Interactive Light Art for Metro Social Engagement — An EPS@ISEP 2026 Project

Abstract. In 2026, an EPS@ISEP team addressed limited social engagement in metro carriages, shared spaces where user interaction is minimal, through CONNECT and share. This low-cost, modular installation for the Porto Metro combines light-based interaction with asynchronous digital communication. Velostat sensors embedded in handrails detect passenger grip and trigger coloured light animations that merge into a shared display, transforming individual actions into a collective experience. A companion QR-based web application enables GDPR-compliant anonymous message sharing. The system adopts an eco-efficient design using PLA and repurposed Portuguese cork. Its distributed ESP32-C3 architecture communicates via CAN for robustness against electromagnetic interference. Validation through Finite Element Analysis and API load testing confirms structural integrity and backend reliability. The results demonstrate a scalable and ethically designed solution that promotes social awareness and inclusivity in public transport.

Keywords: Engineering Education, European Project Semester, Interactive Design, Social Engagement, Embedded Systems, Sustainable Design

1 Introduction

Urban commuters spend significant time in public transport, yet these shared environments rarely promote social interaction. Passengers often remain isolated, focusing on personal devices and routines. Physical proximity alone does not reduce loneliness; rather, inclusion and acknowledgement determine whether a shared space becomes socially meaningful [9]. Existing public interactive installations are typically large-scale systems using cameras, projectors, and motion tracking. While such projects demonstrate the potential of interactive design to create shared experiences, their scale and complexity are high. This research inspired a socially engaging interaction design to be deployed in the carriages of the Metro of Porto.

CONNECT and share is an interactive installation developed for the Metro of Porto as part of the European Project Semester (EPS) at ISEP [3]. The project was delivered by a multidisciplinary, international team of six students with backgrounds spanning information technology, computer science, interactive media, product development and systems engineering. The system integrates pressure sensors into metro handrails; when a passenger grips the rail, it triggers a coloured light animation. These individual activations travel up the pole and merge into a shared ceiling-based visual display, transforming isolated actions into a visible collective experience. In addition, a companion web app accessible through quick response (QR) codes near the exit doors allows passengers to read and leave short, asynchronous messages.

The main contribution of this work is the design and development of a low-cost, modular, and transit-oriented interactive system that combines embodied light-based interaction with lightweight digital communication. More specifically, it contributes with: (*i*) the concept and interaction design of CONNECT and share to foster social awareness during metro travel; (*ii*) a hardware architecture based on distributed microcontrollers and addressable light-emitting diode (LED) strips; and (*iii*) insights from the prototyping and testing within a public transport context.

The paper is organised as follows. Section 2 reviews related work and key considerations. Section 3 presents the concept and design of CONNECT and share. Section 4 describes the prototype and testing results. Section 5 outlines outcomes and future work.

2 Preliminary Studies

This section presents the conducted preliminary studies, covering related work, ethical considerations, market and marketing analysis, and sustainability aspects that inform the design of CONNECT and share.

2.1 Related Work

Several interactive installations demonstrate how technology can foster shared experiences in public spaces. Kinetic Particles uses cameras and deep learning to translate audience movement into real-time digital projections, proving that physical actions can engage people in a collective visual environment [13]. Keitai Trail relies on mobile phones to link personal stories from strangers at a festival, showing how familiar, everyday devices lower the threshold for participation [17]. Closer to CONNECT and share, Strijp-T-ogether introduces a co-creative digital layer to physical spaces, enabling stranger interaction via shared projections [10]. While these installations illustrate the potential of interactive design to cultivate social connection, they typically rely on cameras, projectors, or large-scale infrastructure. Conversely, CONNECT and share adapts these principles into a distributed embedded system specifically engineered for the constraints of a transit environment.

On the technical side, a comparative analysis of microcontroller platforms by Maier et al. indicates that the ESP32 family offers sufficient processing capacity for single-task embedded nodes at low power and low cost [15]. Dzedzickis et al. evaluated Velostat as a tactile sensor material under static, long-term, and cyclic load conditions, confirming consistent and repeatable signals suitable for grip detection [4]. Furthermore, documentation by Bozdal et al. highlights the vulnerability of single-ended protocols such as Inter-Integrated Circuit (I2C) and

UART to electromagnetic interference, justifying the implementation of Controller Area Network (CAN) bus in electrically noisy metro environments [1]. These studies validate the selected hardware architecture: a WEMOS C3 Mini microcontroller, Velostat pressure sensors, and the CAN bus protocol.

Table 1 summarizes the reviewed works and clarifies how they informed the concept, interaction design, or technical implementation of CONNECT and share.

Table 1. Comparison of related work and relevance to CONNECT and share.

Work	**Method**	**Key insight**	**Relevance to CONNECT and share**
Kinetic Particles [13]	Cameras, deep learning, projection	Movement as shared feedback.	Use grip as interaction input.
Keitai Trail [17]	Mobile phones and projection	Everyday devices reduce barriers.	Keep QR participation lightweight.
Strijp-T-ogether [10]	Mobile app and projection mapping	Co-creation supports interaction.	Let passengers shape output.
Hammoud et al. [9]	Smartphone-based assessment	Inclusivity can reduce loneliness.	Avoid forced conversation.
Maier et al. [15]	Comparative microcontroller analysis	ESP32 suits low-cost nodes.	Use distributed WEMOS C3 Minis.
Dzedzickis et al. [4]	Mechanical and electrical sensor testing	Velostat gives repeatable signals.	Use low-cost grip sensing.
Bozdal et al. [1]	Communication protocol survey	Differential signalling resists EMI.	Use CAN between nodes.

2.2 Ethics

The CONNECT and share project is guided by fundamental ethical principles, prioritizing user privacy, inclusivity, and responsible technology deployment in public spaces. The recording of voice messages through the QR code system must ensure full anonymity, with no collection or linkage of personally identifiable information. The selection of providers needs to consider upstream supply chains, particularly the sourcing of electronic components, as it may involve environmentally harmful practices and questionable labour conditions.

These concerns directly inform the design. The system enforces strict General Data Protection Regulation (GDPR) compliance through server-side data management that deletes or irreversibly anonymises recordings, ensuring exclusive alignment with social benefit rather than surveillance or commercial use [6]. In parallel, component procurement prioritises ethically certified suppliers and durable hardware to reduce environmental impact.

2.3 Marketing

CONNECT and share adopts a social marketing approach to transform the traditionally passive and individualised transit experience into an interactive and collective urban environment [20]. The market context is analysed through the political, economic, social, technological, environmental and legal (PESTEL) macro-environmental factors [12] and Porter's five micro-level competitive forces [18], highlighting both a strong institutional dependence on transport authorities (Business-to-Government/Business-to-Business) and a pronounced risk of substitution by smartphone use.

These insights directly inform the system design. User interaction is embedded into existing metro handrails, creating a zero-friction physical interface that reduces behavioural barriers and counters habitual smartphone engagement. Furthermore, digital interaction is intentionally delayed, with QR-based access only enabled after the journey, thereby reinforcing user presence within the physical environment during transit.

The marketing strategy aligns with the 4Cs framework, focusing on customer value through emotional engagement, zero monetary cost, minimal cognitive effort, seamless convenience within transit infrastructure, and bidirectional communication based on community storytelling [8]. Brand development follows a two-stage approach, progressing from initial recognition based on the full wordmark to simplified symbolic identification, in line with Lencastre's Brand Triangle methodology [14].

2.4 Sustainability

CONNECT and share incorporates eco-efficiency principles to minimise environmental impact while maximising long-term social and economic value [11]. Sustainability is addressed through environmental, economic, and social dimensions, including lifecycle considerations of electronic components, cost-effective scalability, and the promotion of inclusive urban interaction that mitigates social isolation [9].

These dimensions directly inform the design. Environmentally, bio-based materials such as Polylactic Acid (PLA) are selected over conventional plastics to reduce manufacturing emissions, benefiting from lower processing temperatures [19]. Operational energy demand is minimised through the use of efficient LED systems, significantly reducing power consumption compared to traditional public displays [21]. In parallel, a circular lifecycle approach is adopted for electronic components, requiring certified recycling processes to limit the environmental impact of disposal and reduce overall global warming potential [7,5].

The project contributes to the United Nations Sustainable Development Goals [22] by addressing well-being and urban sustainability. It supports SDG 3 (Good Health and Well-being) by fostering positive social interaction and reducing urban loneliness, and SDG 11 (Sustainable Cities and Communities) by enhancing inclusivity and cohesion within public transport environments.

3 Proposed Solution

3.1 Concept

CONNECT and share is structured in two phases that combine physical interaction with digital communication. In Phase 1, pressure sensors embedded in metro handrails detect passenger contact. Each pole is associated with a unique colour that propagates along the pole and across an addressable LED strip on the ceiling. When multiple passengers engage simultaneously, their colours merge, producing a shared visual representation of collective presence without requiring explicit social interaction. Phase 2 extends the experience beyond the journey through a QR code located near the exit. This interface enables passengers to read or contribute short messages reflecting positive life lessons, introducing an asynchronous layer of communication. Together, these phases integrate immediate, ambient interaction with delayed digital exchange, fostering both real-time and extended social awareness. Figure 1 illustrates the concept.

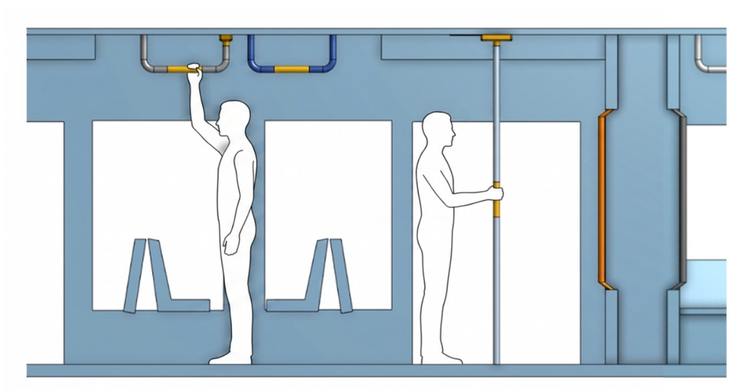


Fig. 1. 3D visualization of the integrated system within the Porto Metro carriage.

3.2 Design

The design of CONNECT and share combines physical hardware, embedded control, digital interaction, and packaging into one modular system. The following subsections describe how the structural components, smart control architecture, user application, and physical packaging support safe deployment, intuitive participation, and maintainable operation in a metro environment.

Structure The physical installation comprises pole-mounted secondary nodes that house the sensing electronics at each handrail and a ceiling-mounted main unit that contains the central controller. Both enclosures comply with EN 45545-2, the European railway fire safety standard governing material flammability and smoke emissions, by using Nanovia PA Rail, a certified polyamide compound.

The team validated structural integrity through linear static Finite Element Analysis (FEA) simulations in SimScale. They applied a distributed load of 100 N to represent passenger interaction and potential vandalism. The ceiling-mounted enclosure reached a peak Von Mises stress of 3.99 MPa, while the pole-mounted node reached 1.60 MPa, both well below the material yield strength [16]. These results correspond to safety factors above 12 and 30, confirming adequate mechanical robustness.

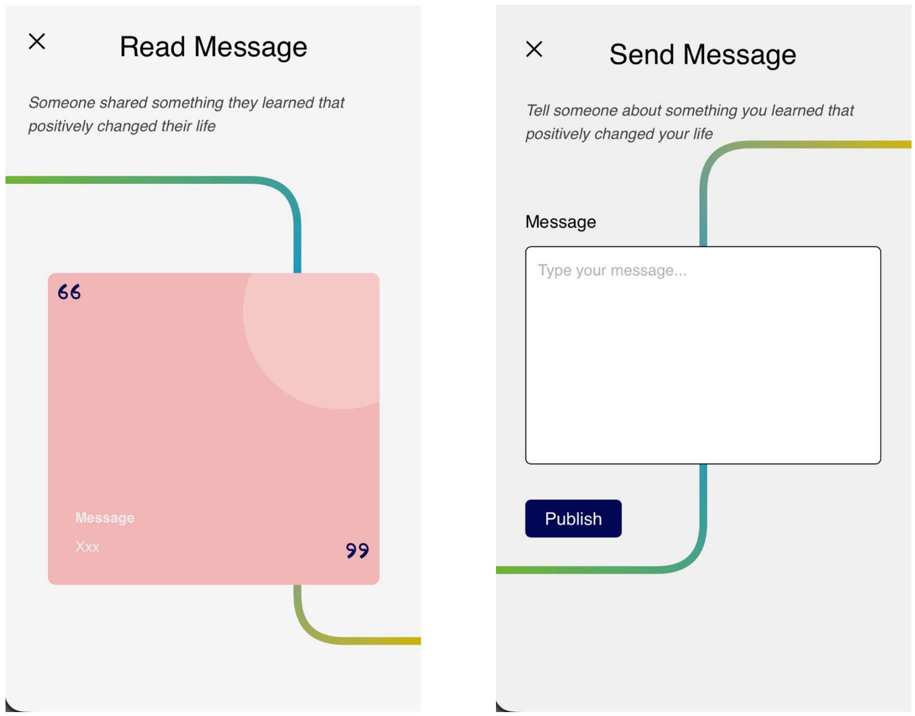
Smart Control The control system adopts a distributed architecture composed of two node types. Sensor Nodes embedded in each handrail pole acquire pressure input from velostat sheets and transmit the data over a CAN bus. A ceiling-mounted Central Node receives these signals and controls the addressable LED strip accordingly. The design selects CAN bus communication due to its differential signalling, which ensures robustness against electromagnetic interference typical of metro environments [1]. Both node types implement interrupt-driven deep sleep to minimise power consumption during inactivity. A full carriage deployment includes ten Sensor Nodes and one Central Node.

The smart system requires approximately 93.7 W, largely dominated by the LED strips (86.4 W), while all other components consume less than 8 W. Including a 25 % design margin, the total power budget reaches about 117 W. Therefore, the power supply should be dimensioned above this value to ensure stable operation under peak load conditions.

User Application The companion web application constitutes Phase 2 of CONNECT and share, extending the installation's social function beyond the physical journey. The application is accessed via a QR code placed near the exit doors of the metro carriage, with access intentionally restricted to post-journey use to preserve passenger presence within the physical environment during transit.

The application uses a Next.js frontend with a Supabase backend and TypeScript serverless edge functions on Deno. It lets users read anonymous messages from previous passengers and share a short reflection of their own, creating an asynchronous community narrative. Figure 2 illustrates the principal screens of the web application.

GDPR compliance is enforced by design. No personally identifiable information is collected or linked to any submission; all contributions are stored anonymously. Server-side content moderation runs automatically on each submission via an AI-based classification pipeline, which filters inappropriate content before persistence to the database. To harden the moderation pipeline against adversarial inputs, boundary injection defences and Unicode normalisation are applied prior to classification, preventing substitution-based bypasses.



(a) Reading shared messages. (b) Sharing a message anonymously.

Fig. 2. Main screens of the companion web application.

Packaging The packaging design uses Portuguese cork, a locally sourced and renewable material selected for its shock-absorbing properties and cultural relevance. The boxes match the hardware dimensions (36 cm × 33 cm × 26 cm) and employ a tolerance-based friction closure, eliminating the need for adhesives or metal fasteners and ensuring a fully monomaterial solution. A modular interlocking geometry enables stable stacking during transport and storage.

The design supports post-deployment reuse. The cork units can be repurposed as modular seating on metro platforms, forming a Social Hub that extends the project's community-oriented function. Reclaimed timber cross-supports provide the required load-bearing capacity for adult use. Stacking two units achieves an ergonomic seating height of 51 cm and three units a standing surface of 76 cm.

4 Prototype Development

The prototype validates the core interaction loop of CONNECT and share: pressure sensing, distributed communication, light feedback, and web-based message exchange. It implements a reduced two-node configuration instead of the full carriage-scale installation, allowing the main technical risks to be tested within the time and budget constraints of the project.

4.1 Assembly

The assembled prototype consists of one sensor node mounted on a handrail segment and one central node controlling the visual output. The sensor node combines a Velostat pressure sensor, a threshold calibration potentiometer, an ESP32-C3 microcontroller, and a CAN transceiver. When pressure is detected, the node sends an event to the central controller, which triggers the corresponding RGB animation on the WS2813 LED strip.

Structure The physical structure combines 3D-printed housings, a handrail-mounted sensor layer, and separated compartments for electronics and wiring. The geometry avoids sharp edges and exposed fasteners while maintaining access for assembly and maintenance. Although the prototype uses PLA for fabrication, the deployment design specifies fire-compliant PA Rail material for transit use.

Smart Control The control system is distributed. The sensor node reads the pressure signal and transmits CAN messages only when the calibrated threshold is exceeded. The central node interprets these events, runs the animation logic, and drives the LED strip. Both nodes use interrupt-driven firmware and heartbeat timeout logic, switching LEDs to static white if communication is lost.

Web Application The companion web application implements the second interaction phase. Passengers access it through a QR code after the journey, read anonymous messages from previous users, and submit a short reflection of their own. The application uses a Next.js frontend with Supabase storage and serverless Application Programming Interface (API) routes, including content moderation before messages are stored.

4.2 Tests & Results

The prototype was evaluated through structural analysis, hardware functional tests, software unit tests, API performance tests, load tests, and a SUS usability questionnaire. The test setup included the two ESP32-C3 nodes, Velostat sensor, CAN transceivers, WS2813 LED strip, bench power supply, deployed web application, and automated backend tests.

Structure Structural validation was performed through static FEA simulations of the ceiling-mounted and handrail-mounted housings. A distributed load of 100 N was applied to represent passenger interaction and possible misuse. The resulting safety factors exceeded 12, indicating that the designed geometry is mechanically robust for prototype-level handling. Fire compliance of the final enclosure material remains to be physically validated before deployment.

Smart Control Table 2 displays the functional results of the smart control system and prototype hardware.

Table 2: Device: functional results

Test	**Success criteria**	**Result**
Velostat touch detection	ADC values aligned with pressure	Pass
CAN bus communication	Packet delivery ratio above 99.9 %	Pass
LED visual response	Correct colours, no dead pixels, no flicker	Pass
Sensitivity calibration	Potentiometer adjusts trigger threshold	Pass
Response time	Touch-to-light latency below 100 ms	Pass
EMI resistance	No EMI-triggered false events	Pass
Thermal behaviour	Enclosure surface below 50 °C after 4 h	Pass
Durability	Stable operation after 1000 trigger cycles	Pass
Fault detection	LEDs turn white on CAN fault	Pass

The results confirm that the two-node prototype performs the sensing, communication, and feedback reliably. The main remaining hardware risk is scaling the network and replacing PLA housings with transit-compliant material.

Web Application Table 3 presents single-request latency measurements for the deployed back-end API endpoints. The read endpoint took 165 ms, while the send endpoint took 367 ms. As data volumes are similar, the higher send latency reflects additional server-side processing, including message filtering and database insertion.

Table 3: API: functional and performance results

Request	**Method**	**Data** (kB)	**Latency** (ms)	**URL**
Read	GET	3.65	165	https://metro-voices.vercel.app/read
Send	POST	3.61	367	https://metro-voices.vercel.app/send

Table 4 shows send endpoint performance from 1 to 1000 requests. Baseline latency was 367 ms. At 10 requests, mean latency dropped to 81.5 ms, likely due to connection reuse or reduced cold starts. Latency then rose gradually, reaching 195.77 ms at 1000 requests. Variability increased (standard deviation: 53.62 to 102.69 ms), but the error rate remained zero, indicating stable performance.

Table 4: API: load results

Requests	**Operation**	**Method**	**Errors** (%)	**Latency** (ms)	
				μ	σ
1	Send	POST	0	367.00	0.00
10	Send	POST	0	81.50	53.62
100	Send	POST	0	124.97	87.26

1000	Send	POST	0	195.77	102.69

The application usability was assessed using the System Usability Scale (SUS) [2]. A mean score of 86.59 ($n = 11$) places it in the "Excellent" range, well above the benchmark of 68. Ten participants scored above 68; one low outlier increased the standard deviation to 14.93. Overall, the platform was rated intuitive, accessible, and straightforward to use.

5 Conclusion

5.1 Project Outcomes

The project delivered a low-cost and modular concept for encouraging social awareness in metro travel through embodied interaction and asynchronous digital communication. Its strongest aspects are the simple pressure-based interface, distributed CAN architecture, scalable LED feedback, anonymous message sharing, and sustainability-oriented material strategy.

The prototype validated the central technical assumptions. Velostat sensing, CAN communication, LED feedback, backend API operation, load performance, and usability testing all produced positive results. The system reached a SUS score of 86.59 and the web backend handled up to 1000 concurrent send requests without errors.

Key limitations include scale, materials, and real-world validation. The prototype used only two nodes instead of eleven, so full CAN behaviour and multi-user interaction were not tested. The dual-rail power system was specified but not built, and PLA housings replace certified materials, requiring further safety and durability testing. The web system was validated, but no real passenger testing was conducted.

5.2 Personal Outcomes

Team testimonies indicate that participation in the EPS@ISEP programme fostered the development of multidisciplinary competencies and broadened technical expertise beyond primary fields of study. Students reported gaining practical experience in areas such as design, electronics, and project management, as well as applying agile methodologies in real-world contexts. The project also enabled the transfer of domain-specific knowledge across disciplines, strengthening the ability to apply core skills in unfamiliar application domains.

The international and interdisciplinary nature of the team contributed significantly to the development of communication and collaboration skills. Participants highlighted the challenges and benefits of working across cultural and academic boundaries, which enhanced adaptability, mutual understanding, and the capacity to integrate diverse perspectives into a coherent solution. This environment reinforced the importance of teamwork, trust, and shared responsibility in achieving project objectives.

Additionally, the experience promoted a broader and more reflective perspective on engineering practice. It strengthened awareness of the relationship between technical design and social impact, particularly in addressing urban challenges such as social isolation. Overall, the project contributed to both professional growth and personal development, supporting the ability to translate complex ideas into meaningful and socially relevant solutions.

5.3 Future Development

Future work should first scale the prototype to the full eleven-node network and validate CAN arbitration, heartbeat recovery, and LED power stability under simultaneous passenger interaction. The final enclosure should be fabricated in certified PA Rail or an equivalent railway-compliant material and submitted to physical fire and cleaning-resistance tests.

The power system should be implemented with the planned dual 12 V and 5 V rails and verified under worst-case LED current draw. For the web application, a pilot in a station concourse or carriage mock-up should evaluate QR code discovery, post-journey message submission, and content moderation under realistic passenger behaviour. Later iterations may reintroduce heart-rate sensing and auditory feedback to enrich the interaction while preserving privacy and accessibility.

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