URBREATH [101139711]

Systemic Integration of Transformative Technical and Nature-based Solutions to Improve Climate Neutrality of European Cities and Regions and tackle Climate Change: the URBREATH Approach

D7.12 - Standardisation Report – V1

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Disclaimer

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Executive summary

The objective of the URBREATH project is to enhance climate neutrality in European cities through the adoption of Nature-Based Solutions (NBS) and supporting tools that assist municipalities in managing their entire lifecycle, including problem identification, solution design, comparison, implementation monitoring, impact evaluation, and scaling up. To achieve this, URBREATH aims to develop, implement, demonstrate, validate, and replicate a comprehensive urban revitalisation methodology that involves community and stakeholder participation in greening and renaturing, supported by digital technologies that the project will further develop and test.

The digital technologies that support this process are part of the comprehensive URBREATH Toolbox being developed by the project. An overview of the URBREATH Toolbox and its tools has been provided in a previous deliverable, D4.7. The tools within the toolbox can then be utilised by different pilot city environments to undertake up-front analysis of the intended NBS interventions based on their specific needs.

Apart from the overall effectiveness of these tools in supporting the implementation of NBS solutions in cities, a key consideration in their design is the ease of deployment and replicability across different city environments. This ensures that more cities can benefit from the developed methodology and supporting tools, maximising the overall impact of project outcomes.

Ease of deployment and replicability, however, requires that tools and solutions are designed with interoperability in mind. Interoperability reduces integration barriers and the effort needed to customise solutions for different contexts. It also allows solutions to evolve more effectively in the future, accommodating emerging technologies, innovations, or competitive market alternatives without vendor lock-in. Adoption of open standards—whether de facto or formal—plays a vital role in shaping system interoperability. Equally important are best practices in applying these standards during the design of individual tools, components, and the overall system.

This document offers an initial analysis of interoperability considerations for the URBREATH Toolbox, aiming to promote its adoption and replication across diverse city environments. It reviews relevant standards and interoperability guidance, highlighting those most pertinent to URBREATH, and provides recommendations for the future evolution of the Toolbox design and related solution implementations.

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List of Terms and Abbreviations

Abbreviation	Definition
AIOTI	Alliance for Internet of Things Innovation
AOI	Area of Interest Application
API	Application Programming Interface
AR	Augmented Reality
BAF	Biotope Area Factor
CKAN	Comprehensive Knowledge Archive Network
CRUD	Create Read Update Delete
CSW	Catalogue Service for the Web
DAM	Dataspace Authority & Management
DCAT	Data Catalogue Vocabulary
DCAT-AP	DCAT Application Profile
DCP	Dataspace Core &Protocols
DDPC	Dataspace Data Planes & Components
DSGA	Data Sharing and Governance Act
DRP	Dynamic Routing Protocol
ETSI	European Telecommunications Standards Institute
FIWARE	FIWARE Platform
STA Server	Fraunhofer Open Source SensorThings API Server
GAIA-X	Gaia-X European Data Infrastructure
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
I18n	Internationalization file used in software development to store all user-facing text (like labels, messages) and locale-specific data (dates, currencies) *outside* the main code
IAM	Identity and Access Management
IDS	International Data Spaces
IDSA	International Data Spaces Association
ITU	International Telecommunication Union
IoT	Internet of Things
JTC25	Joint Technical Committee 25
JVM	Java Virtual Machine
KML	Keyhole Markup Language
KPI	Key Performance Indicator

LDES	Linked Data Event Streams
LDT	Local Digital Twin
LDTI	Local Digital Twin Infrastructure
LIME	Local Interpretable Model-agnostic Explanations
LoRaWAN	Long Range Wide Area Network
M2M	Machine to Machine
MFA	Multi-Factor Authentication
MIM	Minimal Interoperability Mechanism
MIMs +	Minimal Interoperability Mechanisms Plus
MQTT	Message Queuing Telemetry Transport
NBS	Nature-Based Solution
NGSI	Next Generation Service Interface
NGSI-LD	Next Generation Service Interface – Linked Data
OASC	Open & Agile Smart Cities and Communities
OGC	Open Geospatial Consortium
OTP	One Time Password
PDP	Partial Dependence Plot
PoI	Point of Interest
RBAC	Role-based access control
RDMS	Relational Database Management System
SHAP	SHapley Additive exPlanations
SSO	Single Sign-On
TLS	Transport Layer Security
UHIs	Urban Heat Islands
UN	United Nations
VIE-AI	Visual Interpretable and Explainable AI tool
VR	Virtual Reality
XAI	EXplainable AI
XR	Extended Reality
WKT	Well-known text

1 Introduction

1.1 Purpose and scope

The URBREATH project addresses the urgent need for climate-neutral urban environments through the systematic integration of Nature-Based Solutions (NBS) and digital planning tools. To achieve these objectives, the project relies on a diverse ecosystem of tools, data sources, and services that must work together seamlessly.

Although this deliverable is titled *"Standardisation Report"*, its scope extends far beyond simply listing standards. Standardisation alone does not guarantee full interoperability of systems, nor are standards the only means by which certain levels of interoperability can be achieved.

This document reports and describes the first version of a strategic reference point for ensuring interoperability across these components by identifying relevant standards, specifications, and standardisation needs. It also provides preliminary assessment and recommendations that will guide pilot cities in implementing interoperable solutions (URBREATH toolbox), supporting the replication roadmap outlined in Task T7.6. URBREATH toolbox offers a suite of software tools to build a comprehensive technological framework to support the implementation of the different steps through which NBS interventions are planned, executed, and monitored.

1.2 Relation to other work packages and deliverables

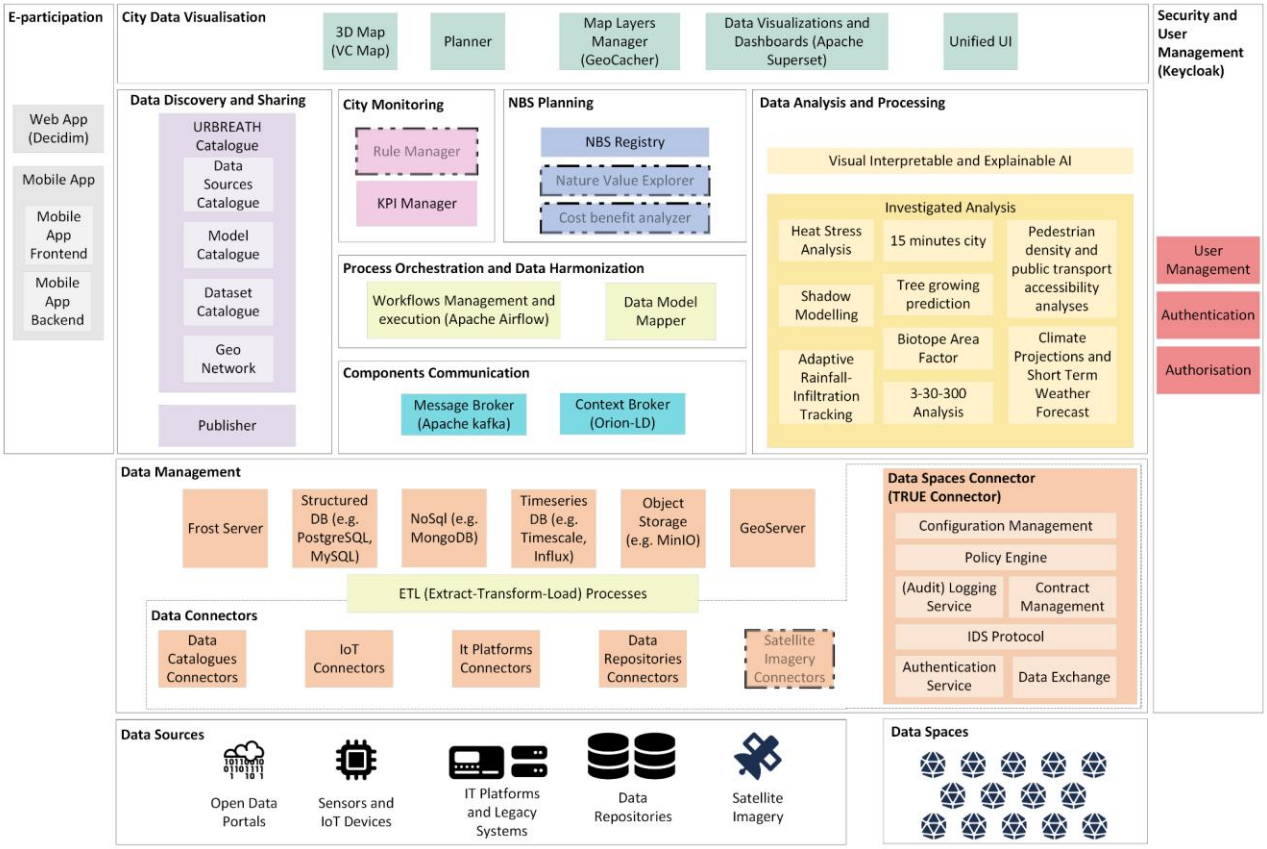
This deliverable is mainly based on the results and connections with two technical work packages (WP3 and WP4), which are responsible for designing, identifying, and validating the URBREATH Toolbox requirements (WP2) in (D2.5), evaluating their technical feasibility, and selecting the initial candidate tools for its concrete implementation (D4.7).

1.3 Methodology and approach

The digital planning tools developed by URBREATH to support the design and lifecycle of NBS solutions rely primarily on access to the right data sources and insights derived from them. Such data may reside in different municipal and third-party systems providing urban services or be collected from additional sensor data, IoT infrastructure, open data portals, GIS systems or even satellites.

The picture below is taken from the UREBREATH project deliverable D4.7[1] and shows the overall system architecture with all URBREATH toolbox components.

Figure 1: Logical architecture of the URBREATH Toolbox



To ensure a coherent end-to-end solution, a subset of these tools needs to be effectively orchestrated and combined with other systems and suitable data flows. The involved URBREATH tools and urban systems/ data sources will depend on the nature of the NBS use cases. It is therefore important that interfaces and data flows between these tools are interoperable.

[1] D4.7 URBREATH NBS ICT integrated solution - V1", Editor: Giuseppe Ciulla, Engineering Ingegneria Informatica SpA, 27/06/2025

A core consideration for ensuring interoperability in the URBREATH project is thus how to effectively access and integrate these data sources across a wide range of heterogeneous city environments.

Consequently, the document identifies relevant emerging standards and best-practice guidance on interoperability within the scope of the URBREATH Toolbox.

To cover the lower layers of the URBREATH toolbox stack, the analysis will focus on **interoperability guidance and standards for data exchange in urban data platforms and data spaces** to facilitate interoperability between the tools.

When it comes to the higher layers of the solution stack, such as data analysis and visualisation, we focus on emerging standards and best practices for **Local Digital Twins and the Metaverse for Cities (CityVerse)**.

Our analysis will consider how far existing tools already implement or align with these standards and best practices and make recommendations for the further evolution of these tools where necessary to ensure increased interoperability.

The document also identifies opportunities where existing interoperability guidance and standards are lacking and fall short of our requirements and might require update or further development.

1.4 Structure of the deliverable

Following an introduction, the document surveys existing standards and best practices on interoperability in Section 2. The survey focuses on areas most relevant to the envisioned project solutions, such as access, management, and sharing of urban data, data spaces and local digital twins. It references specific interoperability guidance, including the OASC MIMs / MIMs+ and significant emerging standardisation activities, which will be important as they are fully defined.

Section 3 analyses the URBREATH tools, grouped into 10 macro areas, each addressing concerns within the overall solution stack. The analysis identifies relevant interoperability dimensions within each area, assesses current technology and specification choices, and highlights where suitable design decisions have already been made. It also notes opportunities to improve interoperability by aligning with best practices and standards discussed in section 2, identifies standardisation gaps, and suggests points where further contribution could foster better interoperability of NBS solutions.

Section 4 builds on this analysis, offering concrete recommendations for further development of the URBREATH toolbox and interoperability assessment of the solutions. It highlights opportunities for the project to contribute to broader standardisation initiatives and to collaborate with standards

development organisations (SDOs), projects, and communities of practice to promote new standards or facilitate NBS solution interoperability.

Section 5 concludes with a summary of key findings and recommendations. Ultimately, this deliverable aims to inform a standardisation approach and technology roadmap for the URBREATH toolbox, which will significantly increase the uptake of URBREATH's solutions, directly supporting the project's Key Result (KR-20) on replicability and upscaling, thereby contributing to the project's Key Performance Indicators (KPIs).

2 Relevant standards initiatives

2.1 Dataspaces

The URBREATH tools require the cities that use them to be able to bring together data from a range of data sources so that these can be analysed to provide information to help manage and implement various Nature-Based Solutions. There are several ways in which such data sharing can be implemented, but the European Commission specifically encourages the use of dataspaces as an effective mechanism to handle this.

2.1.1 CEN/CENELEC JTC25

CEN and CENELEC, two of the three European Standards Development that have been officially recognized by the European Union as being responsible for developing and defining voluntary standards at European level, have a Joint Technical Committee (JTC25) on Data management, Dataspaces, Cloud and Edge, The JTC25 Dataspaces Working Group involves some of the key organisations leading the development of dataspaces such as the International Data Spaces Association, Gaia-X and the iShare Foundation as active members, The Working Group is working on 4 deliverables relating to what it refers to as “Trusted Data Transactions”. Three of these will be formal standards covering:

- Trusted Data Transactions Part 1: Concepts, terminology, and mechanisms
- Trusted Data Transactions Part 2: Trustworthiness requirements
- Trusted Data Transactions Part 3: Interoperability requirements

The fourth is a Technical Report providing a Maturity Model that can be used to assess the strengths and weaknesses of any data sharing ecosystem.

These are at various stages of development, but the aim is to complete and publish them all over the next nine months. What is important is that all of these standards focus on identifying requirements and not solutions. The aim is to use these to set the foundation for an open market of solutions that all address the same sets of requirements.

2.1.1.1 Part 1: Concepts, terminology, and mechanisms

This document provides terminology, concepts and a description of mechanisms in the field of data exchange focusing on trusted data transactions. These elements can be used in the development of

standards in support of trusted data transactions and constitute a basis to identify key dimensions and criteria that contribute to the trust in a data transaction between interested parties.

Therefore, those elements constitute a foundational understanding on which trusted data transactions can be based, independently of any architectural choices or technical implementation.

The value of this document is that it provides not only key definitions of the key stakeholders in data sharing, but it also provides clear descriptions of all the transactions and relationships involved.

2.1.1.2 Part 2: Trustworthiness requirements

Sharing of data can have significant commercial, financial, privacy and other impacts on all stakeholders involved. Therefore, it is important to identify the requirements for trustworthiness of data transactions.

Data transactions can take place in many different organisational set-ups, requiring an interplay between data rights holders, data providers, data users and any involved data intermediaries facilitating the sharing of data, through technical, legal or other means.

Agreements between these actors are established in data usage contracts, containing policies, terms and conditions for the sharing of data between two or more participants. Data usage contracts can be bound by commonly established technical and legal agreements (i.e., policies, semantic models, protocols and processes). In dataspaces, such agreements are managed by a Data Space Governance Authority (DSGA) and documented in the dataspace rulebook, providing the common trust context and supporting services for data sharing.

Specifically, this document defines a set of foundational principles for trusted data transactions and establishes general requirements and guidance that apply to all phases of a trusted data transaction, and specific requirements for each phase of a trusted data transaction.

2.1.1.3 Part 3: Interoperability requirements

This document specifies requirements and guidance for the interoperability of data, data sharing mechanisms, and services within dataspaces. It covers requirements, criteria and implementation guidance on:

- Dataset content, use restrictions, licences, data collection methodology, data quality and uncertainty, and on machine-readable formats to find, access and use of data.

- Data structures, data formats, vocabularies, classification schemes, taxonomies and code lists, and how to describe these elements in a publicly available and consistent manner.
- Technical means to access the data, such as application programming interfaces, and their terms of use and quality of service to enable automatic access and transmission of data between parties.
- Where applicable, the means to enable the interoperability of tools for automating the execution of data sharing contracts.

This standard is applicable to systems used by all organisations participating in dataspaces, regardless of their size or type. The application of this standard aims to facilitate the interoperability of these systems both within and across multiple dataspaces, enabling organisations to engage in data sharing in different contexts.

2.1.2 Eclipse Foundation Dataspace work

The Eclipse Foundation is a European nonprofit Foundation with a global reach that aims to provide a mature, scalable, and vendor-neutral environment for open-source software collaboration and innovation.

It hosts a Dataspace working group, whose mission is to provide a forum for individuals and organisations to build and promote open-source software, specifications, and open collaboration models needed to create scalable, modular, extensible, industry-ready open-source components based on open standards for dataspaces. The working group focuses on participating in standards development, implementation, and onboarding of existing open-source projects including the Eclipse Dataspace Components project and guiding associated projects in alignment with the overarching goal of supporting a broad ecosystem of interoperable dataspaces.

Some of the key dataspace related organisations mentioned as participating in the work of CEN/CENELEC JTC25 are active participants in the work of this Eclipse Working Group and see it as an opportunity to undertake preliminary work on standards before taking them to the CEN/CENELEC JTC25 for them to be formalised, alongside developing open source software solutions to support the implementation of the requirements identified in standardisation.

The work is focused in three distinct groups:

Dataspace core & protocols (DCP)

DCP focuses on the core protocol specifications and their standardisation. It also provides alignment between the protocol specifications an Open-Source Software projects implementing mandatory dataspace functionality.

Dataspace data planes & components (DPPC)

DDPC focuses on alignment between projects that implement data planes, which are essential components for dataspaces as well as additional optional components which enable advanced dataspace scenarios. These include components which are not essential to create a viable dataspace but add capabilities that increase the business value of dataspaces.

Dataspace authority & management (DAM)

DAM focuses on alignment of tools and workflows to enable the implementation of dataspaces. Its associated projects will support dataspace authorities to manage their dataspaces. This includes policy management, member management, and starter kits for dataspace authorities.

Two tools are already on early release; the Eclipse Dataspace Protocol and the Eclipse Dataspace Decentralized Claims Protocol, while the following are still in early development: Eclipse Conformity Assessment Policy and Credential Profile, Eclipse Data Rights Policies Profile (DRP), Eclipse Dataspace Components, and the Eclipse Dataspace Technology Compatibility Kit.

More details are on the Eclipse website[2].

[2] https://dataspace.eclipse.org/projects/

2.2 Local Digital Twins

2.2.1 ITU-T Study Group 20

2.2.1.1 Background

ITU is the International Telecommunications Union and is a United Nations associated agency helping to support global telecommunications. One of its activities is to develop standards and it does this through study groups. Study Group 20 covers standards on Internet of Things, digital twins and smart sustainable cities and communities. It is working on a number of standards related to Local Digital Twins; below are some of those that have been already approved.

Like CEN/CENELEC, ITU does not develop specific solutions but rather sets the common requirements to enable solution providers to innovate and develop an open market of solutions.

2.2.1.2 ITU Y.4600: Requirements and capabilities of a digital twin system for smart cities

This defines a smart city digital twin as “a digital twin for a smart city that can be used to develop strategies to achieve specific goals for a smart city, by conducting simulations and to increase visibility of human-infrastructure-strategy interactions”.

It describes how a smart city digital twin allows the simulation of plans before implementing them, exposing problems before they become a reality. In other words, it describes how it is possible to conduct simulations on a digital replica of the city (virtual cities) before actually implementing the strategy on the real city.

In this way, it shows how a city digital twin enables the city to find the best strategies to achieve a specific goal or strategies that have similar effects while minimising budget and resource usage. Therefore, a smart city digital twin is a tool for improving urban operations, efficiencies and resilience of a city.

2.2.1.3 ITU Y.4224: Requirements for digital twin federation in smart cities and communities

Smart cities and communities may have many kinds of cross domain problems, such as manufacturing, transportation, energy and safety, and it is difficult to resolve these problems by individual digital twin systems.

To solve them, the digital twin systems in various domains can be federated. The federated digital twin systems collect and analyse the information from various domains, provide the solution for the problems, and simulate the effects. For this, some components and functions are needed to support digital twin federation.

This Recommendation defines the requirements for digital twin federation.

2.2.1.4 ITU Y.4605: Information exchange model for digital twin federation in smart cities and communities

The digital twin has been applied in various industry domains including manufacturing, transportation, energy, firefighting, medical and safety. Digital twin federation is the act of sharing application context among two or more digital twins to solve the problems related to multiple domains.

The information exchange model among the components of the digital twin federation, which are the digital twins, the registry and the connection broker, needs to be defined to enable digital twin federation. Information includes the data, functions, and services for each digital twin in various domains. The information exchange model provides the overview and defines the message structure with verbs and nouns. A verb is the action between the components, and a noun refers to the information exchanged as an object of an action.

This Recommendation addresses the information exchange model for digital twin federation in smart cities and communities.

2.2.1.5 Y.4489: Reference architecture of digital twin federation in smart cities and communities

Based on the requirements, developed in Y.4224, this Recommendation addresses the reference architecture of digital twin federation. It defines the functionalities of each entity and the interfaces among the entities. In addition, it also addresses operational flows of digital twin federation in different scenarios.

2.2.1.6 Other ITU standards

There are several standards under development related to Local Digital Twins in ITU SG20 and some of these are listed below:

- Y.dt-RDRM Requirements of digital twin representation model for power grid
- Y.4241 (ex Y.dt-SComCam) Common requirements and capability framework of digital twin for smart complex and campus

- Y.DT-VS-arch Functional architecture of visualization system in digital twin for SSC&C (where SSC&C refers to Smart and Sustainable Cities and Communities)
- Y.DT-SSC-CVP Classification of visualization precision levels for digital twin systems in smart sustainable cities

2.2.2 Other standards work on Local Digital Twins

The IEC System Committee on Smart Cities (IEC SyC Smart Cities) and ISO/IEC JTC1 have set up a Joint Working Group on City Information Modelling and Urban Digital Twins in liaison with ITU Study Group 20 and the Open Geospatial Consortium and are working on a Standards Gap analysis to provide the basis for a systematic programme of standardisation work. The Joint Working Group hopes to start work on a Local Digital Twin Reference Architecture in the near future.

The European Telecommunications Standards Institute (ETSI) through its Technical Committee: TC Data is also about to start work on standardising a Local Digital Twin Reference Architecture and the aim will be to ensure that this will be done in alignment with the IEC SyC Smart Cities/ JTC1 Joint Working Group.

In September this year (2025) CEN TC 465 launched a Task Force on Local Digital Twins in response to the Request of the European Commission for it to initiate a project on the digital twin of cities and territories building on European research and development programmes and multinational projects. The Recommendation further says that the focus should be on using digital twins for the implementation of smart city services, to inform indicators and assess sustainability" and "to ensure the integration of digital twins into the management and governance systems of cities and territories".

Clearly this is early days, but there will be a good opportunity for URBREATH to learn from the work of this Task Force and to feed in its own learning to help inform the developing standards programme.

2.3 Citiverse

2.3.1 Introduction

It is worth mentioning the Citiverse here as this is effectively the addition of Virtual Reality (VR), Augmented Reality (AR) and Extended Reality (XR) onto Local Digital Twins and virtual world generally with the aim of using these to support participatory planning and wider citizen involvement.

The European Commission invites us to: “Imagine a smarter, more connected city where digital technologies make everyday life easier, greener, and more efficient. This vision is becoming a reality through a groundbreaking European initiative that links cities across the EU, fostering a dynamic ecosystem of digital solutions and services. By leveraging Data, Digital Twins, Artificial Intelligence, and

Augmented/Virtual Reality (AR/VR), this initiative empowers cities to co-develop, share and reuse cutting-edge technologies, improving urban living and sustainability for communities across Europe"[3].

Clearly some of the digital twin type tools developed by URBREATH would lend themselves to this wider use, and it is likely that standards developed for the Citiverse would have relevance more generally for Local Digital Twins. For instance, StandICT published The Standardisation Landscape Report for CitiVerse in December 2023. This covers several hundred standards, most of which are very relevant for Local Digital Twins[4].

2.3.2 ITU SG20

Study Group 20 is starting to work on Citiverse standards, and currently there are two under development:

- Y.citiverse-ai-reqts: Requirements for AI-enabled interoperability in Citiverse
- Y.citiverse-reqts: Requirements of citiverse platform for smart sustainable cities and communities

There are likely to be many others in the future.

2.3.3 Other standards initiatives

JTC1 has an Advisory Group on the Metaverse, and, in its plenary in early November 2025 this was extended to include the topic of the Citiverse and to develop a standardisation roadmap for JTC1.

The Electronics and Telecommunications Research Institute (ETRI), a leading state-funded South Korean research institution focused on advancing technology in electronics and telecommunications has recently set up a partnership with OASC to identify and work on standards related to the Citiverse.

2.4 Nature-Based Solutions

There has not been a great deal of standardisation regarding Nature-Based Solutions, but it is worth mentioning that CEN TC465 has a working group focusing on NBS and the first standard they have produced, FprEN 18140 Nature-based solutions – Terminology and classification, is out for final review and will be published sometime in early 2026. This will be a useful reference work for URBREATH, once

[3] https://digital-strategy.ec.europa.eu/en/factpages/citiverse

[4] https://standict.eu/landscape-analysis-report/standardisation-landscape-citiverse

it is available, and it will be important to ensure that the terms and definitions related to NBS that are used in the URBREATH deliverables are in line with this standard to facilitate their uptake more widely.

In general, the CEN TC465 Working Group on Nature-Based Solutions would be an excellent place to review the solutions coming out of the URBREATH project as this could be a good channel to support their incorporation into standards work.

2.5 MIMs - A pragmatic approach to interoperability

2.5.1 What are MIMs?

The Minimal Interoperability Mechanisms (MIMs) aim to deal with the fact that agencies collecting data relevant to any city or community may well use several different and competing sets of standards to collect and manage the data. In some cases, due to outsourcing some ICT functions or the use of heavy-duty software solutions for traffic management or building and facilities management, they may even be obliged to use proprietary formats and processes.

ITU defines interoperability as: “the ability of two or more systems or applications to exchange information and to mutually use the information that has been exchanged”.

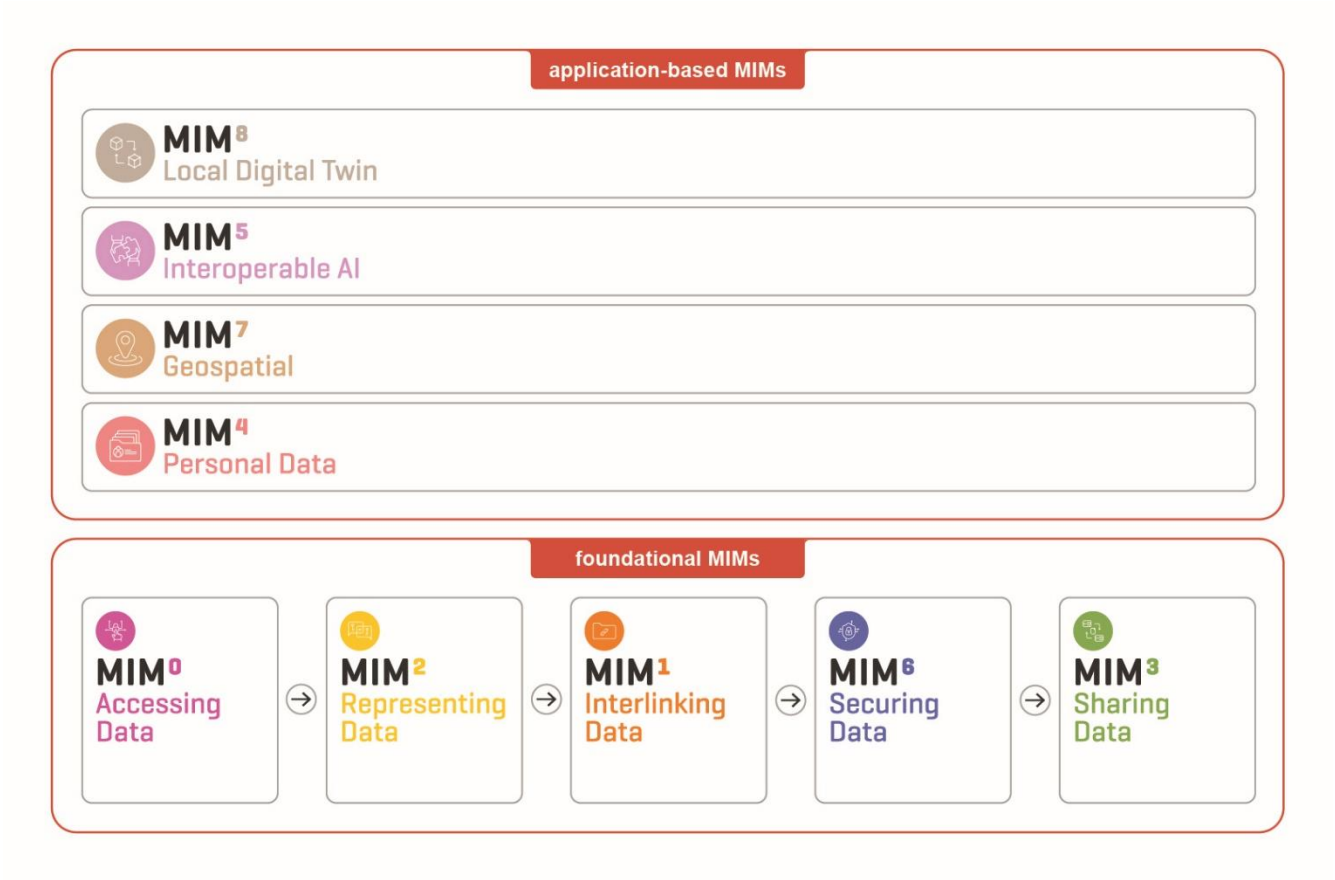
Interoperability is therefore not simply a theoretical-technical attribute but rather focuses on what will enable the achievement of key outcomes related to information sharing and use.

The aim of the MIMs is to provide clear requirements and guidance to support agencies that hold useful information about a smart and sustainable city or community to identify and tackle the issues that could prevent them from exchanging information and from mutually using the information that has been exchanged.

Standards are the foundation for interoperability. However:

- Standards can be very complicated and difficult to implement completely
- Different organisations may use different standards to address common issues
- Integrating data that complies with different types of data standards, such as geospatial data standards or mobility data standards is a resource-intensive challenge to solve.

Figure 2: MIMs Framework Overview



A growing number of MIMs are under development. Each of these MIMs focuses on different aspects of data sharing and/or processing within digital systems of a city or a community. For each area of concern clear interoperability Objectives are defined. The MIM will identify a core set of Capabilities that will allow the Objective to be achieved to a good-enough extent and then translates each of those capabilities into technically oriented Requirements. It also describes several Mechanisms, or sets of technical solutions, that will meet those requirements and provides Interoperability Guidance on how data from data sources using different Mechanisms can be aligned. The Objective might be, for instance, to access data from disparate sources, or to align data models and identifiers between different data sets or to enable the citizen to have greater control on how their personal data is used. See the following section 2.5.2 for more details regarding the structure.

The MIMs can be divided into Foundational MIMs, which address generic issues of data interoperability, and Application Specific MIMs (see figure 2).

The aim of the Foundational MIMs is to tackle all the key issues that need to be addressed to facilitate combining data from two or more different data sources to gain additional information and value. The data sources can be from within the same organisation, from partner organisations, as part of a data platform, within a dataspace, or between different dataspaces. These issues could be technical, syntactic, semantic, organisational or legal in nature.

Application Specific MIMs assume the implementation of the Foundational MIMs, and cover interoperability issues related to specific application areas, such as Personal Data Management, Interoperable AI, Geospatial data, and Digital Twins for cities and communities. Here, the challenge is to identify and address specific issues related to the interoperability of data within each of these different application areas.

The latest version of the MIMs (Version 8.0) can be found online[5].

2.5.2 The MIMs structure

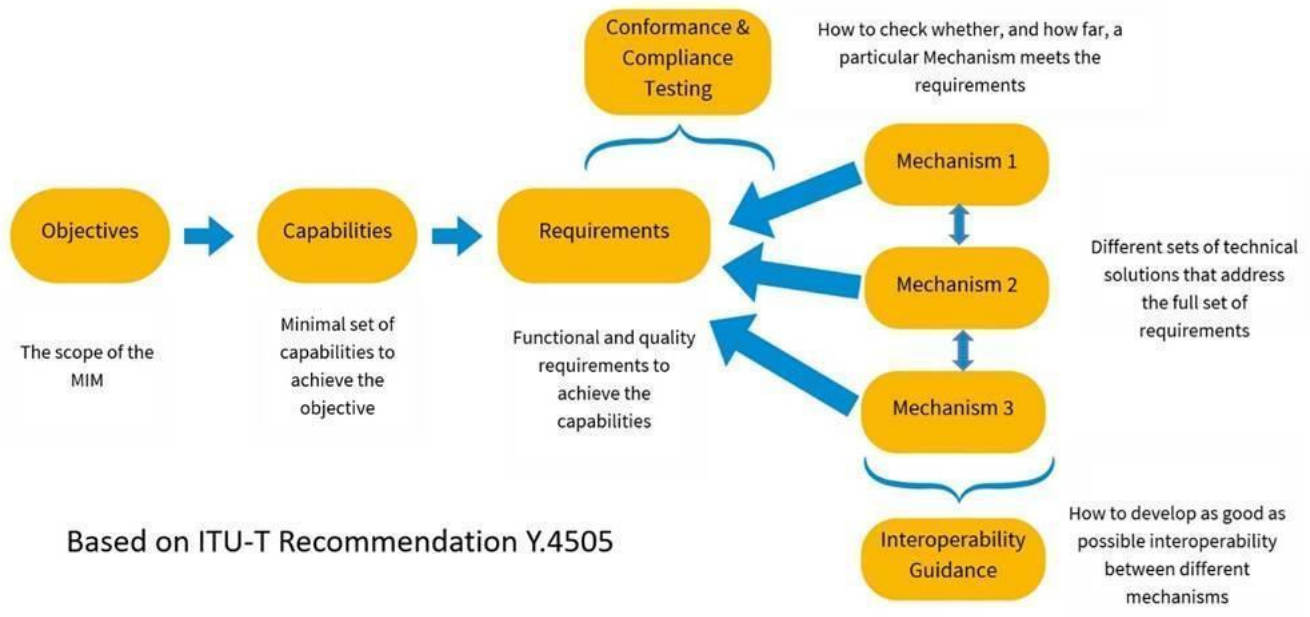
The development process and structure of each MIM have been standardised in the ITU-T Recommendation Y.4505. Each MIM starts from a clear objective related to data interoperability and then breaks this down into several capabilities that are needed to deliver on that objective to a good-enough extent. These capabilities are then translated into a set of requirements that are clear and specific enough to be used in procurements.

The MIM also covers several alternative Mechanisms, or sets of technical solutions, that can address the requirements of any particular MIM. This means that different agencies may comply with the requirements of a specific MIM, but because they use different Mechanisms to do so, the data coming from them may not be fully interoperable. That is why each MIM also provides interoperability guidance to help align data from organisations that use different MIM compliant Mechanisms to address the common requirements.

Figure 3 shows how these different parts of the MIM work together to provide practical guidance for cities and communities.

[5] https://mims.oascities.org/NzWXOO1Fttw4wtqv1Wys

Figure 3: MIM compliant Mechanisms



The value of the MIMs is that, by identifying the key capabilities needed for data sharing and translating these into requirements, it becomes easier to identify commonalities in these different Mechanisms – whether they are using common, more basic standards, for instance. It is also easier to identify the common interfaces across which open APIs can be used. These are all described in Interoperability Guidance that can be used as the basis for good-enough interoperability.

2.5.3 Relevance to URBREATH

2.5.3.1 Introduction

URBREATH has a commitment to ensure that all its tools are MIMs compliant and this clearly facilitates their widespread adoption. The challenge is that even if one of the tools is MIMs compliant and a city aims to incorporate that tool into a MIMs compliant ICT infrastructure if the Mechanisms used by both are different, work may still be needed, using the Interoperability Guidance, to enable this to work effectively.

The most relevant MIMs to URBREATH are MIM1: Interlinking Data, MIM2: Representing Data, MIM3: Sharing Data and MIM7 Geospatial Data. The detailed contents of the latest versions of each of these (Version 8.0) are contained in the link provided above, here we will provide an overview and show how these could be relevant to URBREATH.

2.5.3.2 MIM1 Interlinking data

At its core, any URBREATH tool will analyse data coming from several sources and provide back the information needed to help the city plan and manage an NBS project. One data source may provide information about a number of different objects in the city, such as trees, service centres, etc., and the other data sources will provide context information about each of them that will enable the tool to make the analysis needed. To do this requires the relevant parts of the data in one data set to be interlinked with the relevant parts of the other data sets.

For instance, if one data set is of air quality from different sensors around the city over time, it needs to be possible to automatically link information about the geographic context with the location data of each sensor, so that they can tell that e.g. one sensor is by a busy road, whereas another is in a quiet residential neighbourhood. Similarly, information about timings of the data from the sensors needs to be linked with e.g. information about the weather at that time, or the season of the year, or any event that happened at a specific time that might have had an impact on the readings of the sensors.

Earlier in MIM 1, the approach to doing this was confined to use of the NGSI-LD information model. However, while many organisations use versions of NGSI and increasingly are turning to NGSI-LD, there are other ways that interlinking can be done. Many cities, for instance, see that most useful data sets for smart services have a geospatial context and they manage most aspects of data handling, including data interlinking, using standards from the Open Geospatial Consortium (OGC). Another approach, supported by the European Commission, is that provided by Linked Data Event Streams (LDES).

The focus of MIM1 has therefore changed. NGSI-LD has been standardised by ETSI and there is extensive information available as to how to use it to interlink data coming from different sources to provide the context information needed. It is a complex standard, and so there is still the need for identifying a minimal but good enough version and this MIM1 still aims to do. However, the main challenge is to identify other Mechanisms or technical solutions that are widely used for interlinking data and develop Interoperability Guidance to help align data coming from sources that use different Mechanisms.

The URBREATH tools use NGSI-LD to manage data interlinking and are, in general, therefore MIM1 compliant. However, many of the cities that will be candidates for taking up the URBREATH tools in the future may use LDES or OGC standards and here the Interoperability Guidance could be helpful to enable those cities to take up those tools.

2.5.3.3 MIM2 Representing data

Another relevant MIM is MIM2 on Representing Data. This addresses the issue that when aiming to link data from different sources in order to gain added insight, often the data may be in different formats (CSV, JSON, XML etc) and may use different data models to describe the key objects or entities described.

The challenge is that often some characteristics of the object may be important in one use case but are irrelevant in other use cases. Similarly certain data formats are more suitable for certain use cases than for others. Therefore, there may be very good reasons why both the information about an object, as captured in the data model, and the data format used to capture that information, are different for different use cases.

Because of this, one of the Requirements of MIM2 is that data models used shall be based (wherever possible) on commonly recognised standardised data models and ontologies, with a list of these provided. Clearly, even if two different data sources providing information about the same entities use different data models, it will be easier to align them if each complies with commonly recognised ontologies. This can be made easier by using a domain neutral Top-Level Ontology (as described in the ISO/IEC 21838 standard) to intermediate between them. Such Interoperability Guidance can facilitate interoperability between two MIMs-compliant data sources that may use different Mechanisms.

Similarly, MIM2 is developing guidance on aligning data that uses different data formats.

2.5.3.4 MIM3 Sharing data

MIM3 on Sharing Data is also relevant to some of the URBREATH tools. This MIM addresses the issues of how to find relevant data within a data sharing ecosystem and understand and comply with the conditions on which that data is made available. It also addresses how agreements can be made between the data owner and the data user to enable the data to be used.

This is important for URBREATH because the city administration is not the only agency in the city that is collecting data that might be relevant for the planning and implementation of NBS solutions. There may therefore be a need to find and gain permission for using data from other public and private sector organisations.

MIM3 was in a fairly mature state, but it was recognised that increasingly dataspaces are being seen as an effective way of developing a data sharing ecosystem and so MIM3 is being rebuilt from the ground up to properly address the new processes and approaches of dataspaces, while continuing to take

account of the more traditional methodologies. A mature version of the new MIM3 will be available over the next 12 months.

2.5.3.5 MIM7 Geospatial data

The final MIM to be reviewed here is MIM7 on Geospatial Data. Its objective is to enable cities and communities to easily integrate data about spatial assets such as streetlights, buildings, and streets with spatio-temporal data from sensors, along with other data sources that can provide helpful context information to the geospatial data, and make the data interoperable within, and between cities and communities. This integration should be made possible across technologies and vendors.

At present, MIM7 focuses on pointing to a basic set of OGC standards to be followed in order to effectively handle geospatial data. The two Mechanisms it points to are:

- Web-based Mechanisms where data is made available using OGC WFS, and where GML and CityGML are used for Geospatial encoding; and
- API based Mechanisms where data is made available using OGC API Features and OGC SensorThings API, and where GeoJSON including JSON feature geometry and CityJSON are preferred for geospatial encoding in API-based Mechanisms, with GeoPackage, and CityGML as alternatives.

Many of the URBREATH tools rely heavily on geospatial data and it would be useful to ensure that the standards used are, as far as possible, within the scope of those covered in MIM7.

A basic test suite is being developed to help cities and communities to test whether their datasets comply with the OGC standards pointed to within MIM7.

The next stage of work will be to develop a minimal set of capabilities and requirements to handle data about buildings and the built environment in general, using standards from Building Smart International. Work will also be undertaken to provide specific Interoperability Guidance, not only between OGC and Building Smart International standards, but also between these and NGSI-LD and LDES.

2.5.3.6 Conclusions

Clearly, for a city or community to be able to use an URBREATH MIMs compliant tool, it will be easier if that city or community has MIMs compliant ICT infrastructure. However, it is also important to find out what precise Mechanism the city or community uses to comply with that MIM so that the

Interoperability Guidance in the MIMs can be used to help if these are different from the one used in the tool.

Of course, not all potential Mechanisms have been identified for each of the MIMs. However, this presents an opportunity for URBREATH to contribute to the MIM by collaborating with a pilot city that may employ a different Mechanism than the one used in a tool they intend to adopt and working with OASC to develop guidance on how the data can be made sufficiently interoperable between those two Mechanisms.

While the MIMs are still under development, a good foundation is in place, and the aim is to have a mature version of those covered here within the next 12 months. In addition, the work that will be done within the URBREATH project to trial the tools within the Pilot Cities could provide valuable insights that will enable any interoperability challenges to be addressed within the developing structure of the MIMs.

3 Interoperability analysis of the URBREATH toolbox

3.1 Introduction

A key outcome of the URBREATH project is the URBREATH toolbox, a suite of software tools to support municipalities in the implementation and lifecycle-management of Nature-Based Solutions (NBS) and related interventions. The tools support the entire NBS implementation process, ranging from stakeholder engagement and identification of local needs to the design of possible NBS, simulation of their potential effects, selection of the solution to be implemented, monitoring of implementation, and evaluation of the generated impacts.

Depending on the planned NBS use cases and interventions, cities can choose specific tools from the toolbox to support them in their implementation activities.

To facilitate the deployment of tools across various city environments and contexts, it is essential that the tools in the toolkit can be deployed with minimal configuration effort and are designed for interoperability. Therefore, aligning these tools with widely used standards and Minimal Interoperability Mechanisms (e.g., OASC MIMs) is highly recommended.

3.2 Interoperability consideration for the URBREATH toolbox

The following section analyses the different tools of the toolbox in more detail and identifies key interoperability points for further consideration.

URBREATH toolbox can be divided into 10 different macro areas that group individual tools into logical functionalities that they provide. Table 1 (see below) lists these areas in more detail and highlights important interoperability dimensions for these.

Table 1: Interoperability dimensions for each macro area of the URBREATH toolbox

Macro area	Interoperability dimension
Data discovery and sharing	This area combines different catalogue services to enable search and discovery of data sets and sources, tools, models and 3D design. Catalogues usually store metadata about these different items. Meta-data description formats are thus an important choice, to ensure that existing meta-data can be leveraged in an interoperable way. APIs also play an important role to ensure that meta-data can be effectively harvested from existing catalogues, without the need of custom API integration.
City data visualisation	This area contains a range of visualisation tools and dashboards. The tools are fed with different types of data that might be structured in different ways. Interoperability here refers to the ease how visualisations can import different data sources from different city environments. This means the tools should ideally support most common data standards out of the box or allow easy customisation of data connectors for non-standardised data. Getting data into common data standards is the responsibility of “Process Orchestration and Data Harmonisation”, discussed separately below.
City monitoring	City monitoring provides the ability to generate different KPIs relevant for the monitoring of NBS related indicators of a city. Interoperability in this context would allow the same indicators to be derived consistently across different cities. For this, the use of adequate standards for indicators is essential and that the utilised indicators are aligned to these, so they become comparable across cities.
Data analysis and processing	This area encompasses a range of different data analytic services that provide specific insights based on different types of data. The nature of data for these analytics services will vary. Interoperability relates to the ability of using the analytics service in different cities, where underlying data sources will have to be replaced. The services should be able to ingest data that follows standardised data representations that are more commonly used for the type of data that a service relies on. Again, getting data into common data standards is the responsibility of “Process Orchestration and Data Harmonisation”, discussed separately below.

NBS planning	Relates to a registry where NBS projects are catalogued and made accessible for others to read and track progress on. Interoperability relates to ensuring that the meta-data of the registry follows a common standardised format, which has already been discussed under “Data discovery and sharing”.
e-participation	Tools that enable more effective communication with citizens. Both app and Webtools are provided. Interoperability here ensures that these tools can be accessed across different citizen devices and can include reference to existing data catalogues, data sets and maps across different cities. Interoperability can also encompass that the data captured by the two tools can be re-used in a coherent way.
Data management	Data management is a broader category of components that help a city to access and store data more effectively so it can be used effectively with other tools. Interoperability here relates to data access interfaces towards different internal and external systems and data formats for representation.
Components communication	These are data platform internal functions that ensure that different components in the URBREATH toolbox can effectively work together. Interoperability here ensures that different components can be easily interconnected and orchestrated as needed. In addition, process orchestration and data Harmonisation offer technical solutions for data transformations, allowing the harmonisation according to the common format of ingested data and/or results of analyses.
Process orchestration and data harmonisation	
Security	Relates here to functionality for identity and access management to different services of the toolbox. Interoperability here means to ensure efficient deployment alongside Identity and Access management (IAM) solutions of existing/external systems.

3.3 Analysis of the current interoperability approach of URBREATH tools

The following section examines individual tools of the URBREATH toolbox and assesses their current approach to supporting interoperability. It outlines the present utilisation of standards and discusses their compliance with existing MIM recommendations.

3.3.1 Data discovery and sharing

The tools for data discovery and sharing comprise a set of data catalogues that enable discovery, organisation, and search across a diverse range of datasets.

In URBREATH, the data catalogues enabled by these tools will focus on the following information:

- Dataset Catalogue: Datasets managed by the URBREATH toolbox (e.g., produced by an analysis or coming from a federated catalogue)
- Model Catalogue: Models and tools offered by the toolbox and managed by a city (e.g., documenting tools already in use in a city)
- Data Source Catalogue: Other data sources managed by the municipality or external stakeholders

There are two main drivers for interoperability:

1) the need to federate existing data catalogues of cities and relevant stakeholders, so they can be more easily accessed through (a) common directory tool(s);

2) to ensure that data in a catalogue is represented consistently for easier interpretation by others, regardless of the nature of the data sets.

Table 2 (see below) shows how different data catalogue tools address the above interoperability requirements.

Table 2: Supported standards of URBREATH data catalogue tools

Tools	Purpose	Supported connectors	Meta-data representation
Idra	Manage and share open data sets and meta-data related to these	CKAN, DKAN, JUNAR, OPENDATASOFT, ORION-LD Context Broker, SOCRATA, SPOD	DCAT-AP
GeoNetwork	Manage and share spatial datasets and metadata	GeoNetwork, CSW, OGC WxS GetCapabilities, WebDav, ArcSDE, Thredds, OGC WFS Features, OAI-PMH	ISO, Dublin Core
VC Publisher	Creating and publishing 3D web maps and digital city models	OGC WMS, WMTS, WFS, TMS, OGC 3D Tiles, GeoTiff & Cloud Optimized GeoTiff, OGC CityGML	n/a

In the case of the Idra tool, interoperability requirements are currently well addressed, both in terms of the data catalogue API and metadata. Idra provides out-of-the-box integration with a wide range of existing open data catalogues and data management tools, enabling effective federation through automated metadata harvesting. It also uses a widely used standard for metadata publication (DCAT-AP). This tool is already well aligned with MIM2 and MIM3.

Like Idra, GeoNetwork supports automated harvesting of metadata from common geo-spatial data catalogues and utilises high-level standards such as Dublin Core for metadata representation. This tool is already well aligned with MIM7.

VC Publisher can ingest a diverse range of common 3D related data sources such as terrain models, aerial imagery, point clouds, vector data, and CityGML. In terms of API, it aligns with OpenAPIs and thus is well aligned with MIM7.

3.3.2 City data visualisation

City data visualisation in URBREATH include the following tools (see also table 3):

- UnifiedUI: A user interface wrapper that provides access to other tools in the URBREATH toolbox
- KPI dashboard tool: web-based decision-support tools to monitor, analyse, and visualise data from urban areas involved in NBS interventions, based on Apache Superset open-source tool
- Maps Layer Manager: web application designed to simplify the management of geo-queries against Orion-LD Context Broker and the publication of obtained geographic data in GeoJSON format; it is based on GeoCacher, a microservice developed for managing user-defined GeoJSON map layers.
- 3D Map: versatile web-based platform designed for visualising, analysing, and sharing 3D city models and geospatial data based on an open-source VC Map[1][2] tool developed by Virtual City Systems. The VC Map relies on Openlayers JS and Cesium JS and thus supports well known OGC Standards for visualising 2D / 3D geospatial data.
- VC Planner: a comprehensive suite of tools to empower urban planners and city developers to create, analyse, and manage complex urban projects, based on the proprietary VC Planner tool developed, as a plugin (with backend component) to the VC Map, by Virtual City Systems.

Relevant interoperability considerations relate mainly to the data formats these tools can ingest, utilise, or output.

Table 3: Supported data formats of URBREATH visualisation tools

Tool	Purpose	Supported data formats
UnifiedUI	UI wrapper for toolbox	n/a
KPI dashboard tool	Data visualisations for KPI tracking	Structured data in RDBMS systems, use SQLAlchemy to interconnect
Maps Layer Manager	Tool to publish geodata in GeoJSON	GeoJSON (as output), NGSI-LD entities for instance based on SmartData models and managed on Orion-LD Context Broker (as input)
3D Map	Tool for viewing, manipulating and sharing 3D files	GeoJSON, COG, OGC WMS, OGC WMTS, OGC WF, and 3D Tiles

VC Planner	Urban planning tool	DWG, DXF, Shape, IFC, 3DS, OBJ, DAE, KML, KMZ, GeoJSON and GeoTIFF as input formats
Scene Export for VC Map	Export content of a 3D scene to various output formats	DWG, DXF, Shape, 3DS, OBJ, DAE, KML, KMZ, GeoJSON, GeoTIFF, Geopackage, STL

Overall, most tools make use of existing geo-spatial data standards and are thus aligned with MIM7. In addition, the KPI dashboard tool also links to NGSI-LD-based data brokers, thus aligning with MIM1/2.

3.3.3 City monitoring

City monitoring is currently carried out using a KPI manager tool that monitors, analyses, and manages key performance indicators across organisational levels. The tool gathers information from different sources and allows users to define KPIs tailored to their specific objectives and track them over time.

In terms of interoperability, there are two main dimensions to consider:

1. Ability to integrate a wide range of data sources into the tracking of indicators
2. Standards to describe indicators and how they are computed. This also includes formats for how KPIs should be represented.

Some existing integrations for REST APIs, various databases, and IT systems, such as the FROST STA Server, currently support the first dimension. However, it is unclear whether this can be more effectively integrated into the toolbox's overall data management approach. Currently, two new functionalities are under investigation, both involve the publication of KPI. On the one hand, there is the possibility to publish calculated KPIs on Orion-LD Context Broker as NGSI-LD entities which regularly update once a new value of the KPI is calculated; on the other hand, there is the possibility to publish the KPIs as dataset on Idra, following DCAT-AP for their metadata.

Furthermore, at this stage, there is a gap in the alignment to NBS-related indicators and suitable standards for describing and computing them.

3.4 Data analysis and processing

This represents a larger number of services for data processing and analysis, capable of delivering specific insights into urban planning processes.

Improving the interoperability of such services has the goal of facilitating their easier deployment across cities and their respective data environments.

Table 4 below summarises these services, their input dependencies and the outputs they generate.

Table 4: Analysis of input and output data types used by URBREATH data analysis and processing tools

#	Service name	Scope	Input data	Output data
1	Heat stress analysis	Assess urban heat islands using satellite-derived land surface temperature	L40 LST at 10 meters, Landsat-8/9 at 30 meters, and MODIS at 1-kilometer resolution	GeoTIFF raster with normalised UHI index values
2	Shadow analysis	Analyse and visualise shadow coverage for a given area and time	User defined polygon on a map, day of year	A PNG image (base64) PDF report
3	Adaptive rainfall-infiltration tracking	Diagnostic and predictive tool aimed at assessing water infiltration in urban environments under changing climate and land use conditions	Soil properties, weather data, surface type selection, temporal factors	CSV files with prediction results, PNG/PDF visualisations
4	Biotope Area Factor	Calculate the Biotope Area Factor (BAF) for a given map context	GeoJSON	PDF, CSV and GeoJSON as export
5	3-30-300 analysis	Analysis of tree visibility, canopy coverage and proximity to public urban spaces	Vector points, polygons, raster and topological line networks	Boolean values to validate each rule and aggregate score

6	Public transport accessibility analysis	Quantify the quality and effectiveness of a city's public transportation network (spatial distribution, density, proximity, reachability)	Road-network topology downloaded from open-source repositories such as OpenStreetMap	Public Transport Accessibility Index presented as a visual map overlay
7	15-minute city	Compute a proximity index to services within a specific territory, evaluating how easily points of interest (PoIs) can be reached on foot or by bicycle, in line with the “15-minute city” concept	Network (nodes and edges and their length); POI info (points of interest), divided into 8 categories based on the OSM Wiki classification	CSV file with certain structure and Geopackage
8	Visual interpretable and explainable AI	Assess AI algorithm explainability by generating meaningful insights into how various input features affect model predictions	AI models, along with a representative subset of the datasets used to train those models	Dashboard/visuals providing comprehensive explainable AI capabilities
9	Tree growing prediction	Simulates the growth of trees over a set number of years, allowing users to adjust growth rates and visualise annual changes	Tree positions and species manually set in the VC Planner	Both tabular and graphical outputs, with chart titles and axis labels defined in the i18n files, suggesting integration with a charting library, PDFs, may export canopy area of trees as GeoJSON or Geotiff raster, may export local DSM and DTM as Geotiff raster

Most of the analysed processing and analysis tools discuss the nature of both input and output data. Only in some cases is a concrete reference to the data standards provided for the representation of input and output.

Improving interoperability requires each tool to be more specific about which data standards it supports. Furthermore, utilised data standards should align with OASC MIMs or other widely used standards for such data.

3.5 NBS planning

The core of NBS planning is the NBS Registry, an application designed to track, verify, and manage projects that use nature-based methods to address environmental, social, and climate-related challenges.

NBS is an online catalogue service tool that allows NBS project-related information to be registered, discovered and continuously updated. The projects can also directly link to related open data sets.

Each tracked project in the catalogue is described with metadata. Currently, no specific metadata standards are referenced, so the proposed format is likely proprietary.

For improved interoperability, standards-based metadata formats should be used, such as DCAT-AP. More work is needed to understand whether further standards work to define the exact structure and fields of such data would be beneficial.

3.6 e-Participation

e-Participation tools in the URBREATH project support the co-creation and co-design of effective NBS solutions and interventions through active engagement of relevant stakeholders. Specifically, they consist of two e-participation tools: a web application and a mobile application. Both are designed to meet the different needs of an open and co-creative environment for the diverse stakeholders involved in daily urban life, enabling them to collaboratively address the challenges faced by urban areas in the modern era.

The web app is based on an existing open-source platform Decidim, and the mobile app is a custom-built solution. Both are separate tools which currently capture and output data in different formats. One dimension of interoperability is to align the data formats used by these tools to express user surveys and capture outcomes, making analysis easier across both tools.

Both solutions also facilitate the linking of data sets from data catalogues and 3D maps to support user engagement and visual storytelling. The adoption of specific data standards aligned with MIMs for data catalogues, underlying data models, and 3D maps would promote better interoperability by enabling tools to more easily access data from different cities.

An additional interoperability dimension relates to the nature of supported citizen devices. On the web app site, it includes a responsive web UI designed to support most widely used web browsers and screen sizes. On the mobile side, the app is available on the most commonly used mobile device OS/ecosystems, such as iOS (iPhones) and Android; currently available in the official testing environments for iOS (TestFlight) and Google Internal Testing (for Android) for registered testers.

3.7 Data management

From a data management perspective, the URBREATH toolbox offers a range of data storage options for different types of data. It also supplies a selection of ready-made data adapters for connecting with various systems.

A key aspect of interoperability with these tools is their alignment with standardised APIs and data models, such as those recommended by OASC MIMs. This would facilitate interoperable data exchange, as data can be easily accessed from other systems, stored and interpreted unambiguously.

The URBREATH toolbox includes several data storage solutions, as listed in table 5 (see below). Each of these tools is briefly described and interoperability dimensions are highlighted.

Table 5: Interoperability considerations for URBREATH data storage tools

Component name	Description	Interoperability considerations
FROST STA Server	High-performance, resource-efficient platform for storing and accessing IoT sensor data via a standardised RESTful interface	Reference implementation of OGC SensorThings API
Structured, Timeseries and NoSQL DB	Selection of different data base systems for structured data, time-series data and unstructured/semi-structed data	Currently agnostic to APIs and data models

Object Storage (based on MinIO)	Handle large amounts of data files, both structured data formats (e.g., large CSV datasets) and unstructured data like multimedia files (e.g., images, videos, etc.)	S3 compatible Restful API, custom metadata
GeoServer	Application server to share, process, and edit geospatial data	Implementing OGC protocols and APIs

Both the FROST STA Server and GeoServer are, in principle, well aligned with MIM7.

The Object Storage can handle storage for a variety of static files and offers an S3 API, which is considered a de facto industrystandard API for object storage. The other data storage components, such as Structured, Timeseries and NoSQL databases, provide capabilities for storing data in many ways, without specific details on data formats or APIs.

Care must be taken when selecting data formats for storage and metadata to ensure interoperability of these storage systems.

The URBREATH toolbox also offers a wide range of data adapters to ease integration into other systems. These are listed in Table 6 (see below).

Table 6: Interoperability considerations for available URBREATH data connectors

Connector type	**Description**	**Interoperability consideration**
Data Catalogues Connectors	Allow the interconnection between the Dataset Catalogue of the URBREATH Toolbox and catalogue repositories external to the URBREATH Toolbox	Support a wide range of data catalogue solutions and their APIs Harmonisation of metadata based on DCAT-AP
IoT Connectors	Facilitate the real-time sensor data collection by supporting different communication protocols commonly used in the IoT ecosystem	Allows mapping of data streams from different IoT systems into NGSI-LD compliant data (MIM1/MIM2)

IT Platform Connectors	Facilitate integration of other systems such as legacy ones, municipal databases, and third-party services by providing a modular interface to handle data exchange	Generic integration component that can be adopted towards different legacy IT systems
Data Repositories Connectors	Enables efficient data queries over different types of data bases	Simplifies queries across data storage solutions in the URBREATH toolbox
Data Spaces Connector	Enables connection to other European data spaces	IDS compliant connector, aligned with MIM3

The integrations are valuable for enabling seamless integration into other systems. When used correctly during URBREATH toolbox deployment, they help enhance overall system interoperability.

3.8 Components communication

Tools in this category are used to enable communication between different systems and components of the URBREATH toolbox, commonly referred to as broker systems.

The toolbox "offers" well-defined choices from the market, which are listed and briefly described in table 7 (see below).

Table 7: Interoperability considerations for URBREATH communication components

Broker type	**Description**	**Interoperability consideration**
Message Broker	Based on Apache Kafka, a distributed, high-performance event streaming platform	Supports different types of event data, not prescriptive on data formats
Context Broker	Based on Orion-LD (Context Broker), an open-source, NGSI-LD-compliant context broker developed within the FIWARE community	Supports NGSI-LD API and JSON-LD based data messages (Aligned with MIM1/2)

3.9 Process orchestration and data harmonisation

These are internal tools for orchestrating workflows and perform data harmonisation using Apache Airflow and Data Model Mapper. The first can coordinate interactions among various tools within the URBREATH Toolbox and perform operations on data, such as transform, aggregate, etc. The second is devoted to transforming input data into NGSI-LD entities that are registered in the Context Broker.

3.10 Security

Security functions in the toolbox provide capabilities for user management, authentication, and authorisation. Their implementation is based on Keycloak, an open-source identity and access manager (IAM) compliant with standard identity protocols such as OpenID Connect (OIDC), OAuth 2.0, and SAML 2.0.

Interoperability in this context refers to how IAM functionalities in external systems can be supported, for example, to enable single sign-on or user federation.

The current MIM6 offers limited guidance on this matter at present. Support for protocols such as OpenID Connect (OIDC), OAuth 2.0, and SAML 2.0 could enable interoperability with a wide range of legacy systems.

3.11 Summary of analysis

The initial interoperability analysis of the toolbox examined the readiness of each tool for interoperability in more detail. Depending on the tool's nature, it identified relevant dimensions of interoperability and assessed how well the existing design choices and current use of standards align with Minimal Interoperability Mechanisms (MIMs) and other best practices in standards use within industry.

Overall, a wide range of tools have been found to already use appropriate standards and comply with existing guidelines independently. Some tools require further alignment with common standards for APIs and data models to enable better tool integration within the toolbox and to facilitate easier deployment across different city contexts. Where this was deemed necessary, initial suggestions have been made.

The analysis also identified opportunities for developing new standards and best practices. For example, KPI monitoring and reporting for the level NBS adoption would benefit from consensus on common monitoring and reporting standards to enable better comparisons across cities.

While compliance with MIMs and/or common standards at the individual tool level can enhance the overall interoperability potential of tools to empower NBS solutions and increase their likelihood of being easily deployed across city environments, further challenges remain in ensuring their consistent deployment. As each city will build upon their legacy data and digital infrastructure, of the integration of different tools requires careful alignment to ensure the entire system is interoperable. This, however, necessitates a deeper understanding of each deployment context and the specific use cases across different cities. This is where the development of the URBREATH Interoperability framework will help, which is further discussed in the next section.

4 Interoperability of the tools with a city's legacy infrastructure

4.1 Introduction

A key interoperability challenge that URBREATH and many other EU projects face is how to incorporate a technical tool developed by the project into the existing technical and organisational ecosystem of a city. Any city will have comprehensive legacy IT infrastructures, data handling processes, user interfaces, organisational structure and processes, skill sets, and so on, and incorporating any IT related tool into these is likely to raise many interoperability issues.

It will be vital to address this issue in order to enable the widespread replication of the tools as it will be important to demonstrate to cities considering using the tools that they are ready for implementation with minimal need of adjustment and with minimal risk related to the existing legacy IT infrastructure and processes. Of course, some of the challenges would be easier if the tools are provided as web applications via a SAAS service, but there would still be legacy issues to be addressed related to the data coming from the cities.

This will also be important for the incorporation of MIMs and standards into the URBREATH deliverables, as well as in gaining lessons from URBREATH for MIMs and standards development. For instance, the MIMs provide clear Requirements in order to achieve MIMs conformance, but they recognise that there are often several different Mechanisms or sets of technical specifications that can meet those requirements. An URBREATH tool may conform to one or more of the MIMs, but it may use a different Mechanism to do so than a city that wishes to incorporate that tool.

The MIMs aim to incorporate Interoperability Guidance to help address this, but in some cases, these are still being developed. Where the guidance is available, this will help cities address this issue, and where it is not yet available, the work of trialling the tools in the pilot cities will provide a learning opportunity for the MIMs working groups in developing such guidance.

A similar situation applies to standards, in that the role of standards in addressing interoperability can only be tested when aiming to align two different standards-based systems. In some cases, the standards themselves will include interoperability guidance for such situations. Should these not prove adequate, then the challenges of incorporating the tools within an individual city's legacy system may identify new issues that the relevant standards technical committee will need to address.

4.2 Developing an URBREATH Interoperability Framework

Over the next few months, it will be important to develop an URBREATH Interoperability Framework. This will be based on the European Interoperability Framework (EIF), which is a set of recommendations from the European Commission to help public administrations design and deliver seamless digital public services across EU member states. Its goal is to improve cross-border services by providing guidance on governance, relationships between organisations, and processes, ultimately supporting the Digital Single Market by making services digital, cross-border, and open by default.

The European Interoperability Framework addresses the following four interoperability layers:

- Legal
- Organisational
- Semantic
- Technical

These are the layers that need to be addressed to enable the URBREATH tools to be incorporated into the systems and ways of working of any city that would consider using those tools.

The URBREATH Interoperability Framework will use the EIF as a foundational structure to help identify the key interoperability issues that need to be addressed to enable a city to effectively integrate the URBREATH tools into its existing legacy infrastructure. It will support the development of structured guidance to inform the implementation of the tools within any city. The framework will help guide the teams developing the tools to develop simple adaptations to the tools to enable them to be incorporated within the more common variations within how cities manage their technology at the present time and provide cities with guidance as to how to implement the tools safely and easily within their legacy systems to maximum effectiveness.

The URBREATH Interoperability Framework will also highlight the role that standards and the MIMs can play in this process and identify where these need to be enhanced to address the challenges that the cities face.

While the simple testing of the tools in the pilot cities will not require the tools to be incorporated into the city's legacy infrastructure, it will still provide a good opportunity for the pilot city to review in detail what technical and other adjustments would be needed for full implementation. This process of developing the URBREATH Interoperability Framework can therefore be incorporated into the process of rolling out the tools to the pilot cities, using some of the person hours assigned to each of the partners for deliverables D7.12 and D7.13.

The Interoperability Framework will be based on addressing the following key issues:

- What are the challenges in discovering whether the data needed by the tool is available? What are relevant standards to support this? How can MIM3 help?
- What are the issues in getting permission to use that data? What are relevant standards to support this? How can MIM3 help?
- What are the challenges in accessing that data? What are relevant standards to support this? How can MIM0 help?
- Is the data in the appropriate format and using the appropriate data models? If not, how could the format and data models be aligned? What are relevant standards to support this? How can MIM2 help?
- What are the challenges in interlinking the data from different data sources to use in the toolkit? What are relevant standards to support this? How can MIM1 help?
- What concerns could hinder the IT department in the city from implementing the tool? How can these be addressed? What are relevant standards to support this? How can the MIMs help?
- What other city systems (Digital twins? Dataspaces? Dashboards?) do the tools need to interface with? What are the interoperability issues that need to be addressed? What are relevant standards to support this? How can the MIMs help?
- What lessons are there from work to solve these issues that could be incorporated into standardisation and MIMs development?

The task will involve working with each pilot city's IT department to identify the problems the department foresees would arise should they decide to fully implement each tool. The tech team and the OASC team will then work together to identify simple flexes to the tool that will help, as well as the role that standards and the MIMs might play in this.

Similarly, the pilot city will identify any dataspace, local digital twin, dashboard etc., that the tool will need to interface with. The pilot city will also work with the internal teams that would be using the tools to identify any issues related to incorporating the tools into their existing processes.

The approach to this work will be developed out of the workshop it is intended to hold with project participants in early 2026, as described in recommendation 5.4.

5 Recommendations

5.1 Recommendations for the interoperability of the URBREATH tools

The following subsection follows up on the analysis carried out in section 3 and summarises specific interoperability recommendations across the different URBREATH tools. The recommendations are provided for each individual macro area. A summary of these recommendations can be found in Table 8.

5.1.1 Recommendations for data sharing and discovery tools

All three catalogue tools are well aligned with MIM guidance, including MIM2, MIM3, and MIM7.

The use of DCAT-AP or the Dulin core for metadata provides interoperability in principle at a high level. These could, however, be extended to include more concrete metadata properties to better characterise data sets and models for NBS solutions. Developing a metadata profile for NBS datasets and models could add value to the community.

VC Publisher could also be enhanced to generate consistent metadata for its outputs across the different data types it can ingest.

5.1.2 Recommendations for city data visualisation tools

Most tools are well aligned with MIM1, MIM2 and MIM7. The KPI dashboard tool currently supports only generic RDBMS connections and could benefit from ingesting data in standardised formats. Suitable data adapters could be developed to manage standardised KPI data to support tracking NBS solutions. While such standards do not yet exist, it could be synchronised with the development effort as recommended in section 4.3.

5.1.3 Recommendations for city monitoring tools

The KPI manager tool enables the creation and collection of appropriate KPIs derived from diverse data sources. It provides the KPI dashboard tool with the relevant information needed to track and monitor NBS deployment KPIs. Some work is already underway to support efficient KPI publication from standard-based data sources. This should also be underpinned by suitable KPI standards for NBS solutions, as recommended in section 4.3.

5.1.4 Recommendations for data analysis and processing

URBREATH toolbox offers a wide range of heterogeneous data analysis and processing tools that address various concerns in NBS solution development. Most of these tools currently run as scripts in data science workbenches and use a variety of data formats for input and output, some of which are specific to the tools. To facilitate their deployment in diverse city environments, input and output data formats need to be better aligned with standards-based formats, as recommended by MIM2 and MIM7 interoperability guidance. Based on the nature of the tools, suitable domain-specific data representations should be selected.

5.1.5 Recommendations for NBS planning tools

The online catalogue service of the NBS registry currently does not specify specific metadata standards for describing NBS-related project information. To enhance interoperability, standards-based metadata formats should be adopted, such as DCAT-AP, and potentially extended with appropriate properties to describe NBS project features in a standardised manner.

5.1.6 Recommendations for e-participation tools

The e-participation tools in URBREATH facilitate linking of some datasets from data catalogues and 3D maps to support user engagement and visual storytelling. The adoption of specific data standards aligned with MIMs for data catalogues, underlying data models, and 3D maps would promote better interoperability by enabling tools to access data from different cities more easily. Both phone and web-based tools should converge on common data formats to describe surveys and capture user-generated data, so that easier analysis across tools can be performed.

5.1.7 Recommendations for data management

Data storage solutions in the URBREATH toolbox are currently showing a varying degree of compliance with common data standards and APIs. When using data storage tools, data should be provided using standardised data formats and be ingested from APIs that comply to MIM guidance, specifically MIM1, MIM2 and MIM7.

A wide range of data connectors has been developed to enable more suitable integration with a diverse range of data sources in a standards-compliant way. These integrations are valuable for enabling seamless integration into other systems. When used correctly during URBREATH toolbox deployment, they can help enhance overall system interoperability.

5.1.8 Recommendations for component communications

Several broker solutions are available in the URBREATH toolbox. The context broker aligns well with MIMs specification. Although the Kafka-based message broker offers greater flexibility, care must be taken to ensure that event-streaming message formats align with the interoperability guidance provided by MIM2 and MIM7.

5.1.9 Recommendations for process orchestration and data harmonisation

Tools for orchestrating workflows and performing data harmonisation are essential to ensure the successful integration of tools with other city data and IT infrastructure, enabling the deployment of end-to-end NBS solutions. Together, they can ensure that unaligned data sources in existing legacy systems are harmonised towards MIM-compliant data formats, and individual URBREATH tools can effectively communicate with each other.

5.1.10 Recommendations for security

The toolbox already provides adequate capabilities for user management, authentication, and authorisation. Legacy city IT infrastructure is likely to use existing mechanisms. The selected solutions should allow effective interoperability with these.

All URBREATH tools should align with interoperable mechanisms and protocols for identity management, access control, and policy enforcement to provide adequate end-to-end security of NBS solutions.

5.1.11 Summary

Table 8: Summary of recommendations

#	Macro area	Summary of recommendations
1	Data discovery and sharing	• Develop metadata profiles for NBS datasets and models by extending generic metadata standards • Enhance VC publisher to generate consistent metadata for its outputs across the different data types it can ingest
2	City data visualisation	• Enable visualisations to “natively” ingest standardised KPI data related to NBS solution monitoring and 3D models where needed
3	City monitoring	• Develop tools to support efficient KPI publication from standard-based data sources • Align publications of KPIs to standardised KPI data related to NBS solution monitoring
4	Data analysis and processing	• Align input and output data formats to standards-based formats, as recommended by MIM2 and MIM7 interoperability guidance • Depending on the nature of the tool, use adequate domain specific data models
5	NBS planning	• Adopt standardised metadata formats such as DCAT-AP and extend with appropriate properties to describe NBS project features
6	e-participation	• For linking data sets, adopt data standards aligned with MIMs for data catalogues, underlying data models, and 3D maps

7	Data management	• Data used in data storage solutions should be provided with standardised data formats and be ingested from APIs that comply to MIM guidance • Existing data connectors should be used during URBREATH toolbox deployment adequately to enhance overall system interoperability of deployed NBS systems
8	Components communication	• Align Kafka based event formats with MIM based interoperability guidance to enhance overall system interoperability
9	Process orchestration & data harmonisation	• Ensure data harmonisation follows MIM based interoperability guidance to enable effective communication of URBREATH tools in end-to-end NBS solutions.
10	Security	• Analyse existing IAMs in current city environment and ensure the overall solution is supporting interoperability with these. • Align all URBREATH tools with interoperable standards and protocols for identity management, access control and policy enforcement

5.2 Recommendations for supporting the interoperability of the tools into the legacy infrastructure of potential city users

The team developing an URBREATH Technical tool will identify the legal, organisational, semantic and technical requirements that any candidate city would need to address to incorporate that tool using the key issues listed above.

The analysis will be extended through interviews with the IT and other relevant departments within the pilot cities.

The OASC team will review the analysis and identify the relevance of standards and the MIMs.

This will be tested when the tool is implemented by one of the pilot cities. The tool development team will work with the IT and other key departments of the pilot city to design an implementation strategy.

The OASC team will review how well the implementation strategy works, both during and after the implementation.

The learning from this will then be incorporated into the developing URBREATH Interoperability Framework, which will be one of the key sections of Deliverable D7.13.

The learning from each pilot implementation will also be used to identify lessons that could be brought into the standards and MIMs development processes and this will then be incorporated within Deliverable D7.13.

5.3 Recommendations for contributions to standards and best practice guidance

The initial analysis of tools identified several standards and best practices on interoperability relevant to the URBREATH tools, their current alignment, and potential opportunities for convergence. The focus has been especially on MIMs Interoperability Guidance and the standards referenced by them.

MIMs are not set in stone; many of them are still being developed and updated. Therefore, there is an opportunity for the URBREATH project to actively contribute to their refinement.

Some specific opportunities relate to the metadata for describing NBS-related data assets, models and solutions. As part of work in the MIM2 and MIM3 working groups, generic data, such as Smart Data Models, and metadata standards, such as DCAT-AP, can be refined, and profiles can be developed that are more pertinent to the requirements of Nature-Based Solutions.

The study has also identified specific gaps in standardisation. For example, tools for KPI monitoring and visualisations for NBS solution implementations would hugely benefit from the use of standardised KPIs and associated metrics, so they become more comparable across different cities and deployments. Currently, there is no specific standardisation work or body that captures intrinsics of Nature-Based Solutions. A potentially suitable standard to consider contributing to is the following:

ISO/IEC 21972:2020(en) Information technology — Upper-level ontology for smart city indicators[6]

URBREATH may be able to contribute specific indicators relevant for monitoring and assessing the impact from implementation of Nature-Based Solutions.

[6] https://www.iso.org/standard/72325.html

It is recommended that the OASC team should meet with the teams developing the technical tools once a quarter over the next two years to identify learning coming out of their work that would be relevant to the development of standards and the MIMs, and of relevant guidance documents.

The OASC team would then work with the relevant technical expert to develop formal contributions that could be reviewed by the relevant standards technical committee or MIMs working group.

5.4 Planning the next steps

The proposal is that a **consortium workshop should be run in early 2026.**

- **Purpose:** To collaboratively develop a strategic roadmap for the remaining two years of the URBREATH project; based on D7.12.
- **Role:** Fraunhofer will co-host and co-develop this workshop with OASC.
- **Potential Link:** This workshop may be linked to the topic of replication.

The roadmap developed in the consortium workshop will have three main components:

- **Technical Roadmap:** Working with the pilot cities to analyse any technical challenges that need to be addressed before those cities would be able to fully implement the tools. Reviewing the wider EU/international landscape and assessing the ease/difficulty of adaptation and integration and how feedback from the pilot cities would help.
- **Standards Roadmap:** Identifying practical steps to identify how the tools individually could benefit from the existing and developing standards and MIMs landscape, how standards and MIMs could contribute to the integration of the URBREATH tools into the legacy infrastructure of cities, and how the learning from this could be fed into the ongoing work of standards and MIMs development
- **Translation Roadmap:** A dedicated part of the roadmap will focus on bridging the understanding between technical and non-technical stakeholders.

One potential output could be the scoping out of a guidance document to help cities with the integration of the tools into their legacy infrastructure.

6 Conclusions

The first iteration of the URBREATH Standardisation Report provides a comprehensive assessment of the interoperability landscape surrounding the URBREATH Toolbox and highlights the critical role of standards, MIMs, and emerging European and international initiatives in enabling scalable, replicable Nature-Based Solution (NBS) analysis, planning and monitoring tools deployments across cities. The analysis confirms that many tools within the toolbox already demonstrate strong alignment with widely adopted standards—such as DCAT-AP, NGSI-LD, OGC specifications, and SensorThings API—and therefore offer a robust baseline for interoperability across heterogeneous data environments. This alignment is a significant asset for future replication and supports the project's ambition to create a modular, standards-based ecosystem for NBS planning, implementation, and monitoring.

At the same time, the review reveals several areas that require further refinement. In particular, harmonisation of input/output data formats across analytical tools, clearer adoption of metadata standards for NBS project information, and the development of standardised KPI structures for monitoring NBS performance represent tangible opportunities for improvement. The absence of common indicator frameworks for NBS monitoring presents both a challenge and a strategic opening for URBREATH to contribute to ongoing European standardisation efforts, including work in CEN/TC 465, ITU-T Study Group 20, ISO/IEC JTC1, and the OASC MIMs working groups.

Another important observation is that tool-level interoperability alone is insufficient to guarantee seamless deployment in real city environments. The diversity of the size of cities and corresponding IT budgets, legacy infrastructures, governance processes, and data as well as IT skill maturity levels across European municipalities means that a structured but adaptable approach to integration is necessary. This underscores the need for the forthcoming URBREATH Interoperability Framework, which will extend the analysis beyond technical mechanisms to address legal, organisational, and semantic aspects following the European Interoperability Framework (EIF). This framework will guide pilot cities through the practical steps required to integrate URBREATH tools into their existing systems and will generate lessons that can feed back into standards development.

Overall, the findings of this deliverable offer a strong foundation for shaping the project's technical, standardisation, and replication roadmaps. Continued collaboration with pilot cities, standards bodies, and the broader innovation community will be essential to maximise the long-term impact and reusability of the URBREATH Toolbox across Europe.