DigiTDevOps: A Digital Twins Development and Operational Platform

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Abstract
Digital twins (DT) represent a transformative paradigm with broad applicability across various domains, including manufacturing, healthcare, and infrastructure. While their potential spans many sectors, this study focuses on the application of DT technology within the context of smart cities and urban planning. Despite growing interest, adoption remains slow due to implementation complexity, such as data integration and system scalability challenges. This study introduces DigiTDevOps, an open, modular platform designed for DT modeling, deployment, and operation in a hybrid edge-cloud environment. By analyzing the DT ecosystem and defining key functional and non-functional requirements in alignment with ISO/IEC 25010 software quality standards, the platform ensures scalability, security, and interoperability. Initial findings emphasize the importance of open-access datasets, the reuse of configurable DT fragments as building blocks for digital twins, and the advantages of a standardized DT platform in improving efficiency and reducing development complexity. By addressing integration barriers and fostering scalable, high-performance DT solutions, this work contributes to the broader adoption of digital twin technology in urban applications.

Keywords
Digital Twin, Smart City, Edge-Cloud, CDD, Data Ecosystem, Enterprise Modelling

1. Introduction and Theoretical Foundations

Digital Twin (DT) technology, first conceptualized by Michael Grieves [1], has emerged as a foundational paradigm enabling real-time monitoring, simulation, and informed decision-making across various domains, including but not limited to urban planning, manufacturing, healthcare, and critical infrastructure. A DT typically consists of a physical entity, a virtual counterpart, and a continuous data connection that supports dynamic synchronization and actionable feedback loops [2]. In the context of smart cities, DTs play an increasingly vital role in optimizing infrastructure, coordinating services, and supporting sustainable urban development through integrated, data-driven insights [3]. Despite this potential, widespread adoption remains limited due to fragmented data ecosystems, lack of standardization, and challenges related to system scalability and interoperability [4]. Existing DT solutions are often highly specialized and difficult to extend across domains, reinforcing the need for a more modular and adaptable platform architecture. Addressing these limitations, this paper presents DigiTDevOps – an open, modular platform designed to support the modeling, deployment, and operation of DTs within a hybrid edge-cloud environment.

Through stakeholder engagement, the project has identified 131 functional and 23 non-functional requirements, ensuring that the platform addresses practical needs while aligning with ISO/IEC 25010 software quality standards. This standard guarantee core quality attributes such as functionality, security, maintainability, and performance. Central to the approach is a structured DT data ecosystem that facilitates scalability and reuse and is modeled by Capability Driven Development (CDD) approach [5] principles. The ecosystem is organized into three levels – macro

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(platform-wide), meso (domain-specific), and micro (use case–specific) – following principles outlined in digital ecosystem research [6]. This structure supports integration of heterogeneous data sources and encourages the reuse of configurable DT fragments, which serve as modular building blocks for developing complex DTs. Furthermore, DigiTDevOps enables scenario planning, dynamic resolution adaptation, and simulation-based adjustments, supporting more responsive and efficient urban planning. The project draws on a strong methodological foundation combining DT theory, data ecosystem modeling, CDD, and international software quality standards to create a platform that is flexible, robust, and future-proof. This synergy enables the delivery of high-performance DT solutions that are adaptable across various smart city contexts, ultimately contributing to broader DT adoption by lowering integration barriers and reducing development complexity.

The remainder of this paper outlines the project overview, describes how the structured DT data ecosystem was developed, and details the functional and technical requirements that enhance scalability, adaptability, and efficiency. The findings highlight the potential to overcome integration barriers and accelerate the adoption of DT technologies in smart cities by ensuring a flexible and standardized development framework.

2. Project Overview

The goal of this project is to develop DigiTDevOps, an open, modular platform for DT modeling, deployment, and operation, grounded in the latest advancements in scientific research. Designed for a hybrid (edge-cloud) computational environment, the platform facilitates the full life cycle management of urban-oriented digital twins. By enabling efficient knowledge aggregation, data interoperability, and modular integration, it aims to overcome key technological barriers associated with DT development and operationalization.

A key innovation is the modular approach, achieved through the introduction of reusable, configurable DT fragments. The platform includes a repository of unique fragments, allowing for the efficient composition of new DTs, reducing development time, and enhancing scalability. Unlike existing solutions, which often face rigid architectures and fragmented data ecosystems, this system is designed for flexibility and automation. Its structured multi-scaling approach ensures seamless interoperability across diverse urban applications, while CDD enables adaptive and goal-oriented DT solutions.

Additionally, the platform enhances automation and decision-making capabilities by facilitating real-time data integration and supporting open-access datasets for more informed urban planning. Future enhancements may explore AI-driven optimizations, further improving the ability to automate processes, predict trends, and enhance operational efficiency.

By addressing these challenges, the project increases accessibility and accelerates the adoption of digital twin technologies in smart city applications. It is undertaken within the framework of a European initiative of common interest (IPCEI-CIS).

To foster collaboration and accelerate innovation within the research community, the DigiTDevOps platform will be released as open-source software. This approach ensures that the broader community can freely access, modify, and build upon the platform. In particular, the platform will feature a repository of reusable, configurable DT fragments – modular components that serve as building blocks for constructing digital twins across various domains. By making these resources openly available, the project not only supports transparency and knowledge sharing, but also provides concrete, actionable tools for RCIS researchers and practitioners to advance their own digital twin initiatives.

3. Current project results

The current phase of DigiTDevOps has focused on defining the DT data ecosystem and identifying key requirements for the platform. The ecosystem has been structured using a multi-scaling approach to capture relevant stakeholders, context elements, data sources, and adjustments based on simulations. Additionally, the core functional and non-functional requirements have been outlined to ensure scalability and efficiency.

The following sections provide a concise overview of these results, highlighting the key aspects of the DT data ecosystem and the essential requirements for implementation.

3.1. Digital Twin Platform Data Ecosystem

The DigiTDevOps project has focused on identifying application cases, priority verticals, and key stakeholders essential for scaling DT solutions. A key aspect of this effort involved defining a data ecosystem capable of supporting DT deployment in smart cities and beyond, ensuring both contextual relevance and future scalability. A digital twin data ecosystem is a networked system where multiple digital twins are interconnected, facilitating seamless data exchange and collaboration across various platforms and stakeholders. This interconnectedness enables real-time data sharing, comprehensive analysis, and coordinated decision-making, enhancing the efficiency and adaptability of complex systems [6]. To support the DT data ecosystem development process, a stakeholder engagement workshop was conducted using a silent brainstorming approach, during which participants initially identified thirty-nine DT use cases across five verticals: transport and mobility, energy, civil defense, Industry 4.0, and cybersecurity. Based on the number and diversity of use cases, the three most prominent verticals—transport and mobility, energy, and civil defense—were selected for further analysis. Participants collaboratively developed fourteen use cases from these domains, which served as the foundation for data ecosystem modeling. Following Capability-Driven Development (CDD) concepts, these use cases were structured across macro (platform-wide), meso (vertical-specific), and micro (individual use case) levels to ensure adaptability and scalability. The modeling was carried out using enterprise modeling techniques in combination with established CDD principles [5], which have already proven effective in prior data ecosystem modeling efforts [7], [8].

The DT data ecosystem was modeled using a structured set of interrelated concepts that describe the goals, contextual factors, and stakeholder-driven actions shaping Digital Twin operations. At the center of the model is the notion of Capabilities that adapt to dynamic environments. These are influenced by changing contextual situations and are pursued by specific stakeholders through simulation-informed actions known as Adjustments. Key Performance Indicators are used to evaluate the achievement of goals, while measurable data properties ensure traceability and grounding in real-world conditions. Rather than representing the DT as a standalone entity, the model positions it as the enabling mechanism behind these interrelated elements. The conceptual overview in Table 1 provides the basis for structured modeling of the DT data ecosystem, supporting a consistent and adaptable approach to platform development.

Figure 1 illustrates a meso-level data ecosystem model example developed for the transport and mobility vertical, serving as a representative example of how the conceptual approach is applied in practice. While this case focuses on a single vertical, the overall project targets three key smart city domains: transport and mobility, energy, and civil defense. The model highlights how data sources are linked to contextual elements and how simulation-driven insights lead to targeted adjustments, supporting data-driven decision-making. The modeling is based on the concepts described in Table 1, ensuring consistency and traceability across different verticals and levels of abstraction. This example demonstrates how data ecosystems are structured to reflect real-world complexity and enable adaptive, goal-oriented actions within the platform.

Table 1
Description of DTs data ecosystem modelling concepts

Modelling concept	Description	Visual representation
Capability	An ability and capacity to fulfill goals in a dynamically changing environment (described as a context situation).	Capability
Goal	Purpose of using a DT.	Goal
Stakeholder	Stakeholders relevant to the use of the DT. Each Stakeholder may have different goals for DT.	Stakeholder
Key performance indicator	Measurable characteristics by which the achievement of objectives is evaluated.	Key performance indicator
Context element	Describes key conditions, environment, and factors in which DT will operate.	Context element
Adjustment	Actions that can be performed on the physical and real service, process or equipment based on the simulations performed with the DT. Each adjustment has an owner or Stakeholder who executes the adjustment.	Adjustment
Measurable property	Measurable attributes and data used to describe the context situation.	Measurable property

Further analysis of the data infrastructure underscores the importance of ensuring reliable data availability, efficient retrieval, storage, and processing throughout the Digital Twin lifecycle. To support the modular and reusable design of DT components, open-access datasets have been identified as valuable resources for constructing interoperable DT fragments. This approach addresses a critical challenge in DT development—reducing dependency on case-specific data pipelines and enabling faster adaptation across domains. Ensuring access to high-quality and sustainable data sources remains a key priority for upcoming development phases. The requirements and insights gathered during the current phase form the basis for evolving the DigiTDevOps platform into a scalable, efficient, and generalizable solution, aligned with software quality standards and open innovation principles.

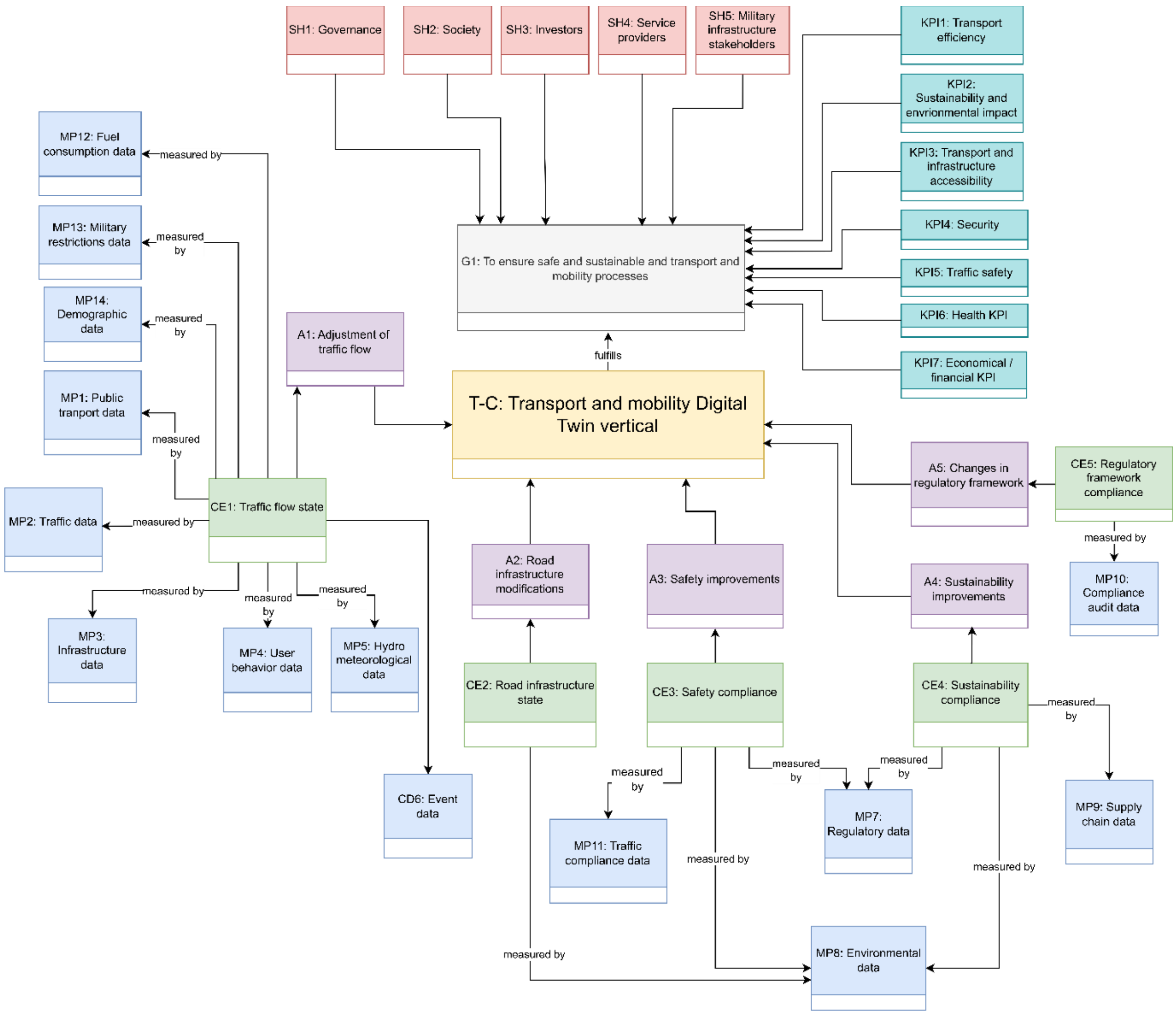

Figure 1: Transport and mobility DT vertical data ecosystem.

3.2. Digital Twin Platform Requirements

The requirements for the DigiTDevOps platform have been defined to cover all core components necessary for delivering an integrated, modular, and scalable environment for Digital Twin development and operation. Rather than focusing on visual representation alone, the project prioritizes data structures, analytics, and automation to support the full lifecycle of DTs. The platform design places strong emphasis on orchestrating systems, services, and processes to ensure both technical depth and operational flexibility.

The identified requirements are grounded in insights gathered from the end-user workshop, where a diverse set of DT use cases across three priority smart city verticals were analyzed and modeled. Additionally, rapid literature review [11] has been conducted to analyze existing approaches to DT platforms. Recurrent needs and challenges observed in these cases were systematically translated into functional and non-functional platform requirements. This ensures that the platform evolves in alignment with stakeholder expectations and domain-specific contexts, while remaining adaptable across future use cases.

Compared to existing DT platforms such as Microsoft Azure Digital Twins or Eclipse Ditto, DigiTDevOps distinguishes itself through its capability-driven foundation, focus on DT fragment reuse, dynamic resolution adaptation, and integrated simulation and scenario management features [9],[10]. DT fragments encapsulate specific, reusable functionalities, wherein all necessary inputs, outputs, and code components required to achieve particular operations are contained within isolated modules, but can also use shared DT data sources. This modular approach facilitates the development of new functionalities that can be integrated into existing or novel DTs, thereby extending their capabilities beyond their original scope. Each fragment is designed to provide its own management and configuration interfaces. These characteristics underscore the platform's objective not only to support visualization but also to actively guide operational decision-making in complex environments.

To date, a total of 131 functional requirements have been identified, covering essential platform components such as User Entity, Core Entity, Data Collection & Device Control, Fragment Repository, Data Management, and Security Management, along with analytics and orchestration engines. In addition, 23 non-functional requirements have been grouped into six critical quality areas: Security, Interoperability, Dependability, Predictability, Reliability, and Sustainability. This structured approach ensures that the platform is not only feature-rich but also robust and production-ready.

To guide the development roadmap, five overarching epics have been defined, articulating the principal objectives the platform must achieve: enabling users to develop and operate Digital Twins; providing real-time views of smart city systems — with the proposed DT platform deliberately designed to be extensible beyond the smart city domain through the incorporation of additional DT fragments; supporting DT-driven analysis and decision-making; ensuring high-performance, cloud-based execution; and automating deployment and operational workflows. These epics function as a high-level coordination mechanism, thereby aligning technical development efforts with stakeholder value and broader system objectives.

All requirements have been aligned with the ISO/IEC 25010 Software Product Quality Standard to ensure coverage of key quality attributes such as performance efficiency, usability, maintainability, and portability. This alignment provides a shared reference for platform evaluation and reinforces the focus on delivering a trustworthy and extensible solution for Digital Twin deployment across diverse application domains.

Following the gathering of initial requirements for the Digital Twin (DT) platform, the project has advanced to the next phase, during which the development of the initial platform architecture is essential. To achieve this objective, a preliminary conceptual architecture diagram has been created (Figure 2).

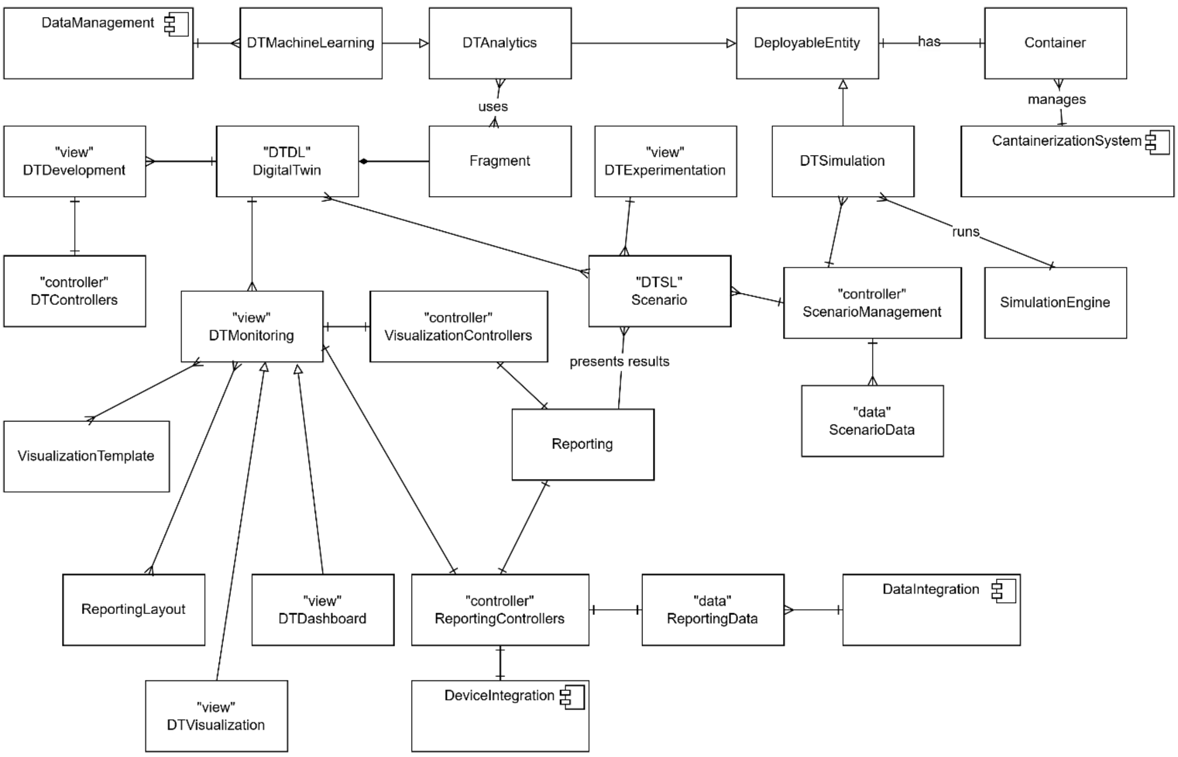

Figure 2: DT platform component diagram.

The UML component diagram in Figure 2 provides a high-level representation of the DT system architecture, detailing the main components and their interactions. At the center of the system is the *DigitalTwin* component, described using the "DTDL" metamodel, and composed of modular

Fragment elements for reusability. The development process is supported by *DTDevelopment* (a "view") and *DTControllers*, which collectively enable Digital Twin creation and lifecycle management. The *DTMonitoring* component oversees runtime observation and integrates with visualization (*DTVisualization, DTDashboard*) and layout components (*VisualizationTemplate, ReportingLayout*) via *VisualizationControllers*.

The system supports scenario-based experimentation using the *DTExperimentation* view, which is connected to Scenario entities expressed in "DTSL", and managed by the *ScenarioManagement* controller. Scenarios are executed through *DTSimulation*, using the SimulationEngine and deployed via DeployableEntity instances managed by a ContainerizationSystem. Analytical insights are derived through DTAnalytics, leveraging both Simulation and *DTMachineLearning*. Reporting is handled by a dedicated Reporting component, coordinated by *ReportingControllers*, and relies on *ReportingData* and *DataIntegration* for data acquisition and presentation. The overall data lifecycle is maintained by *DataManagement*, with hardware interfacing enabled through *DeviceIntegration*.

Given that the development of the detailed architecture is ongoing and will adhere to the C4 model standard [12], deviations from the initial conceptual model are anticipated.

4. Conclusions

This paper has presented the development of DigiTDevOps, an open and modular platform designed to support the modeling, deployment, and operation of DTs in smart city environments. A key contribution of the work lies in the structured definition of a multilevel DT data ecosystem and the systematic derivation of functional and non-functional platform requirements from real-world use cases. By integrating enterprise modelling and CDD principles, the platform fosters adaptability and supports simulation-based, context-aware decision-making.

In contrast to existing DT solutions, DigiTDevOps emphasizes reusability through modular DT fragments, scenario-based experimentation, and a focus on aligning system behavior with dynamically changing context conditions. These design choices contribute to the platform’s scalability and interoperability, while compliance with ISO/IEC 25010 standards ensures attention to core software quality attributes.

Future work will focus on refining platform functionalities, improving integration with open-access datasets, and expanding its application across smart city domains. Additionally, further research is needed to address potential challenges, such as computational scalability, data privacy concerns, and integration with AI-driven decision-making. Next steps include refining system requirements, enhancing detailed architecture design, and evaluating real-world deployment scenarios. Platform prototyping will help identify additional architectural challenges, which must be continuously revised and optimized to ensure a robust and scalable solution.

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[2] https://www.datigroup.com/en/projects/ipcei-next-generation-cloud-infrastructures-and-services-digitdevops

Declaration on Generative AI

During the preparation of this work, the author(s) used X-GPT-4 in order to: Grammar and spelling check. After using these tool(s)/service(s), the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

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