D2.3 BIPED DIGITAL TWIN RELEASE 2

Second release of the Digital Twin including second versions of modelling tools

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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 second release stage after 24 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-sectorial 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, the first release (D2.2) in M12 and will continue to grow and expand throughout the project's timeline and be presented in the final deliverable (D2.4).

The second release of the BIPED digital twin D2.3 includes the refinement and further implementation of energy and mobility models on the digital twin platform (as described in D2.1). As part of the second release of the BIPED digital twin platform demonstrator, this report provides the reader with background information on the development from M12 to M24 of the project, starting with a status update on the digital twin (Chapter 2), outlining the requirements (Chapter 3) and describing implementation and updates of the models to the platform (Chapter 4). The report further offers an updated 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 D2.4 in M36 (Chapter 6).

The document is structured into 6 chapters:

- **Chapter 1 "Introduction"** provides an outline and update about the second release of the digital twin, including the refinement and integration of energy, mobility and initial cross-sectorial models, and how it builds on prior deliverables D2.1 and D2.2. The chapter describes how this deliverable relates to the other deliverables of this project's WP3 (D3.3) and WP4 (D4.3) and concludes with outlining the scope of this deliverable.
- **Chapter 2 "Status BIPED Digital Twin"** describes the update and status quo of BIPED digital twin in its current stage from a technical perspective and builds on the technical development from deliverable D2.1 and its first release (D2.2).
- **Chapter 3 "Requirements"** presents the User Stories and Integration Requirements, the second 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 updated 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 second release of the BIPED digital twin, including updates on energy (T2.2) and mobility (T2.3) models, as well as initial cross-sectorial (T2.4) models as a demonstrator. This report was produced to accompany the deliverable's demonstrator and to document the current work process as of M24. The report offers background information and detailed insights on requirements and model integration, as well as guidance to the user of the demonstrator.

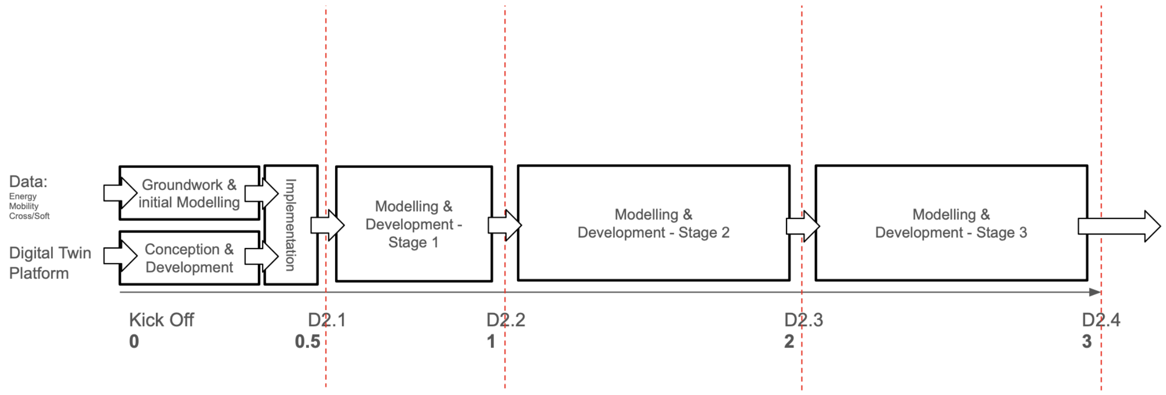


Figure 1. Schematic workplan of BIPED Digital Twin: M01-M36

The second release of BIPED digital twin builds upon the BIPED platform as developed in D2.1 and the integration of initial energy and mobility models (D2.2), by updating existing and introducing new models to the platform, as described in this deliverable (D2.3.). In incrementing development stages, BIPED digital twin will be further extended in the following final deliverable (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).

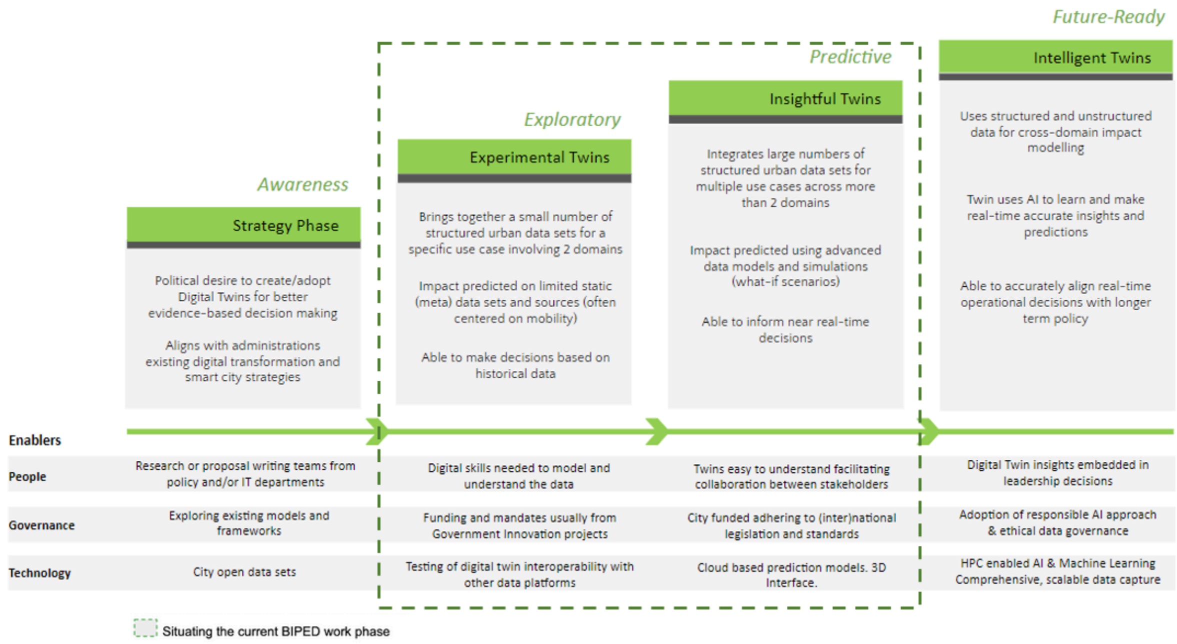


Figure 2. DUET Maturity Model (see Annex 1)

As outlined in Figure 1, the process in this stage focuses on the modelling and further development of existing, as well as the integration of new energy, mobility and cross-sectorial 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 second release. The model describes a high-level pathway for the development of digital twins. The BIPED work phase as described in this deliverable (D2.3) can be categorised into the Exploratory and Predictive 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 D2.3, 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, as well as updating and improving existing models.

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

The primary objectives for deliverable D2.3 are:

1. Improving and extending of existing Energy and Mobility Models:
    - Improve and extend data models for energy (T2.2) and mobility (T2.3) aspects that are accurate and align with the architectural design.
2. Integration of new models - besides from energy and mobility domain also in particular for cross-sectorial aspects (T2.4) - 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.

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

- Ensure the Digital Twin development is in sync with WP3 and WP4 to meet broader project goals.

2. Status BIPED Digital Twin

The BIPED Digital Twin has not undergone core changes in its architecture since first release. This has been a satisfactory validation of the initial design and hypothesis as it has allowed the BIPED partners to continuously use the Digital Twin to share dataset and provide visual representations of their models.

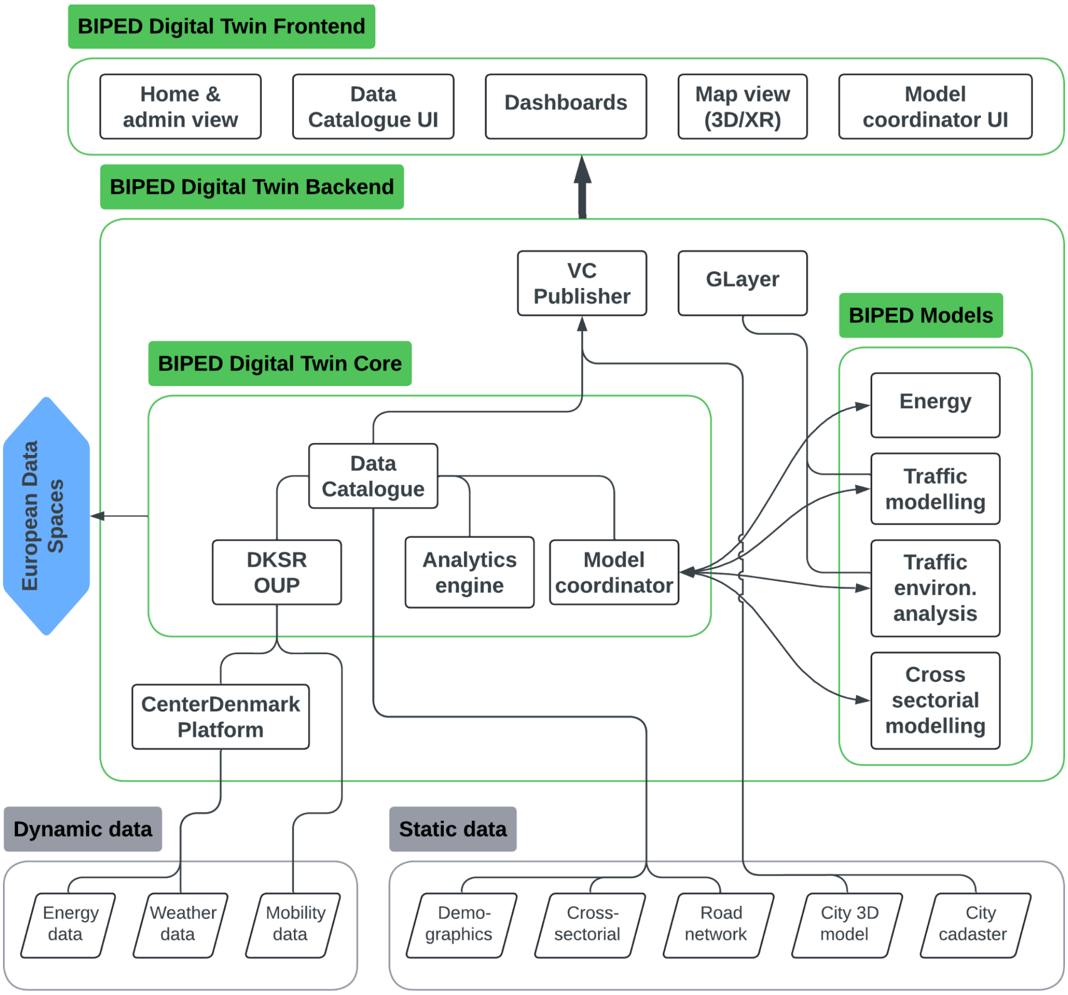


Figure 3. BIPED Digital Twin architecture

Since the last deliverable, technical work on the BIPED Digital Twin has mostly revolved around improving the deployment strategy. The core of the Digital Twin, the CIVORA Data Hub is now deployed using Open Tofu, an open source infrastructure as code tool that allows reliable management of the components and their relations. With a tool such as Open Tofu, we are able to roll out security updates to specific components without having to stop the rest of components. Moreover, Open Tofu enables easier state recovery, so that if a breaking change is found, the system can be reverted to its previous stable state.

Additionally to the technical work, significant UI/UX work has been done, focusing on improving the user-interface of the Model Coordinator, the component that allows the integration of the BIPED Models. This work has involved designers, modelers and end-users alike, to ensure that the needs of all user-groups are met and we develop a tool that matches the needs. More details about the Model Coordinator frontend can be found in section 4.

Finally, and as a testimonial of the use of the BIPED Digital Twin, and specifically of the Data Catalog feature, as of November 2025, 25 datasets have been made available by the partners and shared across teams. These datasets range from building to mobility data, including land-use and solar potential datasets.

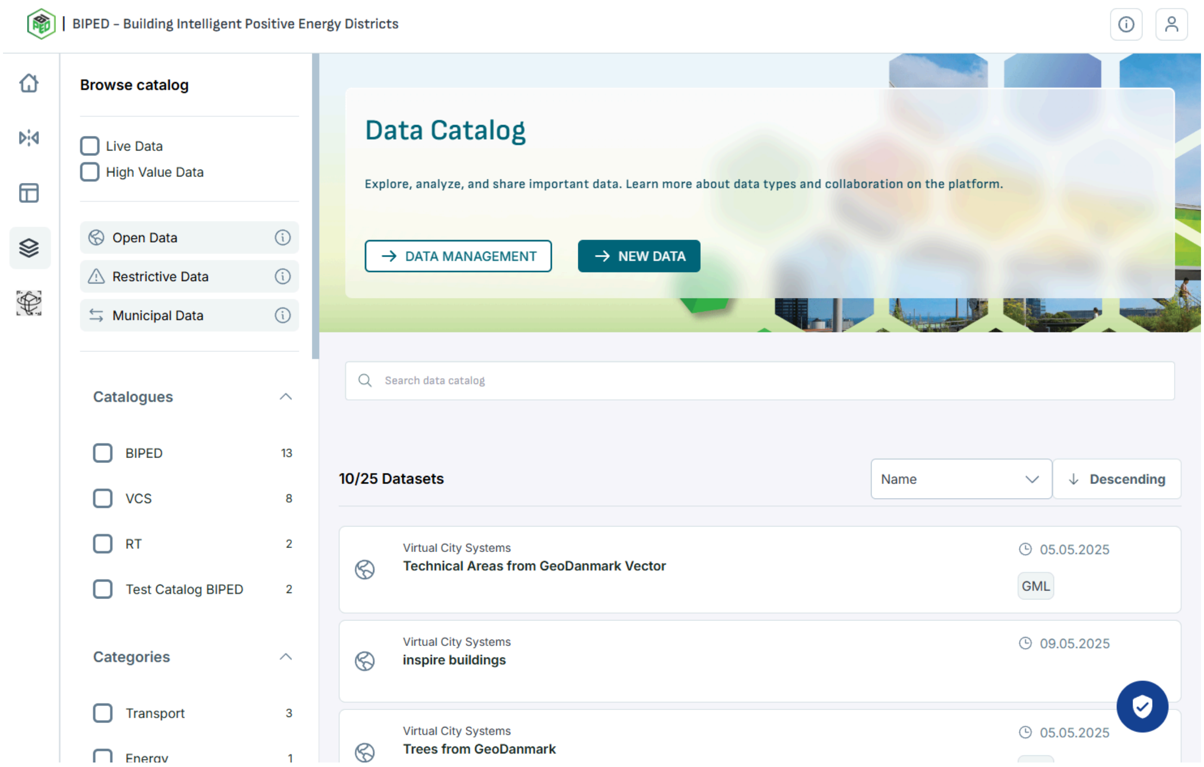


Figure 4. BIPED Data Catalog where partners collect and share relevant datasets

2.1 Agile development

The development of the BIPED Digital Twin follows an agile and iterative approach, reflecting the complexity of integrating heterogeneous models, data sources, and stakeholder requirements. Rather than pursuing a fully predefined solution, the consortium adopted a flexible development strategy that allows the platform to evolve incrementally across project releases (D2.1, D2.2, D2.3, and the final D2.4).

Up to and including this deliverable (D2.3), the technical development of domain-specific models in the areas of energy, mobility, and cross-sectorial analysis has largely been carried out individually by the responsible partners. This approach enabled focused methodological development, validation, and testing within each domain, while keeping integration requirements intentionally lightweight during early project phases. The current release therefore represents a consolidation point where several integration pathways have been demonstrated and mature model prototypes are prepared for systematic integration into the Digital Twin environment.

The agile methodology has been essential in enabling continuous refinement of requirements and user stories, informed by ongoing feedback from WP3 (stakeholder and end-user engagement) and WP4 (KPIs and evaluation). Regular coordination meetings and technical exchanges ensured alignment across work packages while allowing partners sufficient autonomy during the exploratory and predictive phases of the Digital Twin maturity model.

Key elements of the agile process in BIPED include:

- Incremental development and releases aligned with project milestones, allowing gradual extension of functionality and model scope.
- Modular architecture of the Digital Twin, enabling independent development and testing of models with standardized interfaces (e.g. REST APIs, OGC API Processes).
- User-story–driven development, with requirements continuously refined based on stakeholder input and demonstrator feedback.
- Early prototyping and demonstrators to validate concepts, usability, and integration feasibility at intermediate stages.
- Continuous technical coordination across partners to ensure interoperability and architectural consistency.

In the next phase of the project, the focus will shift from largely independent model development toward systematic integration of models into the BIPED Digital Twin. This transition requires closer technical alignment between partners, more structured progress monitoring, and stronger application of agile principles. Planned measures include more frequent sprint-style meetings with the participation of end users, clearer definition of integration backlogs, and tighter coordination between model developers and platform developers to ensure timely, robust, and interoperable integration toward the final release (D2.4).

3. Requirements

3.1. User Stories

Following the BIPED development, user stories establishment happens incrementally. As outlined in D2.1, development of our user stories happens in close cooperation with WP3 activities related to stakeholder & end-user involvement. As these actions had to be developed initially, we started off by implementing more general placeholders that have been described to guide the technical development for D2.1. Based on initial findings from WP3, D2.2 focused then on a set of prototype user stories based on initial findings, that has now in this deliverable D2.3 been refined. As outlined in D3.1, learnings from WP3 feed directly into WP2, ensuring that stakeholder and end-user perspectives inform the qualification and development of the Digital Twin Releases (D2.1–D2.4). Outputs from WP3 — such as stakeholder insights, user needs, and engagement feedback — are translated into user stories and profiles, which function as key dialogue and qualification instruments between WP3 and WP2. This ensures that technical development is grounded in real end-user and stakeholder requirements.

The current Experimental and Predictive Twin (defined in Figure 2) implements a prototype of following User Stories based on end users of the models:

- **UR-DM:** 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-DH:** 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-DAT:** 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.
- **UR-EP:** As an Energy Provider, I want to know at what time of day, day of the week, week / month of year, the people distribution geographically and temporally on fine granularity, to dynamically take action on electricity consumption peaks and lows.
- **UR-CP:** As a City Planner I want to know expected wind comfort on different days and times of days in certain areas, taking informed decisions on land use planning decisions.
- **UR-C:** As a citizen/resident I want to know expected wind comfort on different days and times of days in certain areas, taking informed decisions on my mode of transportation.
- **UR-CP:** As a City Planner I want to know about the population's green space accessibility or the lack thereof, taking informed planning decisions supporting local well-being and urban cooling.
- **UR-CP:** As a City Planner, I want to understand user comfort trends across buildings and times of day, so I can set evidence-based policies for energy-efficient indoor climate control.
- **UR-BM:** As a Building Manager, I want to automatically adjust HVAC setpoints based on predicted comfort levels, to maintain comfort while reducing energy consumption.
- **UR-FO:** As a Facility Operator, I want to use comfort predictions to plan ventilation and heating schedules, optimizing system operation for both comfort and cost.
- **UR-FM:** As a Facility Manager, I want insights into which rooms are over- or under-conditioned, so I can recalibrate setpoints or equipment to improve energy efficiency.
- **UR-U:** As a User, I want to give feedback on comfort levels, so the system can learn my preferences and fine-tune temperature setpoints for future energy-efficient control.
- **UR-DA:** As a Data Analyst, I want to compare predicted comfort with energy use data, to quantify potential energy savings from adaptive setpoint control.
- **UR-CP:** As a City Planner I want to know the thermal response of different buildings, which building has huge thermal energy flexibility potential and which building needs a great effort for energy-efficient renovation.

Table 1. Linking User Stories to Models and their status

Task	Component	Relevant User Stories	Status
2.2	**District Heating Forecast Model**	• **UR-DH**	Forecast models have been implemented for an offline data set for the Gellerup heat exchanger operated by Kredsløb. Work on

			API and setup for enabling data flow with online (i.e. frequent) updates of data and forecasts in progress.
2.3	**Traffic Model**	• **UR-DAT** • **UR-DM**	Traffic model for the City of Aarhus has been developed using data from the TomTom platform, complemented by relevant open data. The model is accessible via an OGC-compliant API and supports the creation of user-defined traffic scenarios. The model is integrated with the Model Coordinator, which is connected to the VC Map front-end interface (see below). Through this interface, users can easily select road segments on the map, apply closures or restrictions, run model calculations, and review the resulting impacts. The model is operational; however, further calibration is recommended, subject to the availability of additional observed data.
2.3	**Traffic Energy and Enviro Analysis**	• **UR-DAT** • **UR-DM**	Traffic Enviro Analyst (TEA) has been integrated into the macroscopic traffic model and its results are available via the same OGC-compliant API, enabling easy connection with Model coordinator in the future. TEA currently provides segment-level energy estimates and distinguishes between electric and combustion vehicles, with the option to extend outputs with additional indicators in the future (e.g. CO_2). All results are based on traffic scenarios defined by the user. TEA is not yet implemented in the VC Map interface.
2.4	**Occupancy Model**	• **UR-EP**	The occupancy indicator has been computed, based on socio-demographic variables, and can be mapped on the BIPED digital twin, showing occupancy variations throughout different times all over Braband, which can be used by an energy provider to detect electricity consumption peaks on fine granular and temporal scale. As the next step and with data availability, the model should be tested against actual electricity consumption data, which has not yet taken place due to lack of data availability.
2.4	**Wind Comfort Model**	• **UR-CP** • **UR-C** • **UR-DA**	The model has been applied to three case study areas of interest to Aarhus municipality and can be used by a city planner and a citizen to take informed decisions, or a data analyst to develop and expand data models.

2.4	**Green Space Accessibility Model**	● **UR-CP**	The model has been implemented, providing information on accessibility to various types of green space and can be used by a city planner to take informed decisions.
2.4	**Indoor Climate Perception Model**	● **UR-U**	The current version of the model which provides suggested setpoints to improve comfort (reduce complaints) has been implemented, and currently is under integration test.

3.2. Integration Requirements and link to User Stories

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 2. Integration requirements

Task	Component	Requirements
2.1	**BIPED Digital Twin core**	**conditional**: a well described Open REST API according to the OGC API Processes standard[2] **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
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
2.4	**Occupancy Model**	**conditional**: a well described Open REST API (documented e.g. in swagger)

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

		not conditional: a well described Open REST API according to the OGC API Processes standard
2.4	**Wind Comfort 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
2.4	**Green Space Accessibility 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
2.4	**Indoor Climate Perception Model**	**conditional**: a well described Open REST API (documented e.g. in swagger) **conditional**: indoor environmental data and use feedback **not conditional**: a well described Open REST API according to the OGC API Processes standard **not conditional:** the API provides a minimum layer of security, such as a token, an API key or a user-password

4. Models Integration

As described in D2.2, 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. (For more information about the Model Coordinator API, please see D2.2).

The refinement and design of the Model Coordinator frontend, with the required changes to the backend component has been carried out through close collaboration between designers, modelers and end-users. Below in Fig. 5 we present the frontend which has been designed and will be implemented in the coming months.

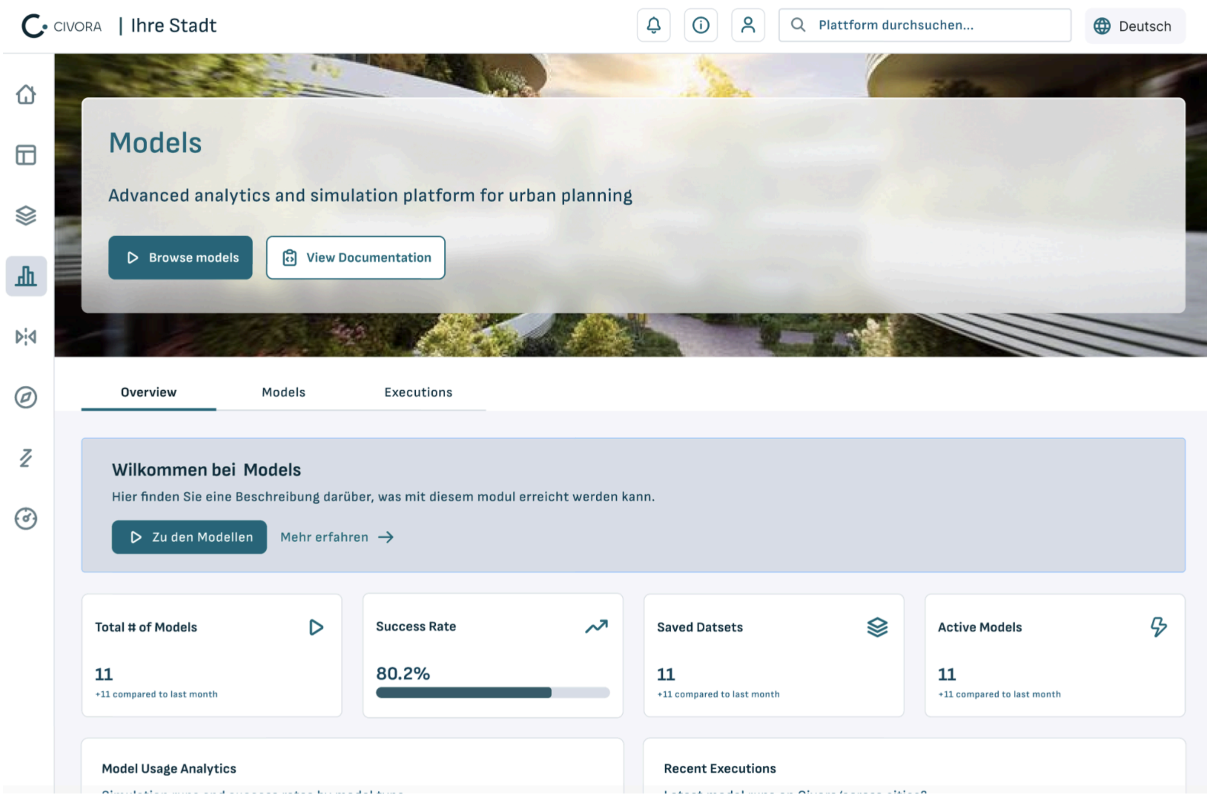


Figure 5. Models overview page in the BIPED DIgital Twin, based on Civora

While the new interface aims to enhance usability and adoption, the core features to integrate models are already in use. The Macroscopic Traffic Model is already connected and delivering results, and the Traffic Enviro Analyst will be integrated in the coming weeks. Moreover, the Model Coordinator is being used to run traffic simulations from the VCMap via the Traffic Module, which allows users to create their own scenarios.

4.1. Energy

4.1.1 District Heating Load Forecasting Model

The load forecasting model has been updated for application to the usecase dataset on the Gellerup heat exchanger. The data is provided by local district heating operator Kredsløb and consists of load measurements at the local heat exchanger in Gellerup. The data is stored and managed using the CDK platform. Initially, the load forecasting model was trained for the east region serviced by the Gellerup heat exchanger, to be used as a baseline model for the remaining south and west regions. Subsequently, additional sub-models were added for the south and west regions. Most recently the model was updated to address a number of data outliers for the east region caused by disruptive demand patterns. In its current state, the load forecasting model uses offline historical data sets for both training and prediction. The model emulates online (incremental) updates on the data, but is not yet coupled to a data flow in which online updates occur.

The data sets used by the model includes:

- Heat load observations from the Gellerup heat exchanger
- Weather observations for the local area
- Temperature measurements from a local weather station
- Weather forecasts for the local area

Heat load and local temperature observations were provided for a period stretching from early 2022 to early 2025. These observations were provided directly by Kredsløb in a static format without data updates. Historical weather forecasts made were extracted from MET Norway's THREDDS open data services for the same period. The next major update should ensure online dataflow between the model hosted by DTU and relevant stakeholders, e.g. Kredsløb. Current work is focused on integrating the updated model according to these initiatives.

4.1.2 Solar Potential Model

Solar potential calculations have been added to the VC Publisher backend framework described in D2.1 as a domain specific module. Because solar energy is an important building block on the path towards carbon neutral districts, city planners need to understand the overall solar energy production potential within the municipality or district, which varies based on the local climate and topography. For planning individual solar modules (thermal collector or photovoltaics) it is essential to estimate the expected energy output based on the installation site, the surrounding buildings and climate conditions. For estimating the energy flux between CV modules, solar batteries, wall boxes for charging EV, heat pumps, and household devices, it is also important to have a very fine grained temporal resolution of potential energy production.

The solar potential module precalculates all necessary values based on the 3D city models, which needs to be stored in a 3DCityDB (an open source object-relational database schema specialized for managing 3D city models). Raw energy potentials are first calculated for multiple positions on the building's roof and (optionally) wall surfaces. The spatial resolution of sample points is chosen so that roof structures such as dormers and chimneys can be clearly identified. The temporal resolution can be adjusted. Typically 24 calculations per day is sufficient - resulting in 8760 calculations per sample point for a cycle of one year. For each sample point the direct light from the sun and ambient light from the sky dome is taken into account. On the geometrical level, a ray-tracing algorithm is used for detecting occluders - which may be other building surfaces or trees. The energy levels of both direct and ambient light are modulated based on a global weather/climate model which contains average levels of luminosity and distribution of luminosity throughout the year and time of the day.

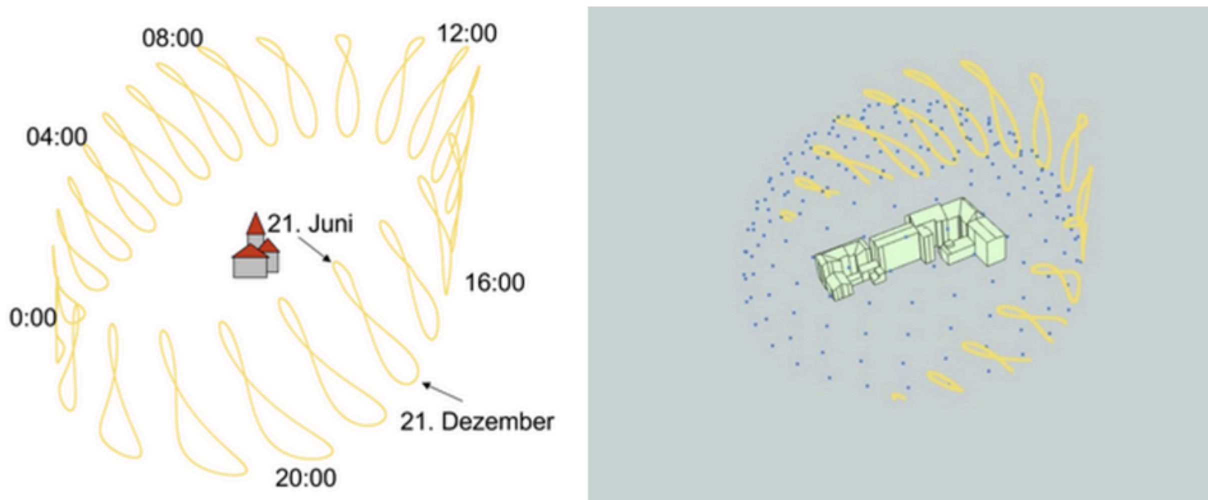


Figure 6. Sky positions for one sample point used for ray tracing and collecting luminance values in the solar potential module.

The results of the calculations in terms of kWh per year/month/hour are attached as additional properties in the 3DCityDB on the building surface elements. Aggregated annual energy levels are attached as color textures containing an easily comprehensible color ramp. The advantage of having a visual overview of solar potentials on all buildings of a district or the entire city is the possibility to identify the most cost effective measures either of private investments, public expenditures or funds granted.

In addition to the area-wide computation of static solar potential values, a tool for planning individual photovoltaic installations on rooftops has been developed and added to the Digital Twin solution as an interactive module. This module is intended to be used by private investors, house owners and energy managers in charge of public building complexes. The tool uses the same algorithms and data sources as the aforementioned backend module. It works very similarly as existing online solar planners but without the need to define slope and orientation of roof surfaces because it is embedded in an existing Digital Twin with accurate 3D information. It is also not limited to single roof surfaces but can cover complex installation scenarios. Figure 7 shows how to draw a rectangular area on a roof surface with high potential (indicated by red color), adjusting basic parameters such as household size and electricity cost and outputting complex financial charts (revenue/expense plan over time).

Figure 7. Solar Energy Planner embedded in the VCMap Digital Twin frontend used for planning individual PV installations.

The types of reports as a result of the calculations include a revenue/expense plan (balancing annual cost savings/revenues and expenses), a liquidity trend (indicating when to expect financial profitability), a financial plan (in case of a loan), a CO2 savings plan (showing the reduction of CO2 emissions in comparison to the national energy mix), and a key data report. Table 3 shows an example of an energy balance (as part of the key data report) of a big household with high electricity demand due to the presence of an EV and a heat pump, the PV modules covering an area of 100 square meters, and a bigger-than usual storage battery. The level of grid consumption can be cut to 46% of the energy demand. The energy used for manufacturing the components is offset after a little more than one year. Due to the surplus of energy yield, the net energy balance is positive. All this information provides very useful insights for grid providers and energy managers when developing scenarios of the future layout and workload of the electricity grid.

Table 3. Projected energy balance of a hypothetical PV installation for a household

Year	Energy yield	Energy demand	Storage losses	Direct consumption	Storage consumption	Grid consumption	Grid supply
1	23,967 kWh	13,700 kWh	822 kWh	4,110 kWh	4,110 kWh	6,302 kWh	15,747 kWh
2	23,847 kWh	13,700 kWh	814 kWh	4,089 kWh	4,069 kWh	6,355 kWh	15,689 kWh
3	23,727 kWh	13,700 kWh	806 kWh	4,069 kWh	4,028 kWh	6,409 kWh	15,631 kWh
4	23,608 kWh	13,700 kWh	797 kWh	4,048 kWh	3,987 kWh	6,462 kWh	15,572 kWh
5	23,488 kWh	13,700 kWh	789 kWh	4,028 kWh	3,946 kWh	6,516 kWh	15,514 kWh
6	23,368 kWh	13,700 kWh	781 kWh	4,007 kWh	3,905 kWh	6,569 kWh	15,456 kWh
7	23,248 kWh	13,700 kWh	773 kWh	3,987 kWh	3,863 kWh	6,623 kWh	15,398 kWh
8	23,128 kWh	13,700 kWh	764 kWh	3,966 kWh	3,822 kWh	6,676 kWh	15,340 kWh
9	23,008 kWh	13,700 kWh	756 kWh	3,946 kWh	3,781 kWh	6,729 kWh	15,282 kWh
10	22,889 kWh	13,700 kWh	748 kWh	3,925 kWh	3,740 kWh	6,783 kWh	15,223 kWh
Total *	**456,572 kWh**	**274,000 kWh**	**14,878 kWh**	**78,296 kWh**	**74,391 kWh**	**136,192 kWh**	**303,886 kWh**

4.1.3 Data-to-physics modeling framework for district heating buildings

A comprehensive, multi-layer framework that bridges data-driven analytics and physically interpretable modeling for characterizing the thermal behavior of buildings connected to the Brabrand district heating system has been established. Starting from raw hourly measurements of supply and return temperatures, flow rates, and total heat consumption obtained from CDK portal, the workflow systematically converts operational data into physically meaningful insights. The process begins with data preprocessing and load separation to isolate space heating demand from domestic hot water consumption. Subsequently, a two-stage clustering analysis is implemented: behavioral clustering captures the diversity of daily consumption patterns, while feature-based clustering built on physics-informed ARX modeling groups buildings according to their thermal response characteristics.

For each representative archetype, a physically consistent 1R1C grey-box model is calibrated using an Expectation Maximization algorithm, yielding key physical parameters such as the overall heat loss coefficient (UA), effective thermal capacitance (C), and solar gain efficiency ($\eta_{\square}$). These parameters are then transferred and adapted across buildings within the same archetype through a lightweight learning process, enabling scalable yet interpretable modeling of large building portfolios. The identified physical parameters can be directly embedded in digital twin simulation for supporting optimal control and flexibility assessment. For example, coupling this framework with real-time monitoring and predictive control will enable adaptive operation strategies that exploit building thermal storage and enhance overall system efficiency and decarbonization potential.

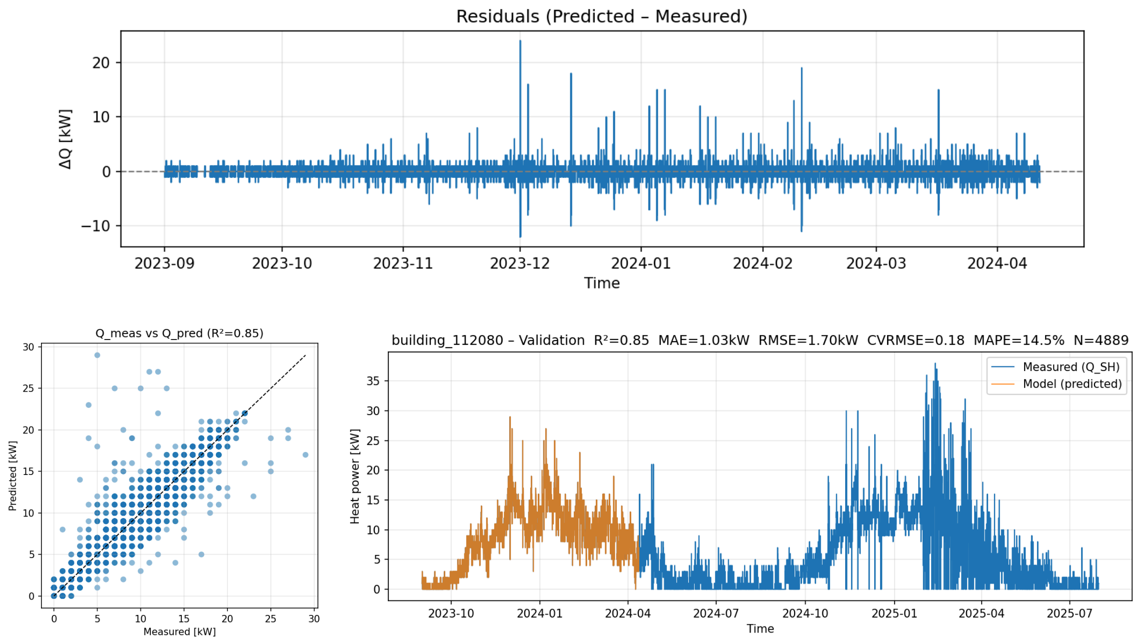


Figure 8. Model validation results ("Engdalsvej 18" as example)

The comparison between the measured and simulated space heating load demonstrates a strong agreement throughout the entire heating season. As shown in the time-series plot, the RC model successfully reproduces both the seasonal and short-term dynamics of the building's thermal demand, with only minor underestimation of peak loads during the coldest periods. The scatter plot between measured and predicted heat power exhibits a tight distribution around the 1:1 line (R^2 = 0.85), confirming the model's high explanatory capability. The residual plot further indicates that the errors are randomly distributed without evident seasonal bias or drift, implying a stable and unbiased model structure. Overall, the model achieves a good balance between physical interpretability and predictive accuracy, with MAE ≈ 1 kW and CVRMSE ≈ 18%, which is well within the typical range recommended by ASHRAE Guideline 14 for hourly models.

4.2. Mobility

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

Besides the integration, updates to the macroscopic traffic model were made. The underlying computation algorithms were significantly revised. A new solution was implemented that applies a dual-graph representation, where network edges are transformed into nodes and intersections into links. This structural change improves the accuracy and efficiency of traffic flow calculations, particularly for complex intersections and turn restrictions, and enhances the model's readiness for integration with advanced energy impact analysis modules.

The macroscopic traffic model has also been integrated into the VC Map front-end interface, where a new module for scenario simulation was implemented by VCS. This feature allows users to interactively define and execute traffic scenarios directly within the application, with computation results displayed within seconds. Compared to the previous release, where only pre-defined scenarios were available. This represents a major step forward in usability and flexibility. Currently, the implemented functionality allows users to simulate scenarios involving closure or restriction of individual road segments.

Despite these advancements mentioned above, the model calibration has not yet been completed. The main reason lies in the limited availability of calibration or high-precision reference datasets. Efforts to obtain suitable data were undertaken in cooperation with AAKS, but sufficient data quality and coverage could not yet be achieved.

Similarly, the planned densification of the network model has not been realized, as it depends on the same data limitations. The current network structure remains operational and adequate for scenario testing; however, its resolution in certain areas remains below the intended target.

Once available, the new data will be included in a GLayer dashboard available on the BIPED Civora Data Hub, similar to the existing limited dataset. The dashboard will be able to take full advantage of the extended dataset thanks to its advanced filtering and aggregation capabilities while keeping the data exploration user-friendly thanks to its visual nature.

The Traffic Enviro Analyst (TEA) has been fully encapsulated within the traffic model architecture, enabling both systems to operate under a unified structure. Its outputs are now accessible through the same OGC-compliant API as the macroscopic traffic model, ensuring interoperability and simplified data exchange. This integration allows external applications (especially Civora and VC map) to access environmental and energy indicators alongside traffic results in a harmonized manner.

The TEA module itself has been extended with higher-resolution energy computations. Compared to the previous version (v1.0 described in D2.2), where total energy consumption was provided only at an aggregate level, the new version delivers segment-level energy use estimates. In addition, results are now differentiated by propulsion type, distinguishing between electric vehicles and conventional combustion vehicles. This refinement enables more detailed assessments of energy consumption patterns and supports advanced scenario-based evaluations of energy impacts.

4.2.2. Integration plans of a microscopic model extension

During the subsequent project phase, further steps in establishing the linkage between the macroscopic and microscopic traffic modeling frameworks were taken. The required model interfaces have been specified and implemented, enabling the exchange of aggregated flow and demand data from the macroscopic model to the microscopic simulation environment. The microscopic base model for the Brabrand district has been calibrated and validated using macroscopic traffic performance indicators to ensure spatial and temporal consistency across modeling scales.

Scenario analyses are currently being conducted to evaluate the system’s response under varying demand levels, network configurations, and control strategies within the defined framework. Although a fully dynamic coupling with the digital twin platform is not feasible within the current project scope due to computational and integration constraints, a proof-of-concept mock-up will be developed. This mock-up will utilize precomputed simulation results to demonstrate the interoperability of the models and the potential for real-time visualization and decision support within a digital twin environment.

4.3. Cross-Sectorial

4.3.1 Building Occupancy Model

The Building Occupancy Model estimates the number of people present in their homes at any given time (i.e. time of day, day of week, monthly and yearly) on a fine temporal and geographic level. Fine granular levels of occupancy allow for the detection and prediction of high electricity demand peaks within Branband, and hence, stakeholders taking informed decisions. It relies on baseline demographic data and categorizes the population into nine distinct age groups, ranging from young children (> 7 year olds) to elderly individuals aged 80 years and above.

The model recognizes that different demographic groups exhibit distinct daily activity patterns and are therefore not equally likely to be at home throughout the day. For example, younger age groups such as school-aged children are typically away from home during school hours, generally from morning until early afternoon, while retirees or pensioners tend to spend more time at home. Across all groups, nighttime hours (00:00–06:00AM) show the highest likelihood of people being at home.

These behavioral assumptions are translated into probability distributions for each demographic group and time period. The probabilities are adjusted for various time intervals (e.g., morning, afternoon, evening, and night) as well as day types, distinguishing between weekdays (Monday to Friday) and weekends (Saturday and Sunday). Combining demographic data with these time-dependent probabilities allows the model to estimate the likelihood of home occupancy for any specific time of day and population segment. The output is generated in tabular format but becomes especially insightful when visualized spatially, as shown in Figure 8. The model currently operates on a 250 × 250 m spatial resolution, allowing the estimation of occupancy patterns across different urban environments, from high-rise residential buildings housing hundreds of people to smaller neighborhoods with detached homes. The aggregated occupancy data can also be explored within the GLayer visualization, which allows user-friendly filtering options and different aggregation methods to gain further insights from the data.

Ongoing developments are focusing on increasing both the spatial resolution (toward 100 × 100 m grids) and the complexity of input parameters. This includes integrating additional variables such as socioeconomic status, employment status, education levels and public holidays, which influence daily routines and time spent at home.

Finally, in a next step, the occupancy model aims to link these occupancy patterns with electricity demand. By correlating occupancy probabilities with electricity consumption data (currently being collected), the model will help identify peak demand periods, e.g., early mornings and evenings, and improve the accuracy of energy consumption forecasting. Privacy protection remains a central consideration, especially as the model evolves toward higher-resolution data and more detailed population characteristics.

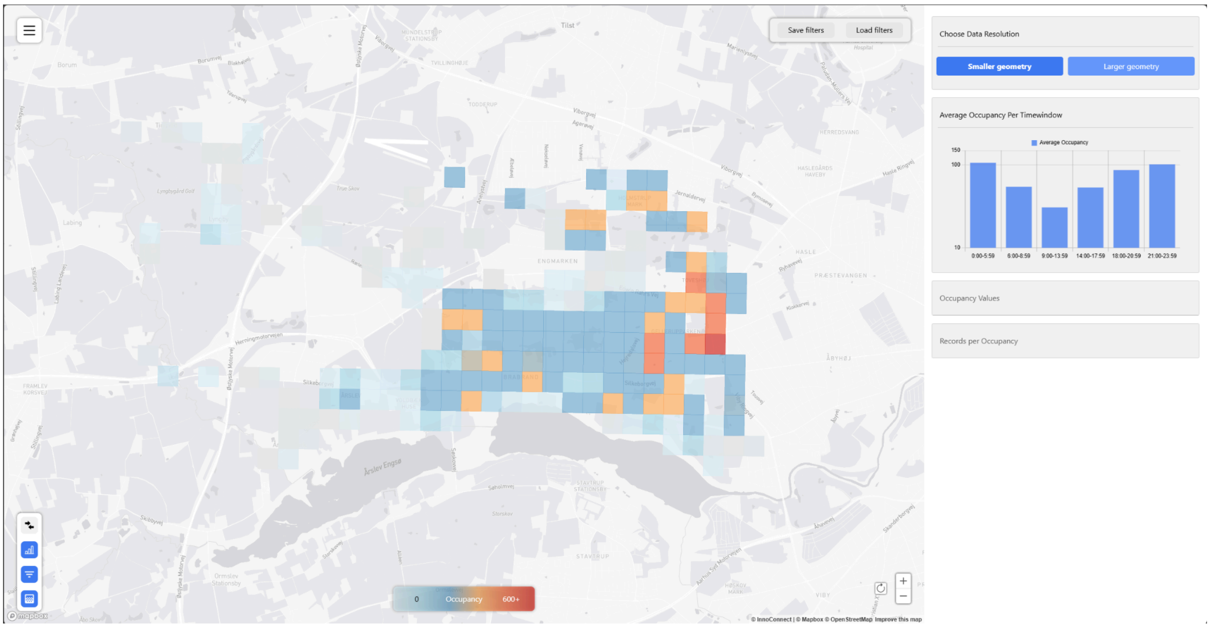


Figure 9. Occupancy distribution showing the estimated number of persons at home per grid cell at a certain timeslot (i.e. 6-9am), based on the area's socio-economic profile.

4.3.2 Wind Comfort Model

The Wind Comfort Model uses an AI-driven approach to calculate soft perceptual properties of wind comfort levels in open space and relates them to suggested activities, such as if an area is inviting for sitting and spending some time (indicated as blue), or just to walk fast through (indicated as red).

All Simulations are based on the full year, all hours of the day (so mean annual values), using the General Lawson Criteria for measuring pedestrian wind comfort. Datasets in use include weather data and the 3D model, as included in the BIPED digital twin.

- **Purpose:** General Lawson criteria act as a more simplified rule-of-thumb design guide for pedestrian wind comfort. While it still draws on extensive research, it offers broader guidance not requiring complex simulations.
- **Interpretation:** Emphasis is on providing threshold wind speed values that indicate "comfort" versus "discomfort" scenarios, balancing design simplicity with engineering reliability.
- **Application:** Frequently employed during early development project stages or in contexts where detailed wind simulation is not feasible.

Simulation areas are limited to 500x500m grid cells, covering in BIPED 5 areas of interest as discussed with and selected by AAKS Aarhuns Municipality: 1. Silkeborgvej, 2. Hovedgaden, 3. Brabrandstien, 4. J.P. Larsensvej, 5. Edwin Rahsvej.

Figure 10. Initial Example Wind Comfort Braband

4.3.3 Green Space Accessibility Model

Accessibility and availability of public green space is an important feature defining urban life quality, public health as well as urban sustainability and energy demand by impacting significantly urban cooling and the appearance of urban heat islands. Knowing about the population's green space accessibility or the lack thereof allows city planners or municipalities to take informed planning decisions supporting local well-being and the city's sustainability by lowering energy demand for cooling.

The green space accessibility model is designed to evaluate and visually represent a region's access and offer of green spaces, taking into account not only physical distance but also visibility and availability as factors in the calculation. Accessibility to green space

The model uses geographic information data on greenspaces and road network data available on different Danish systems, such as GeoData Denmark, the Danish Environmental Protection Agency (MST) and WebKort Aarhus Kommune, among others. The different data sets were pulled directly from the systems in a GeoJSON format, to enable visualization and processing of the green space layers in QGIS. Green space data is combined into one single green-space structure file, considering all types of available green public spaces, as well as kept as separate layers to process individually and provide more detailed information on accessibility to each type of green zone evaluated.

The produce of the model is a heatmap visualization on a 100X100m grid, classifying each grid square in one of four categories, depending on the following parameters:

- A = network path distance to green space 0–50m
- B = network path distance to green space 50–100m
- C = network path distance to green space 100–250m
- D = network path distance to green space >250m

The heatmap grid output of the model is currently integrated within the BIPED platform, showcasing the general green space accessibility analysis and the disaggregated layers analysis.

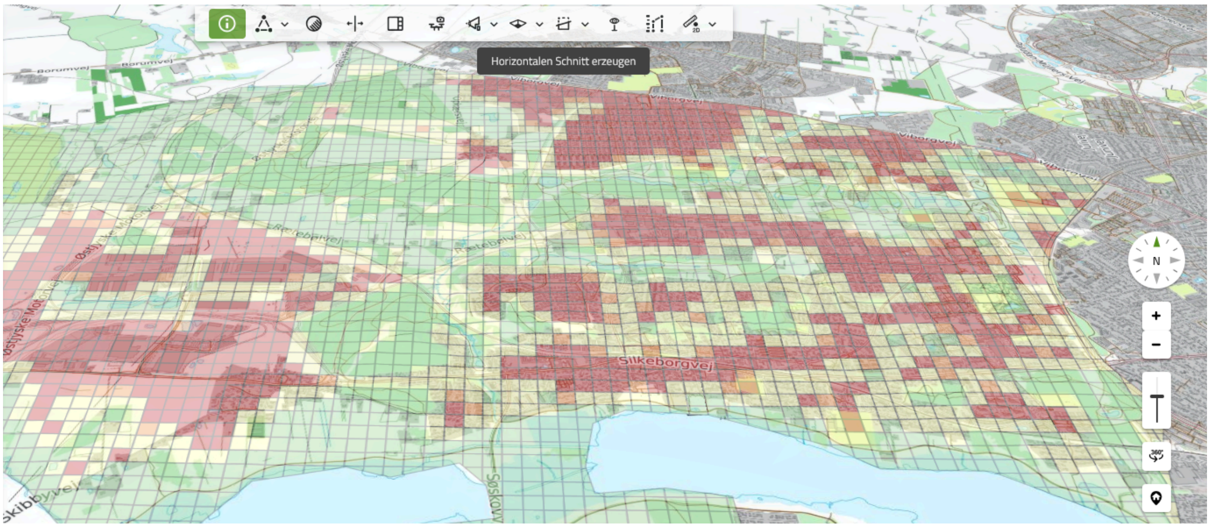


Figure 11. Green Space Accessibility Braband (red >250m - green >50m)

4.3.4 Indoor Climate Perception Model

The Indoor Climate Perception Model is designed to predict and improve occupants' thermal comfort by suggesting optimal setpoints that reduce discomfort and energy use.

The model was trained on data from DTU, Building 303B, with indoor environmental data from sensors (temperature, humidity, CO2) and feedback data from employees (perception of temperature). The example data is available on Dynsyshub platform as datasets, both indoor environmental data and feedback data.

The current version of the model which provides suggested setpoints to improve comfort (reduce complaints) is deployed and available to be used with specific data and format of data.

Data for the model is collected from a few buildings in Aarhus kommune, both feedback data and indoor environmental data. It is live data, regularly updated and available from 05/2025 onwards.

The model is not integrated with the BIPED platform or automated. Currently, the process of automating model execution on Dynsyshub platform is being finalized and results of the model will be available as a live dataset.

The next step is to integrate it with the BIPED platform for automated execution of the model or getting results data of the model for visualization in the platform.

4.3.5 Soft Data

The consortium has defined which soft (less tangible by numerical values) datasets are needed for WP2, and has now a structured list developed together with partners and external stakeholders. These datasets cover a broad set of social, behavioural, organisational and environmental factors that influence how people use energy and interact with their surroundings. Datasets will be collected and combined with quantitative data (i.e. age groups of population demographic properties) to bring findings on quantitative level (see next steps in Chapter 6).

Below is a tentative list of the datasets that have been identified (disclaimer: the list might change slightly as we proceed with data collection and integration):

Table 4. Tentative list of identified soft datasets

Group	Variable	Description
General Well-being	**Sense of safety**	How safe residents feel in neighborhoods, streets, and public spaces.
	Sense of Community / Social cohesion	Trust, neighborly support, and strength of social networks.
	Environmental perception - Green Space accessibility	Opinions on green spaces accessibility
	Mobility experience	Perceived convenience and safety of cycling, walking, and public transport.
	Cultural participation	Attendance at theaters, museums, festivals, and local cultural events.
	Local identity/pride	Emotional attachment and pride in city or neighborhood.
	Inclusivity perception	Feelings of equality, diversity,
Social & Behavioural Factors	**Energy consumption behavior**	how residents use appliances, heating, and cooling systems.
	Awareness of sustainability goals	residents' understanding of the district's energy objectives.
	Willingness to change habits	openness to adopting energy-saving behaviors or new technologies.
	Variability of occupancy	variability in when and how spaces are occupied (e.g., work-from-home trends).
	Community engagement level	participation in shared energy initiatives, events, or decision-making.
	Trust in energy management systems	confidence in digital tools or algorithms managing local energy.
	Social norms	perceived expectations about energy conservation within the community
	Lifestyle preferences	demand for comfort, mobility, and amenities that influence energy use.
	Equity and inclusion perceptions	whether energy benefits are perceived as fair across residents.
	Cultural attitudes toward technology	acceptance or resistance to automation, smart meters, or renewable systems.
Organizational & Governance Factors	**Maintenance culture**	attitude toward regular maintenance and upkeep of systems.
	Data sharing willingness	openness among stakeholders to share operational or behavioral data.
	Communication effectiveness	clarity and transparency in messaging about energy performance.
Environmental Factors	**Noise Pollution**	Perceptions of noise levels in ones home environment (i.e. traffic noises etc)
	Traffic Emissions / Air Quality	Perceptions of air quality in onces home environment
	Wind Comfort Level	Perception of wind comfort

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. The demonstrator can be accessed through:

https://bi-ped.civora.org/app/home

5.1 Data Hub Civora

The BIPED Civora data hub is the central entry point for the digital twin environment. In the latest iteration, a new landing page was developed and made fully public, without password restriction. The new landing page enables different end users (cf. chapter 3, User Stories) to quickly find their way around. In addition to the Digital Twin environment, BIPED Civora Data Hub also allows access to the Dashboards that provide a user-friendly option to visually explore some of the source data used for the Digital Twin models. They are powered by GLayer which allows quick filtering and data aggregation and provides both a high-level intuition about the data, as well as easily ingestible deeper insights.

Figure 12. Updated Landing Page of the BIPED Civora Data Hub

5.2 BIPED Digital Twin

The general software architecture and conceptional user interaction framework of the Digital Twin solution has been outlined in D2.1 and D2.2. The foundation of implementing a predictive and future-ready Digital Twin (see maturity model concept Annex 1) has been established by integrating the man-made and natural environment of the Brabrand district and the entire city of Aarhus in a level of quality which is sufficient for planning purposes and urban simulation tasks due to the usage of reliant cadastral data. The focus of the further developments have been on dynamizing the creation of what-if-scenarios and establishing domain-specific "applications" within the DT for addressing the aforementioned computational models. Furthermore, accessing geospatial data sets managed by the BIPED storage layer and by the INSPIRE data community has been streamlined by leveraging catalog and meta data technologies.

5.2.1 Modularization of the User Interface

In order to facilitate the user interaction with the Digital Twin frontend and streamline working with energy and traffic related use cases, the concept of UI modules has been introduced. Interacting with DT related content and methods happen on various levels using a combination of different tools. Not all of these elements are necessary when working within a specific domain or running PED specific simulations. UI modules can be used as a means to change the appearance of the application by moving hidden content in the foreground or activating additional functionalities. In the BIPED DT map frontend (see Annex 2, Reference 2) these UI modules are presented on startup in order to showcase the topics that can be handled and to allow an easy to comprehend entry point for end users. Figure 12 shows the currently configured UI modules in VC Map.

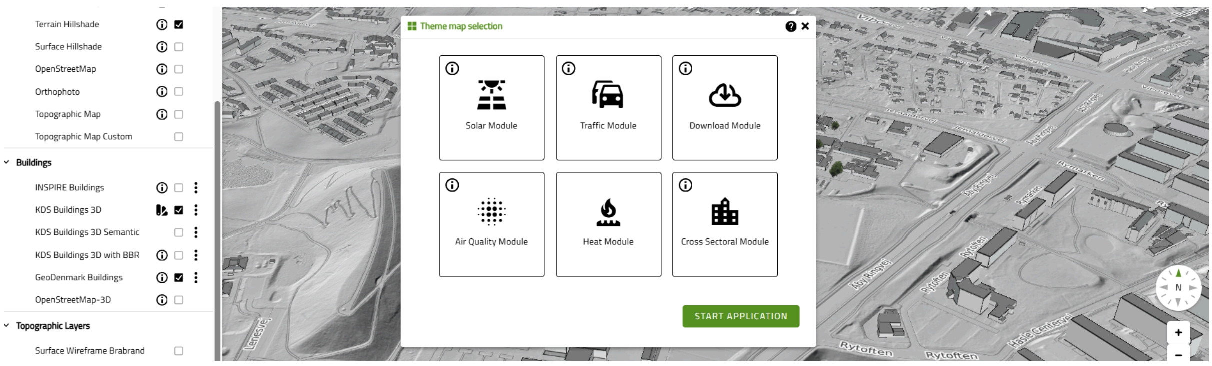


Figure 13. UI modules as presented in the VC Map on startup.

Each UI module can be seen as a group of configuration elements infusion content and functionality in the following categories: 1. new information layers such as vector maps, overlays and background maps; 2. new plugins addressing specific tasks or functionalities, each potentially coming with its own UI; 3. change the operation mode (2D map, 3D globe, oblique imagery, panoramas); 4. new viewpoints zooming to the area of interest; 5. new dynamic styles changing the way of rendering existing content.

As an example, the Traffic Module changes the operation mode to 2D map because the 3D city model was not deemed necessary for traffic related problems. A new road network layer is added to the content tree and activated using a set of new declarative styles to choose from. A new plugin is added and activated allowing users to change the properties of the traffic model and run simulations as described further down in this chapter.

5.2.2 Catalogue integration

Having a consistent data management layer is an essential part of any Digital Twin initiative. Its purpose is not only to enable access by planning, evaluation, communication or simulation applications in an interoperable and sustainable way but also to allow discovery and usage by stakeholders in order to solve analytical problems that have not been identified yet. The catalogue module as part of the CIVORA platform is therefore a key component of the data management layer, making meta data about all data involved in the Digital Twin available in a transparent and self-explanatory manner. For this release of the BIPED Digital Twin, an access point has been developed and added to the frontend map application. It is leveraging semantic web technologies and open communication protocols (e.g. OpenAPI) for discovering and using spatial data provided by catalogue service as implemented by the Piveau open source project and others. Figure 13 shows the user interface of the catalogue module, how to access meta data of spatial data layers and how to use them in a map environment.

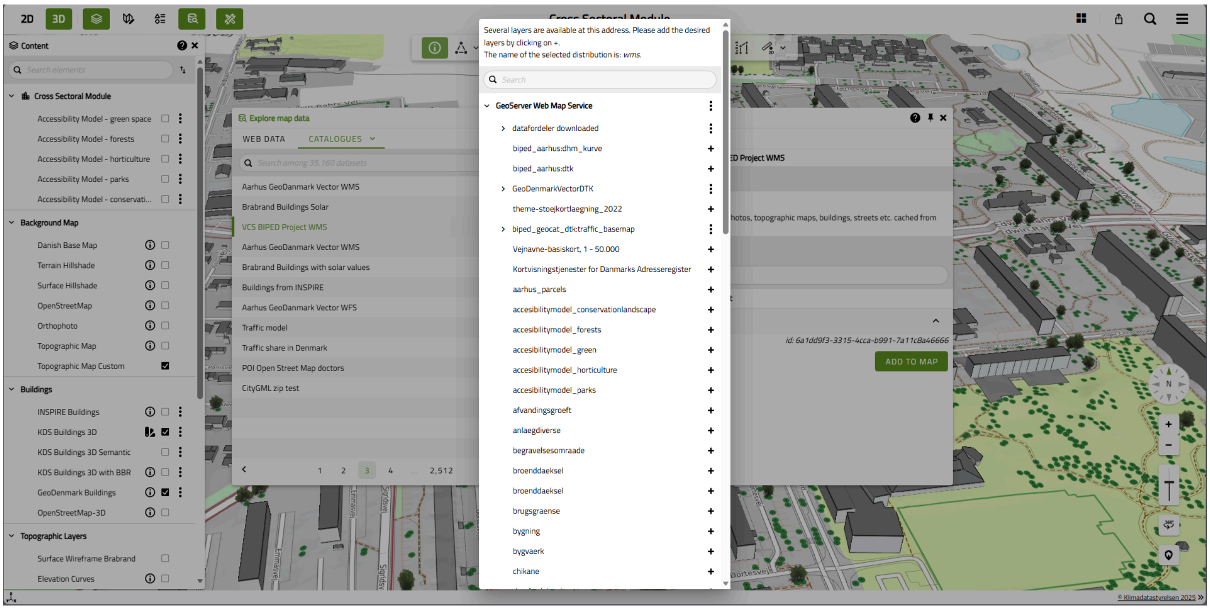


Figure 14. Catalog interface of the VC Map frontend

In case of OGC compliant web services such WMS, WMTS or WFS, content can be added directly to the current work space as a dynamic layer. Currently, two catalog instances have been pre-configured, ready to be used by BIPED stakeholders: the catalogue managed within the BIPED Civora platform and a catalog managed by the European INSPIRE initiative containing more than 1.9 Mio data sets. By infusing external data from European data communities we hope that BIPED end-users may benefit from other urban planning related activities in terms of PED development.

5.2.3 Macroscopic Traffic Model Integration

The integration of the macroscopic traffic model as briefly described in D2.1 has been fully automated and made configurable by the end user. The approach and implementation used for this model integration can be seen as a template and best practice to be applied to other models as well. Each model requires specialized data input strategies and result visualizations, which is why it requires a dedicated VC Map plugin. Figure 14 shows how to interactively select road segments and change the maximum speed or traffic flow on these segments.

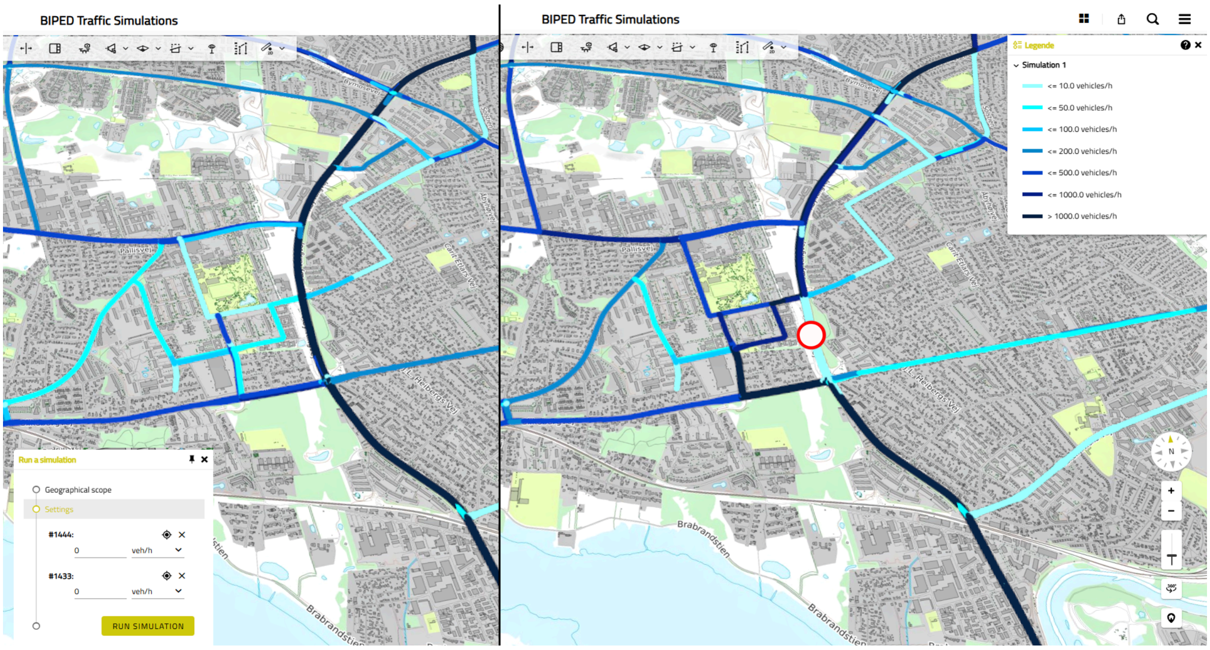


Figure 15. User interface defining traffic calming or road block scenarios. Left: default traffic flow and input dialog for creating a scenario. Right: traffic flow as a result of a modified road network.

The actual computations are handled by the Civora Model Coordinator (MC). The road network modifications are matched to an existing base traffic model by IDs. The communication between the VC Map traffic plugin and the MC follows the principles laid out by the OGC Processes API using asynchronous requests. Once the traffic simulation is complete, the results can be downloaded as a JSON data package. Mapping the resulting traffic values to the road geometries is done by a dedicated server component with access to the reference traffic model. Applying colors indicating the traffic flow is done by the VC Map plugin. We defined two ways to colorize the traffic flow: 1. The absolute number of vehicles per hour; 2. The “traffic level” as an indicator of utilization relative to the capacity. The formula for calculating the traffic level is as follows:

$$\textit{traffic level} = \textit{traffic} / ((\textit{capacity} * 20) / 24)$$

With traffic and capacity measured in vehicles per hour. Low values indicate free flow traffic. High values (larger than 1) indicate severe traffic disruptions (see also Table 5).

Table 5. Symbolizing traffic levels as a result of macroscopic traffic simulations

Traffic level	Traffic level	Symbol
Almost no traffic	<= 0.001	
Fluent traffic, individual vehicles passing	<= 0.45	
Fluent traffic, small groups of vehicles passing	<= 0.65	
Continuous traffic, circulation speed lower than the allowed maximum	<= 0.85	
Traffic jams emerging, circulation speed significantly decreased	<= 1	
Traffic jam, the vehicles do not move at all or only slowly	> 1	

6. Conclusion & Next Steps

This report details the second release of the BIPED digital twin, including updated and extended energy (T2.2) and mobility (T2.3) models, as well as initial cross-sectorial models (T2.4) as a demonstrator. Accompanying and documenting the current work process as of M24, 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 presented requirements and model integration steps, the following lessons and next steps can be highlighted, which will determine the further development towards the Final Release (D2.4) by the end of 2026 (month 36):

Energy:

- The updated load forecasting model is in early stages of integration with the set of tools of the digital twin. It is important that integration is done to match stakeholder and end user needs. Upcoming work on integration should thus focus on aligning expectations and collaborative efforts of the involved partners. The integration should establish a bidirectional, online dataflow between the model and the set of digital twin tools.
- The Testbed model is currently in the development stage. District heating consumption data for the buildings available on the CDK platform has been analyzed, and preliminary analysis results have been produced. Ongoing discussions are taking place to define the potential next steps and guide further model development.

Mobility:

- Following key advances were realized in this project phase: The macroscopic traffic model underwent fundamental restructuring using dual-graph representation, significantly improving accuracy for complex intersections and turn restrictions. An interactive scenario simulation module was integrated into VC Map, enabling users to quickly design and test scenarios—a major usability leap from pre-defined options. The Traffic Enviro Analyst (TEA) achieved encapsulation to the traffic model with segment-level energy computation differentiated by propulsion type (electric vs. combustion vehicles). The microscopic model established interfaces for macroscopic-microscopic data exchange, including a proof-of-concept. Model
- Continued efforts will be made to obtain high-quality datasets necessary for both the calibration and densification of the macroscopic traffic model. Coordination will be maintained primarily with AAKS to secure appropriate data sources. If suitable data become available and sufficient time and resources remain within the project framework, the calibration and network densification will be executed accordingly to improve model precision and reliability.
- Another key objective is the integration of the Traffic Enviro Analyst outputs into the Digital Twin platform (VC Map and Civora). The planned implementation will likely take the form of a new map layer visualizing energy consumption by propulsion type, allowing users to interactively explore spatial patterns of energy use and compare electric versus combustion-based mobility impacts across the city network.
- Work will also continue on the progressive integration of the traffic model within the VC Map interface. This includes the extension of user functionalities such as adding new nodes and network segments, and the editing of traffic generators (zones) that define origin-destination distributions across the network. These enhancements aim to transform the model from a pre-configured analytical tool into a fully interactive

planning environment, supporting both scenario design and direct model manipulation by end-users.

Cross-sectorial:

- The Occupancy Model in its initial stage as presented in D2.3 is based on a geographic granularity of 250x250m grid cell size, including demographic properties of age groups. Currently we are in discussions to receive data on finer level of granularity (100x100m grid cell size) and including in addition other socio-economic properties (i.e. level of income, level of education) to be added to the model. In addition we are in discussions receiving data on electricity consumption, that will be used in relation to our occupancy model outcome, indicating its performance.
- The Wind Comfort Model will be used in discussions with relevant stakeholders, i.e. the municipality, mobility experts and urban planners. For now, the model shows 5 areas of interest that can potentially expand for further discussions.
- The Green Space Accessibility Model will be used in discussions with relevant stakeholders, i.e. the municipality, mobility experts and urban planners. The model will be combined with socio-economic information, relating green space accessibility to different socio-economic groups of population.
- The Indoor Climate Perception Model is in the integration stage now. The model has been successfully developed and validated using sensor and feedback data. The current version provides optimal setpoint suggestions to improve comfort and reduce energy consumption. Data collection has been expanded to include several buildings in Aarhus Kommune, with live data streams available from May 2025 onwards. The model is operational on the Dynsyshub platform and accessible for use with standardized data formats. The next step involves integrating the model with the BIPED platform to enable automated execution and visualization of the results within the digital twin environment.
- Together with WP3 and in some cases supported by students from Aarhus University, questionnaires and interviews will be conducted in a next step to collect soft data variables where the data is not available in a digital format, besides collecting baseline demographic data of participants (i.e. age), allowing us for upscaling results on quantitative level. Data will be then integrated into the BIPED Digital Twin platform together with the modelling teams. A report describing how these datasets have been collected, processed, and incorporated will be included in D2.4.

Data Hub CIVORA:

- Integration of BIPED models. Here a selection of key models will be prioritized and a guide on how further models should be integrated will be delivered. The models that are the most advanced in regards to integration are:
    - Room Comfort model
    - MAPED
- End-user testing in January in Aarhus
- The current Data Catalog will be extended with the feature “dataset level access control”, which will allow owners of a dataset to choose which users/groups should be able to view (or access) their dataset. This feature will enable BIPED partners to continue including more datasets in the Data Catalog. We hope that this will help support the efforts of including more soft data, by providing a solid technical backbone for data governance.

- Integration of further GLayer dashboards, subject to data availability

BIPED Digital Twin:

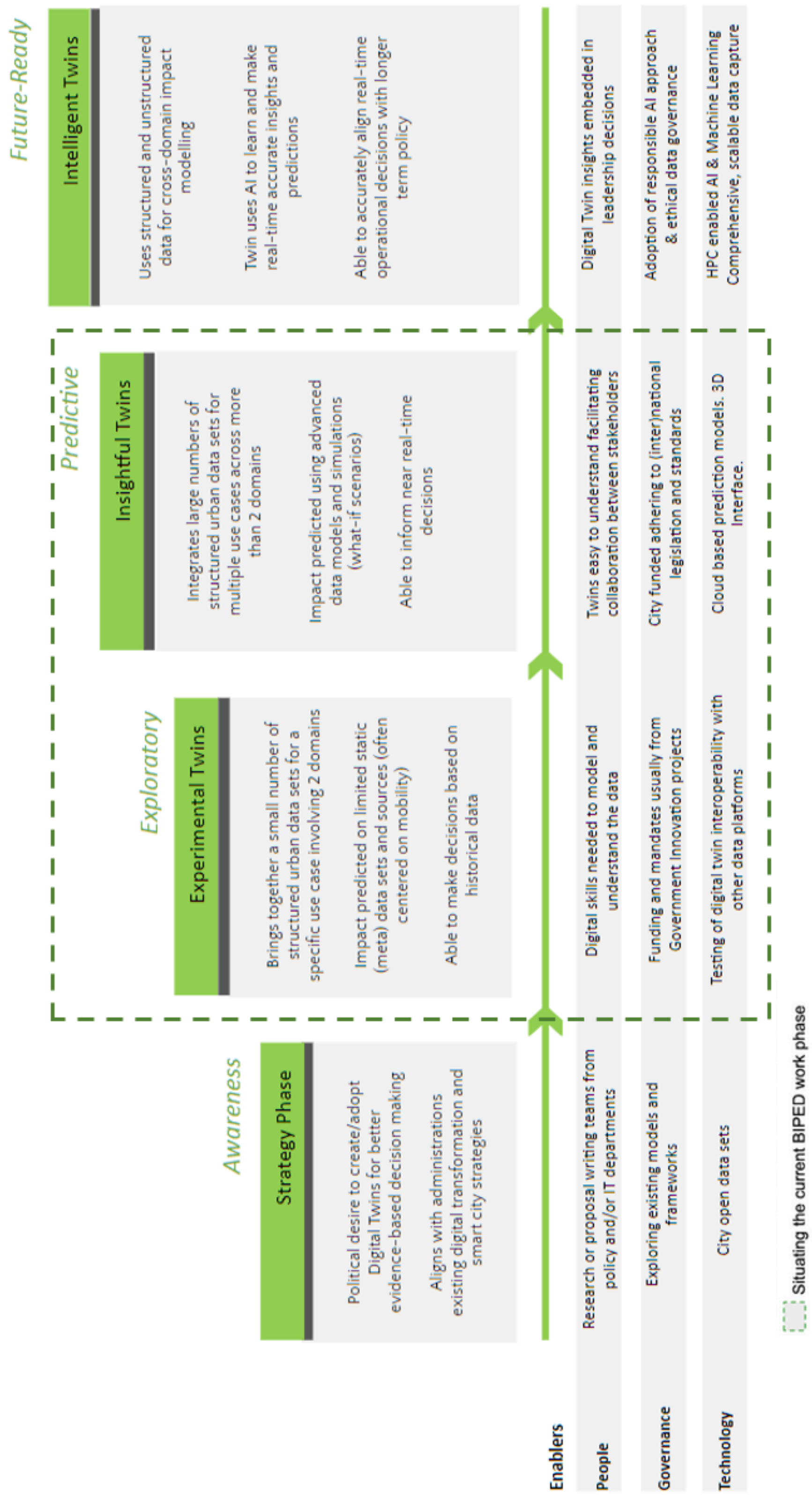
- Key concepts for how to integrate energy-, traffic- and cross-sectorial models have been established in the past project phase. The focus of the further development of the Digital Twin will be on the integration of output generated by these models in terms of data integration and providing additional domain-specific functionalities - especially regarding cross-sectorial content and soft data.
- An upcoming task will be the inclusion of results from Traffic Enviro Analyst (TEA) as a byproduct of the traffic simulations. The methods of how to access the results are already in place.
- Soft data will be evaluated in terms of suitability to be overlaid with spatial content. Not all data points have a spatial component, but if they do then an additional entry point to soft data can be integrated in the map, or symbolization can be used for creating meaningful map overlays.
- Data on the current state of the district heating system in the Brabrand area has been available by CDK to be used in BIPED. This data is accessible via an API and includes the current heating demand of selected buildings. The API provides heat production and demand values on an hourly basis but due to privacy issues with a delay of one day. A strategy will be developed for incorporating this information in the Digital Twin.

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 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
6	Indoor Environmental Quality - User Comfort	Indoor comfort perception model	https://dynsyshub.compute.dtu.dk/models/bb8d36e0-d915-40c4-914f-3fb614c772ce	Model description and example data can be found on the link with direct model on dynsyshub platform. Model can be run via the API https://dynsyshub.compute.dtu.dk/api/docs It is completely open without auth.
7	Building Occupancy	Building occupancy dashboard (GLayer)	https://glayer-dev.innoconnect.net/biped-occupancy-demo	Visualisation of the modelled building occupancy data in Aarhus