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A Participatory Planning Framework using Urban Digital Twins Supporting the Co-Creation of Flexible, Positive Energy Districts

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1 ABSTRACT

The urban socio-ecological transformation requires pathways for an urban energy transition, including the establishment of Positive Energy Districts (PEDs). Technical solutions and simulation tools for urban energy systems are needed for the planning, management and implementation of PEDs. In addition, the involvement of all societal stakeholders is needed to achieve the EU's ambitious target of 100 PEDs by 2025.[1] To this end, innovative research, information and communication strategies must be developed.The transnational funded research project DigiTwins4PEDs[2] focuses on developing an Urban Digital Twin as a dynamic digital representation of urban energy systems using advanced modelling tools. The framework facilitates the integrated energy demand-supply analysis at district scale. It enables the construction and analysis of future development scenarios to simulate the performance of PEDs.It supportsinformed decision-making by citizens and urban administration for a sustainable urban energy transition. The transnational project applies innovative methods and develops implementation strategies supported by a participatory process involving key stakeholders and citizens in co-design, co-creation and co-learning stages of research. Through the framework of living labs in four different case studies, citizens are continuously engaged throughout the project so that citizen-driven actions towards Positive Energy Districts can be considered and implemented more efficiently. New tools and methods are developed and adapted using Urban Digital Twins based on the CityGML data format to enhance public participation in advancing clean energy transition. These toolsenable citizens to actively engage in shaping the future energy transition of their communities and thus supporting informed decision-making.The developed and implemented urban digital twin framework is tested in different urban case study areas (Vienna, Stuttgart, Rotterdam, Wroclaw)within an innovative public participatory process to address the multifaceted aspects crucial for establishing PEDs together with the citizens.

This paper discusses the concept and first prototype of the developedparticipatory planning framework, a shared urban data and modelling scheme,utilizing a digital twin, as well as itsimplementation.It will show how the developed frameworkenables the simulation of urban energy systems with integrated local socio-economic and demographic parameters to identify and visualise current and future energy demand, renewable potential and different energy flexibility strategies in a district. It will discuss how the developed framework can be integrated/combined with other citizens' engagement tools, focussing on the ones used in the case study sites. Furthermore, we draw conclusions on how this framework can be used to support co-design, co-creation and co-learning of community-driven solutions for energy transformation.

[1] https://setis.ec.europa.eu/working-groups/positive-energy-districts_en
[2] https://digitwins4peds.eu/

Keywords: Citizens Participation, Modelling and Simulation, Urban planning, Positive Energy Districts, Digital Twin

2 INTRODUCTION

Several initiatives have been started to support the clean energy transition and drive the sustainable urban transformation, like the EU SET-Plan, Action 3.2 that aims to have 100 PEDs in Europe expected to be by 2025 in concrete planning, construction, or operation1. An analysis [BOSSI et al. 2020] shows the role of stakeholder processes (citizens, urban stakeholders) as a primary factor for the success or failure of such energy transition, followed by the availability of shared information delivered by integrated technological solutions. The involvement of civil society in planning the built environment is well-established and common practice. However, little is known about their inclination towards community-based energy transition. While technological innovation is necessary to realise PEDs, the challenge is also one of societal transformation as energy transition must be accepted and pushed by citizens and not only by authorities. The participation of local communities in urban design is well-established; however, their involvement in the energy transition remains largely unexplored. While various technological solutions exist for green energy planning, achieving PEDs with strong community support continues to be a significant challenge. This ultimately presents a major obstacle to achieving ambitious targets, such as the EU's objective of deploying 100 Positive Energy Districts (PEDs) by 2025. To address this gap, DigiTwins4PEDs aims to implement an innovative public participation process using Urban Digital Twins (UDTs) embedded in a living lab concept on its four case study regions of Stuttgart, Vienna, Rotterdam, and Wroclaw.

3 CASE STUDIES

The case study in Stuttgart will focus on the neighbourhood of Nordbahnhofviertel, which is facing urban, infrastructure and societal challenges due to adjoining constructions of Stuttgart 21 and Rosensteinviertel. In addition to infrastructure and societal development, it becomes important for Nordbahnhofviertel to get itself developed in terms of energy infrastructure, together with Stuttgart 21 and Rosensteinviertel. Thus, its energetic transformation to PEDs can help Nordbahnhofviertel to ensure that it is no longer insular and ensure a sustainable basis of life for its current and future residents.

The case study in Vienna focuses on the project area "Grätzl 20 + 2" as a part of WieNeu+ urban renewal programme of the city of Vienna. Grätzl 20 + 2 is located in the neighbouring 2nd and 20th district of Vienna and was launched in early 2023 as a cross-district programme in the districts of Brigittenau and Leopoldstadt. It combines the area in the 20th district up to the Danube Canal and Stromstraße with the "Volkertviertel" and "Alliiertenviertel" neighbourhoods in the 2nd district, with Nordwestbahnstraße connecting the two areas. A special focus in these areas is to transform the currently gas-based energy supply system to alternative renewable energy sources and evaluate the implications of such conversion on the power and heat load management and related peak loads. Therefore, the intended approach within DigiTwins4PEDs is to co-design different district energy transformation scenarios with a focus on energy flexibilisation options using urban digital twins as simulation tools and co-create solutions and evaluate with residents and decision makers potentials and opportunities to transform the Grätzel 20+2 towards a PED.

The case study in Rotterdam will focus on the neighbourhoods of Prinsenland and Feijenoord. Rotterdam is committed to finding future-proof solutions to reduce its carbon footprint and become carbon-neutral by 2050. However, the city will not be able to achieve its climate action pledge alone: input from the government, province, and industries such as the port, as well as changes in city residents' behaviour, will also be necessary. Within DigiTwins4PEDs the neighbourhoods of Prinsenland and Feijenoord will be used as a test case to experiment living labs and the development and evaluation of new IT-based tools for co-creation and community-based solutions to enable the civil society to drive energetic transformation by information exchange, visualising future energy demand for cooling, potential, flexibility scenarios and its socio-economic impact at a community level. City of Rotterdam has already established a "Digital City Rotterdam" to improve the efficiency of urban planning and management. Connecting the Digital City Rotterdam with the activities and outputs of DigiTwins4PEDs will be a very valuable opportunity to engage citizens in a co-creation process to start the transition towards PEDs.

The case study in Wroclaw focuses on the neighbourhood of Kleczków, which is facing infrastructural and societal challenges in connection with the implementation of "Nowe Kleczków" and the planned functional and spatial changes in the western and eastern parts of Kleczków. For the sustainable development of Kleczków it is important that it continues to future proof its energy infrastructure and thus its energetic transformation to PED can support in providing a sustainable living conditions for its current and future resident. Public buildings, including schools and municipal housing, often have high energy demands due to aging infrastructure. Investments in insulation, energy-efficient HVAC[3] systems, and solar panels could significantly reduce their environmental impact. Former industrial sites, repurposed into offices or cultural spaces, also present opportunities for modernization, such as renewable energy installations and smart systems to improve efficiency. Kleczków's diverse building stock, ranging from modern housing and historic churches to industrial-era tram depots, provides a solid foundation for transforming the district into a "positive energy district," where buildings not only minimize energy consumption but also generate surplus energy through renewable sources, contributing to a sustainable and self-sufficient urban environment.

4 METHODS: CONCEPTS AND FIRST PROTOTYPES

The project usesa bottom up end-use approach to model urban energy systems with focus on the district scale. The modelling methodology relays on sectoral spacio-temporal modells to conduct integrated energy demand and supply analysis,coveringselected flexibility options to balance energy demand with the volatile renewable energy supply in a timely manner. This ensures the required positive annual energy balance for the pilot PEDs.

Starting from the calibration of a base year reflecting the current district energy system, the approach allows for constructing future energydemand-supply scenarios following assumptions on the expected local demographic, socio-economic and technologicaldevelopment, the available local RES potential and the viable interaction with the neighbourhood energy system. The future development scenariosare constructed based on co-creation process involving key stakeholders and engaging citizens.

4.1 Energy flexibility analysis

PEDs represent urban energy systems relying upon variable renewable energy sources (RES) to cover district energy demand.Ensuring the timely demand-supply balance in view of such fluctuating conditions requires the provision of appropriate flexibility options to adjust demand and supply and maintain regional grid stability. Energy flexibility options involve strategies and technologies that dynamically balance energy demand and supply, ensuring optimized management for a positive annual energy balance of the PED.These options includedemand and supply sides, local energy storages, sector coupling (e.g., V2G) and smart energy management. Implementing flexibility options requires data collection and analysis to inform decision-making and develop a comprehensive implementation plan. Additionally, engaging local stakeholders is crucial to gathering qualitative insights, enhancing a data-driven approach, and promoting the benefits of utilizing local flexibility options.

Demand Response (DR) and Demand Side Management (DSM) are key measures for enhancing the flexibility of modern energy systems. It leverages the potential for temporal shifts in energy demand to better match supply fluctuations, optimizing energy use and reducing stress on the grid.Technologies such as heat pumps, thermal energy storage, and electric vehicle charging schedules can be dynamically adjusted to align with the grid conditions, contributing to more efficient and reliable energy systems. DR focuses on shifting or reducing energy consumption during peak times to off-peak periods in response to price signals or grid needs, while DSM encompasses a broader range of activities that include managing energy demand through smart devices and real-time controls. Both strategies rely heavily on advancements in information and communication technologies, allowing for seamless integration of flexible demand behaviours across residential, commercial, mobility, and industrial sectors.

DSM plays a pivotal role in enhancing the flexibility of modern energy systems, especially as the transition toward renewable energy sources accelerates. By dynamically adjusting energy consumption patterns in response to supply conditions, DSM allows for better alignment between demand and variable renewable energy options.This flexibility not only optimises energy use but also reduces strain on the grid, improves system reliability, and supports the integration of clean energy resources.Furthermore, DSM and DR and advanced technologies like smart meters, empower consumers to actively participate in balancing supply and

[3] HVAC: Heating, Ventilation and Air Conditioning

demand, fostering a more resilient and sustainable energy future. An important flexibility option is the active storage technologies like batteries and puffer tanks, but also thermal buildings inertia (concrete core activation)to capture surplus energy produced during peak renewable energy generation periodsfor using during times of low production or high consumption.

The general modelling scheme combining different tools developed in DigiTwins4PEDs enables to analyse the Demand Response and Demand Side Management for the entire district[4] and individual buildings.

4.2 General modelling scheme

The Figure 1 shows the general modelling scheme. In DigiTwins4PEDs, the CityGML 3D City Database (in short: 3DCityDB)for PostgresSQL serves as the central storage and exchange platform for CityGML-based building models enriched with Energy ADE, ensuring structured storage, retrieval, and processing of energy-related attributes. It plays a crucial role in managing complex urban datasets, allowing for efficient data exchange between simulation tools such as SimStadt and MAPED, and ensuring scalability, data consistency, and interoperability within the project's workflow.

Note: At the time of writing this article, Energy ADE 2 is in the Beta 6 stage and expected to be released in Q4 2025. To document a complete and functional workflow in this article, the Energy ADE 1 KIT profile has been used instead, as its full implementation is readily available on GitHub.[5] Once Energy ADE 2 reaches full development, it will seamlessly replace Energy ADE 1 without requiring any new modifications to the system architectures shown in Figure 1.

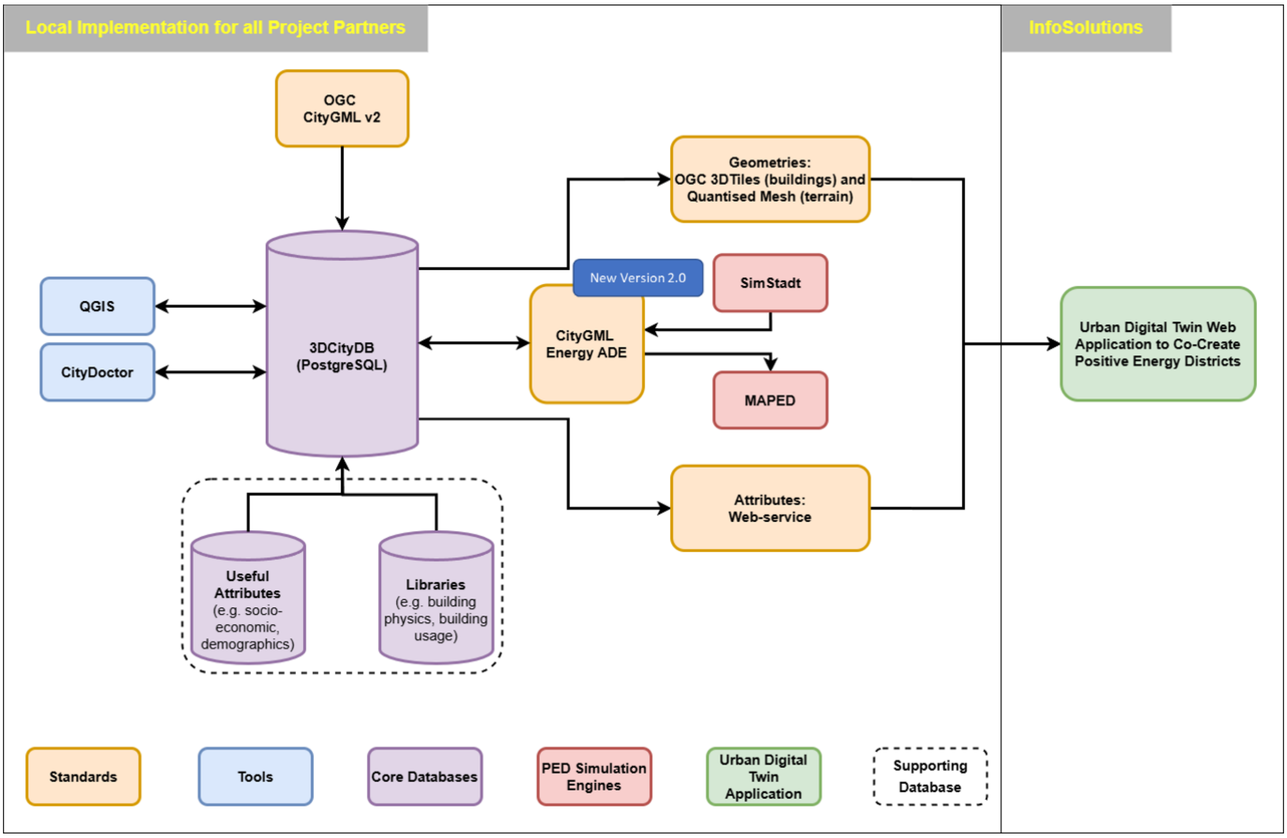

Fig. 1: DigiTwins4PEDs general modelling scheme

4.3 Data and Software Specifications

4.3.1 SimStadt

SimStadt is the name of an urban simulation environment developed at HFT Stuttgart and of a project of the same name, which in turn is the continuation of a project completed in 2015 (SimStadt). At its current stage, SimStadt has the capability to utilise data from real urban planning situations for energy analyses of

[4] System boundaries, not a politcal district
[5] https://github.com/3dcitydb/energy-ade-citydb

buildings, city sectors, entire cities, and even regions. Its application scenarios encompass high-resolution simulations of building heating and cooling requirements, potential studies for photovoltaic installations on roofs, facades, and ground surfaces, as well as simulations of building refurbishment scenarios, renewable energy supply scenarios (including PV and biomass), electricity demand, load profiles, district heating networks, waterdemandand analyses of food demand and potential [1]. Thus, SimStadt can significantly assist architects, urban planners, urban energy experts and local authorities in integrated energy planning processes and the formulation of measures towards sustainable (re)design of buildings and neighbourhoods. As its primary input, SimStadt employs the open and standardised data model of CityGML to store urban objects (such as buildings, land use, trees, terrain, roads, etc.) and their associated attributes as a digital 3D city model. SimStadt processes 3D city models, enriches them with necessary attributes, and generates energy simulation results that can be seamlessly reintegrated back into the CityGML dataset. Beyond the physical shape of a building, which is derived from the input CityGML building dataset, SimStadt requires data on weather conditions and building properties, particularly to simulate the energy demand of buildings. Weather conditions are part of the weather preprocessor module of SimStadt. Based on the EPSGcode of the CityGML 3D city model, it retrieves weather data for the location of the model and creates synthetic hourly values from monthly means. Building properties are further divided into building physics properties and building usage properties. Both building physics and building usage properties are implemented as libraries and respective workflow steps in SimStadt. The buildingphysics library contains benchmarking data of building physics properties, constructions and materials, such as the U-values of the different building elements etc.With building usage, it is possible to define set-point temperatures, inner gains and occupation for different building functions (e.g. residential, office, hotel, retail ...).In the DigiTwins4PEDs project, SimStadt plays a key role in building-level energy simulations, supporting assessments of heating/cooling demand, PV potential, and different electric load profile scenarios.The simulation results are stored in 3DCityDB using Energy ADE, ensuring a structured and standardised data exchange with MAPED. The latest list of publications which use SimStadt for urban energy simulation can be found on https://simstadt.hft-stuttgart.de/about/publications/. The following figure showsan example of the Simstadt User Interfacefor a region in Stuttgart.

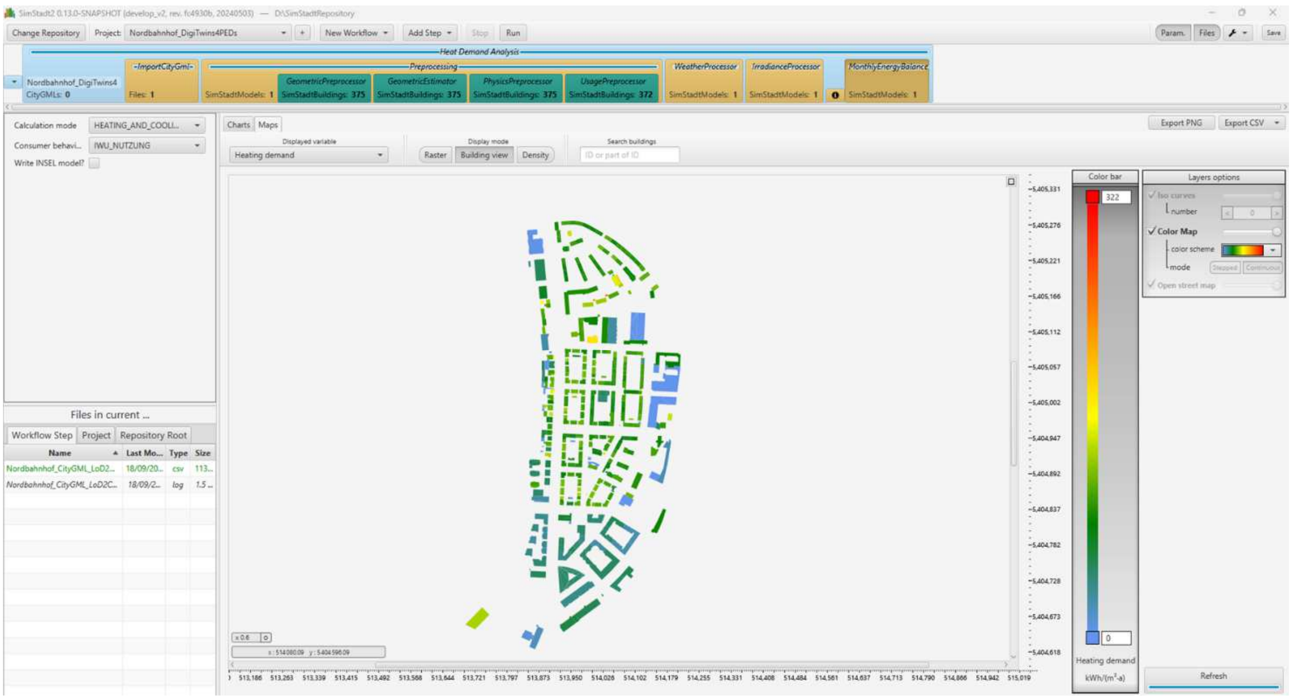

Fig. 2: Simstadt UI and heatng demand for Nordbahnhof buildings in Stuttgart ©HFT

4.3.2 MAPED

MAPED is a bottom-up rapid energy assessment tool for analysing the energy demand and supply of urban districts and assessing their qualification to reach an annual positive energy balance by exploiting local RES to cover district's electricity and heat demand. MAPED has been developed based on the proven end-use concept of the IAEA model MAED(NEUMANN et al., 2021). MAPED focuses on the evaluation of useful and final energy demand at the district scale, covering energy demand for household (residential) and service building (non-residential), urban farming, industry, and mobility. Moreover, it offers a simplified approach to evaluate and estimate the local renewable energy production to cover heat and electricity demand using photovoltaic, solar thermal energy and heat pumps. Other local supply options like biomass, waste heat and micro wind can also be considered given the prevailing boundaries, topology, social acceptance, and the applied regulations. MAPED approach evaluates final energy demand based on demographic, social, and technological data of the considered district. MAPED systematically relates the specific energy needs for providing goods and services to the social, economic and technological factors that affect the demand for a particular fuel. This implies population number and growth, number of inhabitants per dwelling, number of electrical appliances used in households and services, peoples' mobility and preferences for transport modes, evolution of the efficiency of certain types of equipment and market penetration of new technologies or energy forms. The expected future trends for these determining factors, which constitute 'scenarios' are exogenously introduced. This enables evaluating the needed measures to convert the considered district to a PED within the given demographic, social, technical and building types of specification.Since SimStadt and MAPED are integrated within the DigiTwins4PEDs workflow, building-level energy data generated by SimStadt is aggregated at the district scale using Energy ADE and then used in MAPED. This integration ensures that detailed building-level energy assessments, such as energy demand and photovoltaic potential, contribute to district-level energy flexibility strategies, includ-ing energy balancing, renewable energy integration, and demand-response measures.

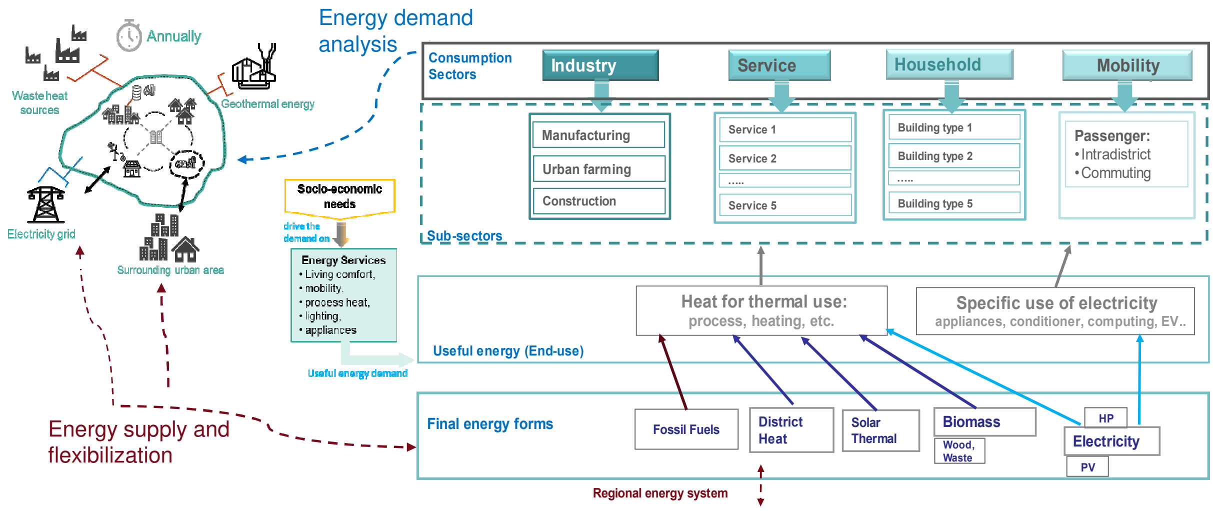

Fig.3: MAPED concept for the disaggregation of district energy demand by fuel and consumption sector, and the conceived energy supply and exchange with the neighbourhood energy system ©AIT

4.3.3 CityGML Energy ADE

The international standard City Geography Markup Language (CityGML), issued by the Open Geospatial Consortium (OGC), offers the possibility to model urban environments, including buildings, in a 3D space. CityGML defines "basic entities, attributes, and relations" of relevant urban objects, functioning both as a conceptual data model for semantically enriched 3D city models and as a storage and exchange format. Currently, the most widely used version is CityGML 2.0, which was released in 2012.CityGML has been intentionally designed to be application independent. Nevertheless, in certain cases, additional classes or attributes may be needed for specific domains. For this reason, CityGML can be extended following two approaches. The first one allows for the definition of so-called generic attributes and GenericCityObjects without the need to extend the conceptual data model. The second one, on the other hand, offers more modelling capabilities but demands an extension of the data model. This second approach is referred to as the Application Domain Extension (ADE) mechanism.

The Energy ADE[6] is such an extension for CityGML [AGUGIARO, 2018]. It builds upon the CityGML 2.0 Core and Building modules and extends them by means of additional classes and properties. As such, it has been conceived and designed as a solution to model and store relevant data needed for UBEM. It offers the

[6] https://www.citygmlwiki.org/index.php/CityGML_Energy_ADE

possibility to model both data serving as input for energy-related applications and as output, for example from the energy simulation results. The overall goal is to foster interoperability of energy-related data between different stakeholders and different software tools to perform city-wide energy assessments based on a bottom-up approach that starts from the granularity of the building. The Energy ADE was released in 2018 through a joint effort of various international parties and stakeholders (familiar/expert with/in either CityGML or UBEM). It is mentioned in the literature as a best-practice example when it comes to ADE development due to its technical maturity and available documentation. As a result, the Energy ADE has already been used in several national and international projects.One of the outcomes of the DigiTwins4PEDs project is to improve the current version of the Energy ADE and to release a new, improved version, tentatively named simply Energy ADE 2.0.

The Energy ADE 2.0 follows the same principles and goals of the previous versions, but it also incorporates the experiences and feedback from the projects carried out since its first release. At the same time, it takes into account new developments both in terms of ADEs and CityGML itself. In the former case, for example, a source of inspiration to improve and extend the data model comes from the Food-Water-Energy ADE (PADSALA et al., 2021) and the i-Urban Revitalisation ADE (AKAHOSHIet al., 2020). In the latter case, a new version of the CityGML data model has been published in 2021, reaching version 3.0 (OGC, 2021).As a result, the development of the new Energy ADE 2.0, although still based on CityGML 2.0, is already incorporating concepts that will ease its future conversion to CityGML 3.0.

Among the most significant changes introduced in the Energy ADE 2.0 is an improved “Building physics module”, which contains classes to model objects such as thermal zones, thermal boundaries and thermal openings, i.e. objects needed to compute the heat transfer through the thermal hull of the building. The new module overcomes some limitations of the previous version, in that, for example, now multiple representations of such objects are allowed (i.e. from LoD1 to LoD3), and, at the same time, the overall modelling approach has been brought closer to the overall “logic” of CityGML.

Additionally, the newly added “Resources module” completely overhauls the previous EnergyDemandclass by introducing the more general concept of resource, i.e. a quantifiable amount of “something” (i.e. energy, but also water, food, construction materials, waste, etc.) that can be associated to any city object and that can be expressed as yearly amount, or a time-dependent variable (via time series). The classes contained in the Resources module take inspiration and further elaborate concepts from the Food-Water-Energy ADE.

Besides other minor changes and simplifications, another addition of the Energy ADE 2.0 is the possibility to create a hierarechical partion of space (e.g. according to administrative boundaries: country, region, city, district, quarter, block, ...). Each of the objects at each level can associated to aggregated values (e.g. energy demand for heating at block, district, city level, etc.). This new addition, consisting in the so called UrbanFuntionArea, takes inspiration from a nearly equal class described in the i-UR ADE.

The Energy ADE 2.0 is currently in active development and is being implemented in terms of Java libraries (needed for the existing tools for CityGML 2.0) and a database schema that extends the CityGML 3D City Database (YAO et al., 2018). Eventually, the 3DCityDB-Tools plugin for QGIS is also planned to add support for it (AGUGIARO et al., 2024).

4.3.4 Urban Digital Twin Web Application

The front-end, the UDT Web Application (Figure 4 and 5), enables to interact with the simulation results and visualises the results at different spatial resolutions. Thus building-related information, as e.g. the specific energy demand over time of a building, as well as the entire demand and energy production potentials of the district.The UDT-Web Application will be developed as an information-sharing, gathering and/or a co-development platform for citizens and stakeholders to simulate and visualise different future PED scenarios for their communities before their real-world implementations. It will be an expert tool, which shall be used by public authorities and urban planners to inform and design together with citizens scenarios to realize PEDs. The system’s architecture has been depicted in the Figure 6below, showing main components and technologies utilised. In the storage layer, we mainly use NoSQL – Firebase and google cloud where we have defined user roles and permissions in the system. Spatial data are stored in dedicated containers for their specific handling. The application layer uses mechanisms of services, business logic, communication API and user interface components to support specialized views and support the geoportal tool. The system components communicate with each other using the http protocol.In the design of the Web GIS application open-source libraries were used to render geospatial data. In particular, the Cesium.js technology for generating views of the globe, as 3D perspectives in a web browser environment.

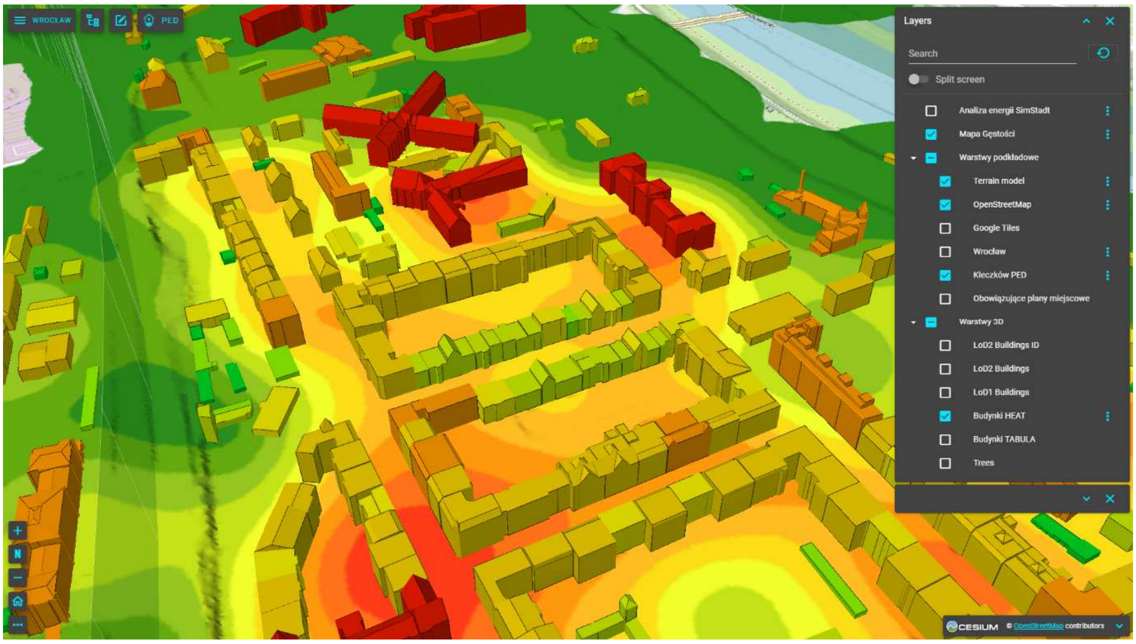

Fig. 4: UDT platform first prototype: Screenshot Wroclaw ULL: 3D Building Heat Demand ©INFOSOLUTIONS

Fig. 5: UDT platform first prototype: Screenshot WROCLAW ULL 3D Building information ©INFOSOLUTIONS

In addition, the service supports tools for generating analytical charts and static data sets. The views are presented in the form of a thematic geoportals for all the fouruse-cases (Stuttgart, Vienna, Roterdam, Wroclaw) equipped with a set of analytical and data management tools, including business intelligence dashlets to present thematic datasets. To build layouts Vue.js with the Vuetify library framework[7] was deployed as it allows building a responsive application.The data structure designed allows for flexible adaptation of the project while adhering to all rules regarding data access and project sharing with other users. By "project," we refer to an isolated, thematically prepared dataset intended for presenting both general views and specific phenomena. Users can configure the project's layer settings, compositions, and dedicated documents for displaying static data. These configurations can then be incorporated into the application's layout and tools, providing a tailored user experience. Once the project is configured, the

[7] https://vuetifyjs.com/en/

application allows presentations of 2D/3D data in formats supported by the Cesium.js API. As a standard, raster base layers such as TMS, WMS, GEJOSON, CZML, tiled 3D data are supported.

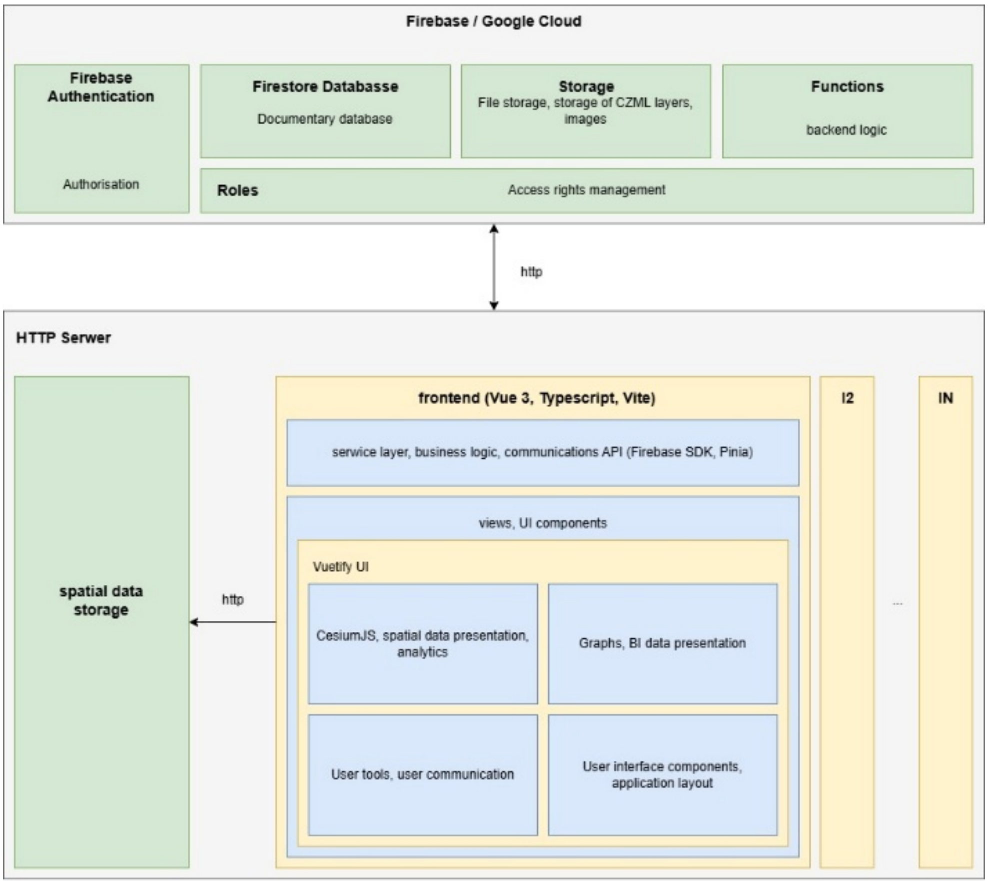

Fig. 6: Web GIS service system architecture ©INFOSOLUTIONS

5 CO-CREATION: A PARTICIPATROY PLANNING FRAMEWORK

5.1 Urban Living Labs

Urban Living Labs (ULLs) represent a dynamic approachfostering participatory community engagement by testing and evaluating small-scale interventions in collaboration with local communities [AFACAN, 2023]. These labs serve as platforms for co-creation, where citizens actively contribute to experiments and innovations, facilitating engagement and transformative change [VAN DER JAGT, 2018]. By incorporating co-design processes, ULLs enable the development of long-term partnerships between science and the community, ensuring that local needs are addressed and tailored solutions are created [MAHAJAN, 2022;ZINGRAFF-HAMED, 2020]. Through collaborative, neighbourhood-based approaches, ULLs activate urban resources and significantly contribute to resilient urban development [PETRESCU, 2022]. They provide a normative framework for guiding real-world experimental processes, aligning them with broader social and environmental goals [ZIEHL, 2021]. These experiments test and refine innovative solutions, strengthen social interaction, promote practice-based knowledge, and inspire new thinking and action [ROBAZZA, 2024]. Moreover, ULLs facilitate cross-sector collaboration, supporting urban transformation and innovation across disciplines [ZINGRAFF-HAMED, 2019]. They offer a promising opportunity to address current and future challenges by developing responsive and innovative urban solutions that enhance participatory resilience [BELFIELD, 2024]. By creating spaces for experimentation and fostering community involvement, ULLs empower cities to align with transformative goals and ensure sustainable, inclusive urban development [FRANTZESKAKI, 2018].

In the DigiTwins4PEDs project, ULLs serve as adaptive spaces for informing, experiencing and learning about everyday energy needs and PEDs, enabling the development of viable transformation pathways. DigiTwins4PEDs uses ULLs to implement a co-design, co-creation and co-learning process, where local communities actively engage in the energy transition. The ULLs bridge the gap between technological innovation and societal needs by integrating new tools and methods using UDTs to support participatory planning at neighbourhood level and make more informed decisions. These digital tools are iteratively designed, tested, and refined within ULLs, allowing communities to explore energy solutions, make informed decisions, and drive urban transformation. To maximize participation and acceptance, hybrid formats – combining digital and analogue interventions – are implemented.The IT-based solutions developed within DigiTwins4PEDs will be integrated into ULLs to assess how UDT platforms can enhance citizen acceptance and encourage active participation in urban transformation. By engaging key target groups, the project aims to explore how UDTs can contribute to enhance urban resilience and quality of life. To raise public awareness, an UDT platform will be made accessible at the citizen level, allowing individuals to explore, test, and provide feedback through interactive participation formats. This hands-on approach will raise awareness among communities of the concept of a clean energy transition and empower them to take an active role in shaping sustainable neighbourhoods. By using UDTs as a catalyst for citizen-driven action, the project seeks to identify strategies for sustaining long-term engagement and strengthening social responsibility. We plan to address three key target groups – young people, tenants, and property owners – and have developed a participatory planning framework with three targeted interventions for integrating UDTs into energy transition.

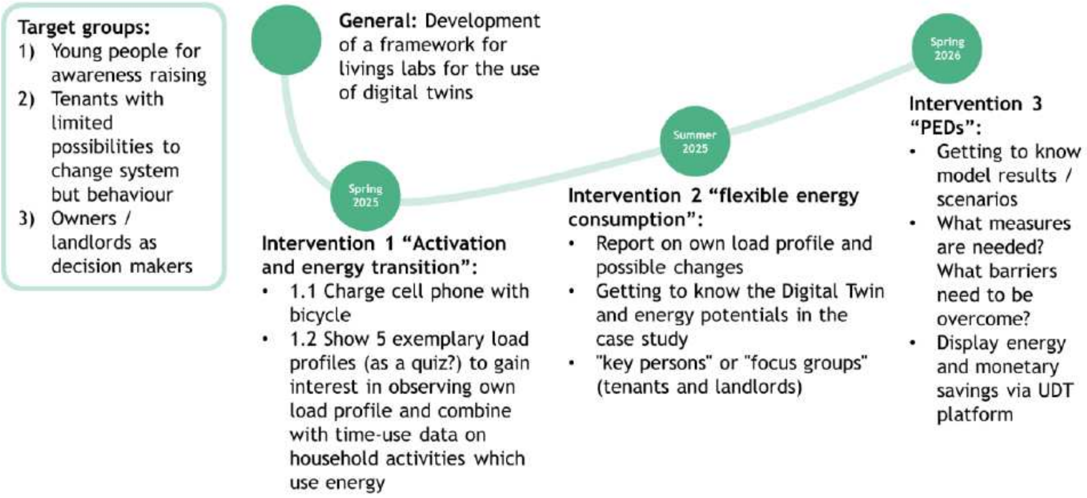

Fig. 7: Framework Idea for a cross-case study co-creation method

5.2 User "Behaviour" Stories for a Better Learning Process

The project'sresearch efforts are linked to the broader question of 1) how consumers can be empowered to become prosumers and 2) which measures are of interest and feasible for the citizens as end users.

The planned interventions will play a key role in enabling the flexibilisation necessary for the energy transition. Thus, behaviour-based scenarios will be created and implemented through the planned interventions covering activation and energy transition (intervention 1), flexible energy consumption (intervention 2) and PEDs (intervention 3). The three interventions developed in the framework focus on the following cross-sectional topics, providing end-users with insights into the impact, timing, and costs of various measures throught the UDT platform:

(1) Energy supplymeasures:such as installing photovoltaic systems, heat pumps, and district heating.

(2) Energy demand measures: actions focusing on energy-saving, including consumer behaviour, and energy efficiencymeasures, e.g., building refurbishment.

(3) Energyflexibilization measures: strategies like power and heat storage, sector coupling (like vehicle-to-grid) and demand-side management (e.g. shiftable use of appliances like washing machines).

The UDT platform will be tested using two prototypes of the UDT system: First, during the 2nd intervention, a prepared scenario will demonstrate the concept by the concept by testing 1-2 measures (e.g. PV installation and washing machine use). Second, if the system performs as expected, users of the UDT will independently formulate questions and select additional options for testing during the 3rd intervention.

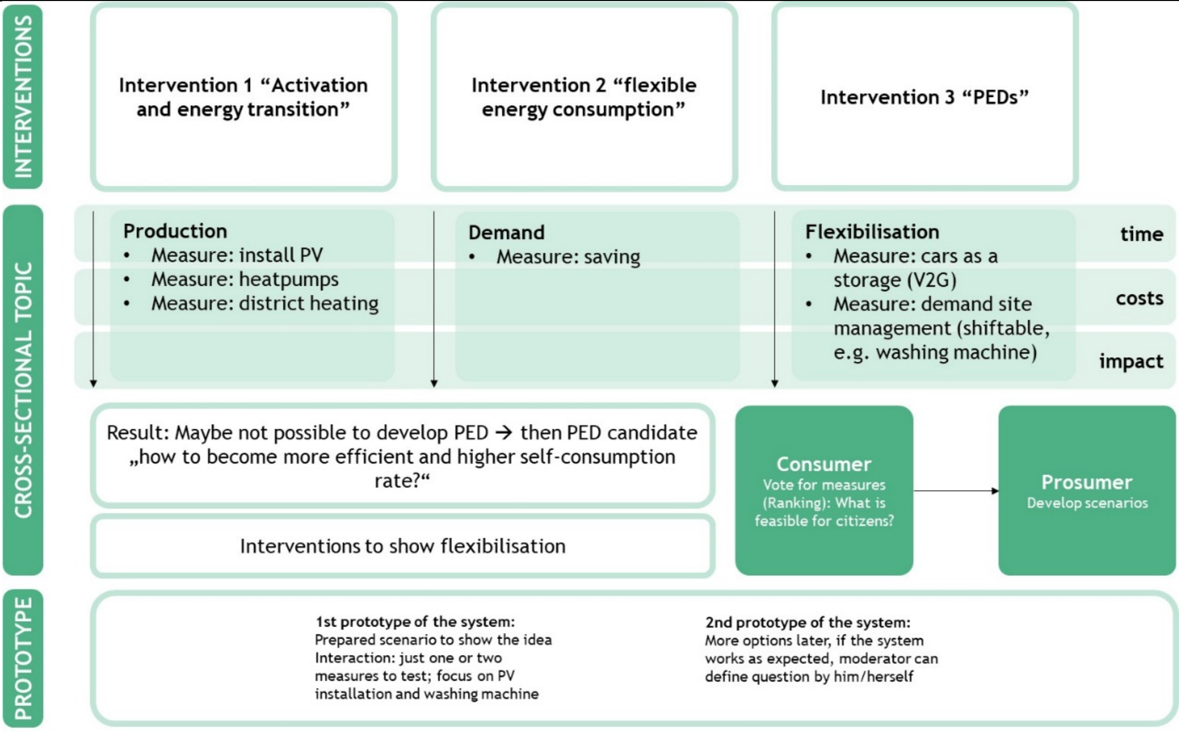

Fig. 8: Behaviour Stories to show energy flexibilisation

6 CONCLUSION AND OUTLOOK

The research project DigiTwins4PEDs develops an urban digital twin framework tested in different urban case study areas (Vienna, Stuttgart, Rotterdam, Wroclaw). Based on the 3D CityGML data format, the UDT integrates two urban energy simulation tools SimStadt and MAPED. To have a structured and standardised way of data sharing amongst the two simulation models, Energy ADE implemented in 3DCityDB PostgresSQL is used. The developed platform can be used in participatory processes to address the multifaceted aspects crucial for establishing PEDs together with the citizens.The concept and first prototypepresented above already show the potentials,e.g. how it can be used to explore behaviour stories for realizing the energy system transition, to change e.g. from pure energy consumer to become a prosumer. The first experiences also show that the UDT needs a facilitator (operator) to maximise its potential. Furthermore, that it is essential to integrate it in already existing citizens' engagement tools (platforms like Wien mitgestalten[8]) to be successful and accepted by the citizens and urban administration. Combining different Energy System Simulation tools, capable of simulating from the building level up to the district, enables us to show the broader picture for the district as well as give citizens (tenants and building owners) andpublic authorities the information to support their decisions and develop jointly sustainable scenarios for the future.The project sofar developed the Energy ADE 2.0, which is one of the major outputs of the projectneeded to enable this from a technical perspective.During the next phase of the projectwe will further improve the concept and test the prototype applied in the planned interventions in the four involved case study. The developed data-workflows in the different cities necessary to prepare the input data for the simulation tools are essential to learn how the framework can be used in other cities with their available data.For the stakeholders involved from the cities,this isan important aspect to keep the effort at minimum, whenever the UDT framework should be transferred after the project.

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