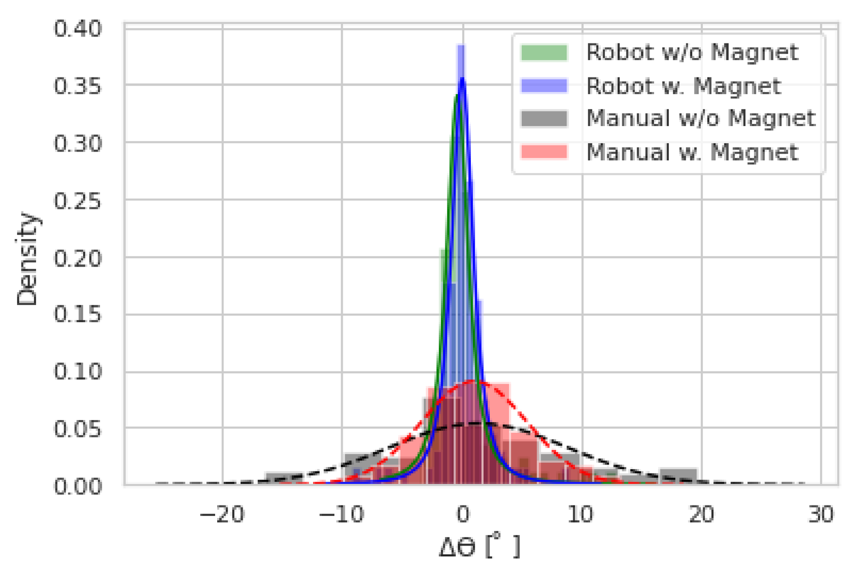
3. Results

3.1. PnP performance assessment

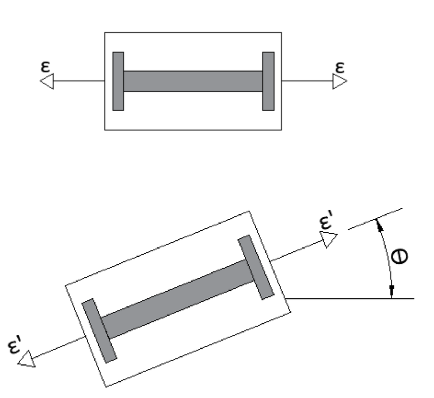
The performance assessment consisted in measuring the error of the angular deviation during the PnP process.

The distributions of angular errors for 4 scenarios plotted below show that the robotic PnP of the magnetic box presents the smallest dispersion.

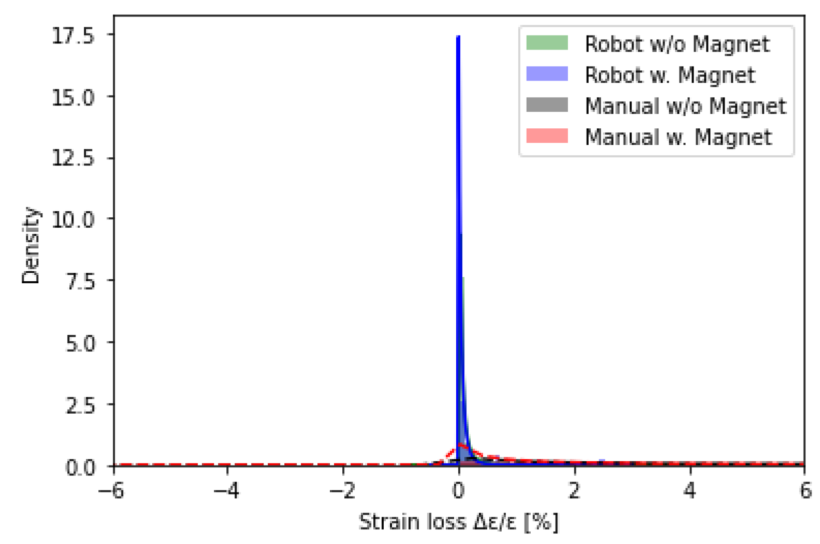




Similarly, the strain loss due to the angular error is smaller when compared to other scenarios.

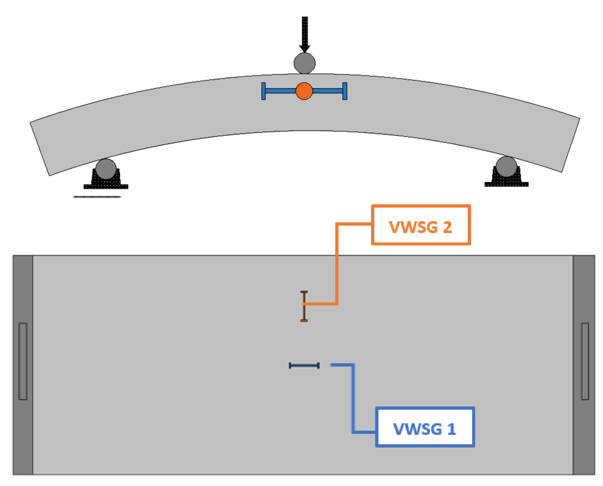


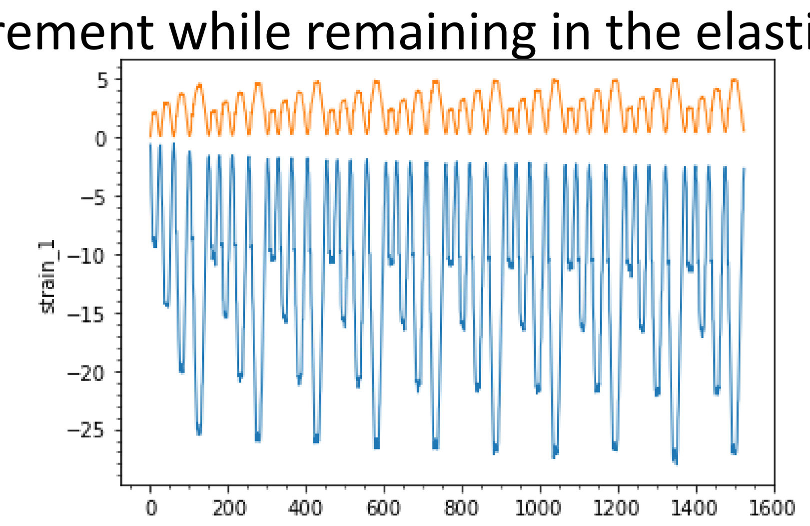
$$\varepsilon' = \frac{\varepsilon}{2}(1+\cos 2\theta)$$



3.2. Smart segment

Through a series of repetitive 3-point-bending tests on smart segments instrumented with 2 VWSGs, we proceeded to assessing The repeatability of strain measurement while remaining in the elastic zone of the concrete.



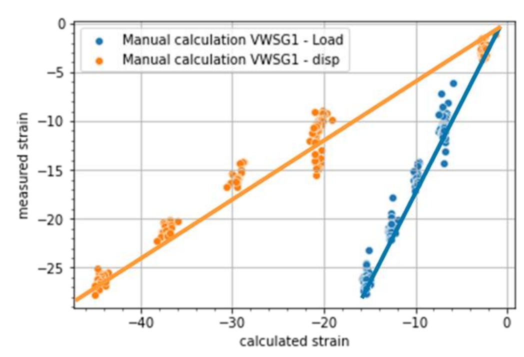


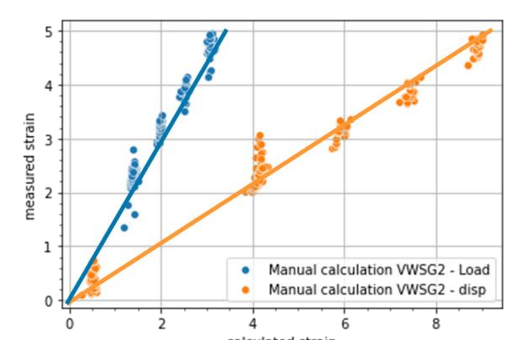
Times series of strains measured from VWSGs

In each cycle, the loading sequence was 0.5-1.5-2.5-4.5-5.5 kN With a 300 N/s loading rate.

After isolating local peaks of strains values we compared them to the calculated strains using a straight beam approximation with respectively the loads and the displacements at mid-span.

While the strain transfer for both VWSGs is inferior to 1 (expected behaviour) for strains from measured displacements, it is alarmingly superior 1 for strains from loads.





The strain transfer is the slope of the trendline

Reference

[1] Mnyusiwalla, H., Triantafyllou, P., Sotiropoulos, P., Roa, M. A., Friedl, W., Sundaram, A. M., Russell, D., & Deacon, G. (2020). A Bin-Picking Benchmark for Systematic Evaluation of Robotic Pick-and-Place Systems. *IEEE Robotics and Automation Letters*, *5*(2), 1389–1396. https://doi.org/10.1109/LRA.2020.2965076

[2] Triantafyllou, P., Mnyusiwalla, H., Sotiropoulos, P., Roa, M. A., Russell, D., & Deacon, G. (2019). A benchmarking framework for systematic evaluation of robotic pick-and-place systems in an industrial grocery setting. *Proceedings – IEEE International Conference on Robotics and Automation*, *2019-May*, 6692–6698. https://doi.org/10.1109/ICRA.2019.8793993