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Climate-Resilient Development Pathways in Metropolitan Regions of Europe – Deliverable

Deliverable 4.2 Digital Twin Architecture

July 2025

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Abbreviations

Abbreviation	Meaning
DT	Digital Twin
CSA	Case Study Area
MRE	Metropolitan Regions of Europe
IoT	Internet of Things
FDMS	Federated Data Management Solution
API	Application Programming Interface
AAI	Authentication Authorisation Infrastructure
IDSS	Impact-Based Decision Support Service
PoC	Proof of Concept
UI	User Interface
OGC	Open Geospatial Consortium
WMS	Web Map Service
WFS	Web Feature Service

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Executive Summary

The deliverable D4.2 Digital Twin Architecture presents the technical architecture and the core concepts of the CARMINE Digital Twin platform that aims to host and support the eight digital twins that are being developed in the CARMINE project, one for each Case Study Area (CSA). The deliverable is of type “Other”, and this document presents the initial architecture of the platform, which will be evolved and updated during the project implementation, to accommodate the needs of the different digital twins, which are diverse in nature, maturity and technical requirements.

The CARMINE DT Platform is being designed in a modular way and can support the digital twins in the decision making and visualisation aspects. Concrete services have been developed to ingest, transform and process data from the digital twins and their models, make them available to the end-users and facilitate the decision making through the support of scenarios and the interactive visualisations of the outputs. This deliverable dives into the technical details of this platform and its services, while also highlighting its interactions with other CARMINE services and tools.

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1 Introduction

Deliverable D4.2 is part of WP4: “Co-developing Digital Twin Simulations to Enhance Cross-sectoral Climate Resilience Frameworks”, aiming to co-develop Digital Twins (DTs) in the CARMINE eight Case Study Areas (CSA), to advance the cross-sectoral climate resilience and the management of disaster risks in the corresponding Metropolitan Regions of Europe (MREs). Each DT has a specific focus based on the areas identified challenges and it delivers a concrete output that targets the relevant stakeholders. To support the different DTs a platform is being designed and developed, as part of T4.2 and this report presents the architecture of this platform.

The digital twins are at different maturity levels and progress at a different pace, and as such the platform’s architecture could be potentially updated and extended to ensure it serves any new requirement that may arise.

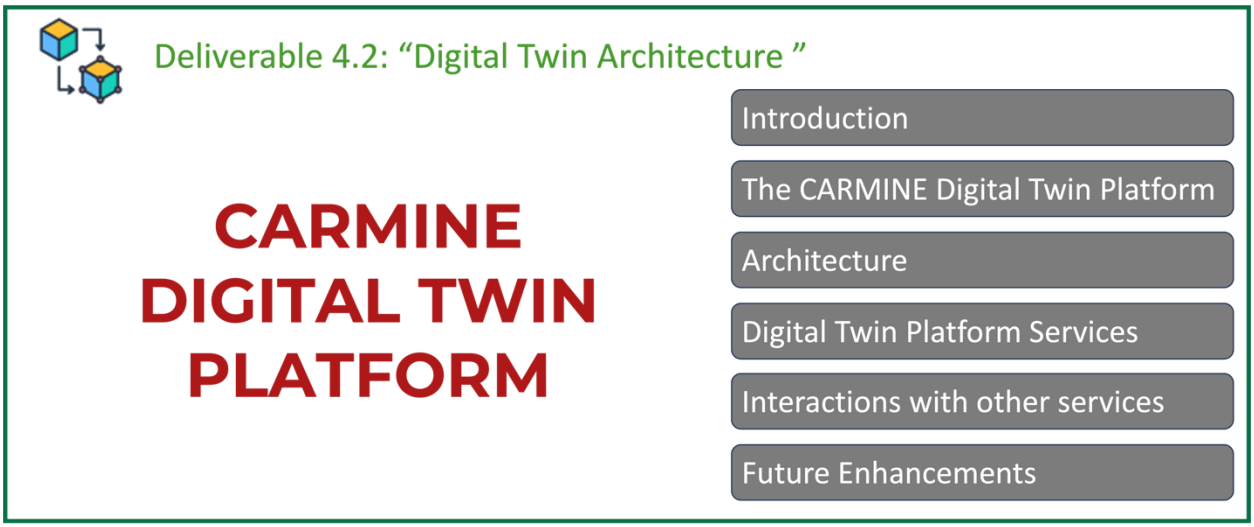

Figure 1: Deliverable D4.2 structure

2 Core Principles of the CARMINE Digital Twin Platform

The CARMINE Digital Twin platform is designed and developed under the following core principles:

- Support all eight CARMINE digital twins.
- Host and process data from different sources, types, and formats.
- Connect with repositories using various APIs and standards depending on where and how the source data of each DT are stored.
- Offer data processing / analysis services on demand, depending on the data and the scenario.
- Offer dedicated / isolated dashboards for each DT, where only authorized users can access them.
- Provide different types of visualizations to support the different scenarios and facilitate decision-making.
- Allow the creation of custom dashboards for each DT.

Expose the available data through standard service APIs respecting any standard.

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To implement these core principles, the platform has been designed in a modular way, where concrete services have been implemented and interact. These services can connect with external providers to harvest the needed data and then pre-process and analyze it. The next section presents the technical architecture of the platform.

3 Architecture of the CARMINE Digital Twin Platform

Figure 2 presents the CARMINE Digital Twin platform's high-level architecture and highlights the main elements, entities and services which are connected and interact with each other, aiming to offer a web platform for the eight CARMINE DTs.

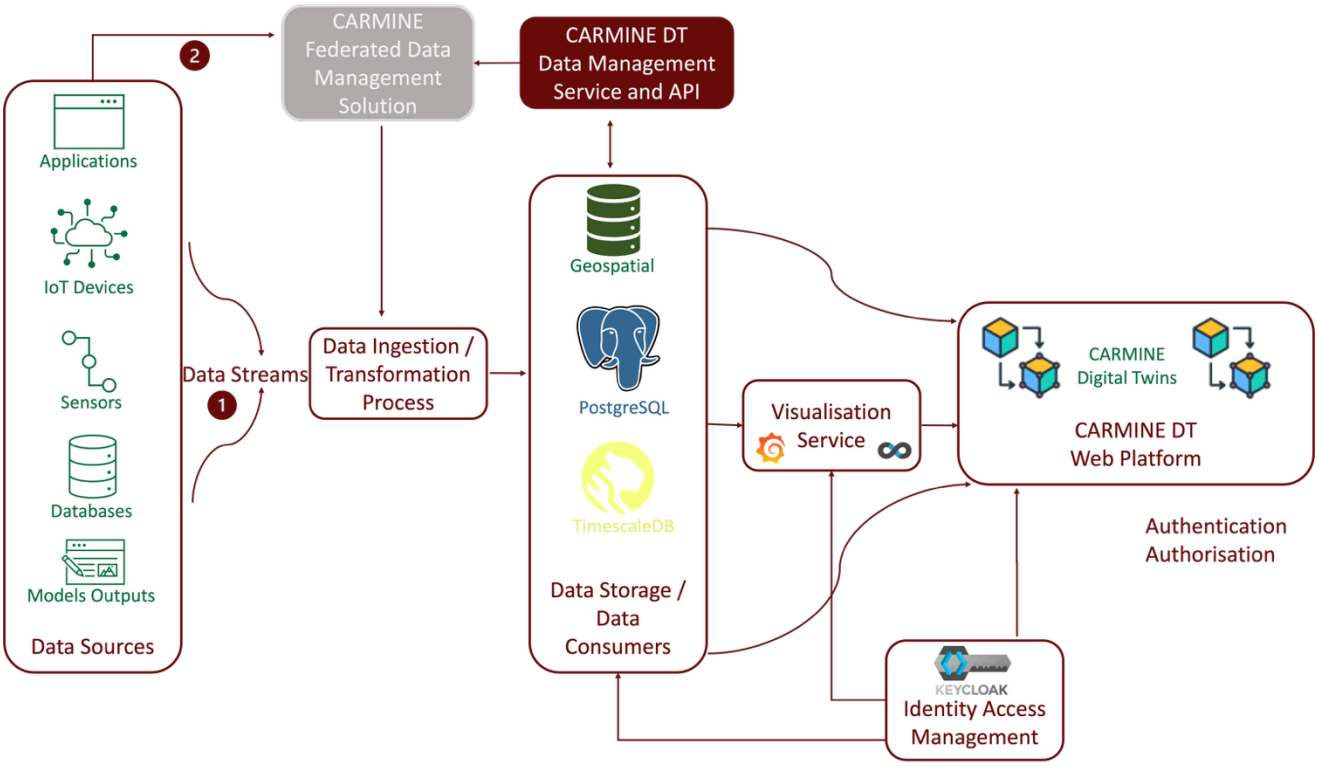

Figure 2: CARMINE Digital Twin Platform Architecture

The platform can consume / harvest data from diverse sources, including models' outputs, sensor data, data from IoT, various databases and / or applications and service endpoints. There are two possible ways for harvesting data from the Carmine DTs local sources into the platform either by (1) directly connecting to the data sources, implement plugins for data ingestion if not available, and consume the data or (2) through the CARMINE Federated Data Management Solution (FDMS) [1].

The source data are transformed if needed and ingested into the Data Storage system, which contains concrete data storage solutions to ensure the appropriate handling of the data based on their format, nature, and size.

The Data Management service provides the processed data directly to the web platform for making them available to end-users or to the visualisation service for generating the required visualizations and then to the web platform, supporting the different DTs and their decision support services.

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All the above are supported by a central Identity Access Management service, ensuring access to each dashboard to authorized users if needed.

4 Digital Twin Platform Services

The core services of the CARMINE Digital Twin Platform, as presented in Figure 2 above, are detailed in the sub-sections below.

Authentication and authorisation service

A central identity management service is deployed and configured based on the Keycloak [2] open-source software that provides authentication through various providers and fine-grained authorisation. Each internal service interacts with this service to retrieve information about the user and its access rights, thus avoiding unauthorised access. Each DT is associated to a distinct organisation and the access to its dashboard is managed through this organisation. Using Keycloak it is feasible to enable different authentication providers, including external ones based on Auth2 protocol. The activation of additional providers will be based on DT requirements.

Protected data are stored per DT and can be retrieved only after successful authentication. This is not the case for public data.

Data ingestion and transformation service

This service is responsible for connecting to the data providers, through the appropriate plugin depending on how the data are made available (service endpoints, standards, etc) and the data type, transform them if needed in another format and ingest into the platform.

This service is also responsible for the periodic update of the data from the specific source. This update is per data provider and it depends on how often the data needs to be updated to the platform. It can be configured and changed at any time to incorporate the needs of the D T.

Data storage and management service

This service is responsible for the intelligent storage of the ingested data, selecting the appropriate provider / mechanism considering the needs for analysis and visualisation. Since the data requirements differentiate per DT additional mechanisms could be implemented in case of new formats and types. At the time this report is being written, the service exploits a TimescaleDB [3], a PostgreSQL [4] relational databased and a postGIS [5] database suitable for geospatial data.

Visualisation service

The visualisation service is responsible for providing different visualisations per DT and deploying dedicated dashboards for each DT. Aiming to be flexible it has been chosen to deploy the Apache Superset [6] open-source modern data exploration and visualization platform, integrate it with the storage service and offer rich visualisations dashboards. Examples of supported chart types include bar charts, pie charts, line graphs, maps, treemaps, pivot tables and snakey diagrams. Integration with many databases and storage systems. Additional frameworks could be potentially exploited to support future requests.

Web Platform

The web platform is the single-entry point for the end users to access the DTs dashboards. It will be accessible through a URL and will offer both a public space providing descriptions and information for each DT, while it may require authentication for accessing the dedicated dashboards for each DT. Based on the requirements of each DT, it can provide access to data

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through a User Interface and / or access to customized visualization dashboards facilitating decision support and highlighting the main outcomes of each DT.

A PoC of the foreseen web platform and a visualisation dashboard based on an initial set of the Odense DT is presented in the figures below (Figures 3-4). The web platform aims to provide access to all 8 CARMINE DTs with its first release.

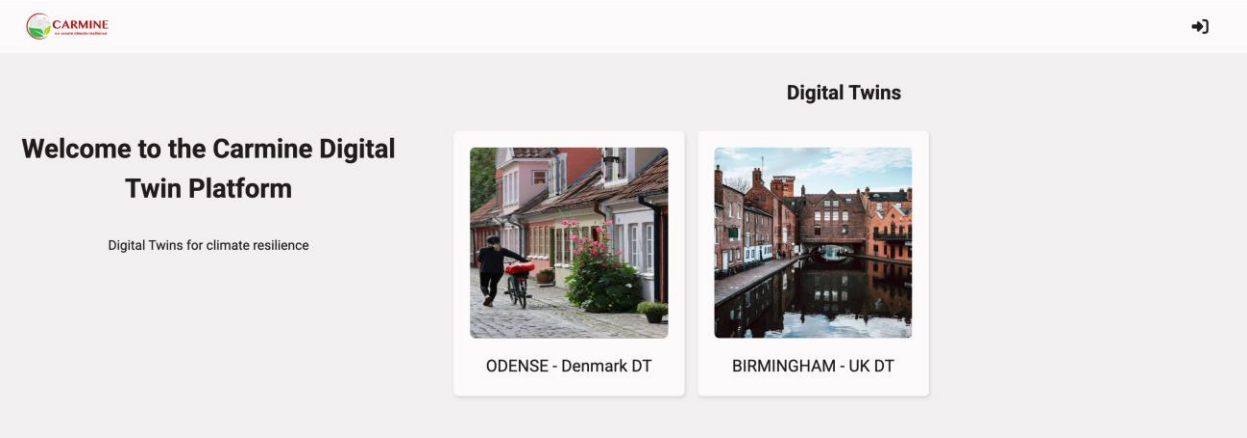

Figure 3: CARMINE DT Web Platform Landing Page

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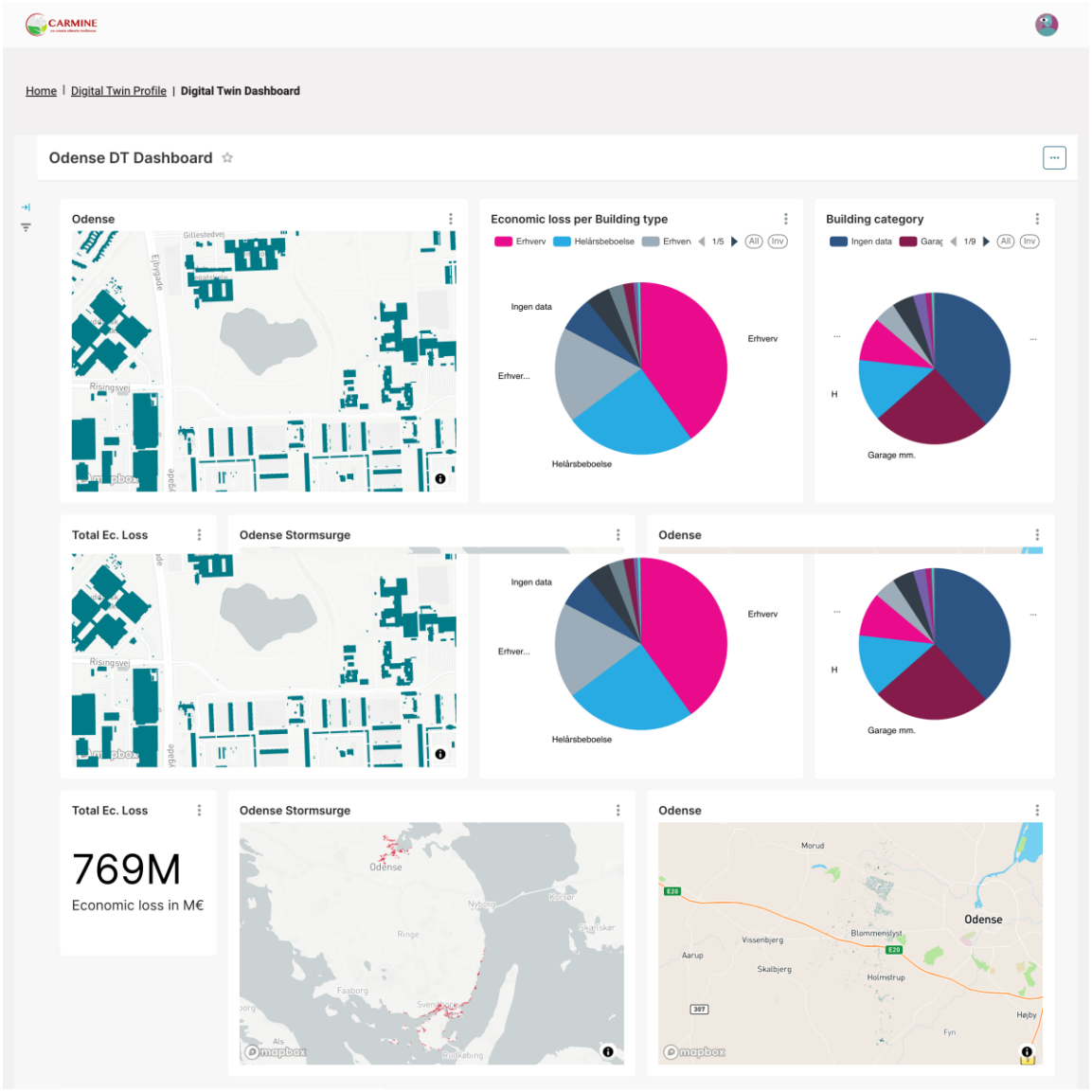

Figure 4: CARMINE DT Web Platform Odense Dashboard

** The above figures are based on the first draft of the web platform. The development is in progress and the UI may be different when compared to the first released version of the platform.*

5 Interactions with other services

The processed / transformed data available in the CARMINE DT platform can be made available to other project internal or external services through the FDMS and the API of the developed Data Management Service, part of the CARMINE DT platform. The APIs are developed based on standards to facilitate the machine-to-machine interaction and to ensure the interoperability of the platform.

The DTs output data will feed the Impact-Based Decision Support Service (IDSS), being developed in WP5, by interacting with the FDMS and receiving the required output data. The interaction between these services through the available APIs could be done either by invoking the FDMS on demand when there is a need for updating the data at the IDSS level, or by

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automatically pushing new data to the IDSS when they become available. The process will be decided and described at the IDSS level. The IDSS, as planned, will combine these data together with local data from the CSAs, physical risk modelling outputs and socio-economic data to support decision-makers and policy makers through an interactive dashboard with tailored data, thus facilitating local adaptivity and climate resilience (Figure 5).

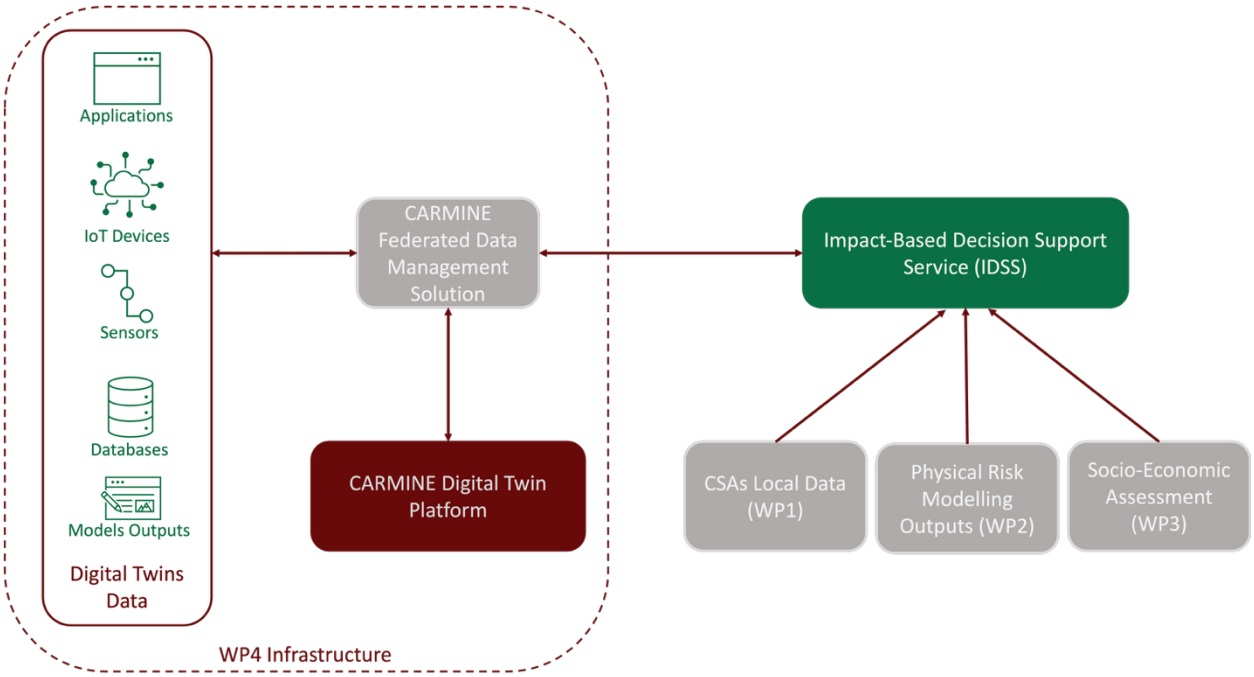

Figure 5: Data Flow

6 Future Enhancements & Conclusions

The architecture and core services described in this deliverable represent the first version of the Digital Twin platform. As work progresses across the different DTs, the requirements related to data processing, decision support services and visualization are expected to evolve. This may lead to updates in the platform architecture and the development of new services or plugins to better meet the emerging needs of each DT.

To support additional data types and formats, new plugins will be created as part of the data ingestion and transformation process. These plugins could be related to supporting different types of data compared to the already supported ones, i.e. data made available through OGC standards (WMS or WFS) that will be the case for the Brasov DT, or data made available through standard APIs and providers, e.g. statistical data from Eurostat.

The final version of the platform will provide access to the 8 CARMINE Digital Twins, which will serve as practical tools to support climate resilience efforts in the eight MREs, each targeting a specific climate-related challenge.

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