From the 5th Generation Road to Roads of the Anthropocene – What are the Synergies between Digitalisation of Transport Infrastructures and Protection of Landscapes and Biodiversity?

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The "5th Generation Road" or R5GMD project, the French version of the "Forever Open Road" project, aims to design road infrastructures that are adapted to the challenges of the 21st century. The project is divided into three phases. The first phase (2010-2015) involved identifying key technologies and preparing the associated research projects, culminating in the publication of a roadmap validated by the Ministry responsible for the environment and transport at COP 21. The second phase (2015-2020) was dedicated to creating demonstrators of these key technologies. The third phrase, which began in 2020, aims for widespread roll-out of the best solutions stemming from these demonstrators. This widespread roll-out requires either public funding which, even if substantial, will only allow solutions to be rolled out incrementally in the territories, or the design and implementation of more innovative business models that will be likely to drastically accelerate this roll-out, considering an R5G backed by new ecological and climatic functions.

In this context, this article presents various avenues currently being explored to address the challenges of mobility, transport decarbonisation and the protection of biodiversity with regard to climate change, inter alia. The Roads of the Anthropocene concept, which is part of the TRÂCE project, is based on a breakthrough vision. It involves rethinking blue and green transport infrastructure verges in terms of ecological and climate corridors backed by the energy, mobility & digital functions of the 5th Generation Road (R5G) project, where we would assess the implementation of a range of geo-engineering solutions via digital twins.

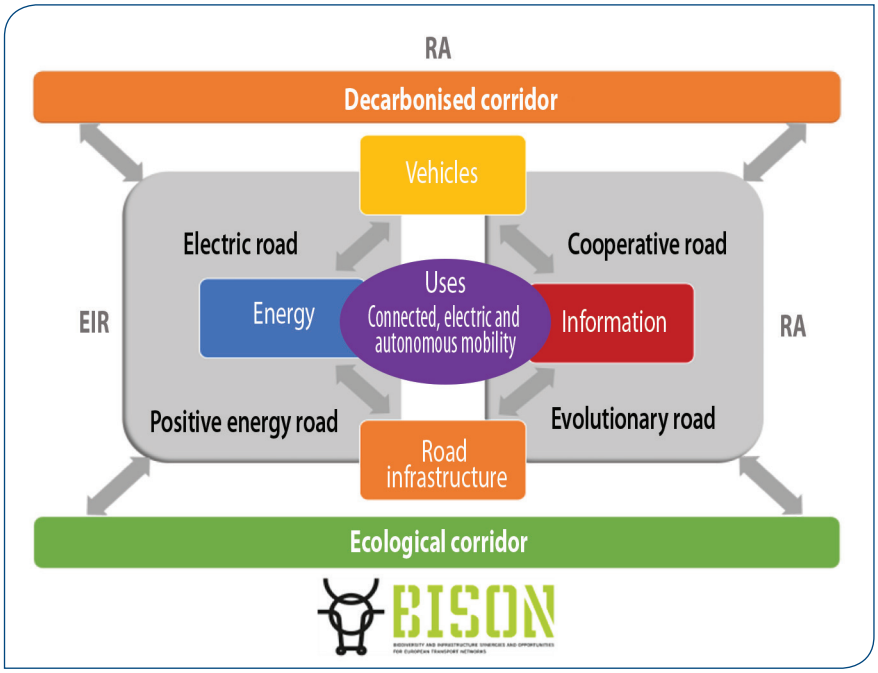

Illustration 1 - From R5G to Roads of the Anthropocene (TRÂCE project) integrating nature-based solutions and opportunistic environmental monitoring

ROADS OF THE ANTHROPOCENE

Vision

By means of a road infrastructure initiative in the broadest sense, we can simultaneously improve urban and inter-urban mobility, enhance neighbouring degraded natural environments and combat climate change. This vision aligns with the proposal recently submitted to Think20 (an engagement group bringing together think tanks for the G20) by Buchoud et al. (2020). The systemic contribution to societal issues of this expanded R5G, including the blue and green verges, is shown in *illustration 1*.

1 Gradually rethink and adapt infrastructures to robomobility (electrification & automation)
2 Contribuer Contribute towards the development of a new energy mix
3 Monitor general trends in biodiversity status and transform the ILTeX into a habitat or corridor for biodiversity
4 Capture, store and recover CO_2 in the ILTeX
5 Develop bio-energies associated with carbon capture and storage
6 Contribute towards agro-ecological transition
7 Develop a circular economy close to decarbonised and bio-sourced materials
8 Preserve water resources and help to decontaminate them
9 Opportunistically observe the territory, monitor general trends in biodiversity conservation status
10 Jointly establish local governance

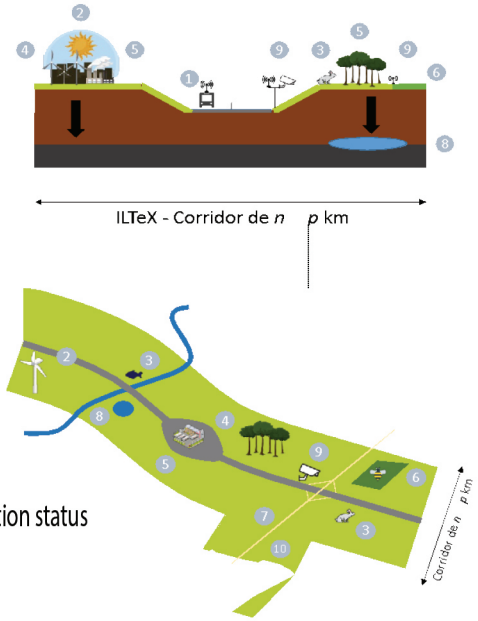

Illustration 2 – Diagram of the extended corridor concept (ILTeX) where the services associated with Roads of the Anthropocene will be deployed

Road design should thus gradually shift from the Vehicle-Infrastructure-Driver (VID) model to the Vehicle-Infrastructure-Information-Energy (VI2E) model. The electric road, the cooperative road, the positive energy road and the evolutionary road form four key technologies that accompany the development of new connected, electric, shared and automated mobility offerings. Thanks to these transformative technologies, road infrastructure will be able to offer new services, including to its immediate environment. Roads (infrastructures and vehicles) will become automated (AR) and energetically integrated (EIR).

Green and blue verges can be designed (and in this sense, be part of the road's functional objectives) as part of a strategy to develop a territory's green and blue belt in order to give fauna and flora the ability to move depending on climate changes and to capture CO_2, thus creating an ecological (EC) and climate corridor (RA, referring to either the Egyptian sun god or Roads of the Anthropocene, as you wish).

Concept

The main idea is to transform (by optimally sizing them) the green and blue verges on road land up to the territories adjacent to transport infrastructures (ILTeX) – essentially interurban rail and road links – into ecological and climate corridors where we can implement our range of bio-engineering and geo-engineering solutions. Such an extended corridor:

- Acts as a biodiversity vector, while enabling wildlife to move in order to adapt to climate change through uninterrupted migration routes, from north to south and from east to west;
- Helps to monitor general trends in the state of biodiversity conservation through sensor networks (acoustic and video sensors);
- Stores huge quantities of atmospheric CO_2, for example by means of reforestation or increasing soil organic carbon;
- Hosts alternative fuel production units from the energy or CO_2 that it captures;
- Makes it possible to monitor watercourses, prevent pollution and host micro-treatment plants;
- Produces bio-resources to maintain nearby road networks;
- Etc.

The aim is to develop operational synergies between the ecological functions of the corridor and the technical functions of R5G in order to reduce costs while creating a clear and coherent whole. The R5G telecom infrastructure and the sensors of the road or rail operating system are used for environmentally monitoring the corridor: for example, the cameras within the networks enable the analysis of animal behaviour, feed data into management systems, including the risk of collisions between animals and vehicles, monitor the state of the flora and control human interventions as and when required, at the same time as they measure traffic and weather. Electric energy and the "smart grid" for charging electric vehicles (occasional charging at stations or continuous charging), as well as decentralised energy production equipment (solar road), power the corridor's vehicles and equipment, including micro-units for water treatment and CO_2 sequestration.

This corridor, shown as a diagram in *illustration 2*, has specific governance rules (to be determined between ecologists, transport network operators and public property managers/private landowners) which are sufficiently attractive to increase the perimeter of the corridor by gradual accession of the owners of the land in question.

It is thus a real open-air laboratory in partnership with teams of researchers who test the solutions and compare, in life cycle analyses, the different strategies implemented in the corridor.

Moving towards more environmentally ambitious global performance contracts

The aim would be to draw up ambitious global performance contracts involving states, local authorities and motorway operators. The corridor, comprising the road land and nearby territories (ILTeX) – within the meaning of "1% landscape and development" – would be sized to ensure the neutrality of its impact on biodiversity and offset all residual CO_2 emissions, including from transport, identified on a given date. Corridor operators and co-financiers would be financially encouraged to reduce transport-related emissions by coming up with a certified low-carbon industrial supply (fuels, materials).

In return for these new "high-performance" contracts, operators could be entrusted with adapting urban networks and implementing solutions for adapting urban motorways, such as those proposed as part of the International Consultation on the Future of Motorways in the Greater Paris Region, which are likely to have a positive effect on the population's health. At the same time, the objective would be to create a solidarity mechanism between the city and the countryside, resulting in a virtuous circle between the transformation of urban motorway networks, capable of becoming urban boulevards with a high quality of life, and interurban networks, which could be transformed into ecological and climatic corridors, and thus contribute, by means of a new approach, to the fight against urban sprawl.

EXAMPLES OF RECENT RESEARCH WORKS SUPPORTED BY ITTECOP[1]

Develop and integrate negative emissions solutions along the ILTeXc

Green areas of road land are obvious carbon sinks. The INFRASOLC project demonstrated on paper that favouring certain plant species and/or management practices, allowing more CO_2 to be stored in the soil, could have significant benefits, particularly if we extend the measure to a strip of several hundred metres around the existing areas of motorway land. However, we still need to test the solution on a full-scale basis and create discourse that will convince stakeholders, especially farmers.

In a less technologically mature way, the solutions envisaged by certain start-ups make it possible to capture 100 kt of CO_2 per year, including land and maintenance costs of the ecological corridor, and take up an area of less than one hectare. In theory, it would therefore be sufficient to install about a thousand such facilities along the existing infrastructures to offset transport emissions, i.e. one installation every 10 kilometres (for a 16,000 km network).

Consider the ILTeX as a corridor and a habitat for biodiversity

Road infrastructures play a role in the pressures afflicting wild bee populations. But in degraded environmental contexts, the PolLinéaire project has shown that green transport infrastructure verges can provide remedies for certain diseases that affect these insects. Indeed, in some places, green verges along roads are the last sites to host natural flora and its associated insects. As such, by developing ecological corridors along transport axes that are adapted to different species of fauna and flora, we develop biodiversity supports and offer solutions to boost the competitiveness of agro-ecological practices, a sector that is itself undergoing an "AgTech" transformation.

Furthermore, wildlife, especially large mammals such as wild boars, are a significant source of accidents. We therefore need to better detect and alert road users upstream in order to prevent possible collisions, which is now possible thanks to the services developed in C-ITS projects. In terms of monitoring, the challenge is now to multiply species counts in order to to feed databases in an opportunistic way and subsequently simulate the evolution of animal populations over time and space, thus taking corrective measures throughout the infrastructure's life cycle.

Secure traffic while monitoring climate change and air quality thanks to existing ILTeX instruments

The reduction of fog in Europe, particularly due to the reduction in pollution, over the past 40 years has contributed to a higher rate of climate change than the global average. In Eastern Europe, up to 50% of the global warming observed in recent decades can be explained in this way. By developing instrumented ecological and climate corridors along transport infrastructures, we envisage the development of new, better defined fog observation/prediction cycles, for example, by using images from traffic management cameras to observe the weather. By subsequently

1 https://ittecop.fr/fr/
2 Such as the Canadian firm Carbon Engineering

reversing these models, we could seek to influence the boundary conditions (on the ground) for fog appearance and possibly design the corridor accordingly, thereby participating in the resolution of associated road safety and traffic issues of automated road vehicles in poor weather conditions. The IPAVIA project thus suggests identifying fog occurrences to provide a rough air-quality indicator that would enable us to assess the national policy aimed at improving air quality and indirectly at restoring landscapes, thus reflecting what is being done by the US EPA in large national parks.

THE DIGITAL TWIN, A KEY TECHNOLOGY OF ROADS OF THE ANTHROPOCENE

Challenges and opportunities regarding the digital twin of infrastructures and associated services

Despite not being particularly standardised, a digital twin is a virtual model of a physical object. It covers the life cycle of the object and uses real-time data sent by sensors on the object to simulate behaviour and monitor operations.

It is easy to understand that creating a digital twin of a road infrastructure and of associated solutions based on the nature and the environment surrounding the ILT, from road land to the adjacent territories (ILTeX), taking advantage of existing sensors for its operation and of the digital infrastructure set up to roll out new forms of mobility, would in theory make it possible to roll out, at a marginal cost, new instruments for environmental monitoring and for assessing the benefits of new services via simulation. Therefore, the digitalization of the aforementioned ITTECOP projects, inter alia, would allow their operationalisation in new territories, first virtually then in real life.

As a digital tool, the digital twin of Roads of the Anthropocene would face the usual digital challenges, i.e.:

- The creation of exchange formats and big data management that is compatible with GDPR;
- The development of shape recognition algorithms by data processing or even machine learning;
- The development of new, non-intrusive, communicating sensors;
- The development of models for monitoring parameters covered by the performance contract.

It also faces all of the current digital challenges, such as the frugality of processing, and the durability of the components (such as connected electronic sensors) and systems making up the digital twin. The idea is to avoid a possible rebound effect of emissions linked to the widespread deployment of digital technologies.

To develop these digital twins, we need to coordinate the efforts of numerous public and private stakeholders from various disciplinary fields (engineering, software engineering, electronics, ecology, etc.) While France has taken the lead through the ITTECOP research programme, on the one hand, and is considering the development of a national digital twin on the other, it is not a question of going it alone. We therefore need to step up investment efforts, and involve the European Commission, in particular, by preparing an ambitious research and deployment agenda, to give more space to biodiversity in the aftermath of the Horizon Europe programme. This is precisely the purpose of the BISON project. Furthermore, since we cannot test everything everywhere, one of the major challenges is to identify various pilot territories where we could collect data sets, learn in one place and evaluate other locations.

Illustration through the development of a digital twin to reduce the risk of collisions with wildlife

The OCAPI project funded by the FEREC Foundation from 2020 to 2021, and certified by ITTECOP, develops a technological building block which uses cameras installed to manage environmental infrastructure measures to check the effectiveness of these measures while mapping of the risk of presence of the species which cause collisions. The medium-term objective is to be able to integrate into the infrastructure's digital twin a map of the real-time collision risk, which can adaptively notify users about the risk of a collision via intelligent signage or by directly notifying the vehicle. This project calls for the collaboration of ecologists, software publishers, electronics engineers and data scientists. The project's current developments involve:

- The design and industrialisation of very low consumption AIoT (artificial intelligence of things) sensors to optimise the energy performance of the data processing from the sensors and their transfer to the digital twin;
- Continuous processing of data from these intelligent sensors;
- Development of business software to interface with or support the digital twin of the infrastructure

ROADS OF THE ANTHROPOCENE TOWARDS THE ECOLOGICAL TRANSITION OF TERRITORIES

The Roads of the Anthropocene concept aims to break down barriers between infrastructure projects and their environmental assessment. It can achieve this partly through the digital technologies and infrastructures being deployed. Digital twins will allow us, in principle, to go from an occasional environmental assessment to an ongoing assessment, which will make a substantial contribution to the ecological transition of the territories. This challenge is to be pursued at different scales, from local motorway managers to continents, in consultation with public and private stakeholders, including research funders but also the infrastructures themselves.#