ECTP Infrastructure & Mobility Committee

Horizon Europe 2022-2027 POSITION PAPER

This document was developed by ECTP's (The European Construction, built environment and energy efficient building Technology Platform) Infrastructure & Mobility Committee with the support of DOWEL Innovation.

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Contents

List of acronyms

AI	Artificial Intelligence
ECTP	European Construction, built environment and energy efficient building Technology Platform
EPDs	Environmental Product Declarations
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
I&M	Infrastructure and Mobility
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MaaS	Mobility as a Service
NBS	Nature based solutions
R&I	Research and Innovation
WLC	Whole Life Costing

I. Introduction

1.1. Overall context and challenges

The Transport Infrastructure sector is one of the major drivers of economic growth and its reach into every aspect of society cannot be overstated. An efficient and effective transport system not only supports the economy with the movement of people and goods, but also has a major impact on the environment and on the communities.

The European transport infrastructure network is a shared heritage of great economic value and largely determines how Europe growth will develop in the future, enabling wealth to be generated across the continent. It is expected to provide reliable services for very long periods of time, covering major technology changes, spanning several generations, and experiencing strong evolutions of the individual and collective aspirations for quality of life.

These infrastructures are facing some major challenges, that research and innovation must tackle in the coming years:

- **New mobility behaviours**, triggered by various factors: some factors are societal, others environmental such as the pandemic, which triggered more remote working and drastically reduced the number of public transport users, more online shopping, and a rise in soft mobility. Some are driven by technological advances, like the deployment of electric vehicles (or its alternatives such as hydrogen for instance) and emergence of autonomous vehicles. These new behaviours challenge the way infrastructure investments are designed and planned and call for new approaches and methods.
- **Resilience to climate change and to man-made threats**: new designs, construction and adaption methods for more robust infrastructures, new operation and maintenance procedures to keep the infrastructure in better condition and more resilient to extreme events, decommissioning methods for a greener environment, new materials and Nature-based Solutions (NBS), IT technologies for asset management (e.g. aging models, from prescriptive to predictive maintenance, digital twins, etc.) and for contingency management are some opportunities to improve the resilience of infrastructures and to address new threats (e.g. cyber) and extreme events related to climate change and human interventions. These opportunities still need to be turned into integrated market solutions and operational practices.
- **Sustainability**: the climate emergency calls for a deep change in the way transport infrastructures are managed: resource efficiency, decarbonisation and support to zero carbon transport, as well as human health and well-being (social sustainability) are to be targeted. Economic sustainability is also to be targeted through improved asset management over full life cycle.
- **Security and availability of supply chains**: COVID-19, but also events such as the war in Ukraine, the eruption of the Eyjafjallajökull volcano, the collapse of the Genoa bridge in 2018 or the Suez Canal incident in 2021, have shown disruptions in the global supply chain and led to shortages of certain critical products in Europe. Supply chains shall be re-thought to be more resilient to potential disruptions in supply.
- **Digitalisation**: the digitalisation of the construction sector at large is a deep trend, that offers many opportunities for operational improvements and sustainability in infrastructures, however the integration of the related technologies and related changes in work practices is still far from being fully achieved.

- **Increasing freight**: by 2050, freight activity is expected to increase by as much as 250%. The cooperation between road, rail, air, and shipping infrastructures through specialised hubs, ICT, automation and robotised facilities will be crucial in enabling increased freight capacity from the port to the last mile.
- **A work force adjusting to these challenges**: to meet all the above challenges, the work force needs to fully master the new technologies and workflows, so that infrastructures can indeed meet their targeted performances in terms of sustainability, resilience, comfort, etc.

1.2. Scope and Approach

This Position Paper aims to give an overview of the research and innovation paths that the ECTP Committee on Infrastructure and Mobility (I&M) recommends as of today and until 2027 to tackle the above-mentioned challenges.

To elaborate those recommendations, a workshop was organised with the Executive Board of the I&M Committee, followed by a collaborative process involving all I&M committee members, and a consultation of key external stakeholders.

This position paper looks to:

- Identify research needs to drive the impact of the mobility infrastructures to the forefront of European research and innovation agendas.
- Focus on future innovations and technologies for those infrastructures.
- Raise awareness and communicate priorities to strategic stakeholders.
- Promote transfer of scientific research results, ensuring the smooth implementation of up-to-date, evidence-based policies and practices.
- Support research-funding proposals and partnerships.
- Advocate and share knowledge within and beyond the ECTP.

1.3. High-level objectives formalised by the Infrastructure & Mobility Committee

Considering the outlined challenges, the I&M Committee has identified three high-level objectives that are critical to meet users' demand, improve the sustainability, resilience, safety and security of the transport system and reduce greenhouse gas emissions over the entire lifecycle of the infrastructure, namely:

- Objective 1: Meeting new mobility practices and user requirements
- Objective 2: Improved sustainability and resilience of infrastructures
- Objective 3: Safe, secure and cost-efficient infrastructures

For each of these high-level objectives, a set of priority areas are identified for the future research and innovation activities of the sector: they each correspond to the specific challenges of these objectives and are complemented by a list of focused R&I topics.

The next diagram provides an overview of the priority areas identified for each objective. The next sections of this Position Paper detail these objectives, R&I priority areas and topics.

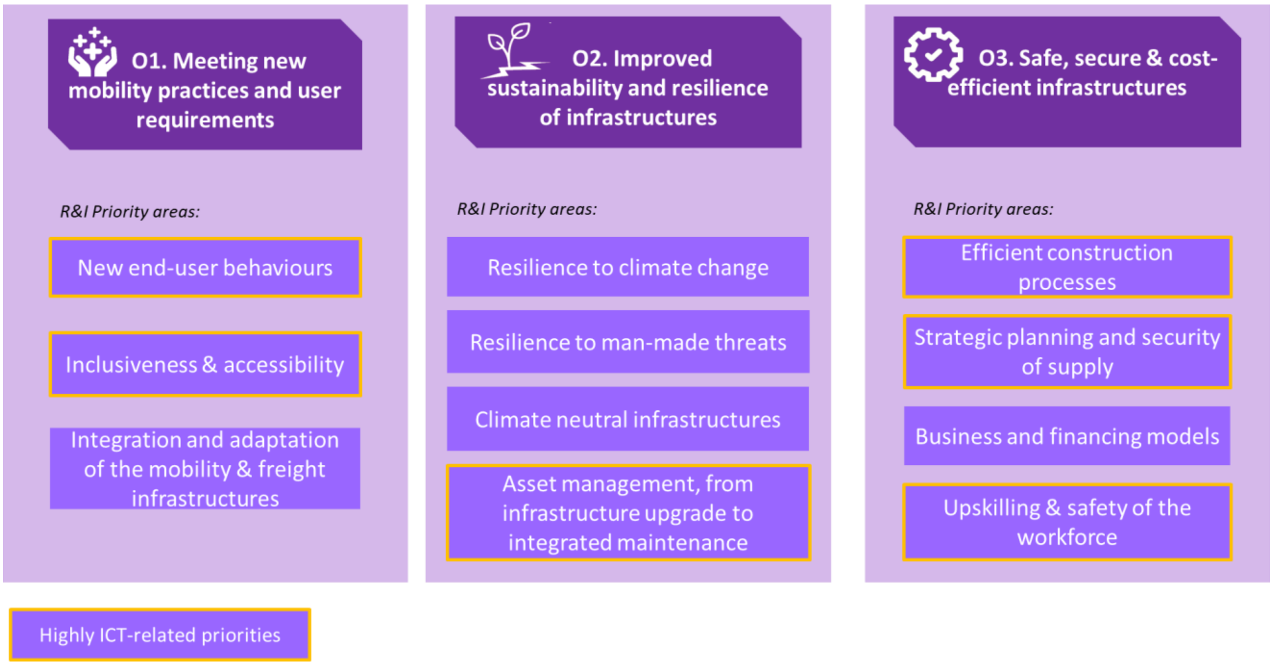

FIGURE 1: High-level objectives formalised by the Infrastructure & Mobility Committee, and related priority areas for research and innovation. In yellow, highly ICT-related priorities.

II. Objective 1: Meeting new mobility practices and user requirements

Transport infrastructures need to evolve towards supporting the paradigm of "Mobility as a Service" (MaaS), to offer seamless mobility experiences to end users featuring very diverse profiles, expectations, and requirements. In doing so, Infrastructure could also be used by travellers following an "Infrastructure as a Service" (IaaS) paradigm, where multiple pieces of infrastructure belonging to different modes of transport can be integrated into seamless trip chains, with payments managed automatically for all legs of every single journey. Notice that in this case and with the diminishing need of car ownership brought by MaaS, the client of IaaS will not only be the travellers but the provider of MaaS services as well.

Understanding the global challenges faced by society is therefore crucial to the sustainability and resilience of infrastructure and the following trends must be considered to understand how people live, work and play and what this means for the development of transport infrastructure and the services to be provided.

Some social trends strongly impact the mobility behaviours:

- Greatly unforeseen events, such as the COVID19 pandemic led to abrupt changes in transport infrastructure use, more remote working and online shopping, some drastic reductions in public transport users, or the rise of active (walking and biking) and micro mobility (privately owned or shared e-scooters, kick scooter, and other new light vehicles). Some of these changes will become permanent, potentially causing a change in urban transportation needs, particularly as many people may not return to the office for 5 days per week. This means that the way infrastructure investments are sized, designed, maintained, and operated must be rethought according to these changing behaviours and that adaptability and use flexibility of the infrastructure need to be considered.

- An ageing society looking for more inclusiveness triggers some inclusive design requirements in terms of access and adaptability of mobility infrastructures which overall enables greater user participation.
- The demand for a door-to-door freight and passenger transport system requiring a refocus of design and operation around customer needs. This in turn should lead to a better integration between transport modes.

Some technological trends also spark off significant changes in end user behaviours:

- The deployment of electric or alternative-fuel vehicles requires some dedicated equipment and services within the transport infrastructures, changes to the power grid and network distribution as well as changes to user behaviour to ensure reliability. In addition, transport services and infrastructure become more dependent on the adjacent built environment.
- The emergence of autonomous vehicles will disrupt the way road infrastructures are built, operated, charged for, maintained, and kept safe.
- ICT and V2X (vehicles to all) technologies enable the development of a whole portfolio of services to the end users, for a ‘smart’ and improved mobility experience and for the first time will connect the vehicle, the user and the infrastructure in one systems architecture.

The economic framework is however adverse to infrastructures: while there is an increasing need for maintenance of such infrastructures as they are ageing, the related investments for road and rail have plummeted in Europe[1] after the economic crisis.

Considering these trends and to enhance the level of service offered to the citizens, the upcoming R&I activities should focus on the following four priority areas:

- Identifying and understanding new end-user behaviours.
- Developing solutions for more inclusiveness and accessibility.
- Integrating the different mobility and freight infrastructures to enable multimodal transport and new urban and e-mobility and meet the growing demand in freight.

These three R&I priority areas are detailed in the next sections.

2.1. New end-user behaviours

Encouraged at the European policy level, many European cities began to introduce measures that favoured soft modes (i.e. active and micro mobility, use of public transportation and sharing concepts)

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[1] See DISCUSSION PAPER “State of infrastructure maintenance”, 2019, European Commission: https://ec.europa.eu/docsroom/documents/34561/attachments/1/translations/en/renditions/native

and a remodelling of the urban space in favour of active mobility. For example, the city of Amsterdam has created 400 kilometres of bike paths and installed 4,000 charging stations. In Copenhagen, around 35% of the locals choose biking day-to-day. Madrid is the European champions of electric car sharing, with 1,600 cars in use. In Paris, some 15,000 e-scooters were in use in 2019[2].

A better modelling of end user behaviours is required to support policy making further in this direction. Mobility solutions and transport infrastructure must ensure safe and healthy commuting modes, and interventions should ensure that consumers regain trust in public and shared transport services. This question of trust and safety also applies to automated vehicles that will change the game in terms of road regulation.

Future mobility (i.e. sustainable and smart mobility) and in particular automated mobility, will have a strong impact on the energy, telecommunications and physical infrastructures, that calls for a convergence of these different networks. It also disrupts the way road infrastructures shall be financed, shifting away from fuel taxes.

Research topics in this area include:

- Propose new standards and policy measures in response to the automation of heavy road vehicles (e.g. distance to vehicles, speed limit etc.) which may have an impact in the adaptation of existing and construction of new infrastructures.
- Propose transition methodologies while there are mixed automated and driven fleets with very different performance and safety characteristics and requirements.
- Search for alternatives to the loss of government revenue that could result from the switch to electromobility in order to ensure the continuity of funding for roads and complementary services (e.g. charging infrastructure, high speed communication channels, congestion management etc). For instance, a pan-European road pricing Infrastructure as a Service scheme can be explored.
- Analyse how new uses change the shape of cities and impact urban planning – (for instance, what spatial allocation by mode and movement will be required, how can it be reallocated efficiently and safely, how do changes in movement affect business case viability, what would priority investment look like for governments over a decade, how can the increase in deliveries be catered for, what behavioural changes will need incentivising).
- Perform qualitative psychological, behavioural, and sociological studies to understand which behavioural changes are temporary, and which are indelible and need to be planned. For instance, identify which changes are beneficial to society and are likely to be incentivised by Government to achieve policy outcomes (particularly climate change).
- Define a new method to measure the accumulation of benefits (including road funding, CO_2 emissions, road congestion, etc.) due to hybrid working and evaluate changes in peak demand.
- Further develop innovative modelling and agent-based simulation approaches to be more usable in the transport markets, i.e. adapt it to mobility behaviour, and propose infrastructure adaptation scenarios considering the connection of facilities and infrastructures (e.g. identify which energy and telecommunications adaptations should be implemented and how the different grids converge).

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[2] See https://www.renaultgroup.com/en/news-on-air/news/is-soft-mobility-the-future-of-urban-transport/

- Identify new legal requirements/policy measures that need to be met by transport infrastructure to reply to the preferred new behaviours.
- Support the development of walkable, cyclable and mixed-use urban centres (relying on smart growth models / infrastructure for health) to reduce overall trip demand per head of population.
- Support the smart deployment of charging infrastructure for new alternatives such as electric and hydrogen vehicles. For example, proposing new public-private partnership approaches and new funding or pricing schemes to install and maintain such installations.

2.2. Solutions for inclusiveness & accessibility

In urban environments that are increasingly complex and heterogeneous, and with an ageing society, there is an urgent need for innovative design approach and new mobility solutions to support longer living with more complex mobility issues (distribution, type of trips, less commuters, etc.) and to ensure a safer, inclusive and accessible society for all. The population of older people (i.e. aged 65 years or more) will rise in Europe [3]. In parallel, younger generations rely on ICT technologies in every aspect of their daily life and will rapidly adopt -and feedback on- smart mobility services. Also, user-centred and co-design methodologies enable a new approach to inventing tomorrow's mobility infrastructures.

Research topics in this area include:

- Develop infrastructure planning tools to accommodate changes in mobility, accessibility, and information needs, as people live longer, and their use of infrastructures and services evolves.
- Develop new technologies and solutions for accessibility improvements in existing infrastructures (age-friendly cities).
- Develop co-creative and collaborative digital design approach, involving all the stakeholders. For instance, use of digital twins, simulation, and virtual reality to create a virtual testing system of infrastructure designs that can be safely measured in an experience lab before committing to detailed design - testing could be by different cohorts including age, gender, and function (driver, passenger, service provider, safety manager etc).
- To assess the needed capacities for infrastructure upgrades considering the potential impact of automated driving on traffic jams (pre-design phase or upgrade phase).
- Advanced simulation of passenger (including modelling of passengers' mobility characteristics) and freight flows in future multimodal transport hubs to make them efficient and accessible from the design, construction and use points of view.
- Design new universal solutions for independent and autonomous boarding and disembarking of Persons with Reduced Mobility (PRMs).
- Develop Communication and Information Transport Systems related to infrastructure - vehicle - user communication. Systems shall integrate real time information about traffic, routes, disruptions, carbon footprint, transport performance, shared mobility, etc., and alert the users so that they could decide to update their travel plans or make mobility decisions depending on existing traffic and services conditions, while pondering their impact on the environment. The solutions developed with the aid of AI/ML should be considered as traffic management and monitoring systems in both urban and extra-urban areas.

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[3] Ageing Europe, looking at the lives of older people in the EU, 2019 edition

- Partnering with industrials from the mobility sector in the development of vehicle-infrastructure technologies and interfacing to support innovative services for smart mobility. Especially in the context of Smart Road and Cooperative Intelligent Transport Systems and Services (C-ITS), equipping the infrastructure for Vehicle-to-Infrastructure communication.
- Develop principles and standards for the provision of shared communications and energy networks on major transport infrastructure to support connected (and later) autonomous vehicles that ensure privacy, safety, interoperability, and affordability.

2.3. Integration and adaptation of the mobility & freight infrastructures

To ensure the seamless mobility experience of end users relying on more diverse transportation means, mobility infrastructures need to evolve towards more interconnection and integration. Multimodal hubs shall be designed and located wisely, considering e-mobility, soft mobility, linking between urban and sub-urban areas, and between people's mobility and freight.

The freight is indeed expected to increase by 250% by 2050[4]. The expansion of e-commerce and instant deliveries contribute to the fragmentation in loads and trips, with environmental impact, but also leads to the emergence of new types of soft modes (cargo-bikes, scooters) for freight movements. New solutions are required to improve the efficiency, sustainability, and adaptability of freight.

<u>Research topics in this area include:</u>

Multimodal hubs

- Develop advanced tools and methodologies to simulate multimodal hubs before construction and whole life-cycle analysis based on provided functionality to better understand the complexity of multimodal hubs (modelling heterogeneous flows -including vehicles, vulnerable users, crowds, etc.- to support design or upgrade of large transport hubs and multimodal urban mobility networks).
- Propose new concepts and processes for multimodal hubs that integrate urban/interurban public transport, MaaS and sustainable districts. They should focus on:
    - optimal use of space (including underground construction) that minimises surface land use, identifying which processes could disturb the least the city life,
    - decarbonation of the last mile, optimal hub locations,
    - resilience against hazards related to electrification (batteries and hydrogen), especially in urban areas,
    - include modular / prefabricated solutions,
    - increased sustainability (i.e., environment, social),
    - solutions for upgrading existing hubs and improving the connection among urban and sub-urban areas,

[4] COMMISSION STAFF WORKING DOCUMENT Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package, 2017

    - smart mobility solutions for improved customer experience.

- Propose Infrastructure solutions to keep safe and integrate the vulnerable road users (VRUs) into conventional traffic.
- Build efficient infrastructure for walking, cycling and other active travel means.
- Define interoperability, performance and safety standards of infrastructures for new road services (e.g., electric roads, etc.)
- Propose new and innovative business models promoting the investment in safe infrastructure and public transport and for the widespread deployment of connected automated road transport systems.

Freight

- Design and develop efficient solutions for integrated infrastructure and mobility systems shared by passenger and freight services.
- Develop data models and machine learning algorithms based on real-time information for optimization, adaptation and building of the surface transport capacity.
- Improve the interoperability between the transport modes to generate effective freight transport not only on street infrastructure (e.g., by speeding up the interchange between rail and street). This includes physical interoperability barriers between manufacturing end of line, the family of modular load units from boxes to (intermodal) containers and intermodal transport & transhipment.
- Design solutions to increase load density and efficiency, such as digital load matching and parcel swapping at intermodal nodes, to reply to the growing freight demand.
- Demonstrate and document the performance of connected and shared logistics networks and compare to actual forecasted performance.
- Identify increases in resilience of the freight transport and logistics systems using Physical Internet concepts[5].
- Investigate how freight supply chain may (re)determine the design of infrastructures to achieve the last mile.
- Simulate what-if scenarios for optimized design of freight flows and logistics infrastructures and networks.
- Develop infrastructures to support green long-distance freight. Linked to electric roads and other alternative fuels (H2).

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[5] See Physical Internet Roadmap, ALICE, 2020

III. Objective 2: Sustainability and resilience of infrastructures

The climate emergency calls for a deep change in the way mobility infrastructure assets are designed, operated and managed over their full life cycle, so as to target higher sustainability and resilience.
On the climate side, higher temperature, extreme events such as intense rainfalls and flooding occur more frequently, and with higher intensity. On the anthropogenic side, threats are as real as ever on the interconnected infrastructures, where the physical and IT domain are inherently coupled and the one serves the other. Mobility infrastructures must therefore adapt to and anticipate these new situations, also considering their own ageing process. But they shall as well evolve towards more climate neutrality.

In this objective O2, ***sustainability*** is meant as environmental sustainability, i.e., resource efficiency and decarbonation of mobility infrastructures (the dimensions of social and economic sustainability are covered in Objective 3).
By ***resilience*** is meant the ability to withstand the effects of climate change and extreme weather events, as well as human hazards, by adapting to them and by recovering from them, learning from past events how to Build-Back Better[6]. The concept of resilience covers different dimensions (physical and technical, economic, social/organisational), span from multiple time scales (from short-term emergency response to medium-term rehabilitation phase and long-term recovery plans) to multiple spatial scales (from a single infrastructure to a network, to a system, at the level of a region, country, etc.).

To meet this objective of resilience and sustainability, it is proposed to organise the required R&I activities along four priority areas:

- Resilience to climate change and extreme weather events (adaptation measures)
- Resilience to man-made threats
- Climate neutral infrastructures (mitigation measures)
- Asset management, from the upgrade of infrastructures to integrated maintenance

They are detailed in the next sections.

3.1. Resilience to climate change and extreme weather events

The number of disasters related to weather, climate or water hazard has increased by a factor of five over the 50-year period[7]. Fires, flash flooding, extreme temperatures are some of the climate change manifestations that impact the mobility infrastructures. Many transport facilities are below grade (tunnels, metro) and vulnerable to flooding. Some airports at low elevations along the coast are at risk of sea-level rise. Extreme heat can cause road buckling, freeze-thaw cycles cause pavement cracking

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[6] See: From Risk to Resilience: Learning to Deal With Disruption, Fiksel et al, 2015

[7] Source: World Meteorological Organization

and potholes. With the increased variability of weather, roads that are designed for particular climate conditions may fail more quickly, leading to reduced use life.

<u>Research topics in this area include:</u>

Frameworks:

- Develop an EU standard for measuring resilience and define an EU score to analyse and compare infrastructure. Existing rating systems should be benchmarked, and their common ground identified.
- Map and assess existing resilience solutions in regions already affected by climate changes and evaluate their replication potential to regions where changes started to occur.
- Map and assess existing R&I projects providing resilience solutions to have a better understanding of the status of development and develop a holistic approach to resilience, covering climate changes, natural hazards, human threats, etc.
- Propose a framework to make operational resilience concepts to the benefit of Infrastructure managers, moving from an indicator-based approach to a service-based approach.

Technologies and materials:

- Use modelling and Digital Twins of infrastructures (real-time info) to forecast/understand the impacts of the Climate Changes; assess the impact of gradual changes and large events that are brought in higher frequency; assess the levels of performance and service required (including material resilience and the optimal mix needed depending on the seasons and locations).
- Build upon the circular economy standards being developed for infrastructure and pavements to include new performance requirements that consider the changing environmental parameters resulting from climate change. For instance:
    - Develop and use new materials or systems to reduce heat islands as well as the impact of heavy rainfalls into soft soils and slopes, improve drainage and soil permeability, adapt asphalt for hot temperature etc.
    - Propose pavement materials standards replying to various weather patterns and the changing climate in Europe (reference to experienced countries facing extremes variations is preferred).
    - Develop and implement new materials with photocatalytic technologies able to degrade air contaminants (VOC, NOx…) as well as self-cleaning and self-healing materials.
    - Develop cost-effective adaptation measures to improve resilience (anticipation, mitigation, recovery).

Workflows and processes:

- Investigate mechanisms to foster social resilience: how people and organisations can anticipate, prepare / prevent / cope and recover from different events/ threats. This includes social studies and behavioural economics.
- Investigate cost-efficient mechanisms for the resilience of supply chains (strategic fuel supplies, minimum maintenance material stockpiles, etc).
- Develop innovative construction methods that aim at climate-proofing buildings and infrastructure.

- Propose revisions of national building codes to include climate resilience criteria and integrate Nature-based solutions (such as permeable material in driveways to increase water absorption and retention capacities).
- Develop a common EU tool for the assessment of transport infrastructure vulnerability in natural or man-made disasters and share the best practices across member states and at local governments level to strengthen strategic and transport planning.
- Develop protection and post-incident recovery plan to extreme events.
- Demonstrate the effectiveness of applicability of de-facto standard sustainability rating systems (or assessment) such as the ENVISION Protocol, in the context of EU transport infrastructure, trying to understand the economy of scale, replication factors and stimulation factor for adoption.

3.2. Resilience to man-made threats

Resilience of infrastructure applies as well to man-made threats such as cyber-attacks, terroristic attacks, and unforeseen events such as voluntary or unvoluntary accidents. Solutions to both protection to an attack and recovery afterwards are needed. In particular, the following attacks must be considered:

- Cyber-attacks: As the transport system becomes more digitised (from design to operation), risks of cyber-attack are increasing. According to publicly available reports and the European Union's Cybersecurity Agency (Enisa)[8], significant malicious attacks against key sectors doubled in Europe in 2020 with more than 50 incidents reported for the transportation industry that faced cybercrime threats affecting the management or functioning of the infrastructure.
- Physical attacks: attacks on the physical infrastructure for malicious purposes, e.g., sabotage, terrorism, fire, etc. Historically, several attacks have deliberately targeted the rail transportation, especially metro systems, within major European cities. These attacks have been specifically designed to cause maximum disruption and a high number of fatalities. Measures to prevent rail or other transportation infrastructure attacks.

Research topics in this area include:

Policy

- Propose European guidelines defining to what human threats transport and mobility infrastructures need to respond and how (e.g. guidelines for the design of structures to resist the effects of accidental explosions).
- Align the research and implementation activities in the field of transport infrastructure with newly proposed EU directives, such as the CER and NIS2 directives on Critical Entities and Critical infrastructure.
- A unified resiliency scorecard (rating system) for transport infrastructures considering a total risk approach, that includes physical and cyber threats as well as natural events. This rating

[8] ENISA THREAT LANDSCAPE 2021

system might be linked to the more classical structural and lifetime rating systems for transport infrastructures.

Technologies

- Combine Digital Twins with what-if scenarios simulation to improve resilience against human threats, identify weak components of infrastructures to manage investments for the reinforcement of existing and new infrastructures weak points.
- Develop virtual training environment for emergency response relying on hazard simulation and cascading effects.
- Define new design solutions that mitigate the impacts of explosions, blasts, and fire to infrastructures
- Define fire mitigation measures for Li-ion batteries of the size that will be fitted to semi-trailers from 2025 onwards and which could cause existing infrastructure to collapse if two such vehicles collide and burn uncontrollably.
- Develop Cyber and Physical combined threats identification and protection solutions applied to critical assets.
- Evaluate the feasibility of removable sections of key corridors in case of hostile activities, to avoid their destruction (e.g., designing bridges and their approaches in such a way that sections of pavement can be removed without blowing up the entire infrastructure to allow a much quicker return to normality at the end of hostilities).
- Develop post-incident recovery plan to cyber and physical attacks, so that infrastructures are resilient enough to provide alternatives in emergency situations.

3.3. Climate neutral infrastructures

Transport amounts for more than 30 percent of greenhouse gas emissions in Europe. Mobility infrastructures have thus a significant potential to contribute to the EU climate neutrality objective by 2050: the integration of lower carbon materials, of ICT technologies for resource management, the question of energy harvesting and the development of circularity of resources are as many enablers that should be pushed further.

Research topics in this area include:

Recycling and reuse

- Set principles to prevent a shifting of environmental problems under the cover of being circular (e.g., recycled materials breaking down with wear, particularly for road pavements, that can end up in the water system).
- Investigate how Construction & Demolition Waste (CDW) can be used as aggregate for new construction (e.g., can sorted and crushed building rubble be used for concrete aggregate in highway slabs, from a site relatively close by?).
- Develop methods to assess and certify the safe and efficient use of recycling materials in larger amounts than today.

Energy

- Develop energy generation solutions integrated in infrastructures (e.g., energy recovery systems produced by vehicular traffic; positive energy roads, solar noise screens and canopies).

- Demonstrate smart solutions for energy management and efficiency of infrastructure systems.

Materials

- Promote Whole Life Costing (WLC), Life Cycle Assessment (LCA), Life Cycle Cost (LCC) and the use of materials and products that have Environmental Product Declarations (EPDs)- in transport infrastructure to reduce the CO_2 footprint (bio-based materials, cement replacement, such as silica fume, slag, fly ash etc).
- Develop multifunctional construction materials (asphalts, paints, concrete) such as self-healing, photocatalytic, self-cleaning, temperature resilient materials and materials with anti-pollution properties.
- Develop and validate innovative materials for pavements and the rational use of resources.
- Develop monitoring and management systems for pavement predictive maintenance optimization.
- Estimate the environmental impact due to pavement maintenance cycle.
- Develop the use of self-healing materials.

Eco design and circularity

- Support the adoption of circular economy principles (i.e., eliminate waste and pollution, keep products and materials in use and regenerate natural systems).
- Develop real time LCA (including reuse) to support decision-making and to prove the neutrality of infrastructures in real time.
- Improve 'circularity by design' and the use of recycled materials from design stage. For instance:
    - Consider aspects such as Design for Disassembly, Adaptability and Flexibility as presented in ISO 20887
    - Promote materials that avoid resource depletion and reduction of biodiversity and emissions
- Demonstrate the impact of circular economy approach on operation and business (including environmental, social, and economic benefits).

Environment preservation

- Use an ecosystem approach to develop infrastructure in a way that is more sensitive to aquatic and terrestrial habitats and can create sustainable habitats, moving beyond typical mitigation measures.
- Develop and deploy methods to prevent / filter pollutants in road runoff / drainage.
- Develop and deploy methods to mitigate air pollutants and Volatile Organic Compounds.

3.4. Asset management, from infrastructures upgrade to integrated maintenance

Under-investment in infrastructure has been chronic in advanced economies over the past decades resulting in an ageing and poorly maintained infrastructure stock.[9] Moreover, with a 50-years design life at an end, a large part of the existing EU infrastructure has reached the end of their lifetime.

In the current context of constrained finance, ageing facilities and rising demand, countries are looking for strategies to maximise returns on infrastructure investment. Opportunities for Life-cycle Costs Optimization decrease as the asset moves through its life cycle, whilst financial allocations for maintaining them are volatile depending on the financial/political context and overall operational needs. Additionally, current standard-based practices for asset management are not fully catching the needs of asset owners.

A new holistic and systemic approach to asset management is then needed to optimise existing infrastructure assets, increase their service life, and make best use of infrastructure to reduce the need for additional transport infrastructure and to support relevant policy goals.

Through effective demand management techniques, "smart infrastructure", innovative maintenance solutions and monitoring the asset whole-of-life performance, assets can withstand external shocks and governments can better understand and manage risks.

Research topics in this area include:

Solutions for monitoring assets behaviour and predictive maintenance

- Develop new measurement systems and artificial intelligence algorithms for infrastructure predictive and preventive maintenance, moving from current prescriptive-based approach to condition-based up to preventive maintenance. The method developed should consider using weather patterns, to forecast the maintenance requirements and costs by infrastructure types and locations.
- Develop cost-effective solutions for inspection and monitoring of assets behaviour and deterioration processes (including the supporting geostructures) and collect real time data for cost and environmentally efficient predictive maintenance (using IoT, robotics, AI, machine learning) and decision support (find the perfect time and reduce costs). In particular:
    - new and non-intrusive sensing technologies (e.g., quantum sensors for magnetic detection) and non-destructive techniques (e.g., electrochemical sensors able to detect carbonation, chloride penetration, or rebar corrosion).
    - realistic material modelling and monitoring approach for a real understanding of materials behaviour under ageing infrastructures.
- Assess the overall state of tunnels using high resolution instrumental survey techniques, integrated by a new expert analysis method for mapping, monitoring and classification of the state of the tunnels and its evolution.

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[9] Building Resilience OECD Report 2021

- Provide recommendations to enhance standards and methodologies for the supervision and monitoring of motorway assets, allowing in-depth study of the behaviour of structures subject to ageing.
- Integrate the use of drones, sensors, IoT to develop new on-site processes and services, including safety, surveillance, and quality control.
- Demonstrate the effectiveness of monitoring and early warning systems: Inclusion of monitoring and early warning systems as a mean to adapt road to extreme weather events.
- Provide recommendations to revise the EN Eurocodes of existing structures to cover Structural Health Monitoring, Smart Inspections and Preventive Maintenance, allowing the End-of-life extension of infrastructure (e.g., bridges and tunnels).

Integrated asset management

- Develop predictive and deterioration models, implementing AI to define optimal intervention routes and to support the activity of operational staff for an optimised management of construction sites.
- Develop decision-support tools based on digital twins, big data, artificial intelligence and risk assessment for transport infrastructure operation and asset life-cycle management perspective (scenario testing and improved asset management processes).
- Implementation of new technologies for a fast assessment of the network condition.
- Develop an integrated methodology aiming at global and local monitoring of existing bridges, identifying the level of risks, and assessing the residual life.
- Understand the life extension of transport infrastructures due to possible changes (i.e., because of events like the pandemic) in traffic volume and type.

Whole-life-cycle approach

- Define comparative approaches to infrastructure development alternatives from the life cycle point of view for a given project. The results of the comparative approach should support and facilitate the discussion with the client to present convincing alternatives. For instance, what is more efficient a "classical on-site construction" or industrialised construction.
- Develop whole life-cycle approach integrating safety as a priority for the transport infrastructures.
- Provide recommendations and performance standards to support small infrastructure owners in the use of sensor technologies and to then build a collective, predictive tool to extend infrastructure lifecycles.
- Ensure that cost and benefit assessments better account of the full costs of both grey and green infrastructure measures (such as the value of ecosystem services to protect against climate risks; the long-term liability and environmental costs of grey infrastructure, etc.).

Innovative solutions for upgrading existing assets

- Develop innovative upgrade systems to existing infrastructures that involve the development of new advanced materials or technologies and incorporate smart infrastructure solutions (IOT and sensors for traffic/weather/ particles detection...).

- Develop and demonstrate solutions based on Robotics and Automation for asset inspection, repair, and upgrade.
- Develop advanced repair systems (such as cathodic protection) to extend service life of existing structures.
- Develop and apply solutions based on increasing degrees of automation for the upgrading of infrastructures targeting autonomous construction systems in the future.
- Develop more durable and high performance materials (more sustainable) for infrastructure maintenance and construction.

IV. Objective 3: Safe, secure and cost-efficient infrastructures

For road, rail and inland waterway transport, the total infrastructure costs (enhancement and renewal costs + operational and maintenance costs) in the EU28 amounted to € 267 billion for the year 2016[10]. While road and rail transport infrastructure investments were on a growing trend before 2007, the economic crisis put a stop to it. Since 2014, investment levels in Europe rise again, particularly in Central and Eastern European countries.

Rationalising the investments in mobility infrastructure is a necessity, but raises questions in terms of decision making, economic efficiency of construction processes, reliability of value chains and competences of the work force.

This objective is therefore broken down into four priority areas:

- Efficient infrastructure construction processes
- Strategy planning and security of supply
- New business, financing, and value chain models
- Upskilling and safety of the workforce

They are detailed in the next sections.

4.1. Efficient infrastructure construction processes

Digitalisation is the key enabler in the process of gaining technical and economic efficiency in the construction process. As stated by European Construction Sector Observatory, “*digitalisation is both inevitable and pivotal for the competitiveness and sustainability of the European construction sector. Despite the lack of data relating to the level of digitalisation of the construction sector across the EU-27, a number of technologies are at a mature stage of development and have been adopted and mainstreamed by an increasing number of companies in the sector”.*

[10] Overview of transport infrastructure expenditures and costs – January 2019, EC

Efforts should therefore focus on the integration of these digital technologies into the construction process, with applications tailored to the specific requirements of mobility infrastructures. Integrating such new solutions also impacts the workflows within and among organisations and value chains.

<u>Research topics in this area include:</u>

Digitalisation and automation

- Digitalization of all construction processes can furnish real-time and historic data to increase efficiency in all processes in new job sites. This will give way to the introduction/implementation of more advanced techniques like AI for the optimisation of construction processes.
- A digital construction site, collaborative and connected, by taking advantages of IoT tools, and integrating them in a data-driven logic for building platforms and dashboards that provide a better situational awareness on site and remotely to controllers to enhance safety of operation, avoid potential issues, minimize delays and additional interventions.
- New tools to increase the reliability of construction processes and materials (e.g., sensing systems to assess the actual state of materials).
- Use of IT and automation for more reliable inspection.
- Development of automation and assisted robotics for critical labour-intensive construction processes and to increase safety.
- Further development and demonstration of off-site & and modular construction.
- Facilitate automated construction by digital design.

Workflows and processes

- Supply chain integration, for instance through the efficient exchange of information and adoption of digital tools.
- Smart planning and low intrusive infrastructure repair processes. Real time communication with infra users and operators.
- Design-to-sustainability:
    - Compliance to the best construction and maintenance standards to ensure climate change resilience.
    - Specific technical sustainability requirements for services and materials tenders.
- Industrialised construction of infrastructure and offsite manufacturing of components.

4.2. Strategic planning and security of supply

Governments play a critical role in providing the framework for investment in the transport infrastructure on which economies depend. The long lifetime of such assets makes the related investments particularly subject to risk and uncertainty. A key challenge to infrastructure planning is to incorporate different demand and supply-side considerations into the decision-making framework. As stated by the OECD[11], the emphasis since late 1990s has shifted to a value-for-money approach, and to a trade-off between costs and benefits.

[11] Strategic Infrastructure Planning: International Best Practice — © OECD/ITF 2017

Research topics in this area include:

Decision making tools

- Develop decision Support Systems (DSS) relying on new technologies such as Digital Twin to enable the simulation of scenarios for what-if analysis.
- Develop tools for political decision-making in the management of urban renovation plans (e.g., urban mobility plans).
- Strategic decision-support tools based on agent-based and multi-method modelling of supply chains to simulate what-if scenarios and disruptions to optimize and improve the resilience of the supply chain.
- Define a design methodology, and a business case methodology, that balances the expectations of city managers and network/transport infrastructure managers (the spatial constraints of cities mean they must put higher value on the movement of people, while linear infrastructure measures and values the movement of vehicles, but the linear infrastructures push vehicles into cities).
- Infrastructures can become outdated and fail due to lack of investment in maintenance, which reduces their service life. Allowing central government funders to understand the relationship between the cost of build and the recurrent costs per maintenance type (beyond a simple ratio, but by type of infra, type of place (city, region etc), climate) to inform about budgets and business cases would be useful.
- Develop prediction models to support governments in better planning interventions, based on the underlying deterioration and evaluate overall performance of infrastructure assets.
- Propose holistic and comprehensive approach to asset management to optimise existing infrastructure assets and make them more resilient, allowing the identification of the trade-offs between objectives, and the enabling of more robust policy choices.
- Adopt crisis- and risk-oriented planning methodologies: Propose methodologies/guidance to assess vulnerability and risk. Proposal of recommendations for adaptation measures and strategies, to be prepared for climate change impacts.

Stakeholder engagement and collaborative processes

- Develop an inclusive approach to project planning, design and delivery which is more citizen/customer driven than procurement driven. This should include capacity building at local level to conduct participation activities, including facilitating tools, and pilot projects on citizen co-creation processes to improve the acceptance of public interventions.

4.3. New business & financing models

Governments are seeking a range of new funding models to enable them to achieve their infrastructure ambitions and help stimulate their economies. Over the last decades, various innovative financing structures emerged, allowing for a greater private-sector role in constructing and operating large-scale public service projects. While public private partnerships still represent a relatively small share of the overall worldwide investments in physical infrastructure, they benefit from a high popularity among policy makers and government institutions. PPPs have not yet enough historical record to properly evaluate their efficiency and optimise them, so best use of this mechanism is still ahead of its current utilisation.

Research topics in this area include:

- Review existing financing and business models to identify success and failure for re-investing and maintenance of infrastructures.
- Find solutions to overcome fluctuations in private investments and guaranteeing rate of return on the long term.
- Propose innovative funding schemes to incorporate new assessment methodologies involving all life-cycle approach.
- Develop innovative financial tools helping the alignment of public and private sector interest in infrastructure provision and management.
- Use of the EU taxonomy for new financing models.

4.4. Upskilling the workforce & safety

There is a strong need to renew the full educational and professional pathway within the construction sector. A variety of EU funded projects is contributing to addressing the skills gap in construction industry, trying to up-skill the existing work force. However, the shortage of digitally skilled construction workers, as well as high-trained IT experts still need to be tackled. Scientific profiles also need to be attracted. Solutions include making the professions safer and more attractive for youth and the female workforce, which potentially could close the gap of youth unemployment and inequality at the same time. The systematic identification of new roles and competencies will help to better define and integrate these new professionals.

Research topics in this area include:

Upskilling

- Investigate the career benefits of the construction sector and propose attractive campaigns to nearly double the supply of labour and have a better gender balance.
- Develop immersive capacitation with AR/VR tools to upskill the blue collars, train the workforce and improve safety.
- Update existing training schemes to take account of technical developments and innovation, including digitalization and green transition.
- Provide recommendations to encourage youth to consider a career in construction and infrastructure operation (including measures enforcing working conditions and its implementation).

Workers' safety

- Develop IoT-based solutions and wearables for worker location and health/safety monitoring, available for harsh environments, open, and underground areas.
- Develop solutions to improve worker-machine interaction increase safety and prevent accidents (e.g. wearables that will stop a machine before an accident happens, like workers being ran over or hit by a machine).
- Develop smart equipment and specialised exoskeletons for construction worker support (Worker 4.0).

- Propose initiatives aiming at developing a culture of prevention amongst construction companies and workers and at strengthening Occupational Safety and Health, considering specific sectoral circumstances.

V. Conclusion

5.1. Timing of the different R&I priorities

Members of the I&M Committee were asked about the most relevant scheduling for the above identified R&I activities, according to three time horizons: the next Horizon Europe's Work programme (2023-2025), the following one (2025-2027), or after the end of the current framework programme (beyond 2027).

The table below synthesises their views. The colour code is as follows:

>75% of votes	between 50 and 75% of votes	between 25 and 50% of votes	<25% of votes	No votes

Objective 1. Meeting new mobility practices and user requirements	2023-2025	2025-2027	Beyond 2027
New end-user behaviours	25%	25%	50%
Inclusiveness & accessibility	13%	63%	25%
Integration and adaptation of the mobility & freight infrastructures	13%	63%	25%

Objective 2. Improved sustainability and resilience of infrastructures	2023-2025	2025-2027	Beyond 2027
Resilience to climate change	63%	38%	
Resilience to man-made threats	38%	50%	13%
Climate neutral infrastructures	50%	50%	
Asset management, from infrastructure upgrade to integrated maintenance	75%	25%	

Objective 3. Safe, secure & cost-efficient infrastructures	2023-2025	2025-2027	Beyond 2027
Efficient construction processes	63%	38%	
Strategic planning and security of supply	13%	50%	38%
Business and financing models	13%	50%	38%
Upskilling & safety of the workforce	63%	25%	13%

5.2. Synergies between the Infrastructure & Mobility position paper and other ECTP committees

The next diagram synthesises the main topics that are addressed by several ECTP Committees and their respective Position Papers.

For the Infrastructure & Mobility Committee, the synergies are:

- The questions of climate mitigation and integration of energy systems, common to the Energy Efficient Buildings Committee,
- The topics of inclusiveness, asset management, skills and safety of workers, and strategic planning that are also addressed by the Digital Built Environment Committee,
- The dimensions of resilience, climate mitigation and circularity, also treated by the Material and Sustainability Committee,
- The questions of inclusiveness and accessibility, also part of the Built4Life Committee,
- The issue of cross-impact assessment between cultural heritage buildings and infrastructure.

	Energy Efficient buildings	Digital built environment	Material & sustainability	Built4Life	Heritage & Regeneration	Infrastructure & mobility
Infrastructure & mobility	Climate mitigation Energy integration & management	Inclusiveness Asset management Skills & safety Strategic planning	Resilience & climate mitigation Circularity	Inclusiveness & accessibility	Cross-impact assessment	
Heritage & Regeneration	Retrofitting solutions & skills	Inclusiveness Digital preservation Retrofit & Maintenance	Resilience & climate mitigation Circularity	Comfort & accessibility Regeneration		
Built4Life	Quality of life Energy communities Biodiversity	Quality of life Inclusiveness & adaptation Smart places	Inclusiveness & adaptation Indoor env. quality Climate adaptation			
Material & sustainability	Retrofit, RES, CCUS Circularity	Construction & renovation processes, incl. circularity				
Digital built environment	Smart buildings Skills & safety					
Energy Efficient buildings						

FIGURE 2 SYNERGIES BETWEEN ECTP COMMITTEES

5.3. Link with other initiatives

This Position Paper is aligned with the other key roadmaps related to EU mobility infrastructures:

- FEHRL Strategic European Road and cross modal Research and implementation Plan 2021 – 2024
- FEHRL Position Paper – Horizon Europe Work Programme (2023-2024)

- ERRAC Rail 2030 – Research and innovation priorities
- ERTRAC roadmaps on Safety, New mobility, Urban mobility resilience and Connected, Cooperative and Automated Mobility
- ALICE roadmap towards zero emissions logistics 2050 and Roadmap to the physical internet
- FIEC Manifesto
- CEDR Action Plan 2022-2024
- EC Strategic Transport Research and Innovation Agenda (STRIA)
- Master Plan (MP) and Multi Annual Work Programme of Europe's Rail Joint Undertaking