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BISON
BIODIVERSITY AND INFRASTRUCTURE SYNERGIES AND OPPORTUNITIES FOR EUROPEAN TRANSPORT NETWORKS

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Report on Application of BIM and other Tools to Standardise Data Record and Management

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TABLE OF ACRONYMS

AI	Artificial Intelligence
AR	Augmented Reality
BD	Big Data
BIM	Building Information Model(ling)
BPMN	Business Process Model and Note
CAD	Computer Aided Design
CDE	Common Data Environment
CIM	City Information Model(ling)
DL	Deep Learning
DT	Digital Twin
EIA	Environmental Impact Assessment
EU	European Union
ER	Enhanced Reality
FAIR	Findable Accessible Interoperable Reusable
GIS	Geographic Information System
IoT	Internet of Things
IT	Information Technology
LCA	Life-Cycle Analysis
LOD	Level Of Detail
MCA	Multiple Comparison Analysis
MBSE	Model-Based System Engineering
NNL	No Net Loss
OGC	Open Geospatial Consortium
RDI	Research Development & Innovation
(M/S)RS	(Mobile/Static) Remote Sensing
SEA	Strategic Environmental impact Assessment
SDG	Sustainable Development Goal
SRDA	Strategic Research & Development Agenda
TI	Transport Infrastructure
TRL	Technology Readiness Level
UK	United Kingdom
UNEP	United Nations Environment Program
US	United States
VR	Virtual Reality
WP	Work Package

TABLE OF FIGURES

TABLE OF TABLES

EXECUTIVE SUMMARY

During the last decades, digitalisation of representation, data and interactive processes underpinning current practices of infrastructures and biodiversity management have taken different tracks leading to the development of specific knowledge that now has to be mainstreamed in order to render transport infrastructure sustainable with the smallest possible impact on biodiversity. In this document, we explore opportunities for both sectors offered by the development of the operative *continuum* between Geographic Information Systems (GIS), Building Information Model (BIM) and Digital Twin (DT) implemented by transport and/or biodiversity infrastructure developers and managers. Such a continuum would require a Common Data Environment (CDE) which still have to be defined in a context where biodiversity theme is almost absent from the BIM environment. Thanks to the survey performed by the BISON project among stakeholders from transport infrastructure and biodiversity sectors, we showed that the digital technology subject of transport infrastructures as well as biodiversity management is still a topic which seems to be mainly handled independently by a small group of experts, researchers and practitioners from both the sectors. In addition, this shortage seems to be shared among the Member States and their related stakeholder network due to a limited permeability between the transport infrastructure, the biodiversity and the information technology sectors. This report thus points out the main digital technologies which uses tend to emerge in order to manage transport infrastructures as well as biodiversity. In this respect, the report follows the data value-chain and identifies at each step the main digital technologies involved, their current use, and what gaps and barriers are hindering their spread in the market, if relevant. Therefore, it identifies the future main trends in terms of new technologies, or changes in their use. These discussions are not turned only toward the benefits for the transport infrastructure sector or the biodiversity one but rather focused on the opportunities offered by the mainstreaming of biodiversity issues within all the infrastructure management life-cycle[1].

First, the deliverable addresses the general aspect of data collection. In this respect, the first technical section focuses on sensors issue with two complementary and non-exclusive scopes. Sensors are initially considered in a mobile context, where they are embedded in vehicles (satellites, common vehicles, drones, etc.) and are recording data along the vehicle trajectory permitting for large-scale recording or places difficult to access. Second, sensors are considered to be static and to monitor the infrastructure or biodiversity assets they have been aimed at tracking. These static sensors are thus expected to be connected and part of the Internet of Things (IoT) to operate as a network. Such a functioning offers the opportunity for long-term continuous monitoring of the transport infrastructure and its environmental assets. Growing especially in the environmental sector, citizen-based data is the subject of the third part of the data collection topic. Citizen-based data are largely used for biodiversity monitoring and should be considered with the mainstreaming of biodiversity in transport infrastructure. For now, citizen-based approaches are rare in the transport infrastructure management sector and including these new approaches might open several new challenges. This section continues with a part dedicated to modelling with a focus on engineering models which aim to produce realistic simulated data to solve engineering problems. Being largely used in the industry sector and in civil engineering, ecological models are developing but their use for solving biodiversity questions occurring in the context of transport infrastructure management is still quite rare. To close the data acquisition aspect, a transversal section dedicated to artificial intelligence (AI) techniques intends to highlight their catalytic

[1] https://handbookwildlifetraffic.info/annex-1-glossary/

effects when implemented with the different data collection techniques addressed in the deliverable. We, therefore, conclude that both biodiversity and transport sectors use these tools and data for specific purposes which can often be mutualised and offer opportunities for cost-efficient improvement of transport infrastructure and biodiversity management.

The second technical section is turned toward data management and sharing issue. We show that transferring knowledge and know-how from the BIM sector, especially regarding processes, constitute a large field of research, development and innovation. This expansion of the BIM application field should be developed and promoted in order to ensure interoperability between the two current silos represented by the biodiversity management on one side, and the transport infrastructure management on the other whilst they are more and more intertwined. The two main keys to address interoperability problems are data structure and exchange file format interoperability between software. Regarding data structure, incorporating BIM-related concepts and methods developed in the industry or in the real estate management are a necessary step. We thus propose to develop good practices inspired by BIM processes which can be applied to data collection as well as data sharing at the EU scale in the context of mainstreaming biodiversity in transport infrastructure. Finally, this section makes a focus on the central challenge encountered to address data spatial and temporal heterogeneity, which is relevant for mainstreaming biodiversity in transport infrastructure management. Particularly, this section discusses some data interoperability challenges. They are related to managing data at large scale with 2D GIS commonly used for biodiversity management and linear transport infrastructure and with BIM with regards to the development of DT tools. Such an interoperability issue must also be put in perspective of the development of smart sustainable cities which have to be connected with transport and/or biodiversity actual and digital infrastructures.

After addressing data collection and their management issues, the deliverable explores some integrative applications which are expected to emerge from the development of digital tools, allowing for the integration of biodiversity themes into transport infrastructure management. Thus, the report pledges for the development of an integrative GIS/BIM/DT *continuum* able to properly integrate biodiversity management into the complete life-cycle of transport infrastructures to ensure their sustainability and prevent them from being a source of biodiversity loss. Thus, this section first addresses the opportunities in terms of development of a practitioner community offered by the joint work of the biodiversity management, the transport infrastructure management and the computer science communities. Therefore, the section addresses the topic of the software development required to ensure data interoperability and collaboration between actors of the mainstreaming of biodiversity in transport infrastructures. We finally explore emerging expected practices offered by the development of inclusive GIS/BIM/DT for biodiversity and transport infrastructure as the integration of biodiversity into the life-cycle assessment of transport infrastructure, the development of virtual and enhanced reality for infrastructure management and relation with citizens or regulating administration, etc. Such an integrative *continuum* would otherwise require massive research, development, innovation and capacity building as it constitutes a new activity sector at the crossroad between civil engineering, ecology and computer science.

Digital technologies are energy and resource consuming. We, thus, provide recommendations to ensure the sustainability of the mainstreaming of biodiversity in transport infrastructure in a digital environment. Similarly, some specific data security recommendations are provided to avoid specific risks associated with the biodiversity data and prevent illegal trade of protected species for instance.

TABLE OF CONTENTS

1. INTRODUCTION

1.1. General context

During the last decades, digitalisation of representation, data and interactive processes underpinning current practices of infrastructures and biodiversity management have taken different tracks leading to the development of specific knowledge. Now, it is necessary to maintream this knowledge in order to render transport infrastructure sustainable with the smallest possible impact on biodiversity. In this document, we explore opportunities of the operative *continuum* between Geographic Information Systems (GIS), Building Information Model (BIM) and Digital Twin (DT) implemented by transport and/or biodiversity infrastructure developers and managers can offer for both these two sectors. Such a continuum would require a Common Data Environment (CDE) which still have to be defined. Thanks to the survey performed by the BISON project among stakeholders from transport infrastructure and biodiversity sectors, we showed that the digital technology subject of transport infrastructures as well as biodiversity management is still a topic which seems to be mainly handled by a small, independent group of experts, researchers and practitioners from both sectors. In addition, this shortage seems to be shared among the Member States and their related stakeholder network. Thus, this report points out the main digital technologies which uses tend to emerge in order to manage transport infrastructures as well as biodiversity. In this respect, the report follows the data value-chain and identifies at each step the main digital technologies involved, their current use, and what gaps and barriers are hindering spread in the market, if relevant. Therefore, it identifies the future main trends in terms of new technologies, or changes in their use. These discussions are not turned only toward the benefits for the transport infrastructure sector or the biodiversity one but rather focused on the opportunities offered by the mainstreaming of biodiversity issues within all the infrastructure management life-cycle.

1.2. Report's objectives

This report aims at producing a comprehensive state of the art concerning the mainstreaming of biodiversity in transport infrastructure with a digital perspective, in order to identify the main past and future trends which would feed the main BISON project's outcome: The Strategic Research and Development Agenda (SRDA). This report also aims at initiating the dialog between biodiversity conservation, transport infrastructure and information technology sectors which would be required to develop a common culture allowing for the mainstreaming of biodiversity with transport infrastructure in the digital environment.

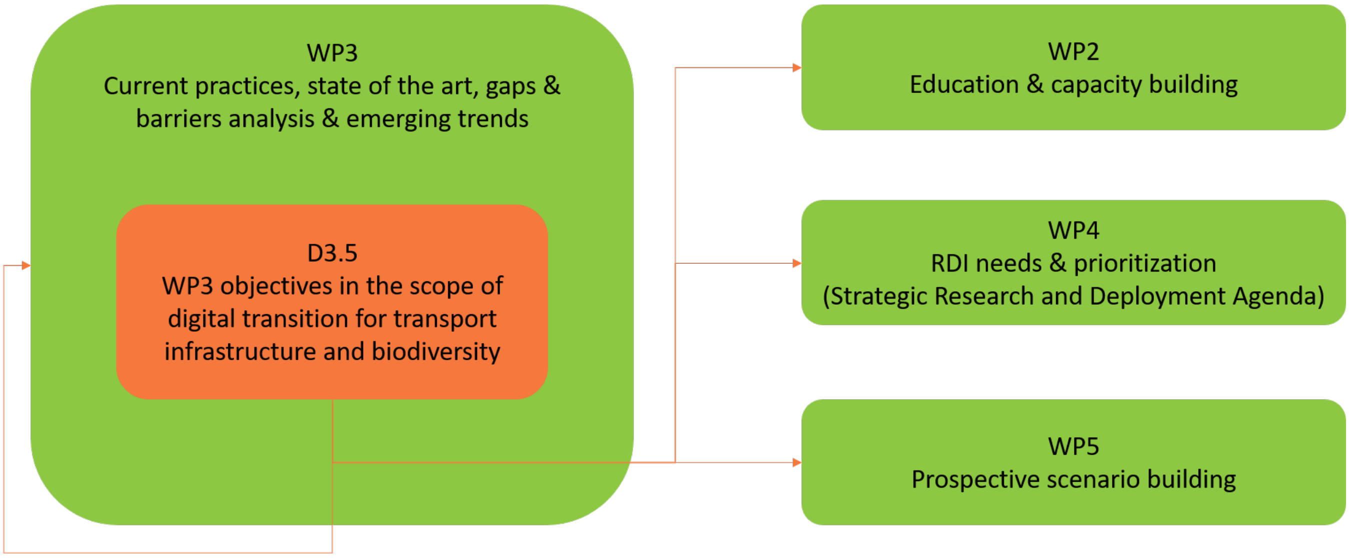


Figure 1: Deliverable 3.5 (D3.5) role in the BISON project

1.3. General methodology

The methodology implemented to produce this report is based on a combination of:

- A non-systematic literature review. We performed a literature review based on scientific and technical publications shared by BISON and associated partners[2] (advisory group members and questionnaire respondents (see below)).
- A stakeholder survey to evaluate transport and biodiversity management awareness about digital technologies.
- Workshops with BISON partners (January 2022) and the advisory group members (February 2022) to share and discuss the literature review and stakeholder survey results as well as enrich the report with substantial additional expertise (see appendices).

[2] https://bison-transport.eu/#about

1.4. Definitions in the BISON project perspective

Geographic Information System (GIS)

*A **geographic information system** (**GIS**) is a conceptualised framework that provides the ability to capture and analyse spatial and geographic data. GIS applications (or GIS app) are computer-based tools that allow the user to create interactive queries (user-created searches), store and edit spatial and non-spatial data, analyse spatial information output, and visually share the results of these operations by presenting them as maps.*

(« Geographic Information System », Wikipedia 2021)

Assuming that Wikipedia's proposed definition is consensual, a GIS is thus dedicated to data storage, management, analysis and representation of spatial information thanks to digital tools. In this context, mandatory main input of this system is data of any kind and its location represented by its real longitude and latitude coordinates. While it was initially designed for data management and representation in a two-dimensional perspective, additional dimensions, such as altitude / elevation, time, and cost have been rapidly integrated to enrich the system.

GIS approaches conceptually appeared during the 19th century (Picquet, 1832) but they have been firstly used with the real current definition of GIS in a planification paper in 1963 by Roger Tomlinson, who is now considered as the father of GIS (Roger Tomlinson | UCGIS, 2015). They were rapidly adopted by landscape planners, and Mc Harg (McHarg, 1971) proposed the first integrative multidisciplinary framework for landscape management and project development based on GIS approaches.

Nowadays, GIS tools are widely used to manage and analyse large-scale datasets dedicated to biodiversity, transport location and as a tool for transport infrastructure management all across Europe (see Table 1). Transport infrastructure management monitoring systems are now used to feed biodiversity datasets. For example, in the Netherlands, within the framework of National Databank Flora and Fauna[3], ProRail monitors biodiversity every 5 years along railways and their assets across the country, gathering data which feed national fauna and flora databases. In France, it is now mandatory by law for developers and infrastructure managers to feed the national information system on biodiversity as soon as an administrative authorisation is delivered.

[3] https://www.ndff.nl/english/

Table 1: Examples of GIS-based data set management and some GIS-based tools used to address transport or biodiversity management and sometimes the mainstreaming of biodiversity in infrastructure management. More examples worldwide in the appendix.

Name	URL	Location	Infrastructure	Biodiversity
GIS-based data management systems				
Alien species in Poland	https://www.iop.krakow.pl/ias	Poland		X
Geoportail	https://www.geoportail.gouv.fr/	France	X	X
Geoservice - General Directorate for Environmental Protection (GDOS)	http://geoserwis.gdos.gov.pl/mapy/	Poland		X
Nature France	https://naturefrance.fr/systeme-information-biodiversite	France		X
Spatial data infrastructure	https://www.idee.es/web/idee/inicio	Spain	X	X
Gencat's corporate SIG Data viewer	https://sig.gencat.cat/visors/hipermapa.html	Spain	X	X
GIS-based tools for mainstreaming biodiversity in transport infrastructure				
Bioccitanie	https://bioccitanie.laregion.fr/	France	X	X
Map of ecological corridors	https://mapa.korytarze.pl/index_en.html	Poland	X	X
Network Rail	https://www.networkrail.co.uk/news/latest-technology-used-to-improve-thousands-of-miles-of-lineside-biodiversity/	UK	X	X

Building Information Modelling (BIM)

ISO 19650:2019 defines BIM as:

> *Use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions.*

The US National Building Information Model Standard Project Committee has the following definition:

> *Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.*

Traditional building design was largely reliant upon two-dimensional technical drawings (plans, elevations, sections, etc.). Building information modelling extends the three primary spatial dimensions (width, height and depth), incorporating information about time (so-called 4D BIM), cost (5D BIM), asset management, sustainability, etc. BIM therefore covers more than just geometry. It also covers spatial relationships, geospatial information, quantities and properties of building components (for example, manufacturers' details), and enables a wide range of collaborative processes relating to the built asset from initial planning through to construction and then throughout its operational life.

(« Building Information Modelling », Wikipedia 2021)

For the EU BIM task group, "BIM is a digital form of construction and asset operations. It brings together technology, process improvements and digital information to radically improve client and project outcomes and asset operations. BIM is a strategic enabler for improving decision-making for both buildings and public infrastructure assets across the whole life-cycle. It applies to new construction projects; and crucially, BIM supports the renovation, refurbishment, maintenance and decommissioning of the built environment – the largest share of the sector" (Baratono et al., 2017).

Following these definitions, BIM is not only spatially representing data, but it is composed of spatially and / or functionally interconnected objects in order to support the decision-making processes underpinning infrastructure life-cycle from its early conception to its maintenance and, ultimately, its decommissioning. Hence, the processes supporting the collaboration of multiple people from multiple disciplines around the infrastructure becomes central as much as data, techniques and representations. Putting interaction between stakeholder at the center of the BIM development and developping processes able to allow these interactions are goals which benefit from a strong background in the definition of Common Data Environment (CDE) and data management modelling, based on the Business Process Models and generally Notes (BPMN) concepts (see section 3.2 for more details on these two central concepts). Ultimately, the BIM approach is expected to support the process of decision-making along a project life-cycle thanks to a shared representation (project visual representation) and a similar access to information (data management) for all the stakeholders involved in the project life.

Conceptually developed in the 1970s for buildings, the BIM term first appears in a Simon Ruffle paper in 1986 (Ruffle, 1986) and its first real application is considered to have occurred for the London Heathrow Airport. Until now, the concept and associated tools are growing up, including more and more disciplines (Fountain & Langar, 2018) and integrative concepts (Catalano et al., 2021). Nowadays, BIM is mandatory in public infrastructure projects in multiple countries. In the Netherlands, BIM has been mandatory for public projects above 7000 m2 since 2012. In the United Kingdom it has been mandatory since 2016 in the public sector and private projects are now also required to use BIM. Finland has made all building conception software to be compatible with the BIM interoperable file format standard. Even if building / infrastructure sustainability evaluation from life-cycle analysis are now largely included in BIM (Carvalho et al., 2020), biodiversity aspects are poorly integrated within this framework (Catalano et al., 2021).

Nowadays, according to the EU BIM task group handbook (Baratono et al., 2017), the use of BIM in the construction sector is expected to save 15-25% of global infrastructure market by 2025, in addition to providing a strong improvement of social and environmental benefits. Indeed, the handbook illustrates how BIM processes help companies improve their competitiveness thanks to a better economic efficiency driven by such processes. The book also shows how BIM processes contribute to the optimisation of resources efficiency (including energy) or major improvements in health and safety for people living and working in the digitalised assets (Figure 2). Unfortunately, biodiversity management issues are until now roughly absent from the BIM environment (but see Moulherat, 2017; Moulherat et al., 2018). As a consequence, in this digital environment they suffer from a lack of representation ability, interoperability with the other sectors acting with BIM models and dedicated embedded tools.

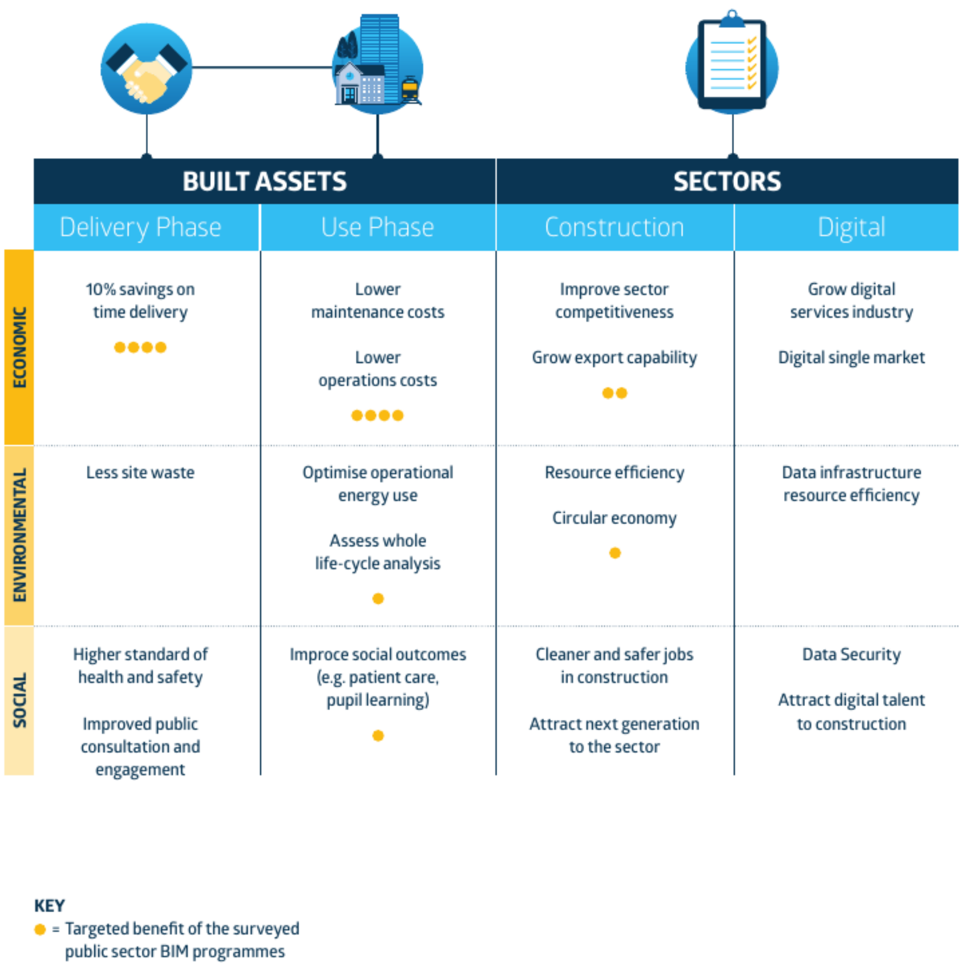


Figure 2: Expected benefits from the BIM massive deployment in the EU (Baratono et al., 2017, p.19). Note that the biodiversity perspective is absent from the analysis.

Table 2: Examples of BIM available for demonstrations in the transport infrastructure sector

Name	URL	Location	Infrastructure	Biodiversity
BIM Infra.dk	https://biminfra.dk/	Denmark	X	
BIM Interministerial commission	https://cbim.mitma.es/	Spain	X	
BIM GENCAT	https://territori.gencat.cat/es/01_departament/04_actuacions_i_obres/BIM/index.html	Spain	X	
BioBIM	https://www.youtube.com/watch?v=iytgSUwNyBM	France	X	X
HS2 BIM model	https://learninglegacy.hs2.org.uk/document/soils-landscape-and-woodland-how-hs2-is-using-integrated-asset-information-management-in-a-bim-environment/	UK	X	X

Digital Twin (DT)

A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process. Through the concept originated earlier, the first practical definition of digital twin originated from NASA in an attempt to improve physical model simulation of spacecraft in 2010. Digital twins are the outcome of continuous improvement in the creation of product design and engineering activities. Product drawings and engineering specifications progressed from handmade drafting to computer aided drafting/computer-aided design (CAD) to model-based systems engineering (MBSE).

Geographic digital twins have been popularised in urban planning practice, given the increasing appetite for digital technology in the Smart Cities movement. These digital twins are often proposed in the form of interactive platforms to capture and display real-time 3D and 4D spatial data in order to model urban environments (cities) and the data feeds within them.

Visualisation technologies such as augmented reality (AR) systems are being used as both collaborative tools for design and planning in the built environment integrating data feeds from embedded sensors in cities and API services to form digital twins. For example, AR can be used to create augmented reality *maps, buildings, and data feeds projected onto table tops for collaborative viewing by built environment professionals.*

In the built environment, partly through the adoption of BIM processes, planning, design, construction, and operation and maintenance activities are increasingly being digitised, and digital twins of built assets are seen as a logical extension - at an individual asset level and at a national level. In the United Kingdom in November 2018, for example, the Centre for Digital Built Britain published The Gemini Principles, outlining principles to guide development of a "national digital twin".

(« Digital Twin », Wikipedia 2021)

A step further in the BIM approach, sometimes coming from a pre-existing BIM or GIS model, is the digital twin (DT) approach. In DT, the digital object of interest is the digital interacting copy of the real existing physical object. Thus, DT are more dedicated to object maintenance and daily exploitation thanks to the development of the Internet of Things (IoT), which allows the monitoring of the actual object in close to real time. Such a concept opens the way to the development of predictive maintenance of transport infrastructure as well as biodiversity assets such as road verges, wildlife crossing structures or retention ponds. Therefore, digital twins are expected to support the development of virtual and enhanced reality (ITF, 2021).

Digital twin is expected to play a major role in the future of infrastructure management along their whole life-cycle, biodiversity conservation as well as human adaptation to climate change. For instance, the DestinE project aims at developing a highly accurate digital model to monitor Earth to predict the effect of natural phenomena on human activities, as a common part of the EU Green Deal and the EU Digital Strategy (European Union, 2022). Indeed, these approaches would allow large-scale continuous monitoring of biodiversity with a high potential for feeding large-scale models able to support adaptive management, conservation and restoration strategies, etc. (Evans et al., 2013; Tuia et al., 2022; Urban et al., 2021).

Table 3: Examples of national strategies aiming at developing sectorial digital twins, driven by institution or large-scale infrastructure operators. Note that biodiversity management is rarely targeted by these strategies

Name	URL	Location	Infrastructure	Biodiversity
Earth Digital Twin	https://www.esa.int/Applications/Observing_the_Earth/Working_towards_a_Digital_Twin_of_Earth	EU	X	X
ASHVIN project	https://www.ashvin.eu/	EU	X	X
Forest Digital Twin Earth Precursor	https://www.foresttwin.org/	EU		X
PortForward	https://www.portforward-project.eu/	EU	X	
Digital Twins for Blue Denmark	https://www.dma.dk/Documents/Publikationer/Digital%20Twin%20report%20for%20DMA.PDF	Denmark	X	
National Digital Twin	https://www.cdbb.cam.ac.uk/what-we-do/national-digital-twin-programme	UK	X	
SNCF Réseau Digital Twin	https://uic.org/events/IMG/pdf/digital_twin_at_sncf_reseau_the_importance_of_a_common_digital_model_for_operation.pdf	France	X	
Principles for Spatially Enabled Digital Twins of the Built and Natural Environment in Australia	https://www.anzlic.gov.au/resources/principles-spatially-enabled-digital-twins-built-and-natural-environment-australia	Australia	X	X

The GIS BIM DT continuum and associated digital opportunities

Finally, GIS, BIM and DT constitute a conceptual, procedural and technical continuum that all the different stages of infrastructures' life-cycle can be addressed along. Hereafter we use GIS/BIM/DT to represent this whole continuum. However, the functional continuity is for now far from being efficient. Indeed, Figure 3 shows the current usage of GIS, BIM and DT along the transport infrastructure life-cycle in infrastructure and biodiversity management. Thus, infrastructure management uses the three different approaches depending on the infrastructure's life-cycle stage while the biodiversity sector only uses GIS approaches. This contrast in implemented approaches in both the sectors highlights the strong changes in practices which should be operated with the digitalisation of data management mainstreaming biodiversity with transport infrastructure.

The use of BIM and its processes has demonstrated strong improvement in the design and management of real estate with substantial gain of competitiveness (see section 3.1 for further details, Baratono et al., 2017; Executive Agency for Small and Medium sized Enterprises, 2021; Fountain & Langar, 2018). Comparable benefits are expected for transport infrastructure management which now have the responsibility for including their environmental assets into their management processes. Thus, the expected benefits would be maximized if the biodiversity theme was fully integrated into these emerging management processes.

One would finally expect that in a not so far future, benefits coming from GIS, BIM and DT approaches will be unified, making their interoperability efficient. In this respect, the two main providers in the infrastructure and biodiversity sectors (ESRI and Autodesk) developed strategic partnership to ensure interoperability between their solutions. From an infrastructure management perspective, the RailTOPOMODEL project has proposed efficient harmonisation for railway network management thanks to interoperable continuum of GIS, BIM and DT[4]. Therefore, data underpinning the digital model representing the infrastructure and its biodiversity assets (including historical data[5]) would be efficiently used regardless of the infrastructure life-cycle phase nor the activity sector needing this information. We should then imagine a unique model connected to existing common accessible database such as the EU cloud to edge infrastructure and services and the common data space[6] developed in the frame of the EU Digital strategy[7]. Such approach would make it possible to manage data coming from sensors deployed on the infrastructure and its assets (including environmental ones), allowing predictive and dynamic maintenance (ITF, 2021) and supporting the consultative and regulatory processes (Baratono et al., 2017; Catalano et al., 2021; Moulherat et al., 2018). However, such a high-tech environment should be adequately adapted to real operative needs (including transport infrastructure environmental footprint) as well as work evolution abilities and thus be fully interoperable with existing and future low-tech solutions.

[4] https://www.railtopomodel.org/en/homepage.html
[5] https://www.railtech.com/infrastructure/2022/02/01/hs2-engineers-working-on-digital-twin-for-new-high-speed-rail-network/
[6] http://dataspaces.info/common-european-data-spaces/#page-content
[7] https://digital-strategy.ec.europa.eu/en/policies/cloud-computing

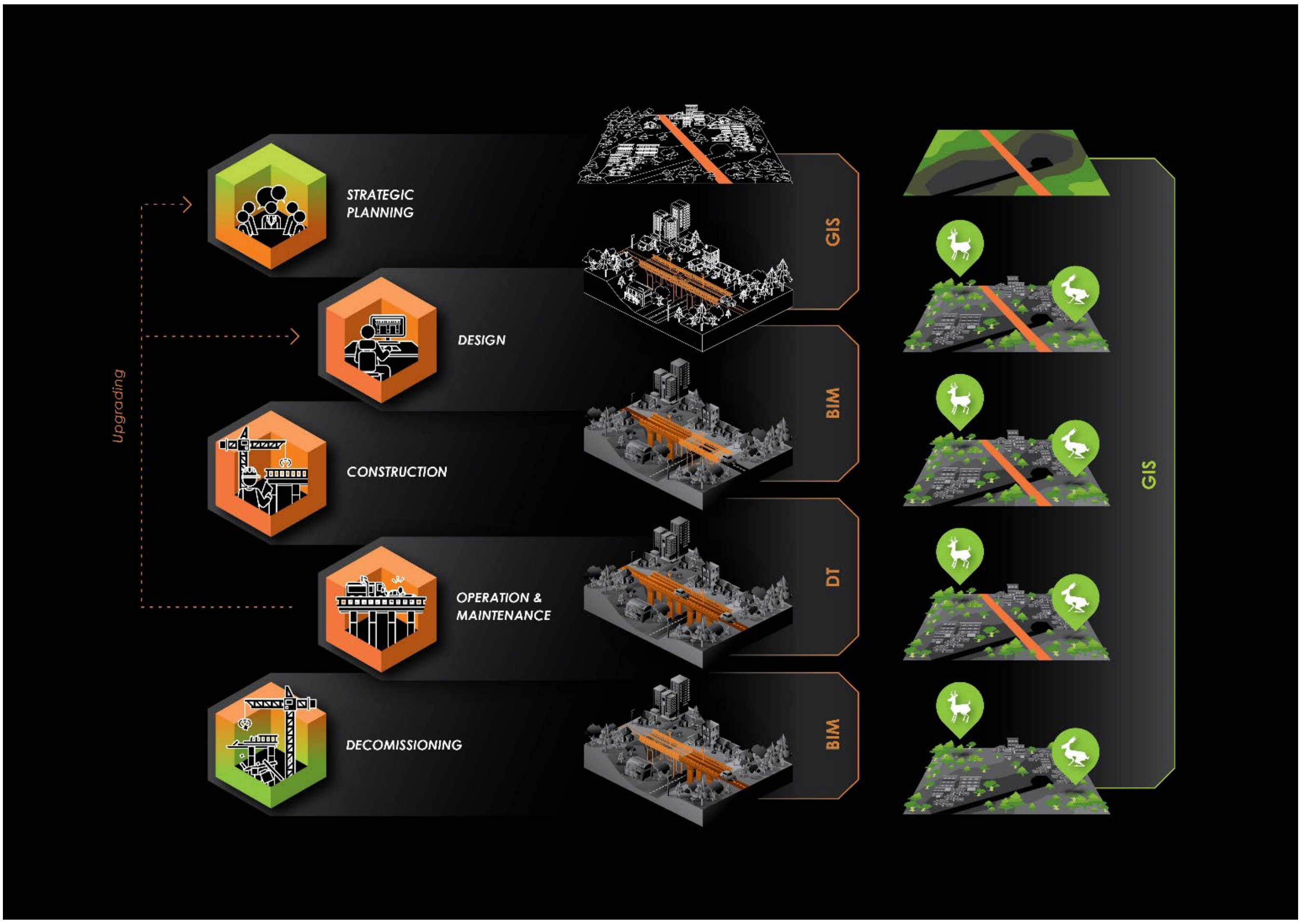


Figure 3: Current use of GIS, BIM and DT along the transport infrastructure life-cycle for biodiversity and transport infrastructure management.

1.5. Current awareness context concerning the digitalisation of transport infrastructures and biodiversity management

Digitalisation of infrastructures and biodiversity management are ongoing processes where research, development and innovation are very active, thanks to the common impulses of global digital transition, supported by the EU Digital Strategy, and the subsequent consequences on EU sectorial policies (including transport, mobility and biodiversity). To assess how aware practitioners are on some of the main themes underpinning this digitalisation of infrastructure and biodiversity management, we performed a survey among the EU stakeholder of transport infrastructure and biodiversity managers.

We use the result of the BISON questionnaire developed by T3.1 to draw the current situation of transport infrastructure and biodiversity management sectors awareness regarding opportunities and threats offered by the development of digital technologies. In this respect, we analysed the answers of 159 respondents to the BISON's questionnaire concerning the 10 questions relevant to our topic presented in Table 4. Among the questionnaire respondents, all of them answered to the generic question about their organisation type, country and action range, but only 25% provided answers to the 7 specific questions (Q125, 126, 129 and 131 to 134), illustrating a limited awareness or interest of respondents to the digital technology development for transport infrastructure and/or biodiversity.

Table 4: Questions from the BISON common questionnaire relevant to T3.4. Formulation is simplified in this document but the comprehensive formulations are available in appendix.

Question number	Formulation	Type of answer	Answer rate (%)
Q5	Respondent's country	Categorial (a level per country)	99.37
Q7	Respondent's action range	Categorial (*Regional*, *National*, *Global*)	99.37
Q10	Respondent's organisation type	Multiple categorial (9 levels)	96.86
Q125	Existing national TI data management strategy	Boolean	21.39
Q126	Existing national biodiversity data management strategy	Boolean	22.02
Q129	Integration of big-data and biodiversity themes in transportation digitalisation strategies	Boolean	27.04
Q131	Transport infrastructure/biodiversity benefits from remote sensing in conception / construction / exploitation	Table of Boolean	25.79
Q132	Transport infrastructure /biodiversity benefits from IoT in conception / construction / exploitation	Table of Boolean	16.98
Q133	Transport infrastructure /biodiversity benefits from big-data & AI in conception / construction / exploitation	Table of Boolean	23.90
Q134	Transport infrastructure /biodiversity benefits from BIM/DT in conception / construction / exploitation	Table of Boolean	22.01

To better understand the sector awareness about the issue addressed in this document, we performed multiple comparison analysis (MCA) on the answers to our 10 relevant questions, in order to understand how the answer modalities are associated to each other. The first MCA performed on the comprehensive data set shows that:

- The respondent population can be split into *technophilic* and *non-technophilic personae* regardless of their country or organisation type.
- Respondent saying that transport infrastructure digital transition includes a big-data and a biodiversity themes tend to identify mutual interest for all the digital technologies proposed for transport infrastructure and biodiversity in both conception and construction phases.
- The BIM/DT and Big Data (BD) / Artificial Intelligence (AI) digital technologies seem to be better handled by or to be more cleaving between respondents than Remote Sensing (RS) and the Internet of Things (IoT). IoT technologies are the worst handled or least understood technologies.
- Non-EU countries seem to present different answers from EU ones, which can support the idea that EU policies and strategies play a role in favour of digital technology spreading into transport infrastructure and biodiversity management sectors. This last result should be tempered by the fact that MCA are sensitive to rare events and only few non-EU participants answered the questionnaire (N = 8).

As EU and non-EU countries seem to present contrasted patterns, we performed a second MCA removing non-EU countries (UK and Switzerland have been considered as EU countries as the UK was part of the EU during the period covered by the survey and Swiss strategies are often strongly influenced by EU strategies). This second analysis reinforced the results obtained at the global scale.

As a conclusion to this survey, results seem to show that the development of digital technologies and the opportunities it offers to transport infrastructure and biodiversity management are currently confidential and rely on a limited number of knowledgeable people regardless of country or organisation type. This statement seems to apply all along the value chain of data related to transport infrastructure and biodiversity. The stakeholder awareness decreases in higher levels of the chain, where the process presents the highest added value. This relatively unsurprising result is probably due to the limited existing permeability between the three main sectors concerned (transport infrastructure, biodiversity and digital sectors). Previous work conducted by Global and EU institutions already observed the need for developing common languages and culture in order to support the development of BIM and digital twin in the construction and infrastructure sectors (Baratono et al., 2017; ITF, 2021). Our results here confirm these trends and highlight the associated challenges in mainstreaming biodiversity management issues in this ongoing dynamic of common culture development.

2. COMMON DATA FOR INFRASTRUCTURE AND BIODIVERSITY MANAGEMENT

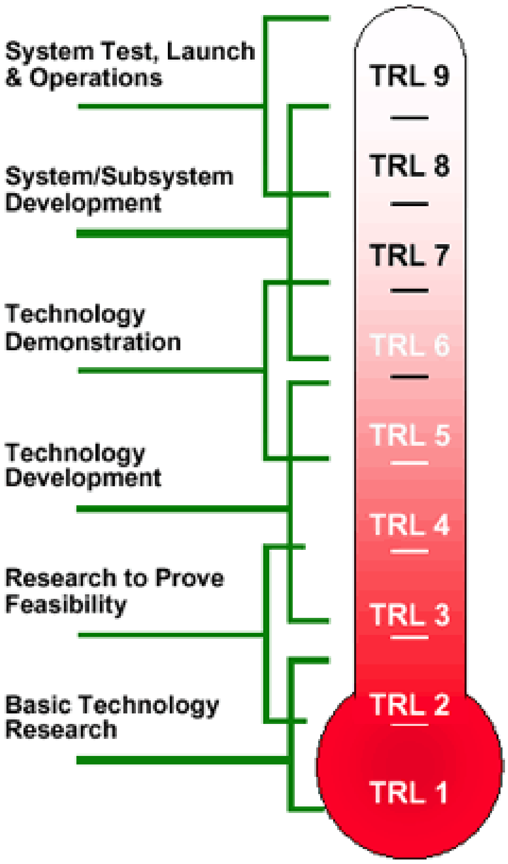
Both the transport infrastructure and biodiversity management require data collection along all the life-cycle of infrastructures. If some of them are clearly specific to a sector or another (e.g. biodiversity inventories, infrastructure maintenance), many can also be shared and feed both the transport infrastructure and biodiversity issues (Moulherat et al., 2018). Hence, this section highlights some of the main data used at the same time by both sectors and points out some possible tracks to mainstream their collection, management and exploitation in order to improve the cost efficiency of the data challenges. In the perspective, data challenges are addressed first by their production mode, and then by the scope of challenges which will emerge with the massification of data production around the future transport infrastructure. As much as possible, the different existing or emerging trends in data collection and management for TI and biodiversity maturity level have been evaluated by the expert contributing to the document edition (Box 1).

Box 1: Technology Readiness Level (TRL)

The Technology Readiness Level (TRL), aims at evaluating a technology maturity on a scale ranging from 1 to 9. The lowest TRL corresponds to technologies benefiting from conceptual definition only, while the highest are those close to or on market.

In this document, experts provided their TRL analysis for different applications as follow:

- TRL 1-3: for applications formulated from a theoretical point of view up to the presentation of a proof of concept in a scientific paper.
- TRL 4-6: for applications benefiting from multiple proof of concept to basic small demonstrators
- TRL 7-9: for applications which have been demonstrated in large demonstrators then in operative environment (actual use cases).
- TRL 9: for commonly used application in operative environment



Technology Readiness Level scale (source Wikipedia)

2.1. Data collection practice

2.1.1. Mobile Remote Sensing common opportunities

In this section, Mobile Remote Sensing (MRS) is used to describe any kind of sensor mounted on a mobile vector. Mobile vectors can therefore be satellites, vehicles, aeroplanes, UAVs, etc. In practice, MRS is generally deployed for specific reasons and with a specific purpose. As an example, the French railway manager, SNCF Réseau developed a subsidiary operating on railways and power lines using LIDAR embedded in drones to monitor, map and inspect the physical state and integrity of networks[8]. Similar technologies are also used in forestry for example, in order to manage wood stock (Pirotti, 2011). However, even when the same methodology is used to collect these two types of data, they are not exploited together, for example to monitor plant growth in offset sites along the transport infrastructure.

2.1.1.1. Mainstreaming Mobile Remote Sensing data collection for infrastructure and biodiversity management

Mobile Remote Sensing (MRS) is emerging to collect information and analyse the natural and built environment (ANZLIC, 2019; Marre et al., 2020; Pelorosso et al., 2021; Ranzoni et al., 2019; Vihervaara et al., 2017). As the need for TI and biodiversity monitoring increases along with public policies evolution, MRS techniques are more and more implemented to perform large scale monitoring (electric lines inspection, land cover dynamics, etc.) or to monitor hardly accessible places (dam or bridges structural inspection) with an increasing number and variety of vectors, from satellites to specifically designed vectors passing by the adaptation of traditional vehicles.

The raw data produced by these sensors are physical measures which are expected to facilitate the common use for different applications and to limit the interoperability troubles (but see Vassart et al., 2016). However, as biodiversity and TI management are traditionally part of separate silos along the TI life-cycle, data produced by a sector is rarely used again by the other (Vassart, Houewtonou, et al., 2016). Such a statement is also true along the research development and innovation (RDI) gradient, where researchers and engineers from both sectors are rarely working together, which is therefore limiting the ability of mutual benefits development (Fountain & Langar, 2018; Høye et al., 2022), while common development is possible along this RDI gradient (Table 5).

[8] https://www.sncf-reseau.com/en/entreprise/newsroom/sujet/drones-the-railway-and-altametris

Table 5: Main applications of MRS for transport infrastructure and biodiversity management

Technology	Applications in the infrastructure management sector	Applications in the biodiversity management sector
Multi-hyperspectral imagery (satellite / aerial / terrestrial / marine)	Structural monitoring – [TRL 9] Soil moisture and flooding risk monitoring – [TRL 7-9]	Vegetation identification, health, phenology, etc. – [TRL 9]] Natural habitat qualification and quality (terrestrial and aquatic) – [TRL 7-9] Light pollution (Sordello et al., 2021) – [TRL 7-9] Animal detection and identification – [TRL 7-9]
LIDAR (aerial / terrestrial / marine)	Volumetric (3D) modelling – [TRL 9] Digital Terrain Model, Digital Canopy Model, Digital Surface Model, etc. – [TRL 9] Structural monitoring – [TRL 9] Electrical network monitoring – [TRL 9] Hydrological modelling – [TRL 4-6]	Verge monitoring – [TRL 4-6] Vegetation volumetric modelling, canopies delineation and carbon storage – [TRL 4-6] Vegetation identification – [TRL 1-3]
Thermal imagery (aerial / terrestrial)	Electrical network monitoring – [TRL 7-9]	Animal detection and identification – [TRL 7-9]
RADAR / SAR etc. (satellite / aerial / terrestrial / marine)	Geological studies – [TRL 9] Structural monitoring– [TRL 9] Movement detection – [TRL 9]	Animal detection and identification – [TRL 4-9] Wetland identification and monitoring – [TRL 4-6]

Mobile Remote Sensing is deployed by infrastructure and biodiversity managers and perceived in the survey as relevant regardless of the life-cycle stage of the infrastructure. Indeed, respectively, 70%, 50% and 73% of the survey respondent consider that MRS technologies are beneficial to transport infrastructure biodiversity interactions during the conception, construction and exploitation phases. Nevertheless, MRS technologies are not currently used in a crossed manner (i.e. data collected for infrastructure management are not used to address biodiversity issues and *vice versa*) (Moulherat et al., 2018; Vassart, Houewatonou, et al., 2016). Reasons for this lack of cross analysis are multiple:

- Awareness issue: most practitioners are not aware that RS data coming from one field of expertise could be valuably exploited by the other – (capacity building issue)
- Skill issues: most practitioners of environmental impact assessment (EIA) or strategic environmental assessment (SEA) have limited skills and awareness of RS technologies and do not use it to perform their studies – (capacity building issues)
- Planning issues: during the conception phase, there is a discrepancy between scales of analysis and level of detail required by infrastructure and biodiversity managers – (innovation in processes)
- Technical issues: infrastructure and biodiversity managers use the listed technologies for very specific purposes which are not systematically deployed – (innovation in processes)
- Technical issues: MRS data analysis is complex and thus can be time consuming and expensive (RS technique is often based on machine learning which requires learning expensive, long and hard to build datasets) – (innovation in process)
- Cost issues: most analyses are based on AI technique which are costly to develop due to the large datasets needed for training the AI.

2.1.1.2. Future trends in the use of Mobile Remote Sensing for transport infrastructures and biodiversity management

Scientific literature (Tuia et al., 2022) and policies (ANZLIC, 2019; Høye et al., 2022; ITF, 2021) tend to promote Remote Sensing for transport infrastructure and biodiversity management. The BISON project's survey shows that MRS digital technology are probably the best handled by the practitioner community (see section 1.2). Such a cross observation suggests the potential for a rapid and efficient development and deployment of MRS in transport infrastructure to mainstream biodiversity.

During the *Digital Ecology* workshop in 2019[9] on the expected usage of MRS, practitioners from both sectors pointed out the fact that:

- *Field access is sometimes hard and human field work extension is limited due to its cost. Remote Sensing offers the ability to deploy multiple complementary approaches at multiple scales.*
- *[…] MRS embedded in BIM tools would allow for fluid workflow, high reactiveness in alert and recommendation management, and would potentially support ecological engineering works.*

[9] https://oikolab2019.onera.fr/

In parallel, existing literature on transport infrastructure associated biodiversity asset design and management, emphasise the current limitation of biodiversity studies which are mainly based on expert opinion and would probably benefit from better surveys and more objective evaluations (Boileau et al., 2022). In this context, Mobile Remote Sensing is considered as a major tool, able to strongly improve the mainstreaming of biodiversity issues along the infrastructures' life-cycle in an increasingly digitalised environment (Boileau et al., 2022; Catalano et al., 2021).

Both the transport infrastructure and biodiversity management are increasingly using MRS for their specific purposes. However, their working scales are often different. Indeed, the biodiversity sector is used to work at large to very large scale (transport infrastructure plus a large area to understand how transport infrastructure influences the landscape scale ecosystem's dynamics) with a low to medium resolution, while the transport infrastructure sector focuses on the built environment with a high resolution (bridge, cable, …). Thus, the mainstreaming of Mobile Remote Sensing data from both sectors become hard due to the different scales and resolutions used and, subsequently, the existing tools to manage and exploit the data produced. These difficulties may lead to interoperability troubles along the GIS/BIM/DT *continuum* between sectors (Catalano et al., 2021; Vassart, Houewatonou, et al., 2016).

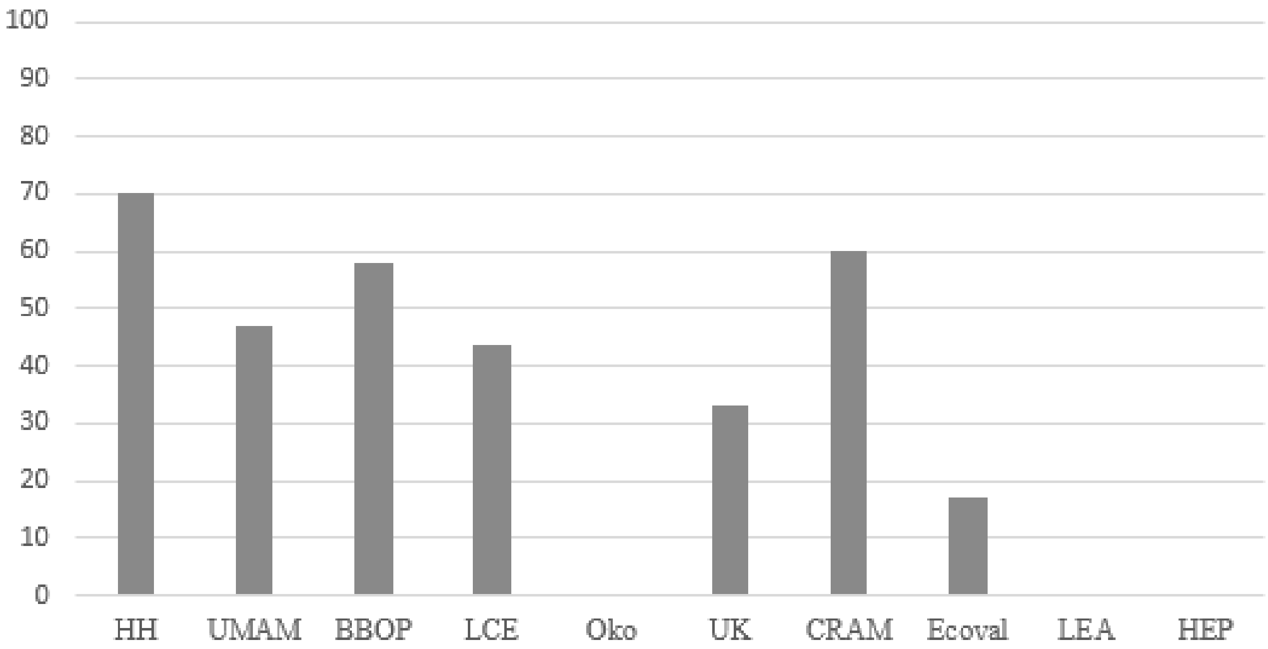


Figure 4: Potential integration of mobile remote sensing technologies (expressed in percentage of indicators) in the 10 main equivalence assessment methods (EAM) used to implement the mitigation hierarchy in environmental impact assessment (EIA) (Adapted from Boileau et al., 2022).

Mobile Remote Sensing data fusion is commonly used to build highly realistic digital models. In this case, LIDAR data are often combined with traditional imagery to model a highly realistic 3D representation of the sector under study. Nevertheless, with the multiplication of data sources, the data fusion research field is growing, offering multiple new applications for transport infrastructure and biodiversity management (Høye et al., 2022).

To date, MRS is mainly supported by specifically designed vectors (satellites, drones, specifically adapted vehicles). With the development of autonomous vehicles, one could expect the MRS massification thanks to the embedded sensors required to provide autonomy to vehicles. Provided that such data can be exploited in adapted contexts, these developments offer the opportunity to survey biodiversity in the transport infrastructure's vicinity at very large scale and in continuous time, requiring completely new ecological data analysis methods (Gimenez et al., 2021; Høye et al., 2022). Fortunately, the EU Digital Strategy and the common European data space implementation tend to support a suitable policy and regulatory context for such data exploitation type.

2.1.2. Static, connected sensors deployment, the (A)IoT common opportunities

In this section, and in contrast with the previous section about MRS, sensors are supposed to be static and to opportunistically record or sample their surrounding environment. Static sensors deployment at large scale and for a long time has been resource-consuming in the past. Nowadays, the development of the *Internet of Things* (IoT) makes it possible to use specific telecommunication networks to make sensors *discussing* together or with external centralised systems such as BIM models or Digital Twins. To improve IoT devices which require the transfer of heavy data, some devices embed artificial intelligence to perform the analysis on the sensor itself (edge computing). Thus, the amount of transferred data is reduced. Then the connected device becomes an AIoT system. Development of such technologies is the target of many sectors (health, industry, telecom, security …) and benefits from dedicated policies and strategies at the EU[10] and national scales. In this section, we will only focus on some main trends having the potential for mainstreaming biodiversity in TI management thanks to AIoT technologies.

2.1.2.1. IoT for infrastructure management and biodiversity monitoring

The infrastructure management and biodiversity monitoring are developing and implementing connected sensors to monitor transport infrastructure's health[11,12] or biological diversity and ecosystem's conservation status[13]. Therefore, an increasing number and diversity of sensors are associated to transport infrastructure, generating massive data beneficial for transport infrastructure management (security cameras, pressure sensors, etc.) which might also be used for biodiversity monitoring (Moulherat et al., 2021).

In a similar complementary way, biodiversity monitoring programs may produce relevant information for other sectors (Weimerskirch et al., 2020) including transport infrastructure management. However, the biodiversity management sector is still mainly using traditional (unconnected) sensors even if new technologies are expected to be of prime interest (Klein et al., 2015) and some experiments have been conducted due to a lack of on market cost-efficient solutions (Høye et al., 2022).

Thus, both sectors are using sensors and try to develop the use of (A)IoT, but this topic seems to be poorly handled by practitioners and stakeholders in general. Indeed, only 17% of the respondents to the questionnaire answered to the issue of the common usage of IoT for transport infrastructure and biodiversity management. It may show that there is an important need for teaching and capacity building

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10 https://digital-strategy.ec.europa.eu/en/policies/internet-things-policy
11 http://www.i4df.eu/
12 https://shift2rail.org/
13 https://econect.cnrs.fr/

to sustain the development of such technologies for transport infrastructure and biodiversity management.

Deployed sensors on the field are closely linked to specific use and implemented approach. Indeed, in IoT, two main approaches are used depending on the monitoring goals:

- Few highly accurate, specialised and thus often expensive sensors are deployed for highly specific goals (i.e. bat sensors)
- Lots of cheap, generic, intermediate accuracy sensors widely distributed are often deployed for general monitoring (i.e. temperature sensors, security traffic cameras, etc.).

Table 6 shows that transport infrastructure management mainly needs direct physical measurements in order to evaluate the infrastructure's health and adapt the maintenance. For this sector, direct measurements are the information required to reach the targeted use. In contrast, for biodiversity management, connected sensors are indirect ways for detecting species or tracking environmental parameters. For biodiversity applications, IoT-based monitoring must often be the raw data for ecological models in order to reach the monitoring goals. Table 6 also shows that most current measurements done by TI dedicated sensors provide relevant information for the biodiversity sector as soon as the appropriate analyses are performed. Such conditions offer the ability of complementary applications between transport infrastructure and biodiversity management based on the same raw data.

Common use for transport infrastructure and biodiversity management of (A)IoT-based data is feasible if data are accessible for both sectors and interoperable between tools they use. Indeed, physical measures benefit from a long history of standardisation and specifications; but the interoperability between systems and sectors is often impeded by limited sensors, API functionalities or sampling design. As a consequence, data interoperability along the GIS/BIM/DT gradient and between specific tools used by the different sectors is often hard to ensure (Høye et al., 2022; Moulherat et al., 2017; Vassart, Houewatonou, et al., 2016; Vassart, Houewtonou, et al., 2016). This statement is exacerbated when collaborators from both sectors have to manage scaling and accuracy issues. For instance, civil engineers would work with sensors providing them with millimetric accuracy data while at the same place, the ecological engineer would only need metric accuracy.

Table 6: Main applications of (A)IoT for transport infrastructure and biodiversity management (non-exhaustive applications)

Technology	Applications in the infrastructure management sector	Application in the biodiversity management sector
Imagery (photos, cameras, etc.)	Safety monitoring – [TRL 9] Vegetation monitoring to detect need for maintenance – [TRL 9]	Species monitoring – [TRL 7-9] Mitigation measures efficiency – [TRL 7-9]
Acoustic including ultrasounds	Noise pollution management – [TRL 9] Noise monitoring – [TRL 9]	Species monitoring – [TRL 4-6] Mitigation measures efficiency – [TRL 4-6] Community monitoring – [TRL 1-3] Ecosystem services evaluation – [TRL 1-3]
Location (individual identification)	Freight tracking [TRL 9] Vehicle tracking [TRL 9]	Individual monitoring (CMR) – [TRL 3-6] Mitigation measures efficiency – [TRL 1-3]
Temperature	Infrastructure health monitoring [TRL 9] Microclimatic monitoring [TRL 9]	Microhabitat monitoring – [TRL 1-6]
Hygrometry	Infrastructure health monitoring [TRL 9] Microclimatic monitoring [TRL 9]	Microhabitat monitoring (ref) – [TRL 1-3/6]
Pressure	Infrastructure health monitoring [TRL 9]	Species recognition (including vibration sensors) – [TRL 1 - 3]

Even if a strong market demand exists especially for long-term surveys often associated to the mitigation hierarchy implementation (Moulherat et al., 2018), for now (A)IoT is hardly deployed for common biodiversity survey due to:

- A lack of adapted on-market solutions (too low TRL) leading to expensive solutions
- A lack of skills in the biodiversity management sector
- Telecom network coverage needed to transfer the collected information

2.1.2.2. Future trends in usage of (A)IoT for transport infrastructures and biodiversity management

With the generalisation of the deployment of the mitigation hierarchy, transport infrastructure managers are now responsible for maintaining environmental assets in the long term as they manage built ones. In line with the "data-driven maintenance" deployment for built part of infrastructures foreseen by the OECD (ITF, 2021), which is expected to provide a significant cost-efficiency enhancement of the infrastructure management, verges and ecological assets would also tend to benefit from this management processes changes. However, such changes in the management processes are based on continuous monitoring of the concerned assets largely simplified by the deployment of (A)IoT systems.

Deployment of such technologies in transport infrastructure would reinforce the emergent research field in biodiversity, working on the development of continuous natural system monitoring (Gimenez et al., 2021). Indeed, the biodiversity monitoring scientific corpus has developed based on the monitoring limitation leading to discrete monitoring session. With the development of (A)IoT, this assumption is not anymore necessary, but common existing models to evaluate population sizes, species distribution, etc. are not able to relax this assumption. Recent works have started developing new models dedicated to address the continuous time observation issue linked to (A)IoT monitoring systems, but also the management of new uncertainty type in data collection (e.g. deep learning labelling uncertainty, detectability uncertainty, etc.).

With the development of autonomous vehicles and connected infrastructures driven by the EU Connected and Automated Mobility policy[14] as a part of the digital strategy, more and more sensors will be deployed on transport infrastructure and their surroundings in order to improve their safety, sustainability and social acceptance. For now, few of such sensor deployments have been handled by the biodiversity management sector. Therefore, a large spectrum of research, development and innovation is opening in this field. Indeed, EU policies and multiple conservation biodiversity reports worldwide are pledging for large-scale biodiversity monitoring systems[15] (Høye et al., 2022). Connected and interconnected (Bolton et al., 2018) transport infrastructure could therefore significantly contribute to such large-scale generic biodiversity monitoring systems (Moulherat et al., 2021). Such large-scale monitoring system would contribute to a better understanding of the effect of transport infrastructure on biodiversity as well as allowing for adaptive maintenance of transport infrastructure (Figure 5).

[14] https://digital-strategy.ec.europa.eu/en/policies/connected-and-automated-mobility
[15] https://geobon.org/

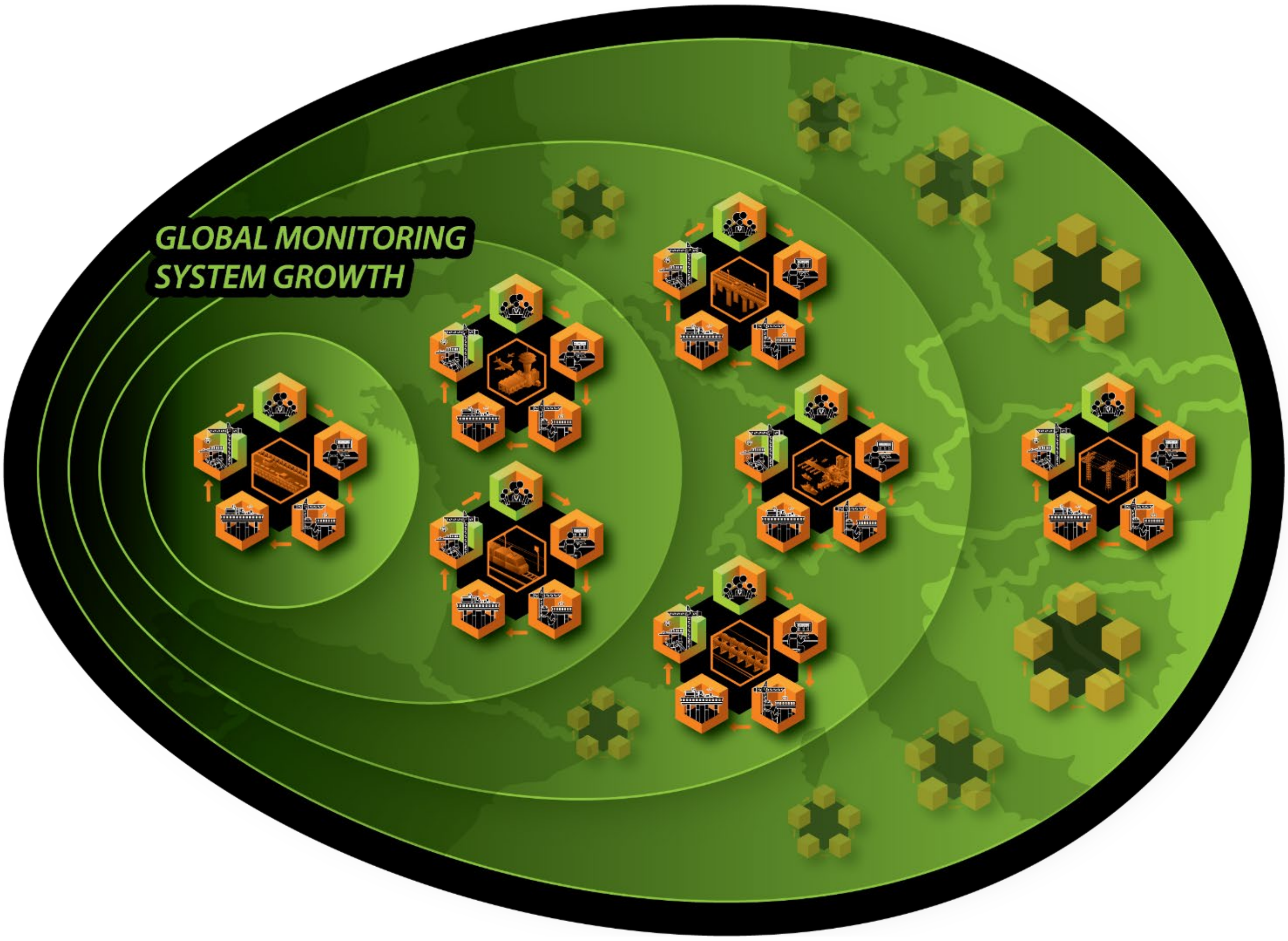

Figure 5: Global biodiversity monitoring system supported by the generalisation of connected infrastructure providing data analysed in a conservation biology perspective. Each connected infrastructure expands the biodiversity monitoring system.

2.1.3. Citizen science

Since it was first defined independently by Rick Bonney (US) and Alan Irwin (UK) in the mid-1990s, the term « citizen science » has seen a lot of evolution from its original definition. The definition given by Haklay (2013) seems to be the most accurate without being too specific. It describes citizen science as the « scientific activities in which non-professional scientists volunteer to participate in data collection, analysis and dissemination of a scientific project ». This wording gives to citizen science a whole new dimension, as it allows considering different levels of engagement and involvement. Currently, citizen science is widely used in diverse fields such as astronomy, archaeology, ecology, meteorology or even art history.

2.1.3.1. Crowdsourcing

The very first level of citizen science can be defined as a mere participation, as data are provided by citizens with a minimal cognitive engagement. Databases set by citizens through crowdsourcing can vary from a local to an international level and can take various forms. People can be asked to send physical samples, to submit observations or to install a sensor at their home. Crowdsourcing takes advantage of the sheer number of people in order to collect a large number of data that scientists would have been otherwise unable to collect. This type of citizen science is commonly used in road management in order to report wildlife road kill, and apps and websites to submit these observations are freely available in every European country[16 17 18]. This information helps scientists and road managers to identify animal-vehicle collision hotspots, and thus to plan the construction of wildlife overpasses or underpasses. In the cases of rare and elusive species, public reports of collisions can even allow abundance estimations (McClintock et al., 2015).

In Germany, a group of scientists asked citizens to submit mosquitoes specimens collected in their immediate surroundings, in order to monitor the distribution and spread of invasive species (Walther & Kampen, 2017). This project is the first of its kind focusing on potential vector species, and its outcomes can be used in the field of public health management, as it is well known that invasive species can be vectors of non-endemic pathogens.

Broadly speaking, crowdsourcing is commonly used to gather data in ecology, but it is still an expanding method for the transport infrastructure field. Concerning this category, the most exploited trait about citizen participation is their wide distribution and their number. They solely have to install or carry around a sensor in order to record chosen parameters. That is the case of a Europe-founded project called Citizen Sense that develops devices in order to monitor air pollution coming from transport infrastructure[19]. For instance, citizens can ask to carry around a particulate matter (PM) device when they have to use their car in order to monitor air quality coming from the road. People partaking in this project are asked to stop for a few minutes at different spots on the road in order to take readings. Readings include a range of readings across the spectrum of air quality, from” unhealthy” to “moderate“ and ”good”, according to the air quality index currently used in the country. The sites identified with particularly problematic air quality are revisited and monitored on a more systematic basis to establish patterns over time and determines how the problem could be addressed.

2.1.3.2. Distributed intelligence

The second level of citizen science deals with active involvement of citizens. At this level, people are asked to use their cognitive ability either to deepen the value of the data or to analyse them.

Providing more complete data monitor one species’ distribution (Yu et al., 2010), to determine density of populations (Dunham & Du Toit, 2012) or even to follow their phenological trends (Horns et al., 2018). In the same way as for crowdsourcing, websites and apps are available in order to submit observations and/or to validate others[20].

[16] http://www.vigifaune.com/
[17] https://projectsplatter.co.uk/
[18] www.viltolycka.se
[19] https://citizensense.net/
[20] https://www.inaturalist.org/,

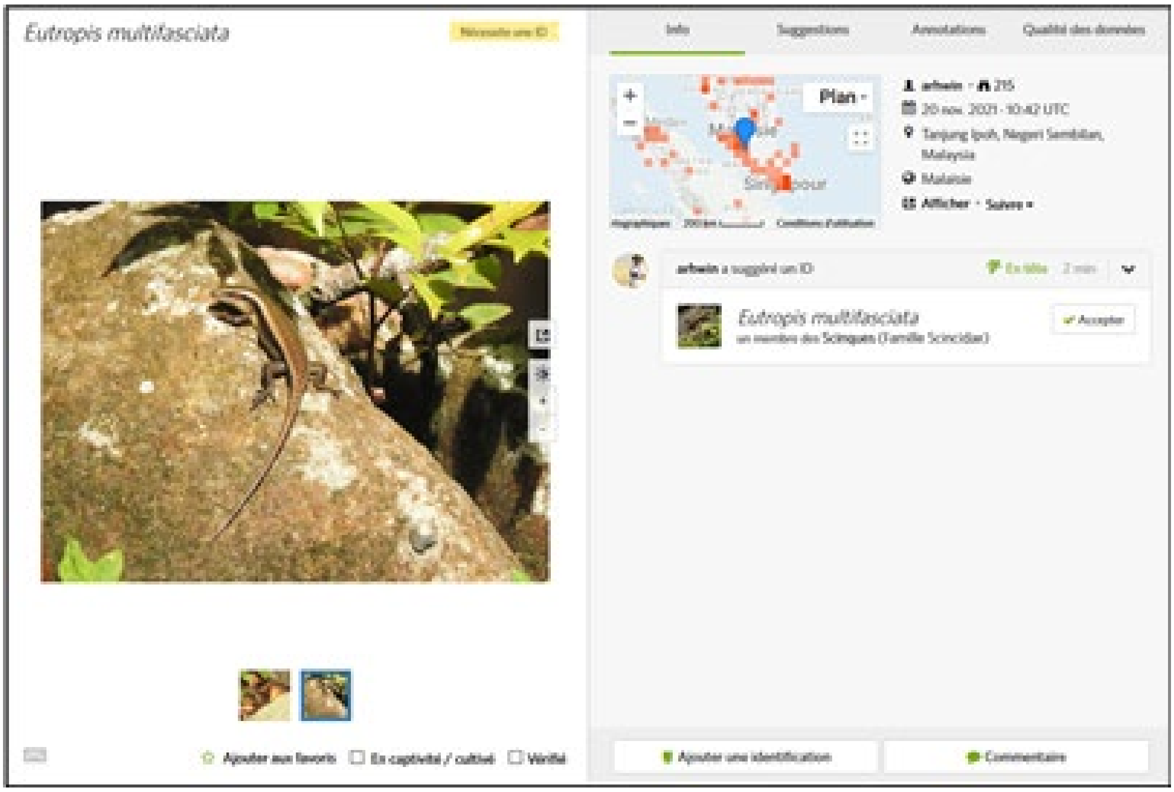

Figure 6: Apps such as Pl@ntNet or iNaturalist are used at both levels of crowdsourcing and distributed intelligence. In these, citizen can post images without identifying the species in it and then depend on other users to submit an ID: it's a community-based validation. Every new picture contributes to the database, which will then be used in scientific projects or as a basis of comparison to automatically identify species on newly submitted pictures.

This level of citizen science allowing to process data is very widely used in ecological projects deploying camera traps. Indeed, camera trapping can produce a large volume of images which would take too long to process by the project's scientists only. Zooniverse[21] is a well-known free website hosting different scientific projects worldwide and allowing citizens to choose on which project they want to contribute. Numerous websites of the same kind exist, at a more or less local level, and citizens can either help projects from another continent or from their own country. For European citizens, Mammal Web could be the primary choice as it hosts European projects only[22].

Databases generated from participants are then available for scientists willing to use them in their research, and a large number of published papers rely on them. Yet, it should be noted that while citizen science has the advantage of treating a large amount of data within a short time span, the quality of these data shall be considered. Indeed, different projects and stakeholders aspire to different levels of data accuracy, and the methodological question ensuring validity and reliability of data should arise before using citizen science databases (Balázs et al., 2021).

2.1.3.3. Future trends in citizen science

We could expect citizen science to be incorporated into any project. Participants could sustain constant monitoring of biodiversity by providing data, thus leaving only the modelling and analysing part to scientists. They could be quickly trained in order to make sure that the data generated will not be as

[21] https://www.zooniverse.org/
[22] https://www.mammalweb.org/en/

"noisy" as they can be currently. This scenario would allow a long-term and well-designed survey of biodiversity worldwide, which is essential in the midst of Earth's sixth extinction event.

The numerous sensors sometimes unknowingly carried by citizens in their phones could be used more purposefully. Even in sleeping mode, phone devices have the possibility to automatically record any sound and/or image surrounding their user. What's more, an ordinary mobile phone has around 20 different sensors. Citizens owning one could be used as one big sensor recording at any time numerous parameters.

2.1.4. Engineering model

Engineering models are dedicated to the investigation of real-life engineering problems. The model outcome can generally be reliably used in real conditions. Such models are increasingly used in all sectors and permit testing part of the modelled system or the full system in scenarios which are expected to arise in the real world.

2.1.4.1. Current practices of engineering model in TI management

With the digitalisation of industries and the improvement of computational abilities, engineering models are becoming fully digital and provide a high amount of information, which are used to manage transport infrastructure all along their life-cycle (Fountain & Langar, 2018; Rafiee et al., 2014; Song et al., 2017; van Eldik et al., 2020). For instance, hydrodynamic models are commonly used to design bridges, pollutants air propagation is simulated to develop risk prevention plans and more complex models and interacting models to automatically design buildings (Figure 7).

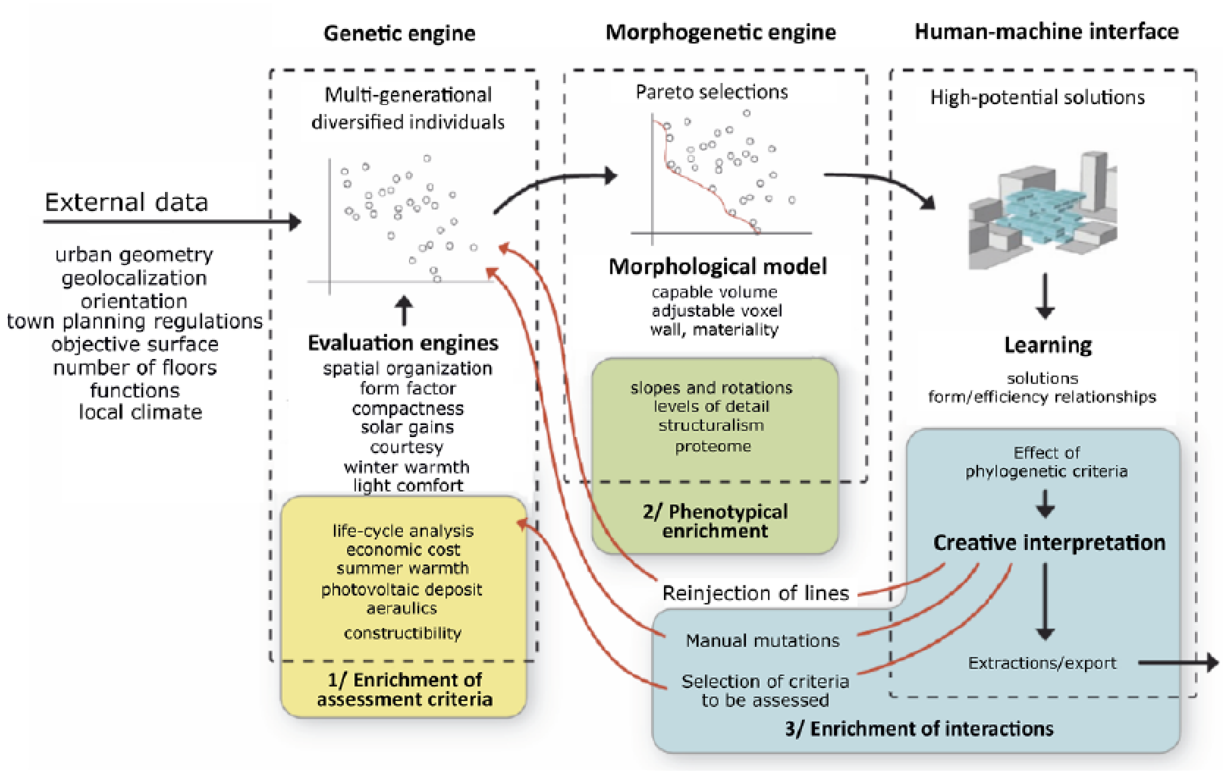

Figure 7: Example for automated architectural design used in the EcoGen2 software thanks to multiple interacting engineering models (engines) inspired from evolutionary processes (Marsault, 2017)

Ecological modelling is also developing for biodiversity management and monitoring (Hunter-Ayad et al., 2020; Zurell et al., 2021). However, engineering models relevant for mainstreaming biodiversity in transport infrastructure are still poorly integrated in GIS/BIM/DT tools and must be implemented in very complex workflows, which often includes strong interoperability issues (Catalano et al., 2021; Moulherat et al., 2017; Urban et al., 2021; Vassart, Houewatonou, et al., 2016). Indeed, most of the engineering models are developed for a specific purpose and they often have specific input and output data formats which may not be interoperable with GIS/BIM/DT tools. As a consequence it can reduce their ability to feed transport infrastructure and biodiversity management with relevant information (see Table 7).

Table 7: Examples of engineering models relevant for transport infrastructure management including biodiversity issues

Model type	Theme	Integration level in GIS/BIM/DT tools
Atmospheric pollution	Environment	Full – [TRL 9]
Acoustic	Environment	Full – [TRL 9]
Population viability evaluation	Biodiversity	Partial – [TRL 6 (BIM) – 8 (SIG)]
Ecological connectivity	Biodiversity	Partial – [TRL 6 (BIM) – 8 (SIG)]
Traffic model	Transport	Partial – [TRL 9 (SIG, DT)]
Ecosystem services	Biodiversity	Partial – [TRL 8 (SIG)]
Vegetation growth	Biodiversity	Partial – [TRL 3 - 6]
Biomechanical interactions	Biodiversity and transport	Partial – [TRL 1-3]

2.1.4.2. Expected trends in engineering model application for mainstreaming biodiversity with TI

In their paper, Fountain & Langar (2018) have shown that the development of highly specific functionalities of BIM tools such as the embedding of ecological models, is driven by specialists rather than generalist software editors. Recent reviews in conservation biology (Urban et al., 2021; Zurell et al., 2021), landscape planning (Catalano et al., 2021; Simmonds et al., 2020) or ecological modelling (An et al., 2021; Drake et al., 2021; Urban et al., 2021; Zurell et al., 2021) are pledging for a reinforcement in the use of ecological modelling to improve the conservation strategies and the implementation of the mitigation hierarchy in strategic and project environmental impact assessments. In their paper, Urban et al (2021), present an “ideal” system of interacting ecological models which should be a first step in the implementation of ecological models in BIM software, as suggested by Catalano et al (2021) for improving the sustainability of smart cities (Figure 8). More specifically, and contributing to the mainstreaming of biodiversity in transport infrastructure, in their paper, Boileau et al. (2022) have shown that ecological modelling would be able to replace 34% in average of the expert-based indicators used in the existing main equivalence assessment methods (EAM) with a strong potential for process standardisation and automation which is expected to significantly improve the cost efficiency of the mitigation hierarchy implementation (van Eldik et al., 2020).

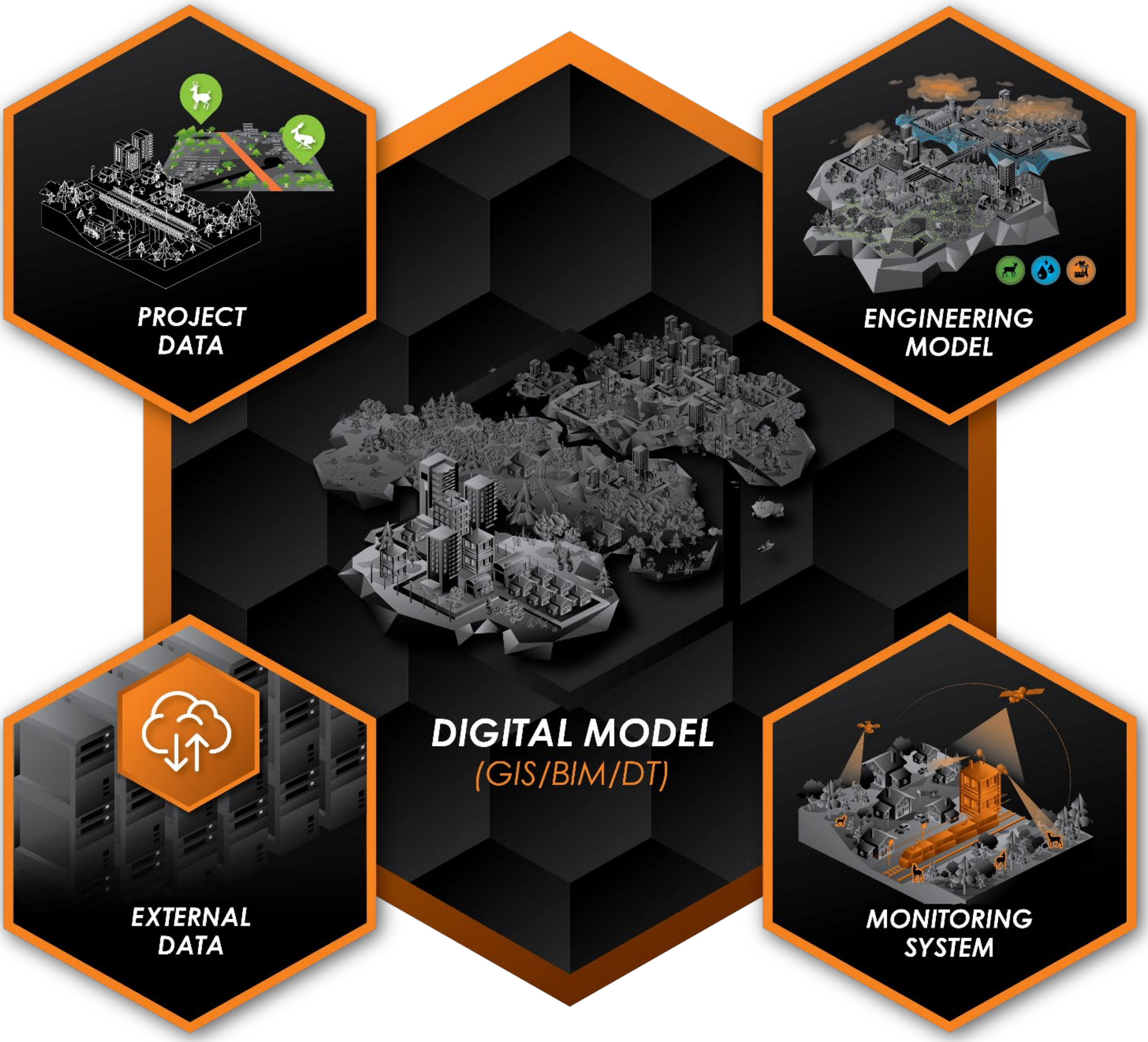

Figure 8: Ecological modelling feed by project and external data embedded in GIS/BIM/DT tool supporting the project management along its life-cycle.

Engineering models are expected to accurately reproduce what is arising on the field in order to test management scenarios before their deployment on the field or evaluate risks, etc. For now, these practices are largely used in the engineering sectors except in ecology, where lack of validated models (An et al., 2021) or the very high level of complexity of validated models prevent practitioners from using them on a day-to-day basis (Mechin, 2020; Urban et al., 2021).

2.1.5. The central role of artificial intelligence

Regardless of the data type and way of producing them, artificial intelligence (AI) is used to manage biodiversity (Tuia et al., 2022) as well as for mobility and infrastructure. However, AI is a large field of various approaches which are implemented to address specific research or engineering questions. This section does not aim to have a comprehensive view on all the possibilities offered by the development of AI in the infrastructure and biodiversity management but rather to highlight some major trends in AI usage which are expected to offer promising solutions to mainstream biodiversity in transport infrastructure.

Machine learning approaches have been partly addressed in the previous section because most predictive models used in engineering models are based on these methods, particularly in ecology (Cornuejol & Miclet, 2013; Tuia et al., 2022). Machine learning techniques feed on pre-existing data to predict similar data in another context. Therefore, they should constitute the core technical tools for predictive management which is expected to be of prime interest for infrastructure resilience in the context of climate change and thanks to the improvement in their cost efficiency (Casanelles-Abella et al., 2021; ITF, 2021).

Among the machine learning approaches, *Deep Learning* (DL) technique allows for recognising features in signals recorded by sensors (LeCun et al., 2015). It is largely used in the development of autonomous vehicles to detect other vehicles or people, but the detection of large animals in this context has only benefited from limited research even if it improved autonomous vehicle safety. In the conservation biology field, DL is implemented to recognise species and therefore monitor the presence of targeted species (Klein et al., 2015). Even though many common EU species can be recognised thanks to DL, this capacity is still relatively low compared to the diversity of species which are concerned by significant interactions with transport infrastructures (Goodwin et al., 2022; Moulherat et al., 2021; Rigoudy et al., 2022; Stowell et al., 2019).

Artificial intelligence by itself should not be an issue to mainstream biodiversity in transport infrastructure management. Indeed, AI is already a central issue in the EU Digital Strategy as well as in the Mobility and Biodiversity ones. However, at the crossroad of these three strategies, the use of AI techniques to improve the integration of biodiversity issues in the transport infrastructure management is at its beginning. Developing AI-based processes should be one of the main targets for future RDI to ensure sustainability of transport infrastructure (Høye et al., 2022; ITF, 2021).

2.2. Data challenges

Using GIS/BIM/DT tools to assist transport infrastructure and biodiversity managers require that practitioners must access and rely on the data available through these tools. There are many perceived challenges such as the integration of data collected by citizens into the scientific progress, ensuring data quality, working with volunteers and quantifying success, among others. Furthermore, these data should be interoperable in order to be used in the GIS/BIM/DT tools (Catalano et al., 2021; Høye et al., 2022; ITF, 2021). Every single one of these challenges must be addressed to properly mainstream TI and biodiversity management in a Common Data Environment (CDE). These challenges are not specific to the mainstreaming of biodiversity in transport infrastructure. They benefit from specific EU policies (such as the Data Act[23]) as part of the digital strategy. This strategy should play a key role in the future RDI aiming at mainstreaming biodiversity in transport infrastructure, in the digital environment.

2.2.1. Inherent data quality issues

Data quality can be referred as "the fitness of data for all purposes that require it" (Turner, 2004). Establishing data quality typically involves a multifaceted evaluation of states such as completeness, validity, consistency, precision and accuracy. Yet, data quality is a relative concept and it has different meanings to different industries, specific areas of applications and data users (Ozmen-Ertekin & Ozbay, 2012). Be it in the field of transportation or biodiversity, good quality data is essential to generate ideas, develop tools from the community (Proprietary or Open Source) and clear-cut solutions to be implemented by decision makers. The ISO/IEC 25012 sets the data quality standard characteristics, for data retained in a structured format within a computer system. This subsection deals with the main challenges regarding inherent data quality (Figure 10) according to most researchers.

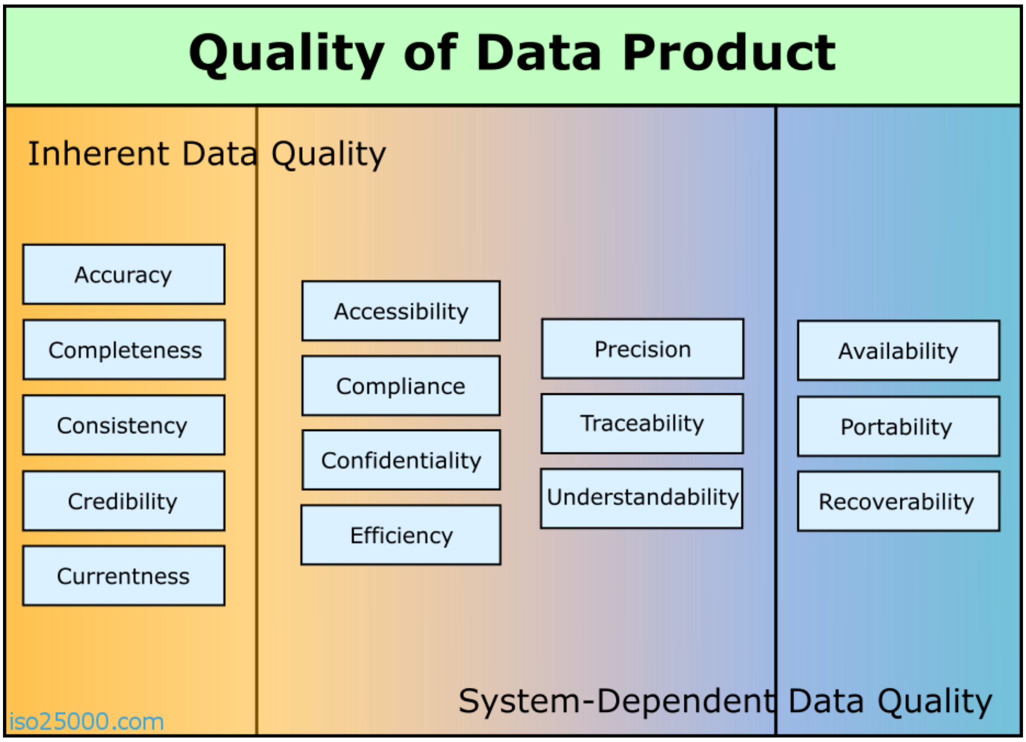

Figure 9: Quality of data products according to the ISO 25012. This ISO provides a general data quality model for data retained in a structured format within a computer system.

2.2.1.1. Accuracy

Among all the dimensions, accuracy is the most important and hardest dimension to assess. Data accuracy is a measure of the extent to which data conforms with reality. For a data to be accurate, it must meet two criteria: form and content. Currently, one of the simplest reasons for data inaccuracy is manual data entry system, where there are chances of feeding incorrect details by mistake. One way of overcoming these kinds of errors is to reduce the rewriting of the data. Nowadays, a large number of applications and tools are developed in order to reduce the chances of such errors from occurring. Yet,

[23] https://digital-strategy.ec.europa.eu/en/policies/data-act

they are far from being perfect and they may even add new biases to data, which raises the need for improvement. There is also a risk of compromised and inaccurate data entries due to personal biases. In their paper, Jóhannesson et al. (2020) identified that another reason for data inaccuracy is the use of estimates and averages for calculations.

2.2.1.2. Consistency

Data consistency is the process of keeping information uniform throughout the datasets. It means, for example, that when the name of a variable is decided, it should stay identical all along the process. This consistency is expected to be strong within the same study, but problems arise when one has to deal with large amounts of data from various sources. There are three different causes and phenomena of data inconsistency (Shi et al., 2019):

- Format inconsistency: refers to data stored under different formats. These can be structured, semi-structured and unstructured. Structured data are often stored as bidimensional tables. Semi-structured data can be an expanded field according to need such as “XML”, “IFC” or “HTML”. Unstructured data refers to irregular formats such as text, images, video, audio;

- Semantic inconsistency: refers to the way an object is described. An object can be described in different terms (synonyms) with no errors, yet it can cause inconsistency throughout a database;

- Value inconsistency: refers to a measured result of physical quantity. There are many inevitable impacts on data value because of the factors during measurement, be it man-made factors or objective factors: reading errors, recording wrong, precision error of experimental equipment, and differences among tested objects.

2.2.1.3. Completeness

Data completeness is defined as expected comprehensiveness. That means that, as long as the data meets the expectations of a given project, then they are considered complete even if optional data are missing. Still, in science, the data incompleteness is one of the most important factors bringing down the data quality. Indeed, researchers may have higher expectations of how complete a database should be. Data incompleteness is often caused by missing values. Missing values can arise for a variety of reasons: some attributes in one project may not exist in others so that the values on these attributes may be missing during data exchange, null values can be created autonomously in web databases since the corresponding values cannot be offered or extracted. This obviously has serious impacts in terms of analysing and querying and can result in wrongly directed efforts (Liu et al., 2016).

One way to overcome this problem is to exclude observations with missing values. However, there is the risk to lose valuable information. One better strategy would be to input missing values, thanks to the existing part of the data: that’s called data imputation. Different data imputation models exist depending on the provided dataset, and in last resort, deep learning can also be used[24].

[24]https://towardsdatascience.com/6-different-ways-to-compensate-for-missing-values-data-imputation-with-examples-6022d9ca0779

2.2.2. Collection-dependent data quality issues

In the field of ecology, high-quality data collected through standardized protocols may not always be available because of the very nature of some of the observed species: moving, elusive, small or cryptic. In this case, opportunistically collected species occurrence data are often used for species distribution model (Van Eupen et al., 2021), for instance. These data are generally provided by citizen science observations, as it has been estimated that as much as 50% of the species occurrence records stored in the Global Biodiversity Information Facility (GBIF) have been collected by citizen scientists (seen in Cretois et al., 2021). Yet, opportunistic data do not arise from any structured sampling design, which leads to conflicting with many of the fundamental principles of data sampling. Observer considerations regarding what, where and when to monitor result in biases (gaps, redundancies) in the aggregated databases (Arazy & Malkinson, 2021), as the data are unevenly distributed in both space and time.

All these biases can impend the ability to draw conclusions about trends in species' spatio-temporal distribution for instance, or even worse, lead to wrong conclusions. This raises a very obvious problem regarding ecology research and species conservation. Consequently, these issues shall be adequately addressed to mainstream biodiversity in the transport infrastructure management, as well as in others projects.

3. STANDARDISATION IN DATA COLLECTION AND PROCESSES TO ENSURE GLOBAL INTEROPERABILITY BETWEEN INFRASTRUCTURES AND BIODIVERSITY MANAGEMENT

3.1. Inspiring from BIM processes to expand its know-how to the whole continuum from GIS to DT

To date, the UK has the highest number of construction companies using BIM and it remains the leader in the earliest use and implementation of BIM into construction projects, thanks to its pioneer policy and regulation about BIM (Bolton et al., 2018). Since 2016, in the UK, all state-funded projects must use BIM. Since 2017, Germany adopted a similar policy for any project over 100 M€ and for any federal infrastructure. In France, BIM has been recommended to the builders since 2019 but it does not benefit yet from dedicated regulation nor standards[25,26].

Interoperability along the transport infrastructure's life-cycle between sectors and stakeholders is one of the main issues of the BIM (construction) sector. Indeed, complex collaborative systems were at the origin of the BIM development. Therefore, the sector benefits from existing processes applied in the industrial field as a support of the 4.0 industry, and in the real estate management for instance, ensuring the ability for multisectoral collaboration and interoperability (Baratono et al., 2017; Carvalho et al., 2020;

[25] https://www.ukconstructionmedia.co.uk/features/whos-winning-bim-adoption-game-in-europe/
[26] https://plan-bim-2022.fr/

Ghaffarian Hoseini et al., 2017; Song et al., 2017; van Eldik et al., 2020). Thanks to the BIM sector dynamism, BIM processes benefit from normalisation with the ISO 19650 for instance.

This ecosystem of processes is spreading to various themes and now applies in the context of the new mobility development[27] for transport infrastructure management. Some experiments in the use of BIM for mainstreaming biodiversity management related to transport infrastructures has been conducted in the last years too (Moulherat et al., 2017, 2018).

To ensure collaborative and interoperable work in a BIM project, two elements are crucial and have to be defined at the project's early stage. The first one is the *Common Data Environment* (CDE) where data are commonly stored and shared between users. The CDE also specifies the software to be used and their interactions. This CDE allows:

- avoiding data duplication,
- ensuring users have access to the same information at the same time,
- securing the data.

The second element is the *Business Process Modelling* which consists in modelling the workflows which have to be managed during the project life-cycle. In particular, these models can describe actor interactions, data life-cycle, interoperability management, etc. (Figure 10).

[27] https://www.mobility4eu.eu/?wpdmdl=2160

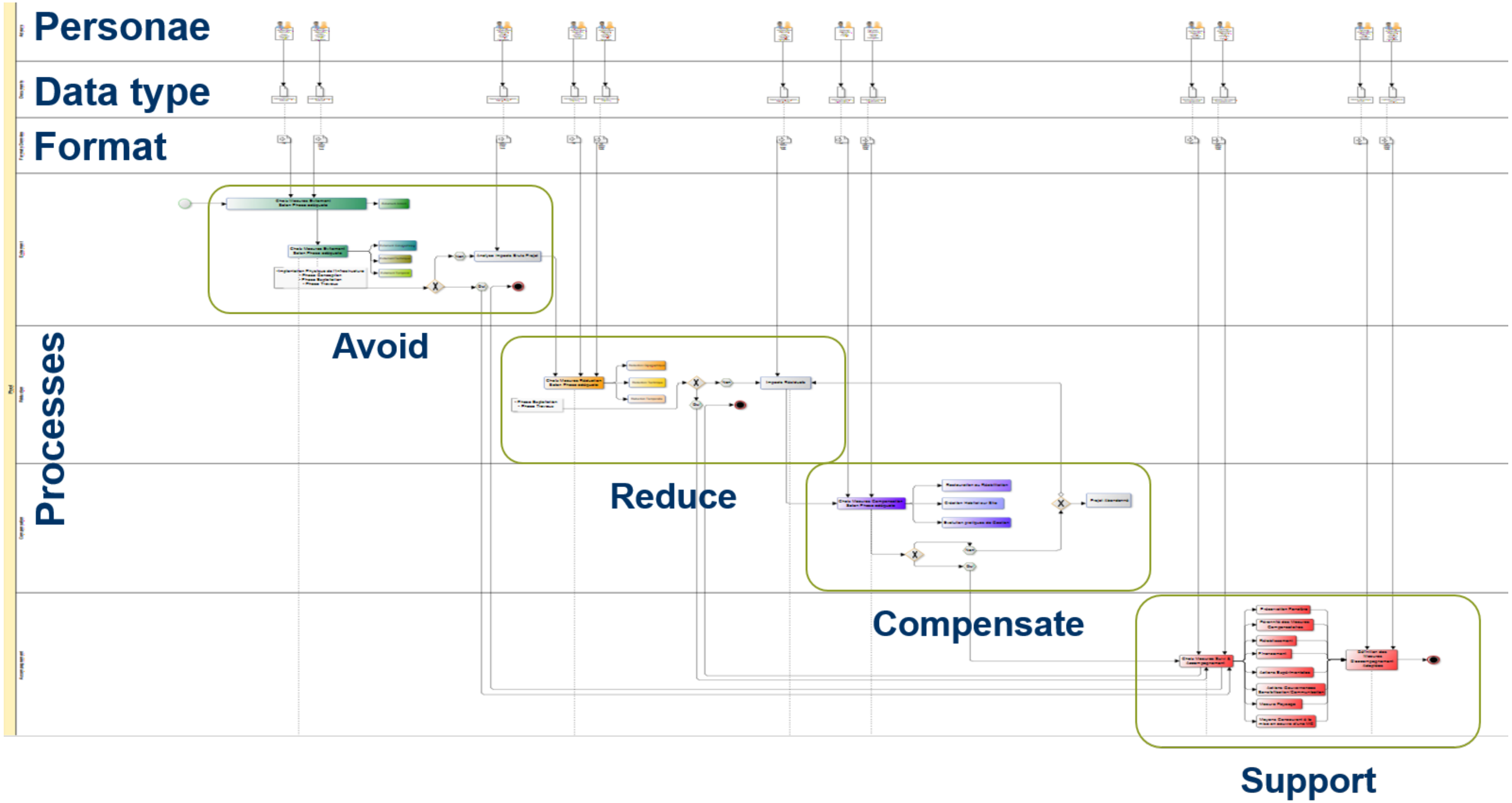

Figure 10: Example of the Business Process Model *representing the role, the data flow and processes involved in the implementation of the mitigation hierarchy (adpated from Djema, 2022)*

Thanks to these above-mentioned elements, BIM processes are expected to ensure interoperability between actors and data by having a comprehensive understanding of data life-cycle, user needs (BIM use case) etc. While such working environment (processes, dedicated tools, stakeholder sensitivity/knowledge, etc.) has been developed in the industry, the asset management and the transport infrastructure sectors, the biodiversity management sector is almost still ignoring its existence (Moulherat et al., 2018; Vassart, Houewtonou, et al., 2016). Mainstreaming biodiversity with transport infrastructure in the digital environment is highly challenging and offers a very wide panel of RDI, education and capacity-building opportunities for both sectors.

3.2. FAIR data for efficient interoperable systems

The FAIR principle[28] (see Wilkinson et al., 2016 for details) for data management assumes that data produced are:

- Findable. Metadata and data are expected to be easy to find by a human or a machine.
- Accessible. Once the data are found, the user easily knows how to access them.
- Interoperable. Metadata is sufficiently detailed to render the data set understandable in order to be integrated with others.
- Reusable. Metadata is rich enough to allow for multiple reutilisations of the data set for various purposes.

Efficient FAIR data are therefore strongly linked to the development of appropriate standards which should consider both biodiversity and transport infrastructure needs in order to mainstream biodiversity with transport infrastructure management.

The EU Digital Strategy and particularly the EU Data Strategy are proposing tools which will have to be implemented in the transport infrastructure and biodiversity data interoperability development context.

3.3. Favouring standardised data management

Interoperability between datasets would be strongly improved with the development and deployment of BIM working environment described in section 3.1. Nevertheless, regulation, normalisation, etc. may be strongly influenced by national regulation and strategies while biodiversity conservation should be addressed in a biogeographical perspective rather than an administrative one (Henle et al., 2009; Høye et al., 2022). In addition, experimental replication can be very hard to find at the regional or national scales, especially if model species under study are highly mobile (migrating species, long dispersal species, etc.). Therefore, an EU-scale experiment should be considered, permitting the mainstreaming of biodiversity with transport infrastructure management (Ouédraogo et al., 2020).

Shared, large-scale experiments would therefore require accessible data collected with compatible processes in order to be exploited at a larger spatio-temporal scale than the one for which unique datasets have been produced. Such dataset should respect the existing international and EU conventions as long as they exist (i.e. INSPIRE directive, Data directive, …) (Høye et al., 2022).

[28] https://www.go-fair.org/fair-principles/

3.3.1. Standards in data collection processes

Within the BISON project several issues have been pointed out as relevant to be standardised at the EU scale. Several EU projects previously got developed and proposed unified biodiversity monitoring systems[29,30]. These projects, which were turned toward biodiversity conservation, can provide relevant guidance for developing unified biodiversity data collection processes, aiming at mainstreaming biodiversity conservation in TI management which does not benefit yet from unified approaches (Table 8).

Guidance to develop such unified approaches are discussed in other deliverables of the BISON project (Table 8) as well as in EU programs such as BiodivERsA[31] (Eggermont et al., 2021). In order to ensure the digitalisation of unified protocols aiming at mainstreaming biodiversity conservation with transport infrastructure management, they should be designed and standardised in a specific way. The goal is to take care of the required processes to embed them and the associated collected data into the GIS/BIM/DT digital environment. Thus, implementation and adaptation of existing process-based norms (e.g. ISO TC 331, ISO 19650, etc.) or development of new better adapted ones should be relevant in the next few years.

Table 8: Examples of biodiversity monitoring themes addressed in the BISON project and expected to benefit from EU scale standardised data collection to mainstream biodiversity in transport infrastructure management.

Theme	BISON relevant deliverable	Other relevant projects surveyed by BISON Task 3.2.8
Mortality survey	D3.3, 5.2	Life Safe road
Invasive species monitoring	D3.3, 5.2, 3.4	EPIC ROADS
Migratory species and large home range species	D3.3, 5.2	

3.3.2. Standards in data storage and sharing processes

Benefiting from the strengthening of global trends on data management as a raw material for the digital economic development, many standards have been developed for data management and formatting (INSPIRE directive, data directive, etc.). Nevertheless, their use and deployment are not sufficiently implemented or unsuitable to the mainstreaming of biodiversity in transport infrastructure management (Høye et al., 2022; Moulherat et al., 2018; Vassart, Houewtonou, et al., 2016).

29 https://www.wur.nl/en/Research-Results/Research-Institutes/Environmental-Research/Projects/EBONE.htm
30 http://www.biosos.eu/
31 https://www.biodiversa.org/

In addition, to date, the lack of data interoperability in the sector of transport infrastructure management as well as in biodiversity management is a main issue which is still not solved. Analysing both sectors in terms of data mutualisation and interoperability will then be a challenge. But it might also provide some opportunities. Indeed, both sectors have their strength and weakness in terms of data management and could feed each other.

Finally, future data storage systems aiming at mainstreaming biodiversity in transport infrastructure would ensure a strong transparency in processes leading to storage and sharing systems (format, access, licence, …). Thus, open data and open format compatible with data sharing conventions would also be favoured in line with the current EU directives on data management and the deployment of relevant EU scale data storage infrastructures such as the common data space. Therefore, appropriate exchanges open format such as *Industry Foundation Classes*[32] (IFC) and languages such as the *Geography Markup Language* (GML) and inherited languages developed by the *Open Geospatial Consortium* (OGC) [33], have to be further developed to better fit the needs and requirements for mainstreaming biodiversity and transport infrastructure in the BIM environment[34] (Moulherat et al., 2018; Vassart, Houewatonou, et al., 2016).

3.4. The multiscale data management challenge in space and time

A comprehensive benefit of BIM approaches in the case of mainstreaming biodiversity in transport infrastructure requires to be able to manage data in a large-scale interoperable environment, with relatively low level of detail, while in most cases it is currently managed in GIS environment (e.g. preliminary assessment of linear infrastructure), with highly detailed data coming from pre-existing models of infrastructure or building occurring in a limited space. In addition, these different parts of a global model can be developed at different dates with highly heterogeneous data. Therefore, future GIS/BIM/DT systems will have to manage the very high heterogeneity in terms of data type, resolution and associated processes to collect them, in order to constitute relevant toolkits for decision-making related to environmental and transportation requirements and objectives (Vassart, Houewtonou, et al., 2016).

To date, information generalisations across spatial scales are hardly managed (Casanueva et al., 2019; Moulherat et al., 2017; Vassart, Houewatonou, et al., 2016; Wilby & Wigley, 1997). Up and down scaling methods would thus constitute a large field of research favouring the mainstreaming of biodiversity with transport infrastructure. It would allow to optimise the impact of information coming from large-scale data collection to the project scale and vice versa.

[32] https://www.buildingsmart.org/
[33] https://www.ogc.org/
[34] https://openbim.fr/openbim/

4. INCLUSIVE GIS/BIM/DT FOR INFRASTRUCTURE AND BIODIVERSITY

The Design with Nature concept proposed by Mc Harg (1971) is the current way to integrate infrastructure development in the landscape planning (Campagna et al., 2020; Catalano et al., 2021). Unfortunately, this concept, considering biodiversity conservation as a constraint to manage along the transport infrastructure life-cycle, has shown its limits and is now not expected to be sufficient to reach the *No Net Loss* of biodiversity (NNL) objectives anymore (IPBES, 2019). More recent approaches tend to include biodiversity conservation facilities of the built environment on the same level as those expected for human activities. In their paper, Catalano et al. (2021) proposed an integrated framework for mainstreaming biodiversity conservation in the *Sustainable Development Goals* (SDG) evaluation of smart sustainable cities thanks to digital tools including the GIS/BIM/DT continuum applied to the *City Information Model* (CIM). Similar approaches should be adapted to transport infrastructures which face similar challenges and must interface with CIM in the context of the mobility 4.0 developments.

While Section 2 focused on the digitalisation of data allowing for mainstreaming biodiversity in transport infrastructure management and Section 3 dealt with the processes ensuring interoperability of collected data between stakeholders, this section aims to draw the main lines of future requirements to operatively benefit from these data in the day-to-day mainstreaming of biodiversity in transport infrastructure management at the era of the mobility 4.0.

4.1. Developing common interoperability knowledge and practice in infrastructure and biodiversity management

BIM processes have been developed to ensure collaborative work around complex projects. In this respect, collaborators have to benefit from similar representation of the physical project, have access to the data, etc. to support decision-making. If interoperability issues are a strong challenge in this context, cultural ones are also to be addressed to spread these new technologies and associated innovative processes.

4.1.1. Developing joint culture of transport infrastructure and biodiversity management

The digitalisation of the transport infrastructure sector is an ongoing process which benefits from its close relationship with the building and real-estate management sectors. In these fields, BIM-like approaches are much more developed, they have demonstrated their strong cost-efficiency benefits (Baratono et al., 2017; Fountain & Langar, 2018) and have a long story of computer aided management. In contrast, the biodiversity sector is poorly digitalised and is not equipped with user-friendly professional tools facilitating the transfer from lab to operative deployment (Boileau et al., 2022; Mechin, 2020).

In parallel, changes in the biodiversity regulations and progress in ecological engineering tend to make the business of ecological engineers evolve, requiring skills close to those existing in civil engineering. For instance, digital skills are required for construction management or ecological engineering design. From the transport infrastructure management sector, an increasing number of researchers, students, and employees express their motivation for working on biodiversity-friendly solutions. Such bilateral evolution is for instance materialised in France through the creation of common research and teaching between public work school and ecology university allowing for cross-sectorial skill transfer[35].

To date, both the transport infrastructure and biodiversity management sectors were in clearly isolated silos, but the above-mentioned evolution of their needs and requirements, sustained by the evolution in the social way of handling challenges related to the global warming and the sixth mass extinction, offer an opportunity to develop a common working culture in order to mainstream biodiversity in transport infrastructure management. Larger than only the digitalisation issues, this partial alignment of both sectors is necessary to effectively integrate biodiversity in the day-to-day transport infrastructure management (Fountain & Langar, 2018; Høye et al., 2022).

4.1.2. Supporting the software development sector

Mainstreaming biodiversity in transport infrastructure management needs digital tools. Both sectors have their own way of managing and representing data which can feed each other. On the one hand, coming from a long history of strongly competitive economic environment, the transport infrastructure sector has a lot of user-friendly tools and thus suffers from proprietary tools and format impeding interoperability. In contrast, with its recent history and relatively low economic interest for software developers, the biodiversity sector has a strong culture of open and free but often hard to handle digital tools (Vassart, Houewtonou, et al., 2016).

To date, biodiversity themes which are addressed along the transport infrastructure life-cycle are not handled by existing tools dedicated to transport infrastructure design or management (Djema, 2022; Moulherat et al., 2018; Vassart, Houewtonou, et al., 2016). Thus, in the main expectations of BIM process deployment as common representation, common data environment is not ensured. Efficiently mainstreaming biodiversity with transport would thus require the development of software able to manage relevant data for both sectors (see Section 2). These software must suit with a BIM-like deployment environment in terms of processes (see Section 3) and provide stakeholder collaboration along the data life-cycle and transport infrastructure life-cycle.

From a biodiversity management sector perspective, embedding biodiversity management into integrated software is only at the very first step of the academic research level (Urban et al., 2021). In addition, BIM concepts are completely ignored in this sector to date (Moulherat et al., 2018; van Eldik et al., 2020; Vassart, Houewtonou, et al., 2016). Therefore, software development for ecological engineering seems to constitute an emerging and structuring market in this young and growing activity sector.

4.2. Biodiversity fully integrated to the infrastructure life-cycle management and its digital twin

The current emerging trends consisting in managing transport infrastructure with digital tools thanks to BIM processes along the GIS/BIM/DT continuum would offer strong opportunities for mutualised RDI in the field of each transport mode. But it would also offer mutualisation across all of them, in order to improve their sustainability and reach the SDG and NNL objectives (ANZLIC, 2019; Baratono et al., 2017; Bolton et al., 2018; ITF, 2021). Mainstreaming biodiversity in the digital ecosystem of transport

[35] https://www.estp.fr/maitrise-doeuvre-en-travaux-de-genie-ecologique

infrastructure would benefit from transport infrastructure and biodiversity RDI at the same time and would open the door for new research, development and innovation topics (Figure 11).

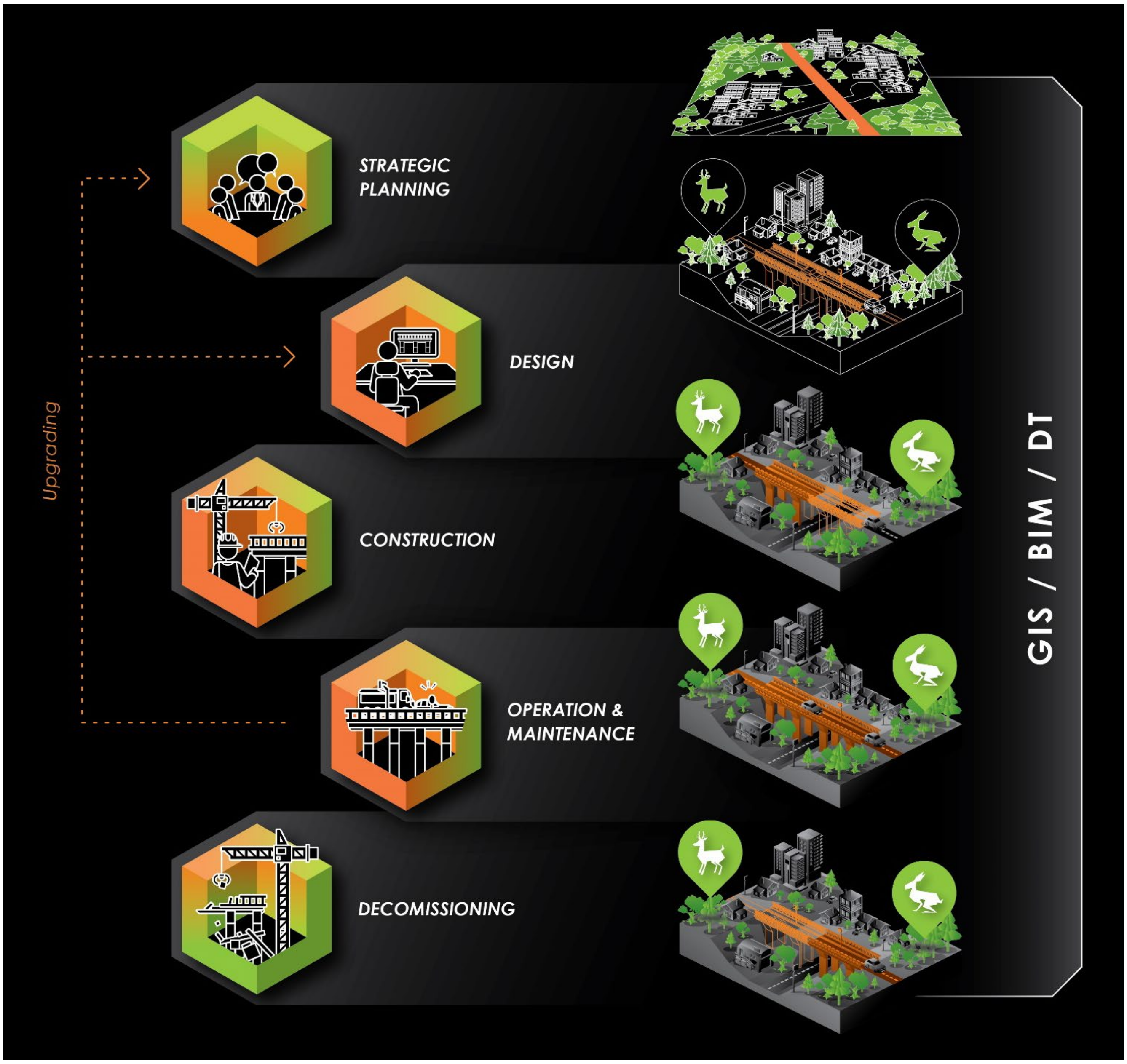

Figure 11: Mainstreaming biodiversity in transport infrastructure along the GIS/BIM/DT continuum.

4.2.1. Embedding biodiversity in the sustainability assessment of TI thanks to GIS/BIM/DT tools

Environmental evaluation practices are currently evolving to become more and more integrative, based on strategic targeted oriented objectives (Gunton et al., 2016; Moilanen & Kotiaho, 2018; Simmonds et al., 2020) and benefiting from robust standardised evaluation processes (Boileau et al., 2022). In this respect, future SEA and EIA would be performed with digital models interacting at the strategic and project levels (Catalano et al., 2021). Some existing strategic documents such as the EU Digital Strategy already anticipate such an interactive functioning between transport infrastructure and across project development phases and scales and provide a relevant context for developing appropriate RDI.

Embedding SDG evaluation processes in BIM tools already benefits from existing research and deployment projects at building or city scales. However, biodiversity issues are poorly integrated into usual SDG evaluation and complementary work is needed to improve this mainstreaming in the SDG evaluation process, then to automatise and embed it into GIS/BIM/DT tools (Catalano et al., 2021; van Eldik et al., 2020). Projects such as the *Essential Biodiversity Variables*[36], or definitions developed by the European Space Agency such as integrated and standardised approaches should therefore appropriately support the development of robust environmental quality standard certification and labelling for transport infrastructure, in line with the current work performed by the UNEP sustainable infrastructure partnership[37].

In their paper, van Eldik et al. (2020) developed a framework to perform automatic EIA in a BIM environment. Thanks to this framework, they showed that the time to perform the *life-cycle analysis* (LCA) in their study case was reduced to 35 min against 1.5 to 3.5 days, in addition to the associated substantial gain of ergonomic and sustainability consciousness. Nevertheless, biodiversity aspects were not part of their work. The integration of biodiversity management-oriented object in the BIM environment, thanks to appropriate RDI, would lead to a comprehensive integration of direct and indirect impacts assessment of the transport infrastructure life-cycle on biodiversity and would therefore improve the integration of biodiversity issues in transport infrastructure LCA. Furthermore, the integration of biodiversity management-oriented objects would also progressively contribute to the BIM's 4th and 5th dimensions. Concerning planning (4th dimension), integrating biodiversity into the BIM environment would allow for linking studies and operations, as well as the associated regulatory processes when relevant, in the global building and management plan of transport infrastructure. Similarly, cost (5th dimension) of biodiversity associated to infrastructure management would be better handled and optimised.

Closer to operative deployment, biodiversity challenges linked to regulatory studies on transport infrastructure are poorly integrated into BIM-like processes (Djema, 2022; Moulherat et al., 2017; van Eldik et al., 2020). However, some forerunner works have initiated the reflection about the translation and implementation of biodiversity studies and survey issuing from the mitigation hierarchy implementation for transport infrastructure management into BIM processes (Djema, 2022; Moulherat et al., 2018). In their work, Moulherat et al. (2018) used engineering models in a BIM environment to assess the expected population dynamics of butterflies and of a tree planting plan under the scope of the mitigation hierarchy implementation during an EIA. They used the engineering model results to define the mitigation measures efficiency criteria. They finally proposed a semi-automated retrofitting process in case of observed deviation from the standard expectation in the mitigation measures efficiency evaluation. Paving the way for various future RDI, these first steps may be used to initiate the dynamics of mainstreaming biodiversity in transport infrastructure management digitalisation process. Such

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36 https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiWv6nKz9L3AhXiz4UKHVXFDtQQFnoECBIQAQ&url=https%3A%2F%2Feo4society.esa.int%2Fwp-content%2Fuploads%2F2021%2F01%2FGlobDiversity_RS-enabled_EBV_RoadMap.pdf&usg=AOvVaw2ku6-4y799xdAPTOFmc4By

37 https://www.unep.org/explore-topics/green-economy/what-we-do/economic-and-trade-policy/sustainable-infrastructure

automation in regulatory evaluation processes would also offer the opportunity to support the development of digital authorisation such as what is experimented for buildings[38].

4.2.2. Virtual and enhanced reality opportunities

One of the main benefits expected by the BIM-like approach development is the ability of sharing the physical representation between stakeholders. Biodiversity dynamics and processes are often long-term and sometimes complex to represent. In the case of transport infrastructure, most of them also experience difficulties in representation due to the large scale of modelling required. Virtual reality (VR) supported by the digital transition could be one of the solutions, although they are still under study, and be used for sustaining the mainstreaming of biodiversity in transport infrastructure management (Moulherat et al., 2018). To overcome the lack of adapted tools, suitable knowledge and efficiency to support dialog and decision-making in the biodiversity management sector, virtual reality supported by GIS/BIM/DT continuum offers a wide panel of completely new RDI opportunities with expected strong implications in terms of transport infrastructure social acceptance progress or decision-making processes for instance (Moulherat et al., 2018). With the expected increase of nature-based solutions implementation, VR may constitute a powerful approach for representing the existing and expected past and future transport infrastructure environment (visual, acoustic, olfactive, etc.). Such an ability to navigate in a realistic virtual sensorial environment is expected to support complex decision-making in line with biodiversity and transport infrastructure relevant trade-off (e.g. trade-off between a “grey” and a “green” solution with respect to their relative efficiency to reduce noise or light pollution).

A step further, enhanced reality (ER) is more and more used for instance in order to avoid buried network maintenance such as pipelines and power lines during works. Expanding the applications of ER in the context of mainstreaming biodiversity in transport infrastructure would also offer wide varieties of completely unexplored RDI. Indeed, such an approach would be deployed at any phase of the transport infrastructure life-cycle with specific RDI preliminary requirement depending on application context and its interacting stakeholder network. For instance, Moulherat et al. (2018) discussed some expected potentialities of ER implemented on GIS/BIM models in the regulation and public debate context, where stakeholder would visit and directly interact with the digital model to support their decision and evaluation instead of working with paper-based extensive reports. This discussion gave life to further ones, about legal implications of such approaches, as well as ethical or sociological additional questioning, thus underlying the clear need for more RDI in these various fields.

[38] https://plan-bim-2022.fr/

5. SUSTAINABILITY AND ETHICAL ISSUES

In this report, we largely developed how to mainstream biodiversity in transport infrastructure in the digital environment. However, digitalisation may have consequences regarding the sustainability objectives as well as biodiversity conservation issues. This section provides recommendations and develops some main issues which should require additional RDI to avoid unexpected effects of the digital mainstreaming of biodiversity in transport infrastructure management on sustainability and biodiversity conservation objectives.

5.1. Information Technologies and Sustainability

Information technologies (IT) development explored in the previous sections should be developed following the green IT[39] recommendations and principles of digital sobriety. Indeed, data storage, sensors or AI training for instance are highly energy and resource consuming and their future development should be envisaged with relevant optimisations. Similarly, future RDI should be performed to optimise data storage needs. They should clearly address how to perform the trade-off between data storage need and associated relevant sustainability issues. In this respect, further training and capacity building should be developed in order to reinforce digital product owners' skills in green IT. This should be supported by the mainstreaming of transport infrastructure digital assets in their LCA.

Future RDI should also address the relevancy of implementing highly digitalised and connected infrastructure and explore relevancy of digitalisation along the full gradient of low to high-tech infrastructure. In addition, the deployment of digitalised and connected infrastructures will be a progressive process. Future RDI would have to address the coexistence of low- and high-tech infrastructure and ensure the ability of mainstreaming biodiversity in transport infrastructure management regardless of their digital technology level.

5.2. Specific data security needs

Data sharing and associated cybersecurity is a usual issue. However, with its low level of digitalisation, the biodiversity sector only benefits from a limited sensitivity about data security issues and in contrast, the IT sector has only a limited sensitivity to biodiversity data risks (i.e. illegal trade of protected species, observation overpressure, etc.). Thus, both sectors should benefit from training and capacity building in order to adequately develop digital tools which ensures at the same time common data security and privacy needs as well as conservation biodiversity ones at the same time.

[39] https://en.wikipedia.org/wiki/Green_computing

6. CONCLUDING REMARKS

Transport infrastructure and biodiversity are two complex interacting systems which resilience can be antagonistic or synergetic. Therefore, relevant decision-making can be hardly performed if a strong imbalance in their relative and interacting resilience evaluation ability does exist. There is an urgent need to integrate biodiversity themes into the digital environment of transport infrastructure, to ensure this balance and subsequently improve transport infrastructure's sustainability.

In this context, the generalisation of BIM-like approaches associated with the development of tools able to manage at the same time GIS, BIM and DT models in the biodiversity management sector would strongly contribute to the mainstreaming of biodiversity in transport infrastructure. However, such a convergence would require the development of a common working culture supported by adapted education and capacity building.

Future RDI seems to offer very interesting opportunities for both sectors, namely biodiversity conservation and transport infrastructure management. This research would also pave the way for future RDI and expected co-benefits in other major sectors such as the development of smart sustainable cities, urban facility management, computer science, etc.

To ensure an efficient transition and proportional deployment of digital technologies to mainstream biodiversity in transport infrastructure, hybrid low/high-tech approaches should be developed. In addition, IT for green developed and deployed to mainstream biodiversity in transport would be considered as a part of project's externalities.

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Stakeholder survey

Data set

The survey analysis has been performed with data provided by T3.1 partners of the BISON project the 20th of July 2021. The data set is composed of 162 answers. Among the 159 questions of the survey. Only ten questions are used for this analysis (questions are presented with their position in the questionnaire ($Q_{question\ number}$). Possible answers are presented between < > with a comma separator between predefined answers when proposed (if a predefined *other* with a free answer is provided, the answer is considered to be free). Data type are presented between [ ].

- Q5: *Country* <Free> [string]
- Q7: *Is your organisation* <International, National, Local> [factor]
- Q10: *What is the type of your institution?* <Free> [string
- Q125: *Is there a national scale data management strategy for Transport Infrastructures?* <Yes, No> [boolean]
- Q126: *Is there a national scale data management strategy for Environment or Biodiversity in the subsequent topics? Land cover, Land use, Species presence/absence, Animal vehicle collisions, Mitigation measures, Defragmentation measures, terrestrial inland coats.* For each, <Yes, No> [boolean]
- Q129: *Does your Transport Infrastructure digitalisation strategy integrate Big-Data issues? Do you integrate biodiversity issues within your TI digitalisation strategy?* <Yes, No> [boolean]
- Q131 to 134 were presented as a table:

	Remote Sensing	IoT	Big-Data & Artificial Intelligence	BIM & Digital Twin
Conception	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
Construction	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐
Exploitation	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐	Yes ☐ No ☐

There is no mandatory answer in the questionnaire. All the question can have no answer.

For further analysis, from Q5, countries have been separated in EU / non-EU countries and western / eastern EU countries. In Q10 only institutions have been kept regardless of detailed activities. Q131 to 134 have been transformed in disjunctive tables.

<u>*Results*</u>

Descriptive statistics

Only 25% of the questions under the scope of T3.4 are benefiting from an answer.

Table 9: Rate of positive answers to the relevancy of co-benefits for TI and biodiversity for the four main technologies under study

	Conception (%)	Construction (%)	Exploitation (%)	Total answers
Remote Sensing	73	49	71	41
IoT	44	60	96	27
Big Data & AI	68	0	71	38
BIM & Digital Twin	77	74	51	35

Mutiple comparison analysis

Multiple comparison analysis (MCA) are multivariate analysis aiming at detecting preferential associations between modalities of qualitative variables. Here, we perform MCA under the R 4.0.1 environment with library ade4, with the above-mentioned data set.

First MCA has been performed on the comprehensive data set retaining 5 axis representing only 25% of the total variance. First axis (~12%), is mainly constituted by Q131 to 134 and therefore can be associated to a *Technophilic* gradient. Second axis (~4%), is more driven by Q5 (country), especially non-EU countries in interaction with answer to Q129. Third axis (~4%), is built of a mixture of Q5 and Q131 to 134 and seems to be driven by the point of view of eastern EU countries on Q131 to 134. Following axis are mixture of many different things without clear relevant *signal* it their meaning.

Main results of this first MCA are:

1. Respondent “YES” to Q129 tends identify the mutual interest of technologies (RS, IoT, AI, BIM) for TI and biodiversity (especially in Conception and Construction phases).
2. Clearer patterns seem to means that BIM and BD / AI issues are better handled by respondent
3. No clear pattern of answers depending on the country (Q5) or organisation type (Q10)
4. Non-EU countries answer differently from EU ones (take care to MCA sensitivity to rare which may over detect this signal)
5. Eastern and western countries have similar answers
6. Q7, seems to not influence the analysis

In a second step, answers from non-EU countries are removed and the same MCA is performed. Note that UK and Switzerland have been kept as EU countries but may be discussed.

Ireland provided only 1 answer very different from other countries and has been considered as an outlier and removed from this analysis

With the reduced data set, 2 axis are kept (~23% variance). First axis (~15%) is driven by answers in Q131 to 134, while axis 2 (~5%) is mainly driven by Q5 and 10 (as all the axis following up to the 5th).

Main results of this second MCA are:

1. A pattern of technology awareness of respondent with a link between the fact of answering “Yes” to Q129 and then “Yes” to the usefulness of technologies depending on the phases (RS for Exploitation, AI for Conception, BIM for Conception).

2. Q5 and 10 seems to not affect the associations

3. Eastern or Western EU is strictly neutral.

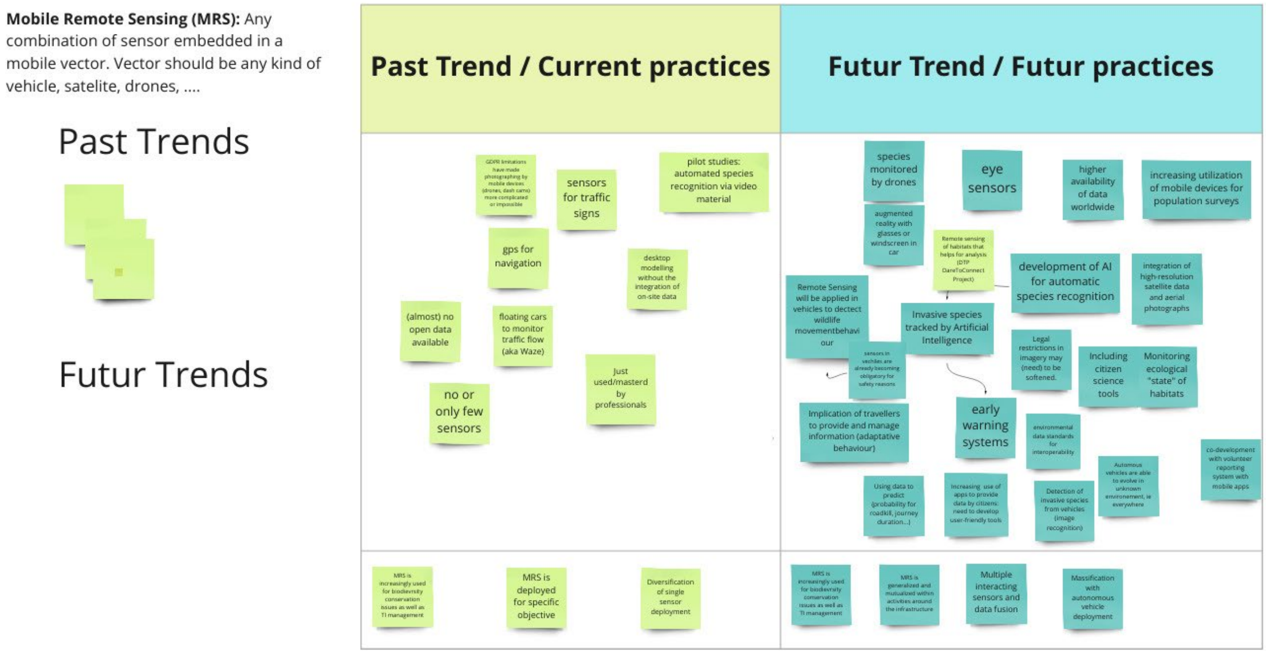
Conclusion

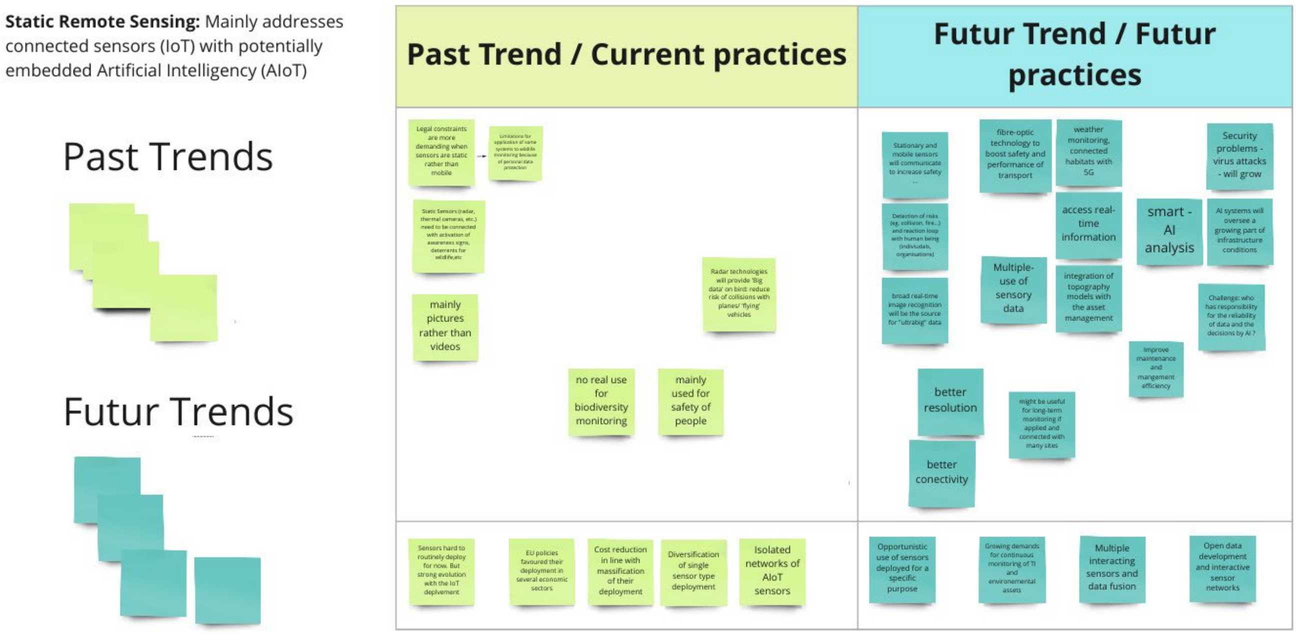
The digital aspect of the mainstreaming of biodiversity with transport infrastructure seems to be unmanaged and poorly handled especially concerning IoT opportunities. In addition, most technologies are identified to be useful for conception and construction but not for exploitation which is in most of the studied cases the opposite of the existing scientific and grey literature recommendation.

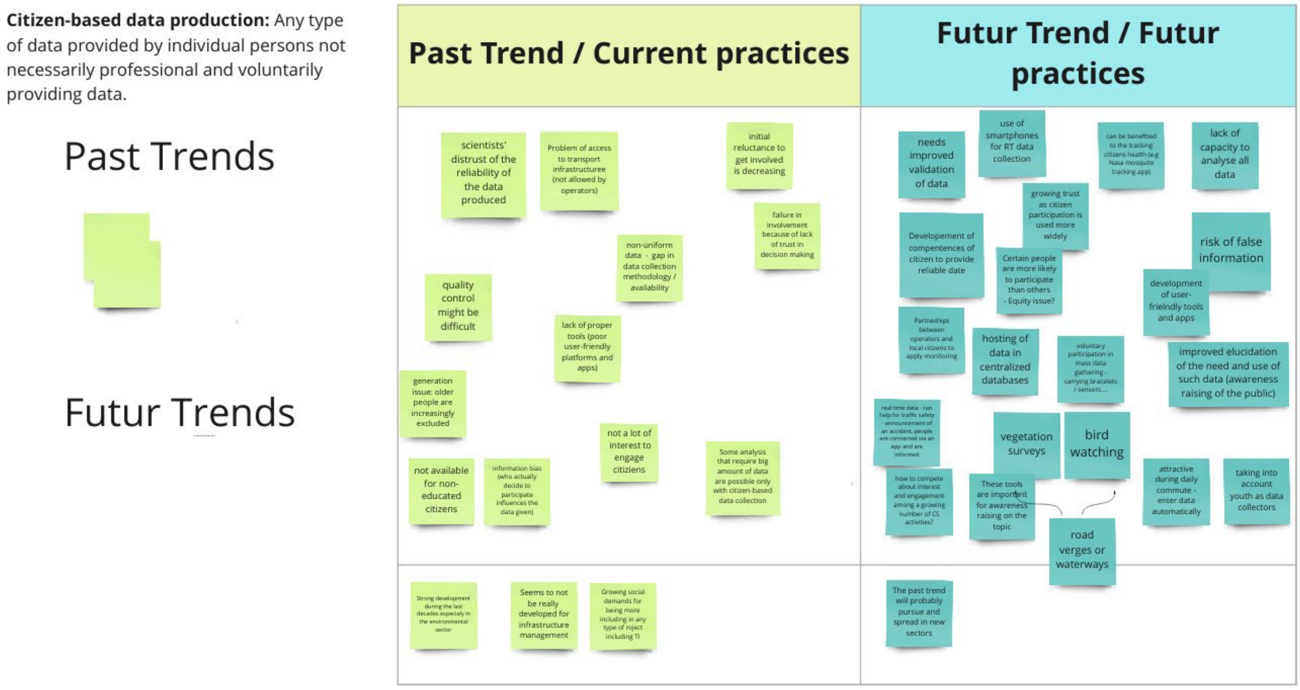
Workshops results

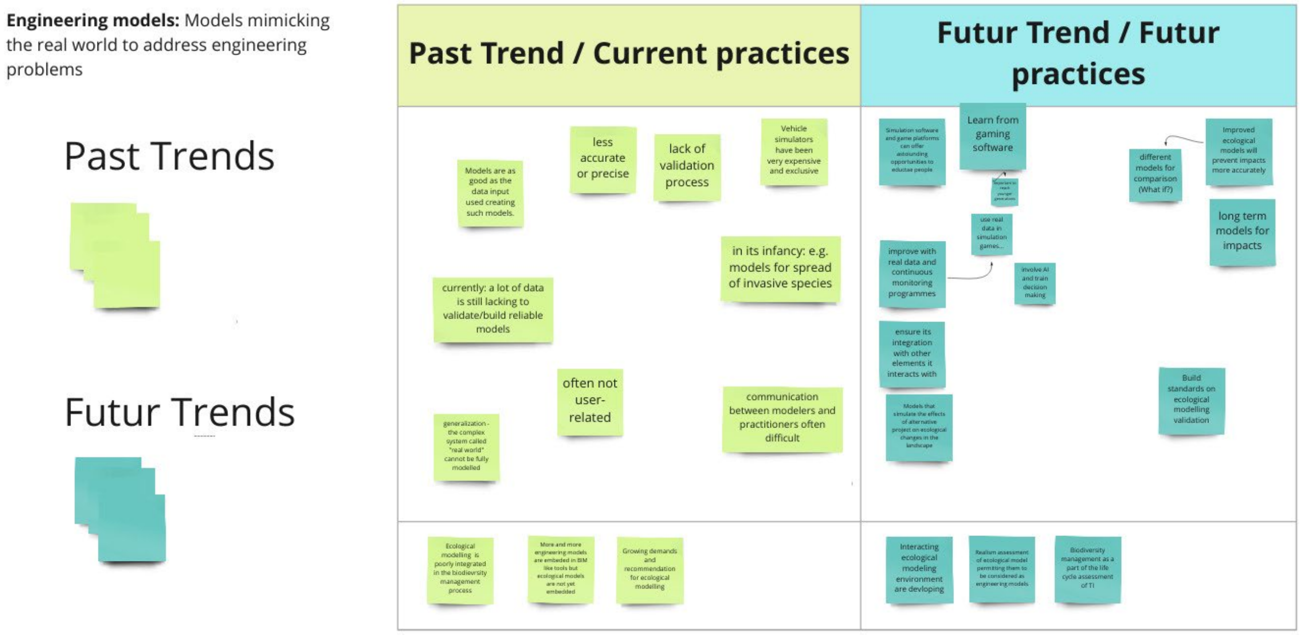
The following section presents the elements discussed the 28th of January 2022 during the common workshop with T3.3 (emerging trends). After a rapid presentation of the T3.4 group production in charge of producing this deliverable, participants were invited to discuss and feed a Miro board (available at https://miro.com/app/board/uXjVOSfWhAU=/). The figures below are extracted from the Miro board.

Participants reaction concerning the data collection issues

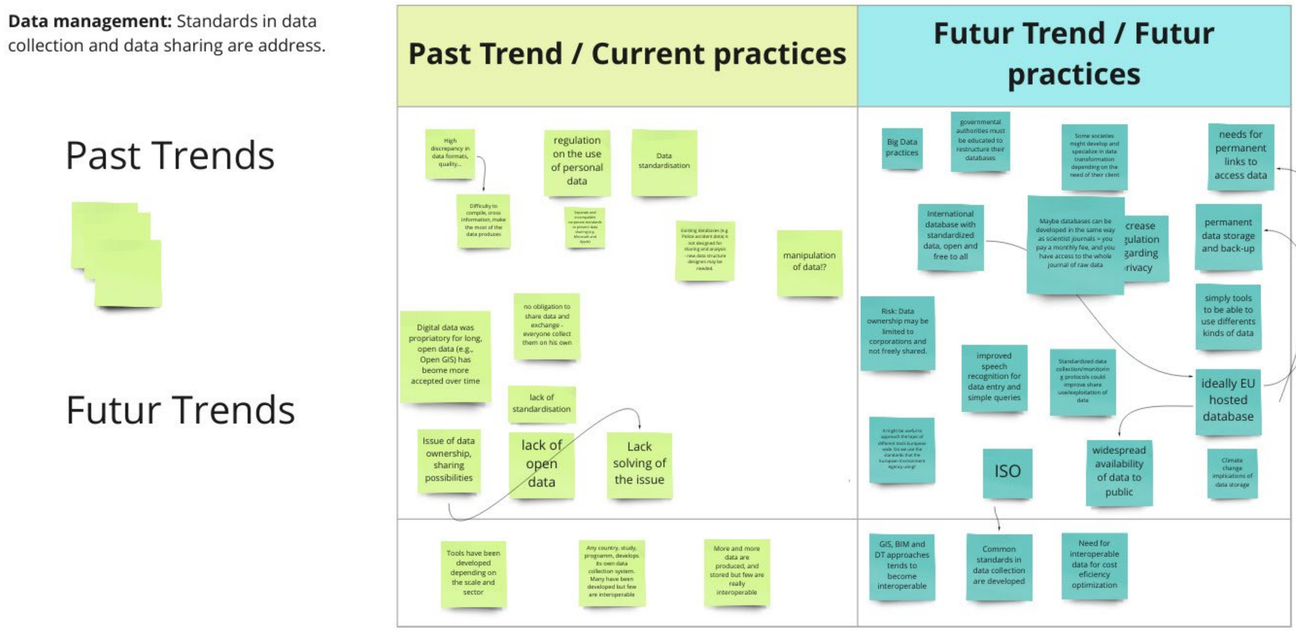




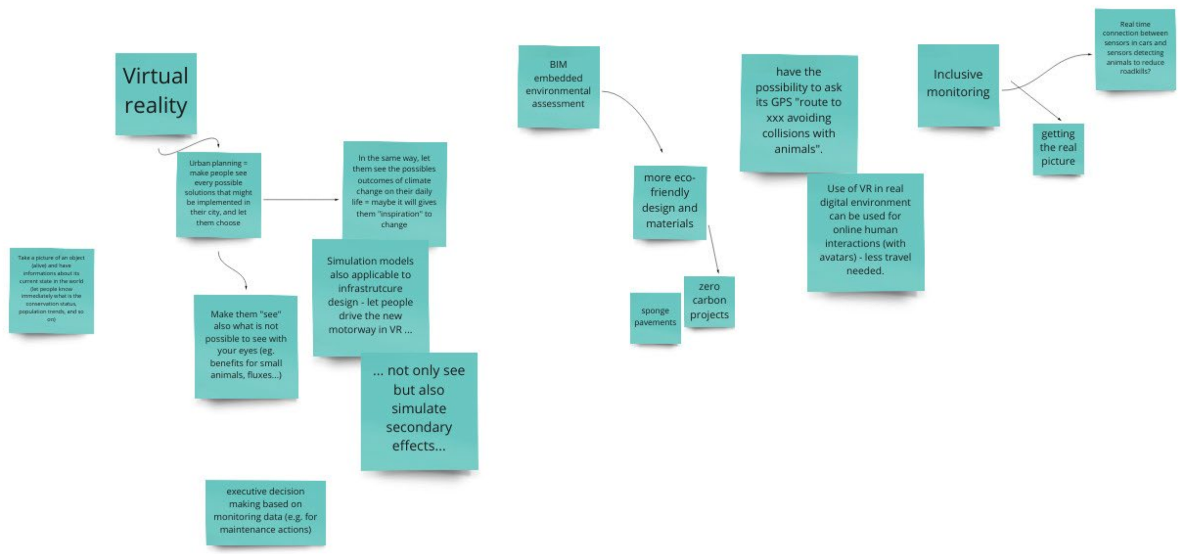

Citizen-based data production: Any type of data provided by individual persons not necessarily professional and voluntarily providing data.
Past Trends
Futur Trends
Past Trend / Current practices
Futur Trend / Futur practices
scientists' distrust of the reliability of the data produced
Problem of access to transport infrastructuree (not allowed by operators)
initial reluctance to get involved is decreasing
failure in involvement because of lack of trust in decision making
non-uniform data - gap in data collection methodology / availability
quality control might be difficult
lack of proper tools (poor user-friendly platforms and apps)
generation issue: older people are increasingly excluded
not a lot of interest to engage citiziens
Some analysis that require big amount of data are possible only with citizen-based data collection
not available for non-educated citizens
information bias (who actually decide to participate influences the data given)
Seems to not be really developed for infrastructure management
needs improved validation of data
use of smartphones for RT data collection
lack of capacity to analyse all data
growing trust as citizen participation is used more widely
Developement of compentences of citizen to provide reliable date
Certain people are more likely to participate than others - Equity issue?
risk of false information
development of user-frielndly tools and apps
hosting of data in centralized databases
improved elucidation of the need and use of such data (awareness raising of the public)
vegetation surveys
bird watching
These tools are important for awareness raising on the topic
road verges or waterways
attractive during daily commute - enter data automatically
taking into account youth as data collectors
The past trend will probably pursue and spread in new sectors


Engineering models: Models mimicking the real world to address engineering problems
Past Trends
Futur Trends
Past Trend / Current practices
Futur Trend / Futur practices
Models are as good as the data input used creating such models.
less accurate or precise
lack of validation process
Vehicle simulators have been very expensive and exclusive
in its infancy: e.g. models for spread of invasive species
currently: a lot of data is still lacking to validate/build reliable models
often not user-related
communication between modelers and practitioners often difficult
generalization - the complex system called "real world" cannot be fully modelled
Ecological modelling is poorly integrated in the biodiversity management process
Growing demands and recommendation for ecological modelling
Learn from gaming software
different models for comparison (What if?)
Improved ecological models will prevent impacts more accurately
long term models for impacts
use real data in simulation games...
improve with real data and continuous monitoring programmes
involve AI and train decision making
ensure its integration with other elements it interacts with
Build standards on ecological modelling validation
Interacting ecological modeling environment are devloping
Biodiversity management as a part of the life cycle assessment of TI

Participants reaction concerning the data management issue



Participants reaction concerning the data exploitation issue (ideation exercise)



The 15th of February, we performed a brainstorming session with the advisory group members. Minutes and extractions from the dedicated Miro board (available at https://miro.com/app/board/uXjVONVNQ0U=/) are presented below.

Brainstorming session minutes

Participants

Partner No	Short name	Names
1	FRB	Julie de Bouville
2	UNEP-SIP	Yaxuan Chen replacing Rowan Palmer
3	SNCF	Cora Cremezi-Charlet
4	AMPHI	Alfred Figueras
6	EWT ACLIE	Wendy Collinson
7	FNTP	Alice Lamoureux
8	PNDB	Yvan Le Bras
9	TerrOïko-UPGE	Sylvain Moulherat
10	FRB	Charlotte Navarro
11	EGIS	Allan Raulline replacing Frédéric Jehan.
12	German Ministry for Digital and Transport	Christian Schlosser replacing Marcia Giacomini
13	CEREMA	Manon Teillagory replacing Olivier Pichard, Cerema
14	T20 - Renaissance urbaine	Nicolas Buchoud

Welcome and agenda:

- The agenda was presented and adopted with the participants.

The role of the Advisory Group:

- Charlotte Navarro reminded the role of the Advisory Group and the expected deliverables to be produced in the framework of the BISON project.

The deliverable D5.3 on BIM and Digitalisation of Infrastructure:

- Sylvain Moulherat presented the current content of the deliverable D3.5 “Report on application of BIM and other tools to standardise data record and management”.

Advisory Group members feedback & Brainstorming Session :

The topics discussed were:

- Management of the GIS/BIM/DT continuum
- Transferability of BIM processes to the entire GIS/BIM/DT continuum, to the infrastructure life-cycle, to all business lines (especially biodiversity/infrastructure convergence)? is this really desirable?
- Regulatory implications (RGPD, data accessibility, file instruction/monitoring)
- Public policies on data and software

The Advisory Group shared its thoughts:

Alice Lamoureux: BIM and biodiversity are perceived as a very advanced topic. In-house training has been conducted recently.

Christian Schlosser: Data research point of view

- BIM implementation part: there are effort to teach the agency (rail, road and motorway), the methodology. The Ministry is working on Incorporating GIS last year, focus on BIM implementation, open data, environmental data, citizen science, covered by the project also. He will be happy to share documents. More information is available on different aspects of biodiversity, match this information with other sources. Process to gather merging BIM with other sources of data collection. Quality of data is very important.

Yaxuan Chen, raised important questions, such as:

- What particular conservation are we willing?
- Technology provided: What somewhat infra twin? Planet twin? Monitory system purpose.
- Data sharing mechanism. What is the limit?

Yvan Le Bras welcomed the importance of developing this theme.

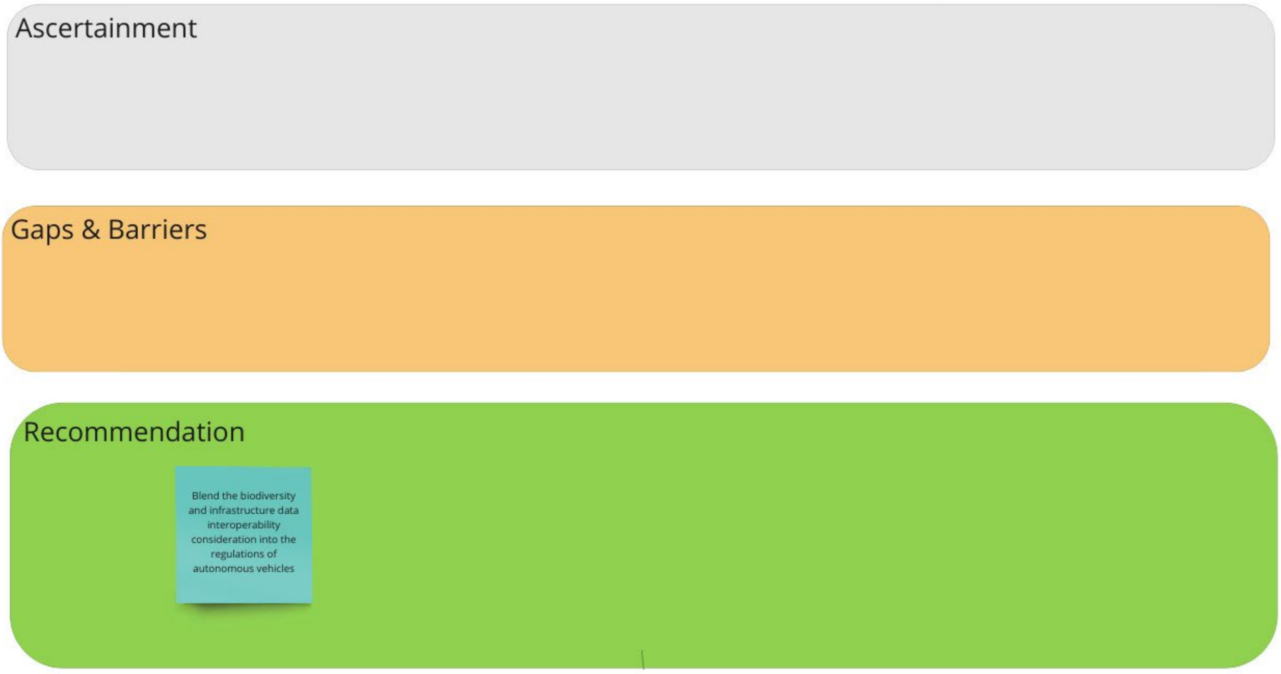
- Lack of accessibility of data; need to focus on mechanism
- IA: way to elevate knowledge of the users on this kind of tools!
- European directive: good way to share data but results are very bad… there are work to do!

Christian Schlosser:

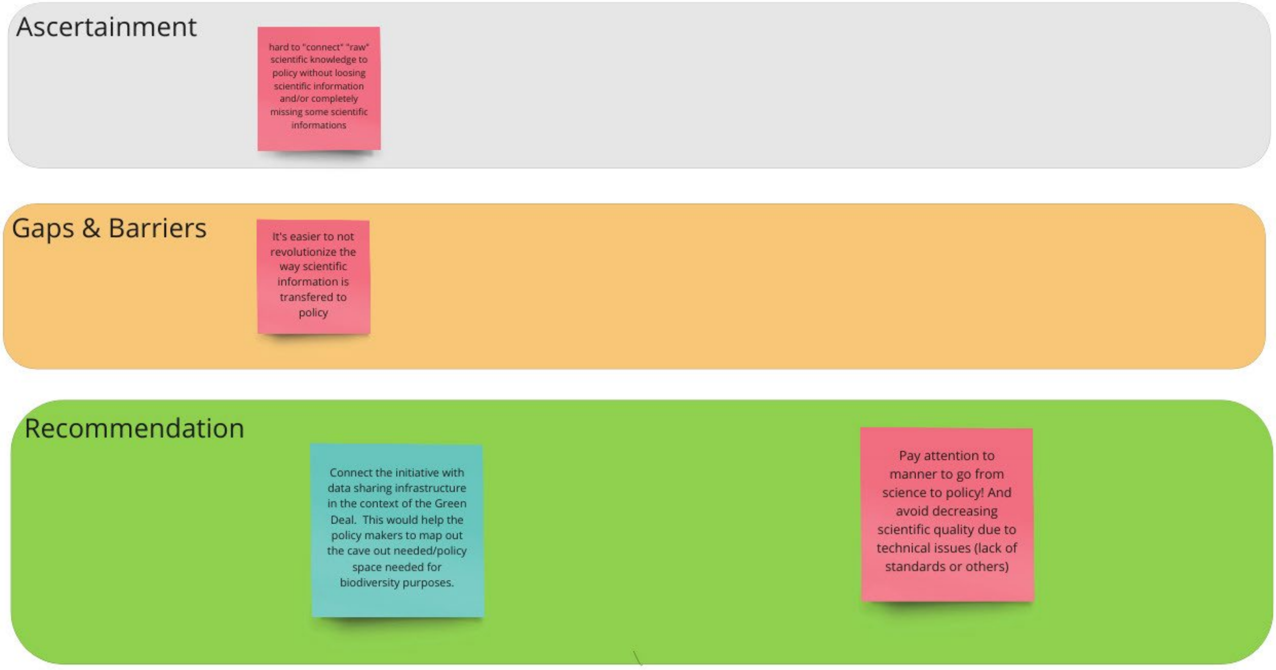
- You could model digital twin, potential impact on biodiversity. Paper plan sent to different agencies. Conceptual model.
- Common language of digital twin needed.

Advisory group members proposal to the different issues addressed

Regulation

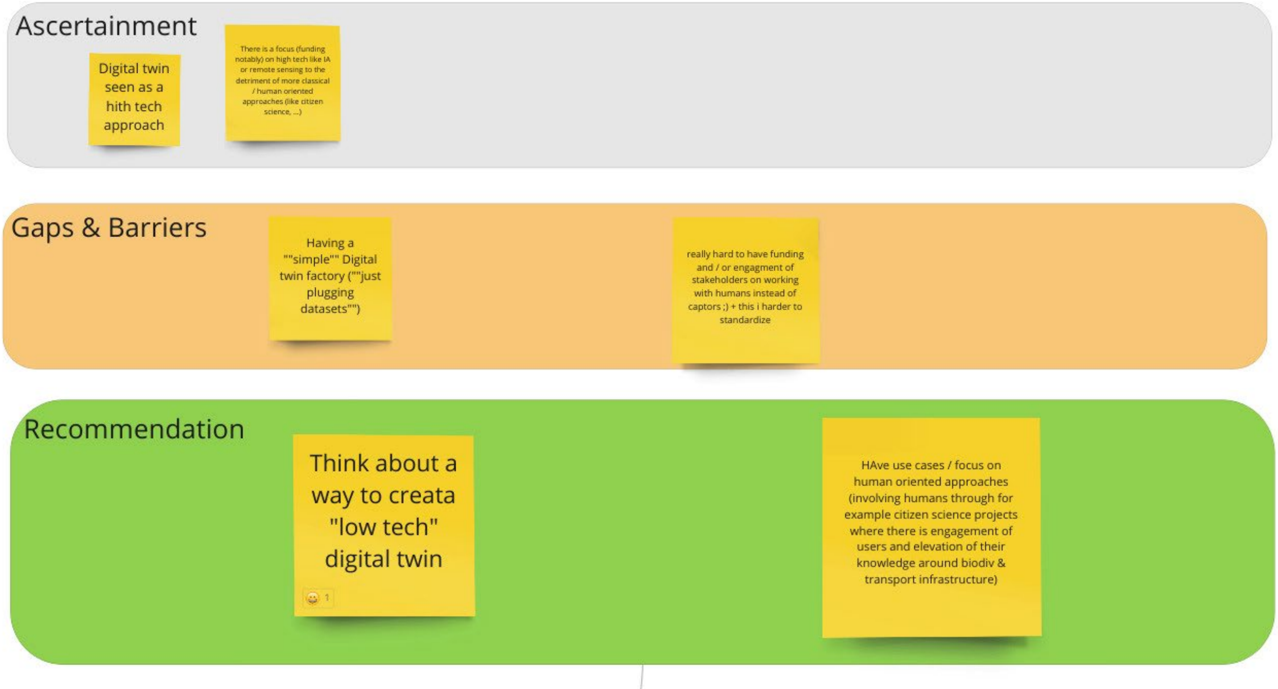


Policy



Business models

Low/High-Tech coexistence



Sustainability

Ethic & Privacy

Skills & capacity building

Comprehensive table of GIS examples provided by partners

Name	URL	Location	Infrastructure	Biodiversity
Global Biodiversity Information Facility	https://www.gbif.org/en/	World		X
Inaturalist	https://www.inaturalist.org/	world		X
Grønt Danmarkskort	https://mst.dk/natur-vand/natur/national-naturbeskyttelse/groent-danmarkskort/ https://miljoegis.mim.dk/cbkort?profile=miljoegis-plangroendk	Denmark		X
Kort Forsyningen	https://kortforsyningen.dk/	Denmark	X	X
Naturdata Miljøportal	https://naturdata.miljoeportal.dk/	Denmark		X
Plandata	https://planinfo.erhvervsstyrelsen.dk/plandatadk/	Denmark	X	
Bioccitanie	https://bioccitanie.laregion.fr/	France	X	X
Data terra	https://www.data-terra.org/en/homepage-english/	France	X	X
Geoportail	https://www.geoportail.gouv.fr/	France	X	X
Nature France	https://naturefrance.fr/systeme-information-biodiversite	France		X

Alien species in Poland	https://www.iop.krakow.pl/ias	Poland		X
Geoservice - General Directorate for Environmental Protection (GDOS)	http://geoserwis.gdos.gov.pl/mapy/	Poland		X
Map of ecological corridors	https://mapa.korytarze.pl/index_en.html	Poland	X	X
Biodiversity Data Viewer – MITECO	https://sig.mapama.gob.es/bdn/	Spain		X
Spatial data infrastructure	https://www.idee.es/web/idee/inicio	Spain	X	X
Swedish Geodata	www.geodata.se	Sweden	X	X
Swedish Species Information Centre	https://www.artdatabanken.se/en/	Sweden		X
Network Rail	https://www.networkrail.co.uk/news/latest-technology-used-to-improve-thousands-of-miles-of-lineside-biodiversity/	UK	X	X