Ref. Ares(2024)9281793 - 31/12/2024

D2.2 BIPED Digital Twin

Release 1

First release of the Digital Twin
including first versions of modelling tools

Project name	BIPED: Building Intelligent Positive Energy Districts
Duration	January 2024 – December 2026
Project ID	101139060
Coordinator	Technical University of Denmark
Type of action	Innovation Action
Call ID	HORIZON-MISS-2023-CIT-01
Website	https://www.bi-ped.eu/
Document name	BIPED Digital Twin Release 1
Document status	Final
Delivery date	20.12.2024
Dissemination	Public
Authors	Martin Traunmueller (AIT), Benjamin Kokoll (AIT), Shahrzad Pour (DTU), Tobias Rønlev-Knudsen (DTU), Pál Jámbor (DTU), Karel Jedlička (UWB), Tomáš Andrš (RT), Max Serra (DKSR), Hugo Matousek (INNO), Arne Schilling (VCS)

Funded by
the European Union

BIPED is funded under the EU Horizon Europe Research and Innovation programme. Grant ID: 101139060. Every effort has been made to ensure the accuracy of information provided in this document, which reflects only the authors' views. The European Commission is not responsible for

Document history

Version	Date	Contributor	Description
0.1	11.10.2024	Martin Traunmueller (AIT), Razgar Ebrahimy (DTU), Shahrzad Pour (DTU)	Table of Content
0.2	29.10.2024	Martin Traunmueller (AIT),Shahrzad Pour (DTU)	First Draft
0.3	29.11.2024	Max Serra, Eva Schmitz (DKSR) Razgar Ebrahimy (DTU), Henrik Madsen (DTU), Tobias Rønlev-Knudsen (DTU), Pál Jámbor (DTU) Karel Jedlička (UWB), Tomáš Andrš (RT), Arne Schilling (VCS), Martin Traunmueller, Benjamin Kokoll (AIT), Hugo Matousek (INNO)	Contributions
0.4	02.12.2024	Martin Traunmueller (AIT)	Refinement, Formatting
0.5	03.12.2024	Johanne Bräuner Nygaard Hansen (AAKS), Shahrzad Pour (DTU), Marie-louise Krogh, Søren Bernt Lindegaard (CDK)	Review 1
0.6	09.12.2024	Lise Frellesen (Klimadatastyrelsen), Ursula Eicker (Concordia University)	Review 2
0.7	18.12.2024	Martin Traunmueller (AIT)	Review 3
1.0	20.12.2024	Martin Traunmueller (AIT) Razgar Ebrahimy (DTU)	Final Version

Table of Contents

List of Figures

List of Tables

List of Abbreviations/Glossary

Abbreviation	Definition
AOI	Area of Interest
AMQP	Advanced Message Queuing Protocol
API	Application Programming Interface
BIPED	Building Intelligent Positive Energy Districts
DMI	Danish Meteorological Institute
DMP	Data Management Plan
DT	Digital Twin
EV	Electric Vehicle
GDPR	General Data Protection Regulation
glTF	GL Transmission Format
GPU	Graphics processing unit
HTTPS	Hypertext Transfer Protocol Secure
IAM	Identity and Access Management
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
KTX2	KHRONOS Texture Compression Format
LWJGL	LightWeight Java Game Library
MIMs	Minimal Interoperability Mechanisms
MQTT	Message Queuing Telemetry Transport
OGC	Open Geospatial Consortium
OUP	Open Urban Platform
PED	Positive Energy District
REST	Representational State Transfer
SFTP	Secure File Transfer Protocol
SRS	Software Requirement Specification
SSL	Secure Sockets Layer
WP	Work Package

Executive summary

This report documents the process and outcome of the BIPED digital twin in its first release stage after 12 months of development. BIPED aims to provide a holistic view on the subject of Positive Energy Districts (PED) development for the testbed of Braband, Aarhus, by establishing in its final version a digital twin platform that includes energy, mobility and cross-sectoral properties describing the urban landscape and its society. This development describes an organic process that has started with the initial release (D2.1) in M06 and will continue to grow and expand throughout the project's timeline and be presented in upcoming deliverables (D2.3, D2.4).

The first release of the BIPED digital twin D2.2 includes the implementation of one initial energy and two mobility models on the digital twin platform (as described in D2.1). As part of the first release of the BIPED digital twin platform demonstrator, this report provides the reader with background information on the development from M06 to M12 of the project, starting with a status update on the digital twin (Chapter 2), outlining the requirements (Chapter 3) and describing implementation of the models to the platform (Chapter 4). The report further offers a guide to the demonstrator (Chapter 5) on how to use BIPED digital twin in its current state and provides an outlook to upcoming steps towards D2.3 in M24 (Chapter 6).

The document is structured into 6 chapters:

- **Chapter 1 "Introduction"** provides an outline about the first release of the digital twin, including the integration of initial energy and mobility models, and how it builds on BIPED's initial release described in D2.1. The chapter describes how this deliverable relates to the other deliverables of this project's WP3 (D3.2) and WP4 (D4.2) and concludes with outlining the scope of this deliverable.
- **Chapter 2 "Status BIPED Digital Twin"** describes the status quo of BIPED digital twin in its current stage from a technical perspective and builds on the technical development from deliverable D2.1.
- **Chapter 3 "Requirements"** presents the User Stories and Integration Requirements, the first release is built upon.
- **Chapter 4 "Models Integration"** outlines the integration of current models from their hosting locations to the BIPED digital twin platform via APIs.
- **Chapter 5 "Demonstrator of the Digital Twin"** offers guidance to the user of the digital twin in its current state, including a description of Data Hub Civora and BIPED digital twin.
- **Chapter 6 "Conclusions and Next Steps"** provides an outlook on next working steps and deliverables, together with findings of other work packages as presented in their respective deliverables, to define a holistic digital twin supporting PED establishment in communities and cities.

The following document is attached to this document:

- **Annex 1:** DUET Maturity Model
- **Annex 2:** Demonstrator

1. Introduction

This deliverable consists of the first release of the BIPED digital twin, including one initial energy (T2.2) and two mobility (T2.3) models as a demonstrator. This report was produced to accompany the deliverable's demonstrator and to document the current work process as of M12. The report offers background information and detailed insights on requirements and model integration, as well as guidance to the user of the demonstrator.

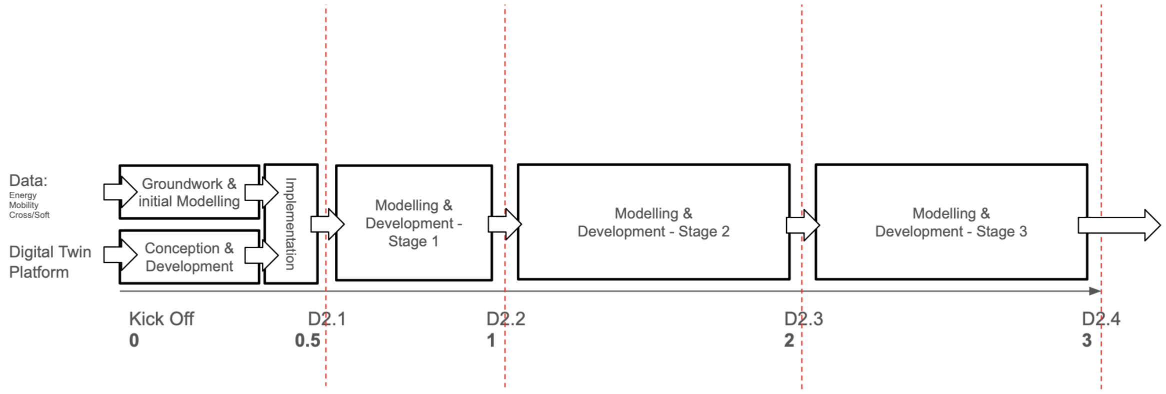


Figure 1. Schematic workplan of BIPED Digital Twin: M01-M36

The first release of BIPED digital twin builds upon the BIPED platform as developed in D2.1, by integrating an initial energy and two mobility models, as described in this deliverable (D2.2.). In incrementing development stages, BIPED digital twin will be further extended in following deliverables (D2.3, D2.4). This comes with the inclusion of more data sources and data models in incremental modelling and development stages to be published. Figure 1 shows a schematic workplan of the overall project (M01-M36).

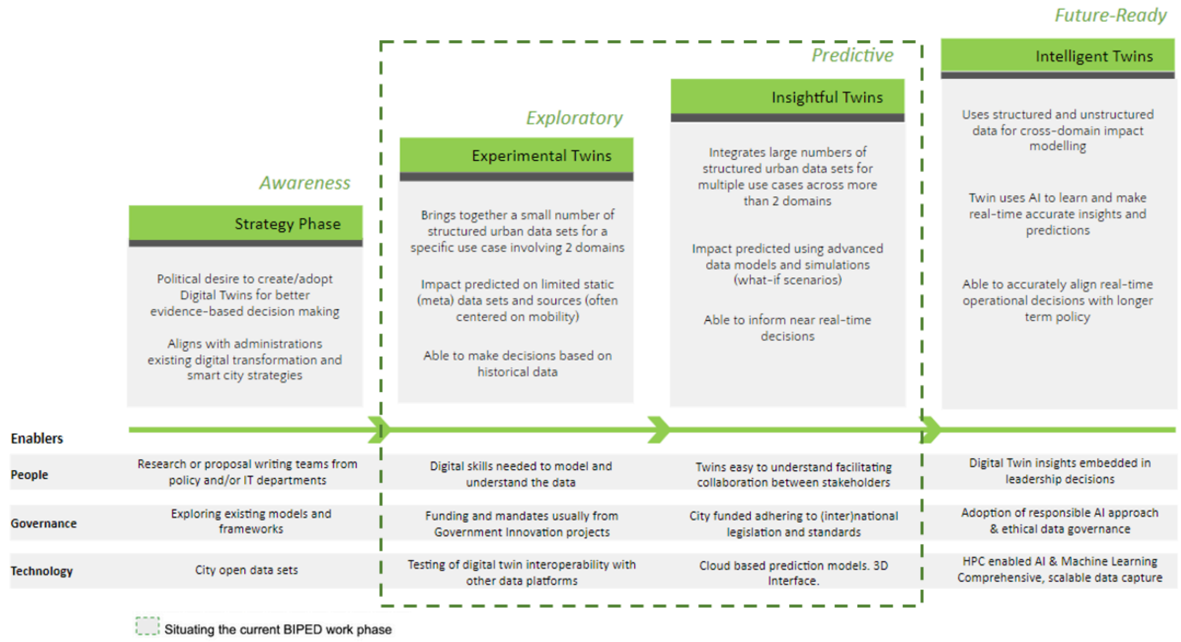


Figure 2. DUET Maturity Model (see Annex 1)

As outlined in Figure 1, the process in this stage focuses on the integration of initial energy and mobility models to the digital twin platform. The Digital Twin Maturity Model (Figure 2) developed in the Horizon 2020 project DUET[1] (Digital Urban European Twins - Grant Agreement No. 870697) helps to validate the organisation and status of the first release. The model describes a high-level pathway for the development of digital twins. The BIPED work phase as described in this deliverable (D2.2) can be categorised into the Exploratory Phase.

The BIPED digital twin will serve city government, decision makers, the local community in Braband/Aarhus, as well as public and private stakeholders in making informed decisions towards PED planning – with the potential to adopt the concept in communities all over Europe. Therefore, the technical development has been aligned with activities in the work packages WP3 and WP4 as well as related work on stakeholder and end-user involvement and the engagement with broader data space communities in T2.5.

The steady communication and feedback from those stakeholder groups ensures a digital twin design serving real-world challenges towards PED establishment for the community by defining specific user requirements, while opening doors to access highly relevant, yet restricted data sets by raising awareness of data owners as extended project partners.

Furthermore, based on the project's aim of establishing BIPED digital twin not only in Braband in Aarhus, Denmark, but in towns and cities all over Europe, the development of BIPED digital twin is deeply grounded in the European data space environment. In doing so, our technical development has been guided by this principle. For instance, the incorporation of open high quality data sources and priority datasets, as defined by the European Commission (EC) has been seen as a priority. This goal is also embedded in the T2.5 activities with key relevant European data space initiatives, raising awareness, exploring opportunities for cooperation and assessing broader applicability and replicability of BIPED solutions beyond the pilot setting.

1.1. Scope

To accomplish deliverable 2.2, two main activities were carried out by aligning and integrating contributions from various partners and work packages (WPs): Model Preparation and initial Model Integration into the digital twin platform.

The scope encompasses collaborative efforts of joint knowledge building, definition of software requirements, basic technical development, data mapping and handling, and synchronisation with parallel workstreams.

The primary objectives for deliverable D2.2 are:

1. Preparation of initial Energy and Mobility Models:
    - Develop initial data models for energy (T2.2) and mobility (T2.3) aspects that are accurate and align with the architectural design.
2. Integration of models into the BIPED Digital Twin platform
    - Integrate developed models into the BIPED platform on a technical level, from different hosting platforms via APIs and show initial results
3. Integrate and Align with Parallel Workstreams:
    - Align with stakeholder and end-user feedback from WP3 and KPI requirements from WP4.
    - Ensure the Digital Twin development is in sync with WP3 and WP4 to meet broader project goals.

[1] DUET: https://www.digitalurbantwins.com/

2. Status BIPED Digital Twin

Throughout the last six months, the BIPED consortium has made considerable progress in the BIPED Digital Twin. This work has been a combination of exchanging ideas and debating possible solutions, aligning our understanding of how the system should be designed, and implementing and integrating the components.

After presenting Civora to the BIPED partners, it was agreed that such a platform would greatly help the city of Aarhus with using the BIPED Digital Twin. Civora is a DKSR open source product that integrates multiple components into one single application, providing a unified interface where city managers, planners and citizens can interact with their data and digital twin. Therefore, it was decided to use this data hub as the user interface for the BIPED Digital Twin as it can easily integrate the already developed VCMap quickly thanks to previous collaborations between VCS and DKSR.

Additionally, Civora includes two components that can provide great value to BIPED: Apache Superset to create and publish dashboards and Piveau to manage all data sources with a compliant data catalogue standard DCAT-AP[2]. These components are integral parts of the DKSR portfolio and are tightly tied to the functionalities of Civora. An example of this, is the ongoing work between VCS and DKSR to bring all georeferenced data listed in the Piveau catalogue to the VCMap. Moreover, Apache Superset will play a major role to communicate with different stakeholders as dashboards provide a more simple communication format. With the possibility to include text, descriptions and references easily, Apache Superset dashboards enable tailoring the message to the target group and providing only the relevant information.

One remarkable outcome of the last six months is the general agreement on the OGC API Processes standard[3], which provides all BIPED modelling partners with a guideline to design their model APIs. This has allowed the Model Coordinator component from DKSR to integrate the Traffic Model from RoadTwin in a very short time. This approach has been shared with the rest of the BIPED modelling partners and will, in the coming months, enable the connection of further models without the need of major customizations. The Model Coordinator, which we present in more detail below, is inspired by this standard and it extends it to the case where there are remotely hosted models in more than one model server.

The DKSR Model Coordinator also has a user interface that is embedded into the Civora frontend, making the interaction with the backend smoother and accessible for non-technical users. Currently this enables only the execution of the RoadTwin Macroscopic Traffic Model, which is the first model integrated into the platform. The further integration of other models will happen in the coming months as the models become available over API.

[2] DCAT-AP data catalog standard: https://interoperable-europe.ec.europa.eu/collection/semic-support-centre/solution/dcat-application-profile-data-portals-europe/release/300

[3] OGC API Processes standard: https://www.ogc.org/publications/standard/ogcapi-processes/

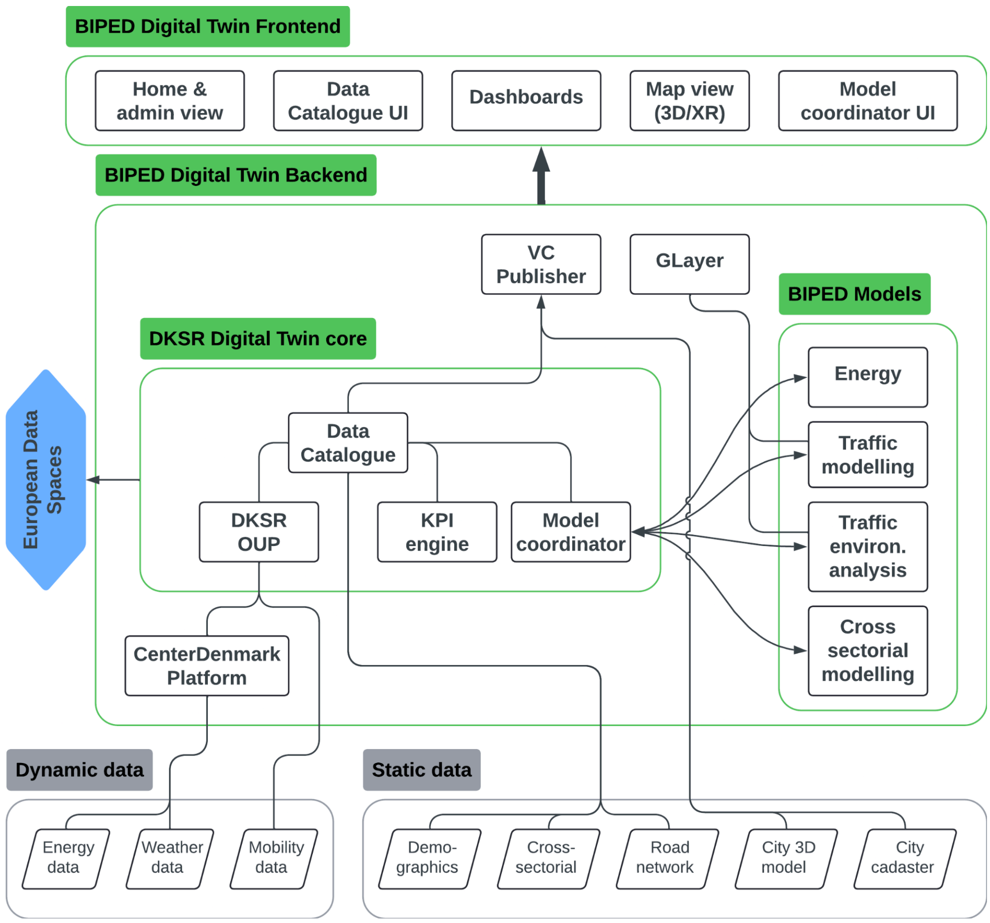


Figure 3. BIPED Digital Twin architecture

Underlying all the work and progress of the last six months, the BIPED Digital Twin architecture has also evolved. In Figure 3 we present the updated version of this architecture, where the different components from DKSR Civora are included. In comparison to the architecture presented in D2.1, the main difference is the introduction of the Data Catalogue. This component, which builds upon the Piveau data catalogue developed by Fraunhofer Institute, includes a Data Provider Interface which enables importing static data files to the Digital Twin.

3. Requirements

3.1. User Stories

The current Experimental Twin (defined in Figure 2) implements a prototype of following User Stories:

- **UR-1.1DM:** As a Decision Maker, I want to know what influence a considered measure will have on the traffic itself, so that I can consider alternative measures and select the optimal one. (In a later stage, not covered in D2.2 this can be extended to include a measure on traffic energy consumption and on the traffic environmental impact).

- **UR-1.2DM:** As a District Heating Operator, reliable heat load forecasts enable efficient heat production operations. These forecasts allow for optimization, particularly through the lowering of effluent temperatures.
- **UR-3.1DA:** As a Data Analyst, I want to iteratively explore the history of traffic in the district so that I can look for spatiotemporal traffic patterns.

3.2. Integration Requirements

Data models can help to discuss above mentioned user stories. Suggested models from the BIPED consortium include following integration requirements, defined into “conditional” and “not conditional” or “nice to have”:

Table 1. Integration requirements

Task	Component	Requirements
2.1	**BIPED Digital Twin core**	**not conditional**: a well described Open REST API (documented e.g. in swagger) **not conditional**: the model/analytical results aiming to be integrated to the platform are available in a consistent format **not conditional:** the API provides a minimum layer of security, such as a token, an API key or a user-password **conditional**: a well described Open REST API according to the OGC API Processes standard[4]
2.2	**District Heating Forecast Model**	**conditional**: a well described Open REST API (documented e.g. in swagger) **not conditional**: a well described Open REST API according to the OGC API Processes standard
2.3	**Traffic Model**	**conditional**: a well described Open REST API (documented e.g. in swagger) **not conditional**: a well described Open REST API according to the OGC API Processes standard
2.3	**Traffic Energy and Enviro Analysis**	**conditional**: a well described Open REST API (documented e.g. in swagger) **not conditional**: a well described Open REST API according to the OGC API Processes standard

4. Models Integration

The BIPED Digital Twin core functionality is to integrate multiple models from different domains and different organizations. The integration of these models is achieved with the so-called Model Coordinator component, a module developed under the scope of BIPED which implements an abstraction of the OGC API Processes standard to bring the models from the different tasks (T2.2, T2.3 and T2.4) together.

[4] OGC API Processes standard: https://ogcapi.ogc.org/processes

The **Model Coordinator** provides a simple yet versatile API to execute models which are remotely hosted. This API, which is OpenAPI compliant and provides a comprehensive Swagger UI as documentation, can be used by either the VCMap frontend to execute models directly from the 3D city model, or via a dedicated graphical interface which is accessible over the DKSR Civora frontend. The current use of the Model Coordinator is to correctly route the model execution requests and collect the model results, however, it is envisioned that the Model Coordinator will enable the combination of models, to use for example the output of a mobility simulation as input to an energy forecasting.

The last and most relevant part of integrating models is to visualize the results. To this aim, the models' results are stored in the DKSR Civora storage modules and made available to the VCMap and a dashboarding tool like Apache Superset, making the model results more accessible and providing context and complementary information.

4.1. Energy

4.1.1 District Heating Load Forecasting Model

The energy modeling which is included in this version of DKSR platform, is “District Heating Load Forecasting Model”[5]. The heat load forecasting model provides adaptive point forecasts for heat loads using simple and robust methods. The model inputs include historical heat load meter data, local numerical weather forecasts, and possibly weather observations. It employs adaptive parameter estimation methods, allowing for online estimation and prediction. The model outputs point forecasts of heat loads matching the time horizons of the inputs.

The model is hosted and deployed internally on a virtual machine at Technical University of Denmark (DTU), where an Open API is responsible for facilitating the communication and integration with the DKSR platform (see Annex 2, Ref 5 for access details). The DTU Open API provides a streamlined way to manage and execute jobs associated with specific processes, registered in the api, which are the models in this case. For this to work, the models and processes should be encapsulated and expose an endpoint for submitting data and returning results.

This enables models to be registered, users can submit jobs to those processes, retrieve job statuses, and access results.

The API will communicate with the given endpoints for the processes/models and streamline it through the job/routing. All models and processes are registered to the service by adding an entry with input, output and their endpoint specifications to the appsettings file. After this, these are available through the Data routing API as processes and jobs can be initiated with them.

The API uses token authentication, where the Authentication parameter has to be included in each request with a valid token. Only if this token is included and valid, can systems or users make requests to the endpoints and initiate jobs.

4.2. Mobility

4.2.1 Integration of the Macroscopic traffic modelling and its' energy and enviro impacts modelling

The Macroscopic Traffic Model provides city-wide traffic simulations and supports the creation of "what-if" scenarios to analyze the effects of changes such as road closures or

[5] District Heating Load Forecasting Model: https://biped.compute.dtu.dk/api

traffic reductions in specific areas. The model relies on inputs including a calibrated traffic network, an origin-destination (OD) matrix, and demographic data. Its outputs, such as traffic flow and average volumes, provide insights at an aggregated level, serving as foundational inputs also for the Traffic Enviro Analyst.

The model is developed using OpenStreetMap as the base street network, with manual modifications to enhance detail, including additional streets and specific traffic features such as one-way routes and on-ramps. The OD matrix, obtained from TomTom, uses data from embedded SIM cards and transportation records. However, limited data coverage (15–25%) constrains its accuracy, with further calibration efforts planned as data becomes available.

The model[6] is currently hosted on RoadTwin's development servers and supports integration with digital platforms via Open Rest API (see Annex 2, Ref 3 for access details). This allows for scenario customization, where users can modify traffic parameters to simulate localized and city-wide impacts. Planned upgrades include increased network density, particularly in the Brabrand district, and calibration to deliver more accurate and actionable results. These advancements will also ensure better integration with microscopic traffic model (see 4.2.2) for seamless multi-scale analysis.

The Traffic Enviro Analyst – Energy Model calculates traffic-related energy consumption by analyzing outputs from the Macroscopic Traffic Model. It evaluates traffic flows across road segments and incorporates propulsion type distributions (electric, hybrid, and conventional vehicles) to provide detailed energy assessments for urban mobility systems. Designed for integration with the RoadTwin platform, the model supports planners in assessing the energy impacts of proposed traffic scenarios and contributes to district energy positivity evaluations.

The current version (v1.0) of the model calculates overall energy consumption for traffic scenarios simulated by the Macroscopic Traffic Model. Future iterations, integrated with RoadTwin's main API, will feature more detailed energy analyses by propulsion type. This functionality is planned to support user-defined scenarios for both environmental and energy assessments.

The model is hosted on RoadTwin's servers and can be accessed via an Open REST API, enabling smooth integration with urban planning workflows. The API allows for seamless submission and retrieval of simulation jobs, ensuring compatibility with digital twin platforms. Future development will expand its capabilities to include traffic pollution assessments, further enhancing its role in strategic urban planning.

4.2.2. Integration plans of a microscopic model extension

Urban transportation systems are increasingly complex, requiring detailed models to analyze and optimize traffic flows at both macro and micro levels. While macroscopic models are effective for large-scale analysis, they often aggregate data to the extent that localized effects, such as bottlenecks and emissions, become less noticeable. The macroscopic model provides aggregated outputs, such as average traffic volumes and flows, which serve as inputs for the microscopic extension. The objective is to provide detailed representations of traffic dynamics and associated environmental impacts within the district with the potential for integration into digital twin platforms for real-time monitoring and control. The microscopic model simulates individual vehicle movements within the Brabrand district. The model incorporates:

- Road Network Geometry: Detailed representation of intersections, road segments, and traffic signals.
- Driver Behavior: Variability in acceleration, deceleration, and route choices.
- Traffic Dynamics: Simulation of congestion, queuing, and spillback effects.

[6] Macroscopic Traffic & Energy Model: https://dev.api.roadtwin.com/swagger

The model will be designed using SUMO-framework[7], leveraging the output of the macroscopic model to ensure consistency between scales.The potential for direct integration within the digital twin platform will be evaluated based on the model's performance and resource requirements.

5. Demonstrator of the Digital Twin

The BIPED Digital Twin will be represented in multiple interfaces to provide data services with highest benefit to future users. It is important to combine the benefits of a digital twin, such as improved efficiency and better decision-making, with the benefits of a data hub, such as centralized data management, improved data quality, and increased data accessibility. This combination can help organizations to gain a deeper understanding of their assets, optimize their operations, and accelerate innovation. In order to still offer a centralized user experience, the decision was made to use a data hub that houses the 3D twin and can be developed further if required.

5.1 Data Hub Civora

Figure 4. Civora Data Hub & Governance tool

The BIPED Digital Twin frontend must serve requirements of different user groups, e.g. a Data Analyst or Decision Maker in the city administration, but also citizens (see also D2.1: UR-1.1DM, UR-1.2DM, UR.3.1DA). Due to these multifaceted user needs it has been decided to use a frontend that allows to integrate different screens and forms of publication for data. To fulfil this requirement, we use the flexible open source smart city data hub and governance tool from DKSR called Civora[8] (Fig. 4). Civora integrates the 3D twin as a screen (as described below 5.2 in detail).

[7] "Microscopic Traffic Simulation using SUMO"; Pablo Alvarez Lopez, Michael Behrisch, Laura Bieker-Walz, Jakob Erdmann, Yun-Pang Flötteröd, Robert Hilbrich, Leonhard Lücken, Johannes Rummel, Peter Wagner, and Evamarie Wießner. IEEE Intelligent Transportation Systems Conference (ITSC), 2018.

[8] CIVORA: https://www.dksr.city/en/smart-city-data-hub-2/

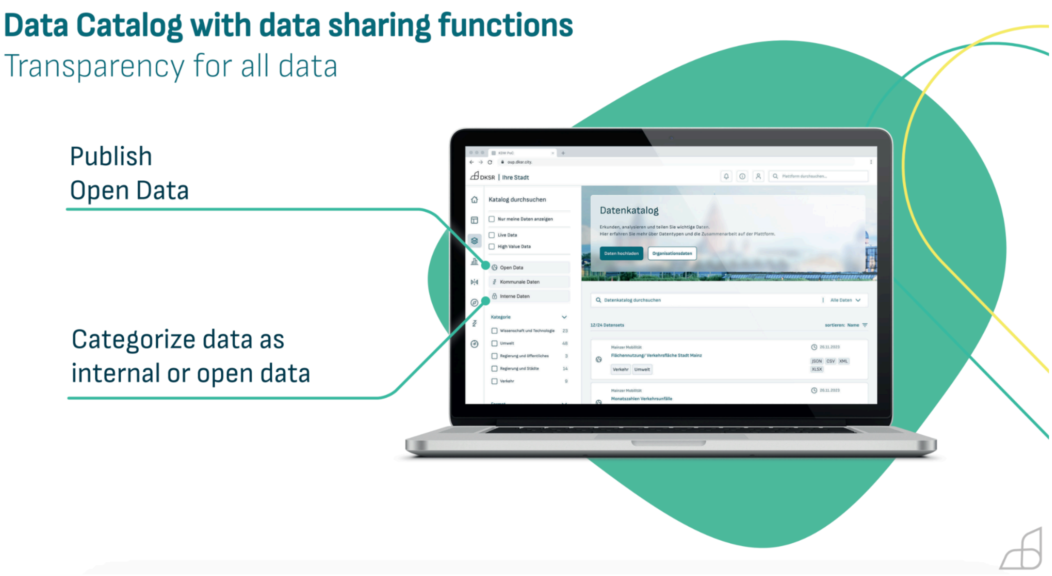


Figure 5. Metadata Data Catalog (DKSR Mock-up)

With this deliverable D2.2, an initial set-up of Civora has been deployed[9] with following features (see Annex 2, Ref 1 for access details):

- A **basic home screen** provides an intuitive welcome page tailored to each user group, offering easy navigation and relevant information.
- A **secure login page and individual user profiles** manage access, roles, and rights for different user groups, ensuring data security and personalized experiences if needed. It also allows sharing data between different partners built around a data governance.
- The **metadata catalogue**, built on the open-source catalog technology Piveau using the DCAT-AP standard, lists and describes all datasets used within the Digital Twin context, facilitating data discovery and understanding (see Fig. 5).
- The Digital Twin itself (see chapter 5.2.), provided by VCS, is integrated and acts as a **geo model**, representing the physical world and connecting the results of data analysis to real-world locations and assets.
- Finally, the frontend contains the **Model Coordinator application**, which executes the provided models, automating complex calculations and simulations within the Digital Twin environment.

In the outlook, diverse dashboards and data analysis tools can showcase specific data analysis products, allowing users to explore and interpret results effectively. Furthermore, applications and a data exchange tool can be integrated. Civora follows a modular and open source approach and the BIPED solution can benefit from feature developments of the Civora user community.

5.2 BIPED Digital Twin

The demonstrator[10] has been already introduced in D2.1 (see Annex 2, Ref 2 for access details) and now has been linked in the CIVORA frontend. It is primarily focused on making geospatial information available in a way that is comprehensible by decision makers and citizens alike. Additional content has been incorporated into the platform and made available through the online map interface. Most importantly 3D models of all buildings within the

[9] BIPED Data Hub and Model Coordinator: https://bi-ped-staging.civora.org/
[10] Demonstrator: https://vcmap.bi-ped.eu/

Aarhus municipality were acquired from NIRAS[11] and imported into a 3DCityDB Database[12]. This dataset comprises 174,910 buildings in different levels of detail. The inner city has been modeled with the most details, including dormers and other roof structures. Most of the buildings in the district of Brabrand have been modeled as LOD2 with basic roof shapes derived automatically from point clouds. Some buildings in the outer districts are modeled as simple LOD1 with flat roofs.

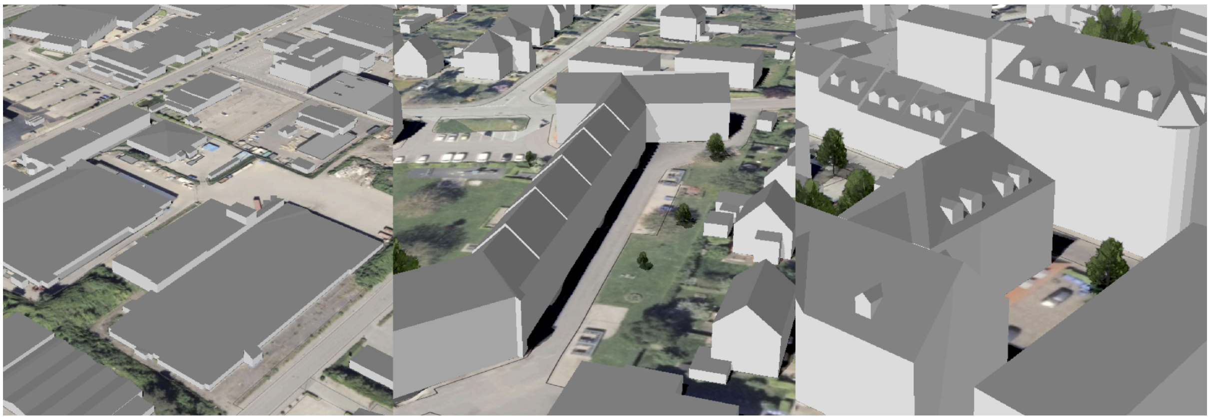


Figure 6. Levels of detail of building representations.

The 3D city model will provide essential information for energy related calculations that are based on the geometrical properties of buildings and the environment. For example, wind field simulations for assessing pedestrian comfort levels are based on LOD2 models. Additional roof structures are important when planning solar panels.

In a similar context, accurate representations of trees are important for calculating the solar potential of roof surfaces. They act as occluders especially during summer and can reduce the expected electricity output of solar modules. Trees have been made available as point data source from the Geospatial Data Infrastructure[13]. Height information has been derived from the surface mesh model and attached as property to the data source. A tree library was used for mapping 3D objects to the locations.

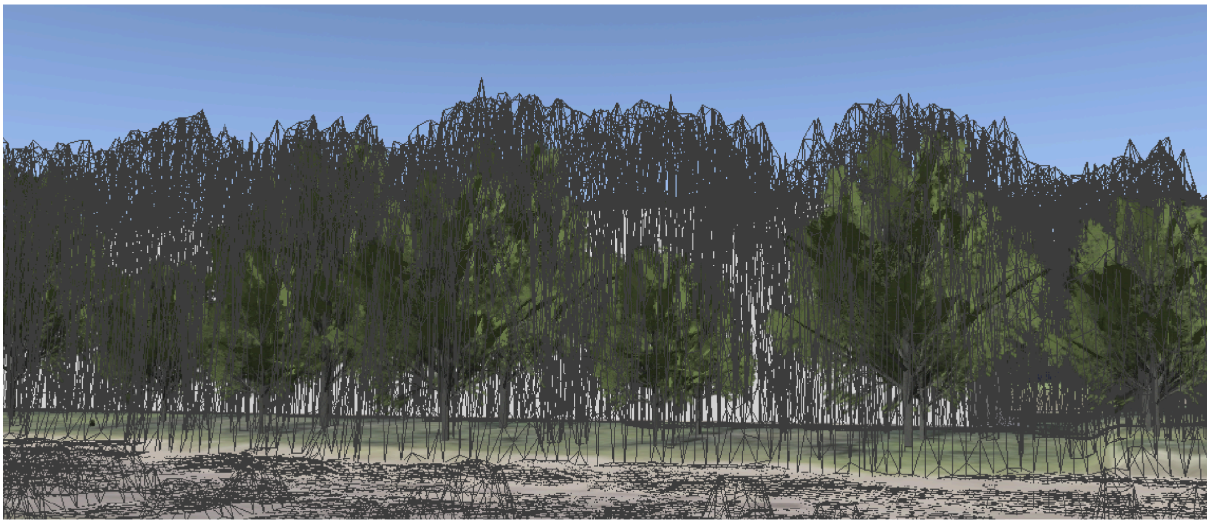


Figure 7. Surface mesh and realistic tree models.

The VC Map framework as described in D2.1 shows both the current state of the Digital Twin in terms of built-up environment, socio-economic data and sensor data as well for analyzing

[11] NIRAS: https://www.niras.com/
[12] 3DCityDB: https://www.3dcitydb.org/3dcitydb/
[13] Geospatial Data Infrastructure: https://datafordeler.dk/

results of complex simulations and what-if-scenarios. For the first release of the Digital Twin, results from the mobility domain and energy domain were integrated as information layer. More results are available through the domain-specific platforms.

The macroscopic traffic model as described in 4.2.1 was made available through RoadTwin's API. It provides information of the traffic flows on major roads in Aarhus under typical conditions. As a calibrated base layer it can be used for comparing the typical traffic flow at a specific time of day with simulated traffic flows as a result of network modifications caused by a construction site. The API distinguishes between the road network geometry, which is provided as GeoJSON package and traffic flow information, which is provided as a property table. The road network has been imported as a static geometry layer in the Digital Twin (DT) backend database. Simulation results are requested through the API and attached to the network based on the edge IDs on demand. Presentation strategies for the visual assessment of what-if-scenarios are currently being evaluated. A simple categorization of traffic conditions using color-mapping and varying line widths is shown in Figure 8.

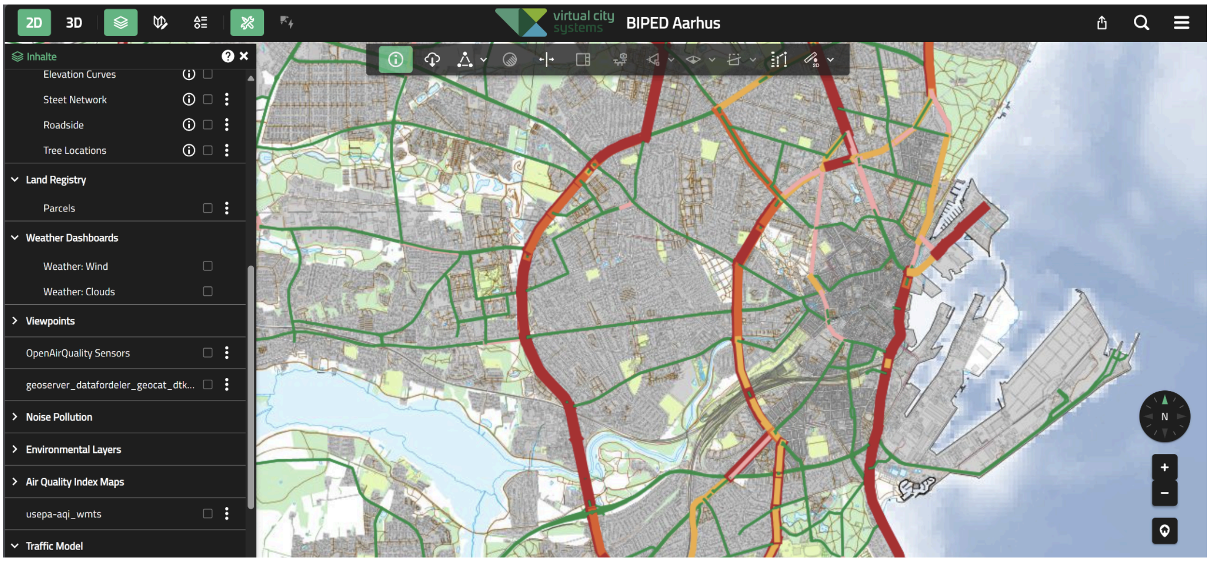


Figure 8. Result of a traffic simulation showing traffic congestions as red line segments.

From the energy domain, results of an initial solar potential analysis covering all buildings in Aarhus were integrated as a static 3D-layer. Figure 9 shows the texture output of annual potential values providing the best spatial resolution. The display solar properties on individual roof and wall surfaces (monthly/hourly values) can be activated using dynamic styling.

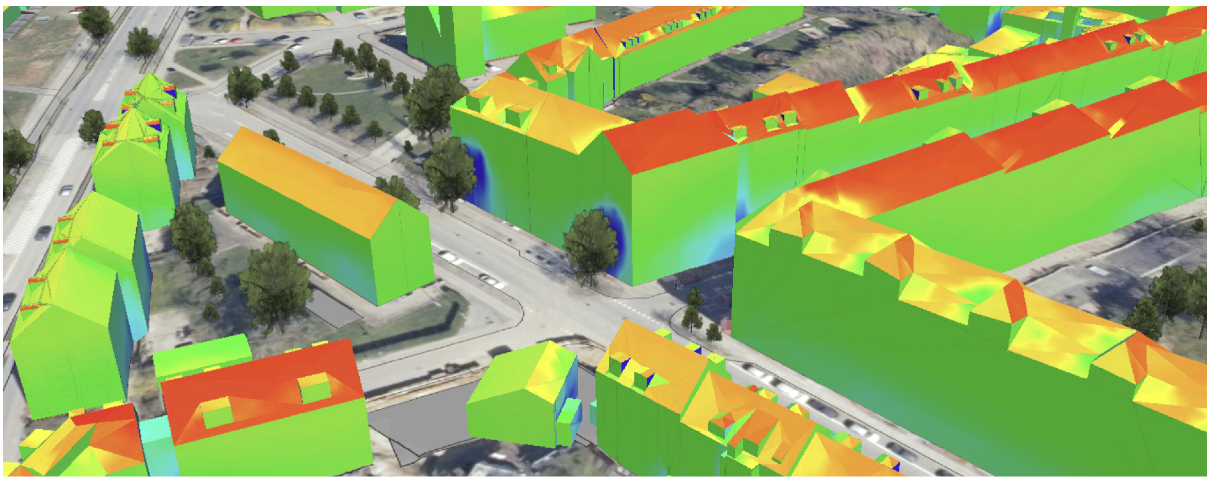


Figure 9. Solar potential analysis: red to green - high to low potential

Traffic dashboard

TomTom Traffic Stats data, which provides information such as average speeds, average travel times, and sample sizes for selected road segments and times, is leveraged for visualizing traffic and its trends during specifically chosen representative time windows. This visualization is accessible via the GLayer frontend application with corresponding filters and data outputs. Furthermore, RoadTwin also uses this data for further calibration of the traffic model (see above in section 4.2.1), in addition to the TomTom OD matrix, by connecting to the GLayer API for an easy access to the data.

The time windows for traffic data selected were 15.-21. January 2023, 15.-21. April 2023, 15.-21. July 2023, and 30. October 2023 - 6. November 2023. These time windows, thus, cover a representative full week of each season (Winter, Spring, Summer, Autumn) without any public holiday, and provide an informative sample of traffic during the year. For each individual day within the windows, a full TomTom report covering all road segments (with the exception of the smallest streets - level 6, in TomTom's terminology) was generated, with data points aggregated on an hour level. The information from these reports was parsed via a custom configurable script and each record for each segment, hour, and date was mapped to a corresponding database entry.

The data from the database is used as a data source for a configured GLayer project that provides a user-friendly way of accessing the data. It allows the user to filter by the period, exact date, time, and street segments, to get both the aggregated data across selected segments, and also specific data (based on the time selection) for a particular segment. There are no textual queries involved and everything can be done via an intuitive graphical user interface. See an example of the GLayer frontend application in Figure 10.

Figure 10. GLayer traffic speed dashboard of Aarhus with segment visualization and charts

GLayer and the traffic data is currently hosted on INNO's development servers[14] (see Annex 2, Ref 4 for access details). Besides the GUI frontend, GLayer also supports integration with other BIPED components via well-documented Open Rest API. This API is currently used

[14] Traffic Speed Dashboar (GLayer): https://glayer-dev.innoconnect.net/biped

by RoadTwin to access the data, and leverage the same options of filtering and aggregating the data (as the GLayer frontend provides) for further calibration of the traffic model. In addition to that, the API also offers extended capabilities of accessing the data that goes beyond the options of the frontend GUI without a need to touch the data source or reconfigure the underlying project.

6. Conclusion & Next Steps

This report details the first release of the BIPED digital twin, including initial energy (T2.2) and mobility (T2.3) models as a demonstrator. Accompanying and documenting the current work process as of M12, the report offers background information and detailed insights on requirements and model integration, as well as a description about the demonstrator as guidance to its user in its current state.

Based on the three presented requirements and model integration steps, the following lessons and next steps can be highlighted, which will determine the further development towards Release 2 (D2.3) by the end of 2025 (month 24):

Energy:

- The district heat load forecasting model is provided in a prototype form, ready to be configured and applied to specific cases. The current iteration of the model offers generic functionality to model and forecast heat loads, but further work is required to configure the model for a specific dataset. As of writing, the required data is unavailable. Once the data becomes available, this configuration will be carried out, and operational results will be generated. This step is essential for most further work with the model. The generic capabilities of the model may be extended, initially through the inclusion of forecast reconciliation for temporal hierarchies. This feature will be included in a future release of the model.

Mobility:

- The macroscopic traffic model is provided as a prototype, designed to simulate city-wide traffic patterns and support "what-if" scenario analysis. The model is currently in its initial operational phase (Version 1), with subsequent versions planned to improve detail and calibration as additional data becomes available. Key dependencies include calibration data, a precise origin-destination (OD) matrix, and demographic inputs, with data acquisition efforts ongoing in collaboration with stakeholders like Innoconnect.
- The model's foundational traffic network is based on OpenStreetMap, enhanced with manual adjustments to include features like one-way streets and motorway ramps. However, the network's density is limited, particularly in certain areas, with planned improvements to address these gaps in future iterations. OD matrices, derived from the TomTom platform, underpin the model but are constrained by partial data coverage (15–25%), impacting accuracy.
- While the model is currently functional and capable of simulating traffic scenarios, its full potential will be realized in Version 2.1, contingent on calibration using high-quality data. This version will also expand the network density, particularly in regions like Brabrand. In its current state, the model can estimate emissions and energy consumption in conjunction with the Enviroanalyst tool, enabling assessments of environmental and energy impacts tied to traffic scenarios.
- Future developments include addressing challenges in data acquisition and calibration, essential for refining the model's accuracy. Despite these challenges, the

model remains a valuable tool for urban planning, offering insights into localized and city-wide traffic dynamics.

- The Traffic Enviro Analyst – Energy Model is provided as a prototype, designed to calculate the energy consumption of traffic flows based on data from the macroscopic traffic model developed by RoadTwin. The model analyzes traffic scenarios, factoring in propulsion type distributions (electric, hybrid, and conventional vehicles), and enables energy consumption assessments for specific areas. It supports urban planning by contributing to evaluations of district energy positivity and is intended for integration with RoadTwin software, hosted on UWB or RT development servers.
- The model's operation depends on input from the macroscopic traffic model and propulsion type data from AAKS. Currently in its initial prototype phase (v1.0), it calculates overall traffic energy consumption for scenarios generated by the RoadTwin Traffic Model. Future versions will enhance functionality, including integration with the RoadTwin API and more granular energy calculations by propulsion type.
- Development of a microscopic traffic flow model extension for the Brabrand district, aiming to address the limitations of the macroscopic traffic model in capturing fine-grained dynamics within localized urban areas. By leveraging the output from the calibrated macroscopic model, the microscopic extension will provide detailed insights into traffic flow quality and associated environmental impacts. Key performance indicators (KPIs), such as level of service, waiting times, queue lengths, and emissions, are analyzed at the district level. This model extension has potential applications within the upcoming digital twin platform, but has to be evaluated based on the model's performance and resource requirements.

Cross-sectoral:

- The development of cross-sectoral models is a step towards enabling integrated solutions that address interdependencies across various domains, potentially but not necessarily limited to energy and mobility. Following models are currently being developed to be integrated for the second release (D2.3):
    - A **soft data model for indoor climate** that emphasizes the user's perception of the indoor climate within a building. This model serves as an initial demonstrator and can be further refined in future versions to enhance its precision and usability.
    - A **Building occupancy model**, incorporating demographic and economic properties of the testbed Braband, linking them to land-use patterns and energy consumption. This model aims to detect and potentially predict energy demand peaks in areas, allowing energy providers to make informed decisions.
    - **Climate risk model for critical infrastructures**: A cross-sectoral model designed to assess climate-related risks and their implications for key infrastructure systems.
- These models, once integrated, will contribute to a more comprehensive cross-sectoral domains, enhancing BIPED's capability to address interconnected challenges across domains. Moreover, Validating integrated model outputs against real-world data is part of the next steps to ensure applicability, practical scalability and accuracy.

Digital Twin:

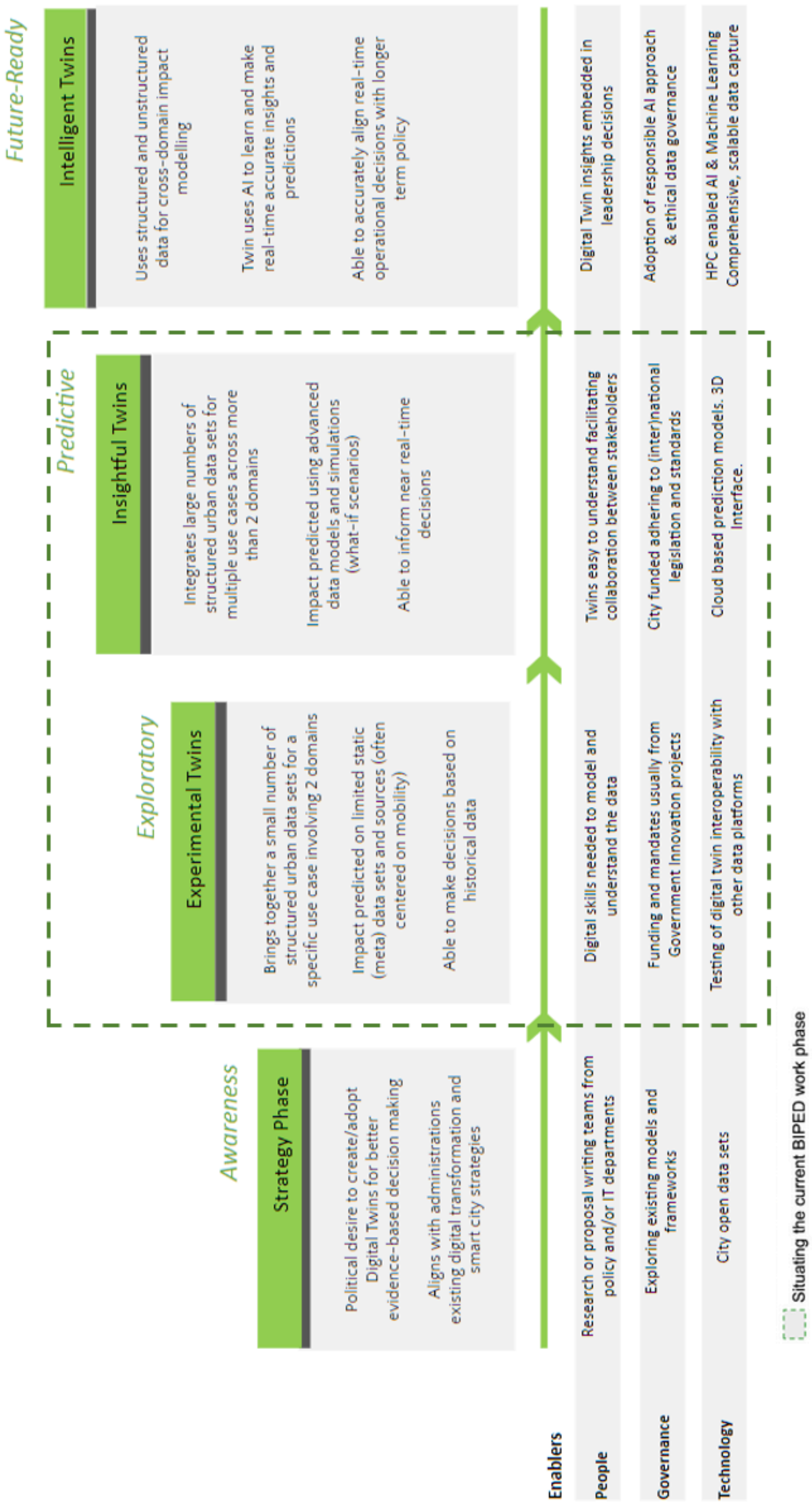
- DKSR will continue to maintain the BIPED Digital Twin demonstrator set up for this milestone (available at bi-ped.civora.org, see Login Details in Annex 2).

Closed Product Components:

- All the BIPED partners will be able to continuously see and explore the developments published by other partners.
- The Model Coordinator will integrate more tightly with the VCS solutions, ensuring a good user experience. Additionally, integration with the DKSR Data Catalogue and Dashboarding solutions will ensure that the city of Aarhus can have visibility and control over the BIPED Digital Twin.
- Geospatial databases will be extended to incorporate static information layers from more domains, e.g. district heating, electricity networks, and building occupancy model. The VCMap as a visualization frontend component will be used for making most static data available for decision makers.
- A catalog interface will be added for browsing and adding new geospatial content to the map / 3D interface. This includes results of what-if-scenarios that have been registered to a catalog service in a structured way including metadata.
- The focus of the software development will be the technical integration of domain specific analytical modules, so that users of the DT platform can define custom scenarios and assess the implications on energy consumptions, traffic flows, air quality levels and other indicators. Data flows will be managed by common network APIs and protocols. User inputs from individual domain specific applications will trigger backend processes and make results available through a common information pool.

7. Annexes

7.1. Annex 1: DUET Maturity Model



7.2. Annex 2: Demonstrator

Reference	Topic	Model / Component	URL	Additional Information
1	Digital Twin	BIPED Data Hub & Model Coordinator	https://bi-ped-staging.civora.org/	User Login: user: "biped"; password: "biped-admin!"
2	Digital Twin	Map and Visualization Component	https://vcmap.bi-ped.eu/	no login required
3	Mobility	tm_aarhus_m24_v240911	https://dev.api.roadtwin.com/swagger	Open API of the macroscopic traffic model of Aarhus. The API is capable of providing the geometry of the model together with the possibility to create and calculate traffic scenarios. Enviro Analyst is built on this model, so the API also contains environmental impacts.
4	Mobility - Traffic Dashboard	Traffic Speed Dashboard (GLayer)	https://glayer-dev.innoconnect.net/biped	Traffic dashboard of Aarhus provides information such as average speeds, average travel times, and sample sizes for selected road segments and times. The dashboard was developed with the TomTom Traffic Stats data.
5	Energy	District Heating Load Forecasting	https://biped.compute.dtu.dk/swagger/index.html	The API interacts with specified endpoints for

				processes and models, managing them via job routing. Models and processes are registered in the appsettings file by specifying input, output, and endpoint details, making them accessible through the Data Routing API for initiating jobs. Token authentication is required, with a valid token included in each request; only authenticated users or systems can access endpoints or start jobs. Contact email: shmp@dtu.dk