FINAL REPORT - SWEDISH NATIONAL PROJECT PART

DigitalTwin4PED

Dialogue and Quality Assurance Support for PEDs by Digital Twin District Energy Models

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Energimyndigheten

Front page: Parallel coordinates plot visualizing results of parametric simulations for combinations of retrofit packages.

Image: Sara Abouebeid

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Preface

The project *Dialogue and Quality Assurance Support for PEDs by Digital Twin District Energy Models (DT4PED)* has been conducted within the joint programming initiative JPI Urban Europe together with consortium partners in Sweden, Austria and Türkiye. The Swedish part was also part of the call Viable Cities: Energy Positive Neighbourhoods for Climate Neutral Cities. The project has been financed by the Swedish Energy Agency and the Swedish project partners Framtiden AB, Framtiden Utveckling AB, Poseidon and the City Property Administration of the City of Gothenburg. Additional funding has been received from the Energy Area of Advance at Chalmers and a donation from the Danish fund "Fonden af 20. December". The project has also been linked to the national Vinnova competence centre Digital Twin Cities Centre (Diary no. 2019-00041). Special thanks go to our project partners, workshop participants–including energy companies, municipalities, architects, and consultants—and international collaborators such as e7, Austrian Institute of Technology AIT, Ekodenge, and Sakarya University of Applied Sciences for their valuable contributions and productive exchanges throughout meetings, workshops, seminars, and study visits. Finally, thank you to all colleagues within the international group "Expert Support Facility" for inspiring conversations and critical reflections on PED.

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Summary

The project *"Dialogue and quality assurance support for PEDs using digital twin energy models" (DT4PED)* has developed and tested a Digital Twin (DT) Viewer for the mixed-use district Jättesten in Gothenburg. The DT-Viewer is a powerful tool for informing planning and decision-making around climate transition, positive energy districts (PEDs) and energy communities in existing urban areas.

The results show that the development process is just as important as the tool itself. A co-design approach with project partners and wider stakeholder groups in the form of workshops, seminars, and regular meetings was essential for joint learning and to be able to develop solutions that respond to different perspectives and needs. The DT-Viewer integrates data from various sources as well as energy and optimization models via an easy-to-use and visually appealing user interface. In a developed logbook, data, assumptions, and modelling results are documented to facilitate reuse in future projects. The optimization was carried out at the district level for selected renovation measures (energy efficiency) and heating systems, renewable energy (solar PV) and battery energy storage systems (BESS) over a ten-year horizon with hourly resolution, with the goal of minimizing life cycle costs and climate impact from operation and embedded in materials. Applied to Jättesten and based on the chosen solutions, the analysis shows that it is very challenging to achieve full PED status. While optimized solutions reduced electricity dependency (to ~63% with PV and BESS under volatile prices) and total carbon emissions (by ~13% compared to baseline), neither full net-zero energy input, full carbon neutrality, nor an energy surplus were achieved. Optimal solutions were sensitive to local conditions, especially low carbon dioxide in district heating and volatility in electricity prices.

The analysis of stakeholder configurations, governance models and value-creating processes showed a multidimensional (economic, environmental, social) value creation but also some contradictions between different actor types, missed opportunities due to limited stakeholder participation and governance based on the project's theoretical approach. The project also explored the possibility of developing business models linking PED/energy communities and DT. The results show that DT can be seen as part of the governance infrastructure and can serve as knowledge platforms where plan and reality are compared, which strengthens predictability and legitimacy. However, since there are no established business models for either PED or DT, further research and innovation is needed.

The main contributions of the project are energy and climate modelling at the district level instead of the building level, the development of a tool, a web-based DT-Viewer, for decision support co-designed with project partners, optimization of energy efficiency, costs and climate impact, and reinterpretation of the PED concept to include climate impact. In the next step, the DT Viewer is further developed by the partner organisation Chalmers Next Labs. The development focuses on adaptation to different target groups, improved data and transparency, scalability for application of the model in other contexts (Gothenburg, nationally and internationally) and extended scenario testing related to energy systems, renovation measures packages and target images.

Introduction

In response to climate change and climate goals, cities are undergoing a transition with an increasing focus on energy resource efficiency and inclusion, not least linked to existing buildings. Among the strategies driving the transition are the concept of Positive Energy Districts (PEDs) – urban areas that balance local energy consumption with on-site renewable production and achieve a net positive energy performance over the course of one year (JPI 2021). Transforming existing neighbourhoods PED requires integrated planning to address complex challenges related to energy use, cost and life cycle perspectives.

Energy and climate transition at the district level sets new demands on planning tools and data infrastructures. Established methods model buildings most often individually and overlook local energy system potentials that shared renewable energy and battery storage entail. Although the models are technically robust, these often lack the capacity for integration across different scales and domains and tend to be inaccessible to non-experts. In addition, urban energy systems are increasingly dynamic with real-time interactions between distributed energy production, flexible loads, and digital controls, further challenging static modelling and planning. Designing and evaluating PEDs involves navigating complex interdependencies between buildings, energy systems, stakeholders, and regulations. Digital twins are seen as a promising tool to support urban energy and climate planning. However, while digital twins have gained widespread adoption in manufacturing and operations, their application in planning, management, and transformation of urban districts is still underexplored, especially at the neighbourhood level.

The goal of the project *"Dialogue and quality assurance support for PEDs using digital twin energy models" (DT4PED)* was to develop a quality assurance process based on a digital twin (DT) as a dialogue and decision-making tool, to inform planning and support decision-making towards climate transition, PEDs and energy communities in existing areas. Specifically, for the Swedish project to:

- Develop a DT for a pilot district.
- Use a DT to generate scenarios and explore new technological and process-related solutions with upscaling potential, including business models and the social dimension.
- Use a DT to support stakeholder dialogue, decision-making, and facilitate collaboration.
- Build transferable knowledge to other areas with PED ambitions regarding climate neutrality and energy efficiency.

Our PED framework included energy for the use of buildings (heating, cooling, hot water, operation), household and operational electricity, local energy production, energy storage and energy flexibility. Since Sweden's energy sources have a low climate impact compared to other countries in Europe, we also included the climate impact from the production of materials, i.e. embodied climate impact from a life cycle perspective for energy efficiency measures (renovation).

The project was conducted October 2022 to December 2025 with Chalmers as project manager and administrating organisation. The project was part of the joint programming initiative JPI Urban Europe and carried out in an international consortium with partners in Austria, Vienna, Sweden, Gothenburg and Türkiye, Sakarya. The Swedish project was financed by the Swedish Energy Agency and our project partners Förvaltnings AB Framtiden, the public housing company Poseidon, Framtiden Byggutveckling AB and the City Property Administration of the City of Gothenburg. Additional funding was obtained from the Energy Area of Advance at Chalmers and a donation from the Danish fund "Fonden af 20. December".

Implementation

The project applied a transdisciplinary approach where the main questions, delimitations and choices were discussed and developed iteratively together with project partners in workshops, seminars and focus group meetings. An Urban Living Lab (ULL) served as a PED pilot district. In-depth studies were based on an interdisciplinary approach with researchers and experts in architecture, building and energy modelling, programming, mathematics and economics. Different methods were used based on the requirements of the sub-studies, ranging from needs inventory, scenario development, stakeholder analyses, energy modelling, optimization, DT concept development, programming, visualization, interface design for a web-based DT Viewer, and evaluative user study.

District Jättesten as Urban Living Lab (ULL)

The selected ULL for the project was the district Jättesten in Gothenburg. The buildings are owned and managed by two municipal actors: the housing company Poseidon (rental housing and premises) and the City Property Administration (school and preschool), Figure 1. The starting point for the exploration of PED possibilities with a DT was to combine renovation measures for existing buildings combined with densification. Unfortunately, the detailed plan for the new development was delayed and therefore our project only included renovation of existing buildings.

The ULL is a typical district in Gothenburg, representative of many homes and multi-family houses built in the late 1940s and during the 1950s. Knowledge generated for this area therefore has considerable upscaling potential—it can be translated and applied to similar areas in other parts of the city and nationally.

Figure 1. Urban Living Lab Jättesten in Gothenburg with residential blocks, school, preschool and premises. Background map: Google Maps.

Focus and work packages

The project focused on four main areas and was carried out in seven work packages. Focus was:

- Development of *PED framework and quality assurance process*. Inclusion of the basic PED pillars, circularity dimension, and application of PED framework at different stages of the life cycle of buildings.
- Development of a *DT Viewer* to simulate and visualize potential future scenarios for energy efficiency (renovation) and renewable energy. Energy modelling and optimization at district level.
- *Stakeholder analysis* to gain a structured understanding of the key players. A framework with a multi-layered perspective was applied.
- Exploration of *business cases* in company-driven PEDs/energy communities and DTs. The analysis was based on a phased framework divided into formation, goal setting, investment and operation of PED/ energy communities.

The work packages (WPs) are: *WP1 Project Management* (Chalmers) with the aim of ensuring successful implementation with a goal-oriented process within the Swedish consortium and contributing to the international consortium. Regular project meetings, communication and documentation of activities and participation in international management team meetings. Most meetings were held online.

WP2 Input to Expert Support Facility, ESF (Chalmers) with the aim of contributing expert knowledge for joint knowledge building on PED within JPI Urban Europe/ Driving Urban Transitions (DUT). Chalmers participated in international meetings, seminars, workshops and contributed to the development of a PED landscape framework. Results were presented at Deep Dive webinars on the theme of Digital Twin and Stakeholder Participation. The ESF work was conducted together with participants from international PED projects funded within the same JPI call. A total of nine meetings, two of which were on-site (Figure 2) and seven online. Deep Dives have been summarised in short reports.

Figure 2. Expert Support Facility meetings. Planning of activities 30–31 January 2023 in Copenhagen (left). Project presentations with feedback (middle, right). Work package 2. Photo: Sara Ghaem Sigarchian (left), Liane Thuvander (middle, right)

WP3 Development of a PED framework and quality assurance process (QA) (Chalmers) with the aim of defining the QA process. Exploration of the potential of linking energy model to a DT and development of a requirement specification for a DT at different stages, from design to management. Literature studies, two co-creation workshops with the international team for broader discussions (Figure 3) and workshops with the Swedish project team. The workshops focused on mapping and backcasting. The results have been summarized in two conference papers.

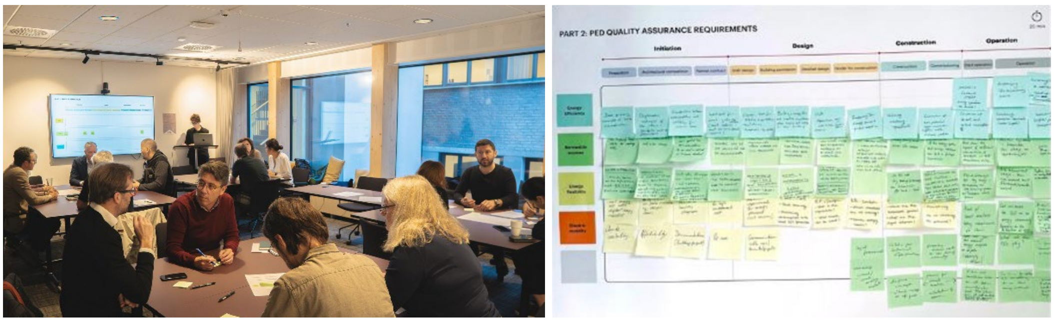


Figure 3. Workshop on quality assurance PED and DT with participants from the international consortium Sweden, Türkiye, and Austria, October 2023 (left). Filled in template for PED-requirement specification and quality assurance (right). Work package 3. Source: Malakhatka et al. (2024). Photo: Liane Thuvander

WP4 Implementation of the process and development of DT-Viewer adapted for Urban Living Lab Jättesten (Chalmers) with the goal of developing, testing and evaluating the potential of a DT at district level. Programming of backend and frontend (user interface), energy simulation and optimization. WP4 can be seen as the project's core work package. The following steps were carried out: Development of a common vision and roadmap for area development, development of DT concept for PED, data collection, development of baseline and renovation scenarios, energy modelling for PED components and optimization based on energy efficiency, costs and climate impact, design and testing of user interfaces. Figure 4 shows the process steps for DT Viewer development. WP4 also included stake-holder analyses with a focus on configurations, governance models and value creation processes through workshops, document studies and a multi-theoretical lens combining multi-layered perspectives, ULL frameworks, innovation eco-system theory and the Cambridge Value Mapping Tool. Participatory workshops with national project partners and broader stakeholder groups such as energy companies provided additional input. The results have been summarized in two scientific journal articles, three conference papers and two technical reports.

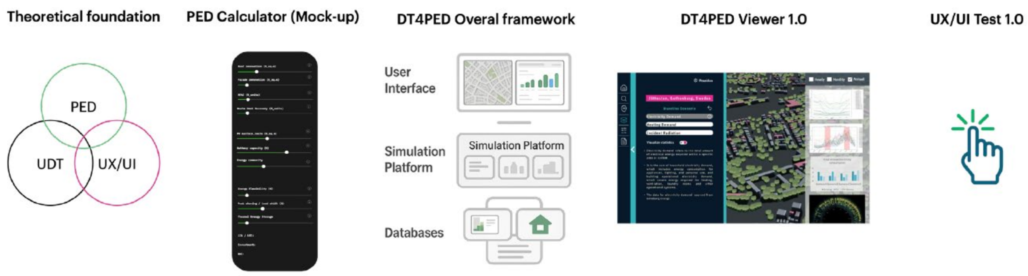


Figure 4. Overarching methodology for the DT Viewer development. Work package 4. Source: Malakhatka, Abouebeid, Arvanitis, et al. (2025)

AP5 Business Models for Digital Twins at district Level (University of Gothenburg) with the aim of identifying business models that can be applied for DT and PED. Literature studies, workshops, observations and analysis of empirical material from the project (Figure 5). The results have been summarised in a report.

Figure 5. Workshop with international project partners on business models October 2023 in Gothenburg (left). Anders Sandoff, School of Business, Gothenburg University, leads the workshop (right). Work package 5. Photo: Liane Thuvander

WP6 Success factors and lessons learned from Urban Living Lab experiences (Chalmers) with the aim of evaluating and exchanging experiences from the DT process and project results. International consortium workshops and study visits to all three countries for knowledge exchange and systematic review (Figure 6). Demo workshop with national partners and international evaluation workshop, follow-up interviews with all Swedish project participants and development of logbook for documentation of data and process.

Figure 6. Workshops and study visits for collaborative learning. Study visit Jättesten in Gothenburg (left), study visit City Intelligence Lab (CIL) at Austrian Institute of Technology (AIT) in Vienna, Austria (middle) and evaluation workshop in Sakarya, Türkiye (right). Work package 6. Photo: Liane Thuvander

WP7 Dissemination (Chalmers, Chalmers Industriteknik) to regularly inform about project status and results and contribute knowledge that can support energy and climate transition linked to urban districts. Information dissemination at national and international level, adapted to different target groups and channels through websites, the project's LinkedIn page, visual graphic identity, videos and project brochure. Participation in fair, industry conferences, and webinars (Figure 7). See Appendix A for a summary of completed workshops with date, theme, purpose and participants, Appendix B for a list of dissemination activities and Appendix C for visual material produced within the project.

Figure 7. Filming in Jättesten (left), presentation of project results at Climate and Energy Kick conference for public housing in Sweden, 12–13 November 2025, Örebro (right). Work package 7. Photo: Liane Thuvander (left), Björn Berggren (right)

Participating organisations and project participants

Due to the complexity and breadth of the project, many organisations and people in academia and practice were involved.

At *Chalmers*, the *Department of Architecture and Civil Engineering* (ACE) and the Department of *Mathematical Sciences* (MV) participated. Most of the work was carried out at ACE through Liane Thuvander with overall project responsibility; Elena Malakhatka with responsibility for project coordination and management of development and implementation of PED frameworks, DT concepts, DT Viewer and stakeholder analyses; Sara Abouebeid with main responsibility for energy modelling and simulation in different programming environments, design of user interfaces and production of results video; Holger Wallbaum with responsibility for scientific anchoring in a broader context and coordination with other related research projects and partners. Jessica Lundin contributed to the stakeholder analysis, David Sindelar and Seidpooyan Ghafoori to data collection, and Alex Gonzalez with initial energy modelling. MV was responsible for the optimization part through Jenny Enerbäck who developed the mathematical model and carried out the calculations and Ann-Brith Strömberg with overall scientific responsibility. *Chalmers Next Labs*, which became a partner towards the end of the project period, through Elena Malakhatka and Sara Abouebeid to package and further develop the results after project completion.

The City of Gothenburg participated through three municipal companies and the City Property Administration. All contributed with valuable insights into portfolio development and specific needs to address in the project. The housing company *Poseidon*, through Lars Brändemo and Carl Molander, provided information for the ULL's apartments, premises, and building-specific data. *Förvaltnings AB Framtiden* through Nina Jacobsson Stålheim and Hanna Öberg contributed with strategic perspectives and challenges linked to large housing portfolios and *Framtiden Byggutveckling AB* through Joa Ivarsson and Marcelo Arancibia with insights into new construction and mobility issues. The *City Property Administration* through Karl Oddmar provided data for the ULL's schools.

The *University of Gothenburg*, through Anders Sandoff contributed with insights into the establishment of business acumen in DT and PED. *White architects* through Keith Boxer, Lise-Lott Larsson Kolessar and initially Andreas Teggertsen Teder contributed to the stakeholder analysis, vision and roadmap development and experiences from previous PED projects (Positive Energy Planning Process). The *Digital Twin Cities Centre* (DTCC) through Themistoklis Arvanitis responsible for programming the user interface, Orfeas Eleftheriou responsible for programming 3D visualization and Vasilis Naserentin for linking the project to DTCC. *Chalmers Industriteknik* (CIT) through Dag Wästberg and Morten Kristoffersen who contributed to the development of the DT concept and Maria Hammar and Dana Gilliland-Wiström with responsibility for the website. Initially, Johanneberg Science Park (JSP) participated through Emilia Pisani with responsibility for communication and website. However, since JSP was closed during the project period, the website was transferred to CIT. Our international partners from Austria and Türkiye contributed with complementary expertise.

Results

The results are presented based on the four focus areas: PED framework and quality assurance process, DT-Viewer, stakeholder analysis, and business models with emphasis on the first two areas.

PED framework and quality assurance process

The project has developed a PED framework that describes how specific requirements are linked to different stages in the buildings' lifetime to ensure the development of PED according to plan throughout the process (Figure 8). Quality assurance is supported by an accompanying checklist (Figure 9). The framework and checklist have then been linked to DT potential and how DTs can be applied at different stages (Figure 10). The framework, checklist and DT integration have been developed together with the international project partners in workshops and with the support of literature.

The PED framework is a multi-criteria framework. It includes both renovation and new construction, and the construction process has been divided into clear overall stages to suit different countries: preparation, design, construction, operation and end-of-life (EN 2023). The framework is based on the basic PED pillars of energy efficiency, renewable energy and energy flexibility, but within the project there were also wishes and needs to expand these with circularity and business models, see Figure 8. The circularity pillar emphasizes the importance of resource efficiency, waste reduction, and the promotion of a circular economy within the district. Business models are seen as a crucial driver for the development of PEDs, as they affect economic viability and attractiveness. The checklist's ambition is to ensure that each stage follows established methods. Note that although mobility is a significant element of the PED framework, the project was omitted to reduce complexity, and the partner organisations gave it a lower priority.

The DT framework maps DT functionalities over time for the different stages. The starting point was a hierarchical categorization based on IoT Analytics (2024) and Malakhatka et al. (2024) with the following division: Digitize, Visualize, Simulate, Predict and Orchestrate (Figure 10). In the preparation phase, Digitize and Visualize provide a basis for feasibility studies (Negri et al. 2017). In the design phase, Simulate and Predict support scenario modeling and energy forecasting (Madni et al. 2019). During the construction and operation phase, Orchestrate ensures real-time coordination and follow-up of the PED intentions. In the final stage, Simulate facilitates decommissioning, impact assessment, and planning for recycling (Anderson et al. 2022).

Ihe planned DT for Jättesten included renovation of existing buildings and design of new PED-compliant buildings. By adapting DT applications to the different project phases, better support is provided for the follow-up of PED goals throughout the process. The synergies between PED and DT are considered to have significant potential for holistic and sustainable urban development.

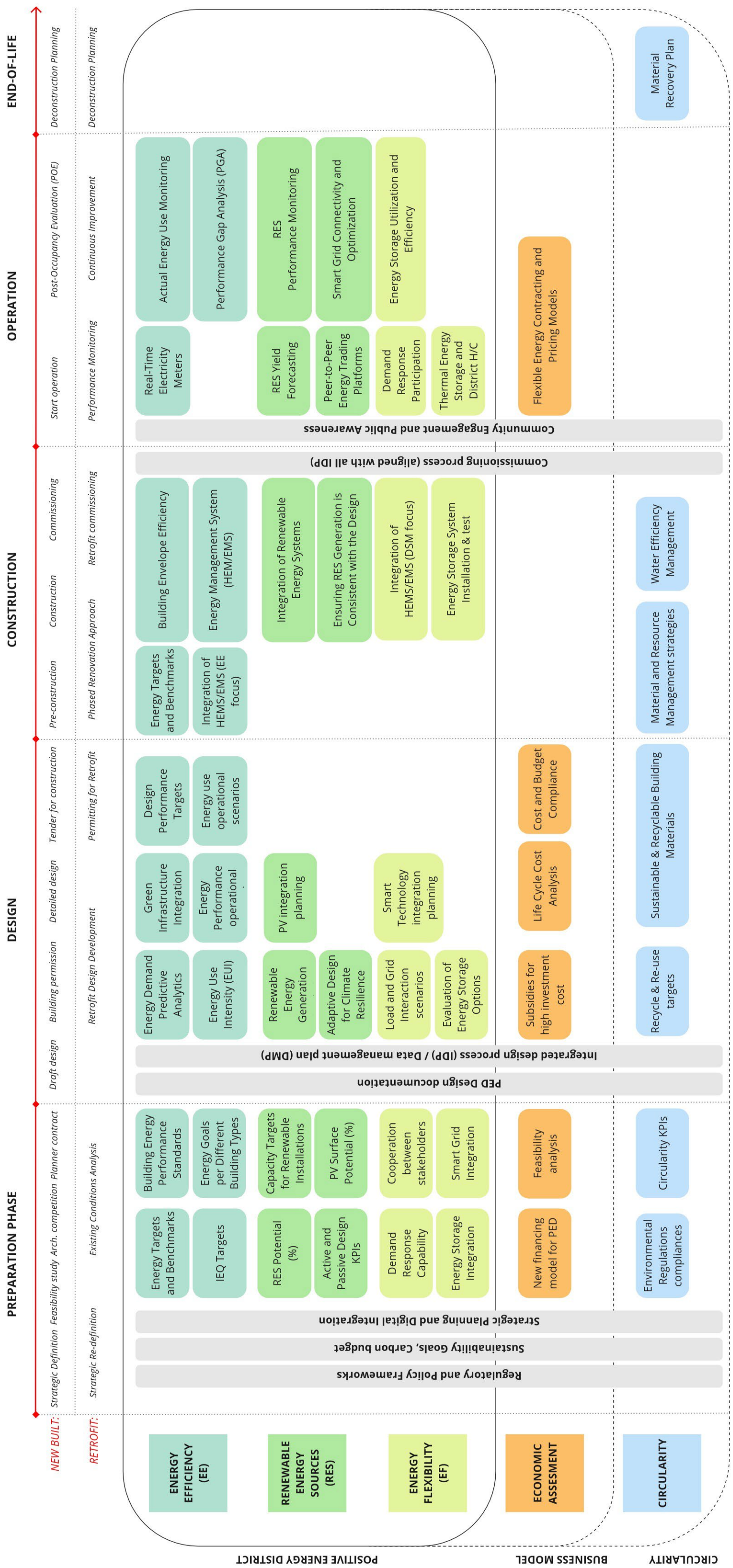


Figure 8. PED multi-criteria framework. Development based on workshops with project partners and literature studies. Source: Malakhatka et al. (2024)

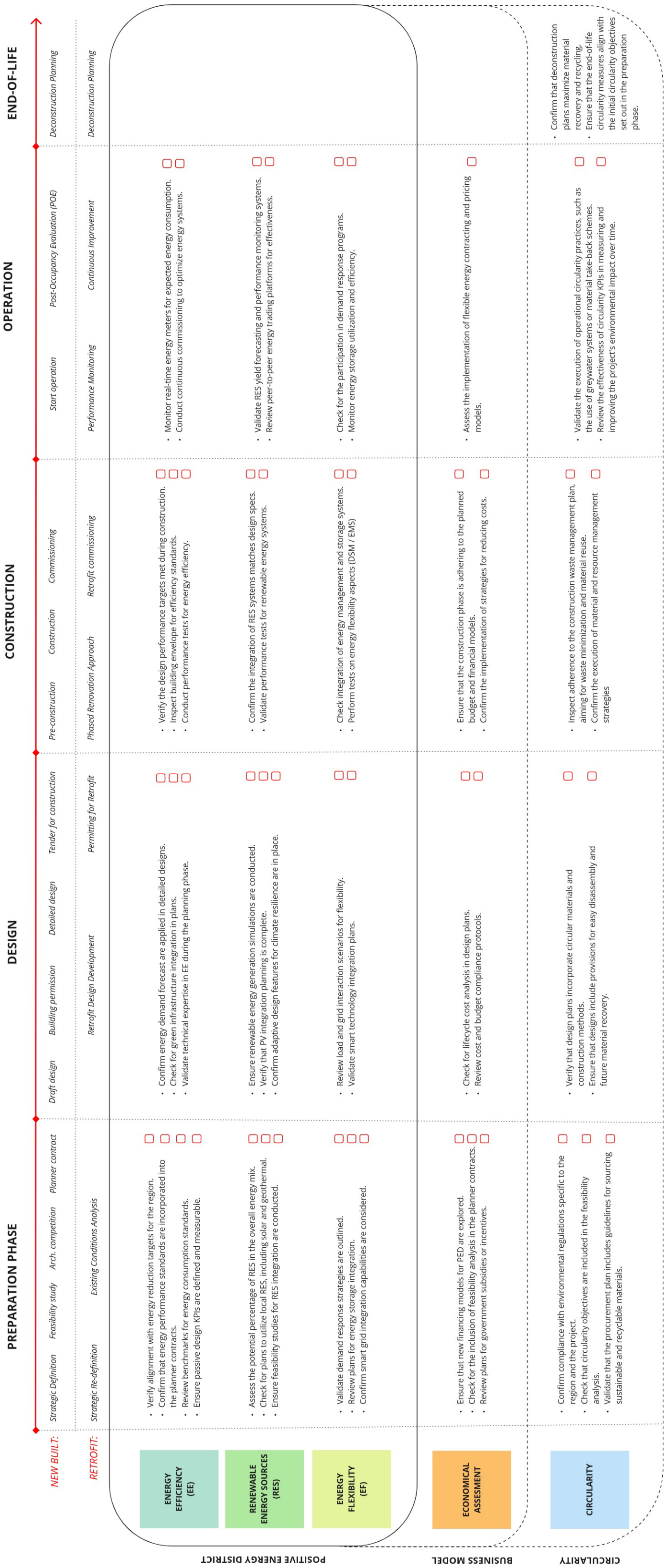


Figure 9. Checklist for quality assurance in PED-process. Source: Malakhatka et al. (2024)

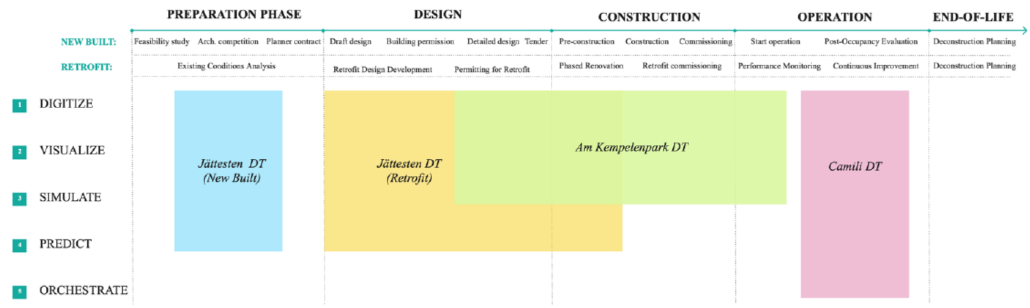


Figure 10. Framework for linking Digital Twin to different stages of buildings lifetime. Mapping for all three ULLs (Sweden–Jättesten, Austria–Am Kempelenpark, Türkiye–Camili). Source: Malakhatka, Wallbaum, Abouebeid, et al. (2025)

The backcasting workshop served as a planning tool where different stakeholders (project partners) gathered around a common vision for a sustainable urban future. The backcasting included several steps: establishing the baseline for existing conditions (energy use and systems, status of infrastructures, environmental impacts, etc.), defining a long-term vision for the PED, identifying mid-term milestones, and specifying actions required in the short term that contribute to the implementation of the long-term vision (Figure 11).

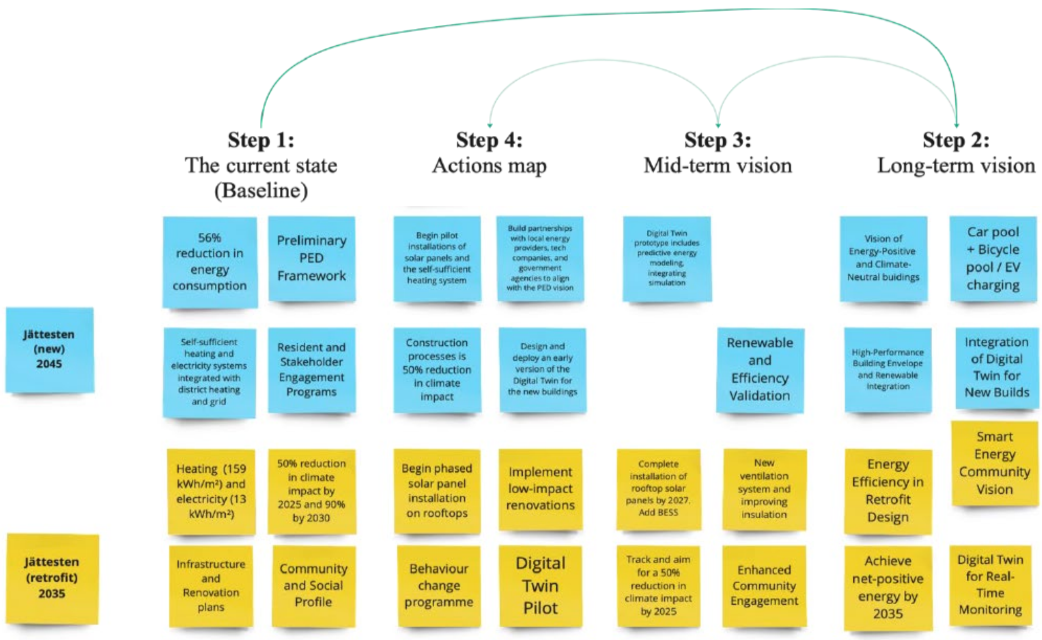


Figure 11. Strategies for Jättesten-renovation and Jättesten-new construction. Results from backcasting workshop.

The results from the PED framework, the backcasting workshop, and the DT applications underscore the importance of an iterative, data-driven approach to PED development. Backcasting supports long-term vision work and stakeholder engagement, and DT supports the implementation and follow-up of these visions. The analysis highlights that a) PED strategies require continuous alignment and balancing between stakeholder-driven visions and data-driven implementation tools, b) the choice of DT varies depending on the stage of the PED. Early stages/new construction benefit from BIM-integrated DT, projects with both renovation and new construction (densification), on the other hand, require hybrid methods that integrate modelling of building stock with new construction. For PEDs in operation, DT for real-time monitoring and adaptive energy management is advantageous and c) collaboration between different stakeholders is crucial at all stages. Backcasting workshops promote initial consensus formation, DT enables continuous decision-making and dialogue between stakeholders through data visualization, energy forecasting, and scenario modelling. For detailed description of the PED framework and checklist see Malakhatka et al. (2024), for DT adaptation and backcasting results see Malakhatka, Wallbaum, Abouebeid, et al. (2025).

DT Viewer

One of the main results of the project is the development of a web-based, interactive *DT Viewer*. Based on the theoretical foundation laid with the PED framework and the quality assurance process, a conceptual DT framework was developed with three main parts: a data layer, a modelling/application layer, and a decision layer (Figure 12). The framework was then translated into a system architecture for the DT platform and a fully functional user interface designed to visualize simulation results and support user-defined scenario testing. The user interface (UI) and user experience (UX) were tested and evaluated in a structured format at a Demo-day.

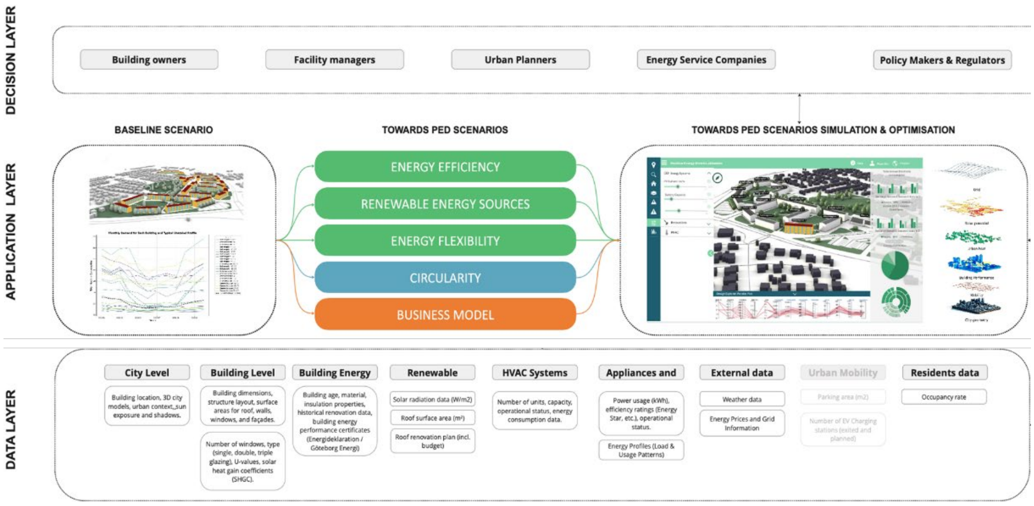


Figure 12. Conceptual DT framework for PED. Modified: Malakhatka, Abouebeid, Arvanitis, et al. (2025).

Data were collected for different geographical scales and aggregation levels – city, district and building and from different sources such as the Swedish mapping, cadastral and land registration authority (Lantmäteriet), property managers, energy companies, energy declarations, the National Board of Housing, Building and Planning, and more. The data include, among others, the geometry of buildings, vegetation (trees), energy for heating and hot water, operational electricity, household electricity and the costs of renovation packages.

An Urban Building Energy Model (UBEM) was established with a focus on the integration of PV systems for renewable energy and renovation strategies for energy efficiency. Subsequently, a mathematical model for multi-objective optimization (MILP Mixed Integer Linear Programming) of renovation alternatives, investments in energy systems, planning of energy use and energy production in the district was developed with a time horizon of 10 years. The goal was to calculate Pareto-optimal solutions to minimize life cycle cost as well as climate impact. By including the longer planning horizon of 10 years, decisions on renovations and investments in energy systems could be evaluated based on their long-term effects on costs and emissions. The workflow is shown in Figure 13. For details on data, UBEM and MILP optimization, see Abouebeid, Enerbäck, Malakhatka et al. (2026).

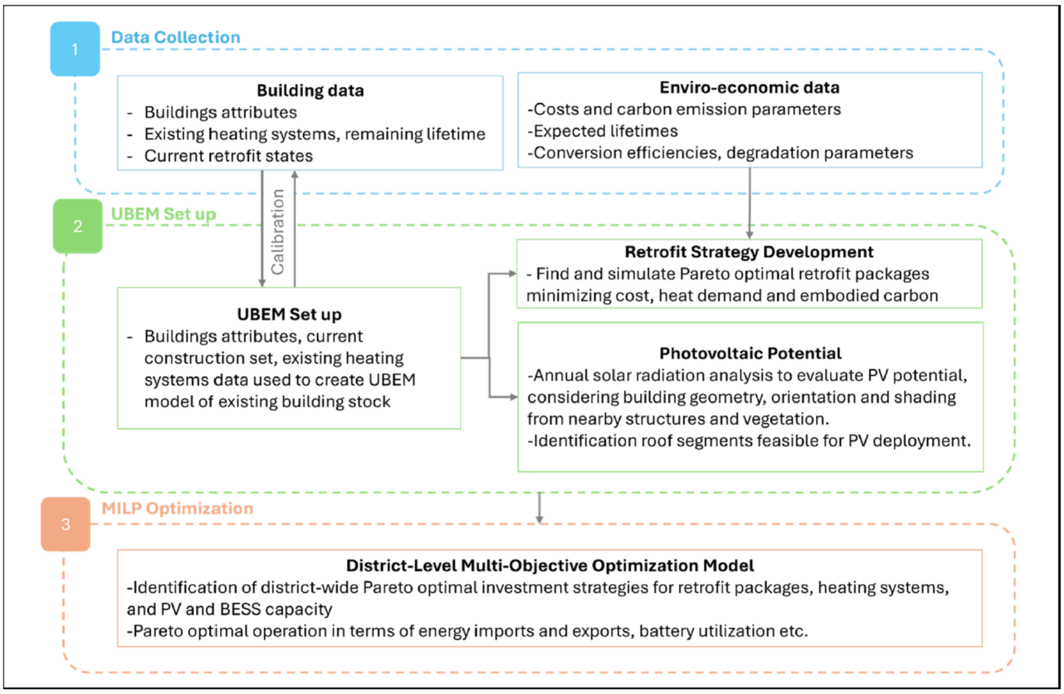


Figure 13. Integrated UBEM–MILP framework for transformation to PED. UBEM = Urban Building Energy Modelling. MILP = Mixed Integer Linear Programming. Source: Abouebeid, Enerbäck, Malakhatka et al. (2026)

For the calculation of solar energy potentials, a visual parametric tool was developed where the proportion and power of solar panels can be adjusted for each roof (Figure 14). The tool calculates the monthly solar power production, which is directly compared with the electricity consumption.

Energimyndigheten

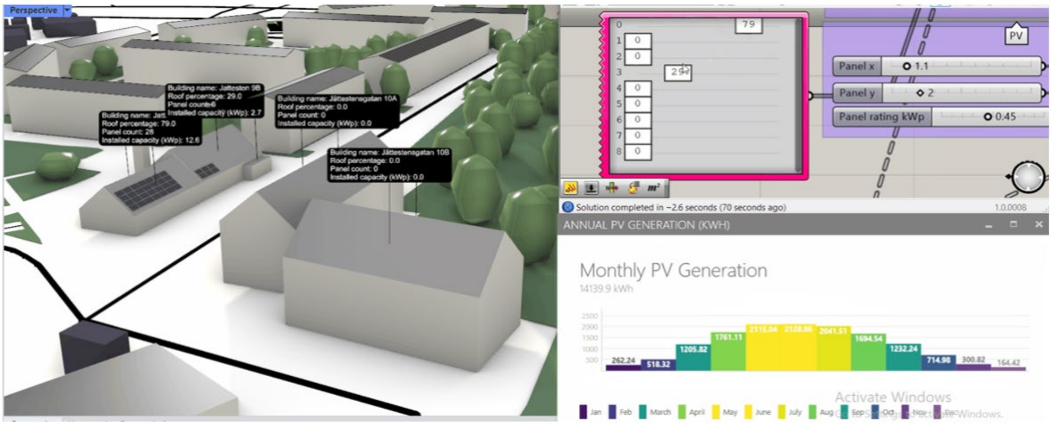


Figure 14. Parametric tool for calculation of solar energy potential, programmed in Grasshopper.

Renovation measures for energy efficiency focused on roofs and walls. To test the model, 18 renovation materials were selected, resulting in more than 43,000 simulations of different combinations of building materials. The impact of these combinations was then analysed in terms of reduced heating needs, climate impact and costs. Based on these results, which are visualized in Figure 15, six combinations and corresponding simulated values were selected to proceed with in the optimization step. Optimization was carried out at the area level for selected renovation measures (energy efficiency) and heating systems, renewable energy (solar PV) and battery energy storage system (BESS) over a ten-year horizon with hourly resolution. Applied to Jättesten and based on the chosen solutions, the analysis shows that it is very challenging to achieve full PED status. While the calculated solutions reduced electricity dependency (to ~63% with PV and BESS under volatile prices) and total carbon emissions (by ~13% compared to baseline), neither full net-zero energy imports, full carbon neutrality, nor an energy surplus were achieved. Pareto-optimal solutions were sensitive to local conditions, especially low carbon dioxide in district heating and volatility in electricity prices.

Figure 15. Parallel coordinates plot visualizing the results of over 43 000 parametric simulations of roof and wall retrofit packages combinations run on representative residential building. Each line represents a unique material configuration and is linked to simulated performance outcomes in terms of heating demand (kWh/m2year), material embodied carbon (kgCO_2e), and retrofit material cost (SEK). Source: Abouebeid, Enerbäck, Malakhatka et al. (2026)

The backend of the DT Viewer has been programmed in Python, using Rhino, the visual programming tool Grasshopper and the plug-in tools Honeybee, Ladybug, Dragonfly, as well as URBANopt, EnergyPlus and OpenStudio. The combination of these tools formed the basis for modelling buildings' energy use, climate data, urban context and energy systems at the district level. The frontend design was created in mock-ups using the web-based UI/UX design platform Figma, which facilitated communication with stakeholders during development. The frontend was then built with HTML and JavaScript integrated into the Unreal Engine (UE) which was chosen for its high-resolution 3D rendering and real-time interaction. The geometry for Jättesten was modeled in Rhino/Grasshopper and imported into UE via Datasmith with semantic metadata (building ID, PV areas, usage types). The user interface can be seen in Figure 16, more details can be found in Abouebeid, Enerbäck, Malakhatka et al (2026) and Malakhatka, Abouebeid, Arvanitis et al (2025).

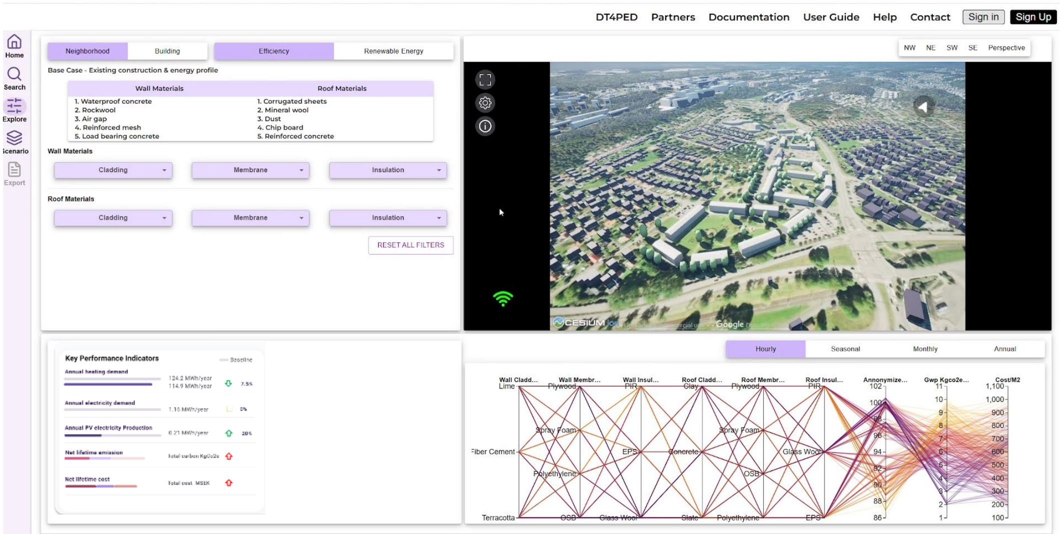


Figure 16. Interactive, web-based user interface integrating simulations and visualizations of energy performance for Jättesten on building- and district level.

Finally, a logbook has been developed for systematic documentation of data, meta-data, simulation and optimization results for better transparency, reproducibility and reuse of data and results in future projects and contexts (Figure 17).

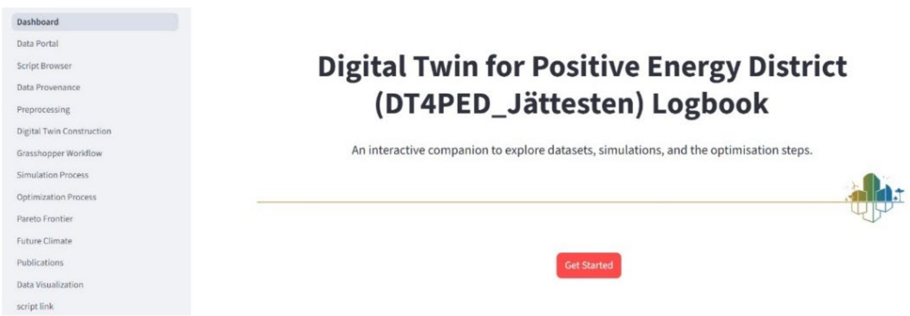


Figure 17: Logbook developed for Jättesten. The logbook documents data, modelling assumptions, workflows, simulation results as well as a catalogue with publications.

Stakeholder analysis

The analysis of different stakeholder configurations, governance models and value-creating processes for the ULL showed a multidimensional value creation (economic, environmental, social) but also some contradictions between different actor types and missed opportunities through, for example, limited stakeholder involvement. Jättesten was more academically driven, with the university acting as key coordinators and a network of municipal property management actors and an architectural firm (Figure 18) with limited inclusion of tenants and the public. Jättesten's strength lies in digital experimentation, especially the use of digital twin technologies to inform the choice of renovation options and energy simulations. However, the approach risks that the innovations become techno-centric due to limited co-creation with the users of the area: residents, school students and companies.

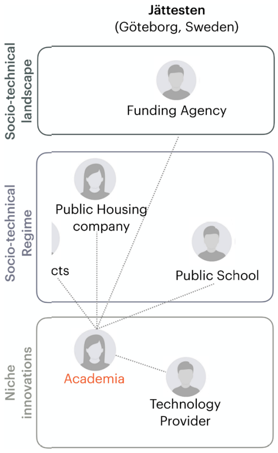


Figure 18. Analysis stakeholdernetwork for Jättesten. Orange: keydriver. Source: Malakhatka, Shafqat, Sandoff et al. (2025).

Jättesten creates value by experimenting with DT development linked to renovation strategies (Table 1) and academic and technical institutions benefit from real-world environments for learning. However, values are missed out due to a theoretical exploration with limited societal inclusion and partly disinterest from established energy suppliers. This imbalance creates inefficiencies in governance. Social value destruction, not taking advantage of all social aspects, arises as a result of missing participation from residents, which reinforces perceptions of top-down technocratic control. Future opportunities include participation via digital platforms, iterative feedback on energy issues and coordination of electricity companies.

Table 1. Capture Value Mapping Tool applied to Jättesten. Source: Malakhatka, Shafqat, Sandoff et al. (2025)

VALUE CAPTURED	VALUE MISSED	VALUE DESTROYED	OPPORTUNITIES
Digital twin, academic learning, retrofit gains	Tenant involvement, utility engagement	Governance friction, low legitimacy	Energy system alignment on different levels, participatory feedback loops

Several principles for the design and implementation of ULLs with a focus on PED/energy communities have been identified. These are: *Promote hybrid governance* by balancing top-down institutional leadership with bottom-up distributed governance. *Strengthen transition intermediaries*. Actors who can bridge between different institutional levels are important for success. *Strategic use of value mapping*. Value is a multidimensional concept and using value mapping tools from the start can ensure that the project addresses the social, environmental, and economic values of all stakeholders, which can prevent loss of legitimacy. *Design for replication*. To move away from single projects and towards broader implementation, ULL should be designed as part of a continuous process of institutional learning and not as isolated experiments. The results from this sub-study provided insights into how to design ULLs that are technologically efficient, socially integrated and enable just and sustainable urban energy transitions. See Malakhatka, Shafqat, Sandoff et al (2025) for more detailed results and discussion.

Business models

The project explored the possibility of developing business models linking PED/energy communities and DT. Given the early stage of the project and the fact that there are no established business models for either PED or DT, instead of in-depth analysis of the complex business and financial aspects of PED, a study was conducted with a more exploratory character in the Swedish context and for energy communities. Based on the knowledge generated in partner workshops and broader stakeholder groups, business case in company-driven energy communities with a focus on the real estate and energy sectors were analysed.

The study shows that business acumen is not a characteristic of a single calculation or contract but arises as a result of a chain of decisions that must be consistent over time. To understand these decisions, a phased framework was used that divides the life cycle of the energy community into formation, goal setting, investment, and operation. The theoretical foundation is based on three research tracks: business models, energy efficiency gap and governance. The business models are analysed as modular configurations of building blocks rather than as universal recipes. The energy efficiency gap explains why profitable measures are often absent and why institutional solutions are required to translate calculations into decisions. The governance perspective shows that long-term sustainability requires a combination of rules, incentives and norms, as well as neutral intermediaries that can coordinate actors. DT can be seen as part of the governance infrastructure that can serve as knowledge platforms where plan and reality are compared, strengthening both predictability and legitimacy. Value only arises when they are embedded in institutional orders with clear measurement plans, data rights, and auditing.

Empirical data from show how questions about system boundaries, goal conflicts and risk sharing are actualized in practice. Since the project did not focus on the formation of an actual energy community and was dominated by municipal actors within the same group, there is a lack of sharp negotiations between independent real estate companies. Although the project focused on a district with mainly municipal actors and a more theoretical exploration which limits the transferability of results, several insights are typical: system boundaries and membership criteria set the framework for the business, goals need to be operationalized in indicators and risk, data and mandates need to be formalized early.

Four key conclusions can be drawn. First, business acumen in energy communities is a process that requires benefits to be proven, risks to be manageable, and decisions to be controllable. Second, business communities differ from cooperative models in that they are governed by returns and risk management rather than legitimacy as an end per se. Third, scalability from pilot to established practice is dependent on standardization, institutions for verification and the ordering capacity of actors. Fourth, new frameworks for risk management and adaptive governance are needed, as contracts are always incomplete. For more detailed insights, see Sandoff (2025).

Discussion and conclusion

The DT4PED project has developed a simulation tool and Digital Twin Viewer adapted for positive energy districts. Jättesten with housing, schools, and premises served as a pilot district to theoretically investigate the district's PED potential. The ambition was to generate scenarios and explore new technological and process-related solutions with upscaling potential. The exploration focused on the existing buildings as the new construction part did not develop as planned within the project period. With a theoretical approach, discussions between partner organisations are not as sharp as in a real implementation process and the social issues become abstract. But having said that, the process, discussions and joint development of the tool have had value in themselves, for the development of the DT concept, choice of the parameters, knowledge exchange between the partner organisations and interpretation of the PED concept.

The tool is an operational prototype that uniquely combines detailed energy simulations (UrbanOpt, EnergyPlus) with an interactive web-based DT-Viewer (Unreal Engine, Pixel Streaming) to simulate and visualise possible alternatives to transforming an existing area into a PED. Using a scalable, modular backend, users can dynamically create and test different scenarios. The project has laid the foundation for building transferable knowledge to other districts aiming at climate neutrality and energy efficiency. The tool is considered to have high potential to support dialogue, decision-making and facilitate collaboration. However, for a more reality-based exploration of different solutions, data needs to be refined, with better transparency around energy and emissions data that reflects metering data for all buildings and local conditions. The tool also needs to be tested more in-depth for different purposes, operational and strategic applications, and communication with different actors and stakeholders. The logbook is a first step to increase transparency and get an indication of the reliability of the results.

A recurring discussion within the project was the interpretation of the PED concept and the choice of system boundaries. The PED concept is interesting as it lifts energy and climate issues from individual buildings to entire areas, which opens for interaction and energy exchange between buildings. At the same time, energy sources in Sweden usually have a lower climate impact compared to other European countries, and from a climate benefit perspective, other components need to come into play. Therefore, in addition to energy efficiency, renewable energy and flexibility, the project also included the climate impact of materials from a life cycle perspective in the PED. Another discussion concerned how the PED energy system relates to the city's energy system in general. It is an interesting question that needs to be studied, to compare the energy and climate benefits at the PED level with the benefits at the urban system level.

Reflection – to be part of the project

Individual conversations with all project participants provided additional insights, not least for future projects. The conversation revolved around two main parts: a) reflections on being part of the project including expectations, benefits of results, collaborations, and challenges and b) interest in the continued development of the tool. Depending on the experiences and expectations the organisations had, the results and learning were experienced in different ways.

In general, it was interesting for everyone to be involved in the process, and the joint learning about energy and climate issues was highlighted as a positive aspect. Several of the project participants mentioned, for example, the opportunity for open discussions, synergies, strengthened dialogue within and between organisations and insight into each other's working methods and challenges. The study trip to Austria was particularly inspiring, to be able to see what knowledge is available "outside the office". At the same time, project partners entered the project with different experiences and expectations and there was a certain ambiguity about the project's purpose, which led to a long start-up period and recurring discussions, not least about system boundaries and what the pros and cons are with a PED in the context of Gothenburg. The discussions pointed out the need for an openness and critical reflection on the PED concept in a Swedish urban context.

Project partners have indicated an interest in being involved in the future development process, but it is important to be able to adapt the tool to the organisations' needs, which can be on a strategic, operational, or project level. The models and tools developed in the project are considered to have substantial potential and a good basis to build on, not least experiences from the design process and the discussions linked to DT development illustrating how this type of platform can be built and reused in future projects. The further developed tool should be able to answer which locally adapted measures are most beneficial from a climate perspective for a district but also for the city as a whole.

Contributions and insights

The main contributions of the project are energy and climate modelling at the district level instead of the building level, the development of a tool - an interactive, web-based DT-Viewer for decision support and co-created with project partners, optimization models that include energy efficiency, costs and climate impact for different renovation measures, and reinterpretation of the PED concept to include climate impact.

Insights from the project are

- *The process is just as important as the tool itself.* The workflow was shaped through iterative discussions and workshops with many partners who had different needs and preconceptions. This co-creation approach was crucial for collaborative learning and for developing solutions that respond to different perspectives.
- *The tool as an enabler.* The tool is more than just software, it is also an enabler for parametric thinking, modular workflows, and offers adaptability in complex design and planning contexts.
- *Optimization for planning.* Through collaboration with the Department of Mathematics, a well-founded optimization model was developed that can contribute to more reliable planning and decision-making.
- *Digital Twin Viewer for pedagogical communicatio*n. Although the developed DT-Viewer is the first version and needs further development for full implementation, it has high potential to communicate simulation results in a pedagogical way.
- *Systematic documentation is key*. The developed logbook with systematic documentation of data, metadata, modelling assumptions, workflows and simulation results contributes to better transparency of input data, adaptation to local conditions and sensitivity analyses. This is fundamental to the credibility of the tool and its continued development.
- *Broad stakeholder involvement from the start.* Actors and stakeholders need to be involved early in the process and there is a need for an awareness of the target groups' specific needs regarding energy issues at the local level.
- *Business models need more exploration.* The project raised the issue of business models, but the conditions for developing the models within the framework of the project were limited. Further research and innovation are needed here.

Next steps

The DT-Viewer will be further developed by one of the partner organisations, Chalmers Next Labs, which is a research-related organisation at Chalmers. The development will focus on *improved data quality* to increase data transparency and reliability by better input data; *testing scalability* by investigating how the workflow can be applied in other contexts, for example in other areas in Gothenburg but also nationally and internationally; *integration and testing of more scenarios* related to different energy systems, renovation packages and goals by utilizing the built-in modularity of the backend system, and *adaptation* to different and more specific needs together with future users as well as opening up to include transport, charging stations for electric cars and alike.

List of publications and other material

The project results have been published and communicated through a number of channels. In total, we published two articles in scientific journals and five articles in international scientific conference proceedings. Two conference papers have received the award "Best paper". In addition, four background reports and a data logbook have been produced for detailed documentation. The Swedish project has contributed to reports produced within the international consortium, contributed to a webinar and report linked to overall JPI/DUT activities within the theme of PED. For popular science spread, the project and the results have been summarized in three short films, presented at an exhibition at an international event, at two conferences with a focus on public housing and regular posts on the project's LinkedIn page.

Scientific journals

1) Abouebeid S, Enerbäck J, Malakhatka E, Strömberg A-B, Sindelar D, Mazidi M, Sridhar A, Wallbaum H, Thuvander L (2026). Urban building energy modelling and multi-objective optimization for PED transition in an existing neighbourhood in Sweden. *Energy and Buildings,* 352 (2026) https://doi.org/10.1016/j.enbuild.2025.116783

The article introduces an integrated framework for energy modelling and optimization of life-cycle costs, carbon dioxide emissions and energy efficiency in connection with building renovations, applied to housing district from the 1950s in Gothenburg. The results show that it is very challenging to achieve full PED status (net-zero energy imports, net-zero carbon dioxide and energy surplus) with the evaluated solutions. While optimized solutions reduced grid dependency (to ~63% with PV and BESS under volatile prices) and total carbon emissions (by ~13% compared to baseline), neither full net-zero energy imports, full carbon neutrality including embedded effects, nor an energy surplus were achieved. The proposed framework provides a decision support tool for strategic PED planning in existing urban areas, enabling the exploration of complex techno-economic and environmental trade-offs.

2) Malakhatka E, Shafqat O, Sandoff A, Thuvander L (2025). Positive energy districts and energy communities: how living labs create value. *Buildings and Cities*, 6(1), 783–799. https://doi.org/10.5334/bc.630

The article presents a comparative analysis of six Urban Living Labs (ULL) focusing on positive energy districts and energy communities in Austria, Germany, Sweden, and the Netherlands. Different stakeholder configurations, governance models and value-creating processes are analysed using structured documentation of the six areas, a multi-theoretical lens combining a multi-layered perspective, ULL framework, innovation ecosystem theory and the Cambridge Value Mapping Tool (CVMT). The results show significant variations in governance, from centralized and municipal-led models to distributed, cooperative, or academic leadership. Mapping shows critical tensions between regime holders and niche actors, and the CVMT analysis shows that value creation is multidimensional but often uneven. The results provide actionable insights for design of ULLs that are technologically efficient and socially integrated for just and sustainable urban energy transitions.

Scientific conferences

1) Mazidi M, Sridhar A, Steen D, Malakhatka E, Abouebeid S, Niklasson F, Tuan LA, Wallbaum H (2026). Evaluating the Potential for Developing Local Energy Communities in Sweden: Case Studies at Jättesten and Chalmers Campus. In: Martinac I, Jørgensen BN, Ma ZG, Unnþórsson R, Bordin C (eds) Energy Informatics. *Lecture Notes in Computer Science,* 16096. Springer, Cham. https://doi.org/10.1007/978-3-032-03098-6_12

The article quantitatively evaluates the potential of Local Energy Communities (LEGs) to improve the efficiency of Sweden's electricity system. Two demonstration sites were evaluated: Jättesten, which represents housing, and Chalmers Campus, which represents a commercial building. The indicators that are focused on are annual operating costs and the ability to cut power peaks. The results show that a combination of residential and commercial loads within a single LEG significantly improves overall performance by leveraging the diversity of demand. Participation in LEG can reduce annual operating costs by up to 14%, improve self-consumption and self-sufficiency by up to 4%, and lower peak load by up to 20%. In addition, the analysis emphasizes the potential for further gains through increased integration of solar cells and battery storage systems.

2) Abouebeid S, Malakhatka E, Thuvander L (2025). Future-proofing positive energy districts: climate change impacts on energy demand and supply in Jättesten, Gothenburg. *Journal of Physics: Conference Series*, 3140 062001 DOI 10.1088/1742-6596/3140/6/062001

Presented at the CISBAT conference The Built Environment in Transition, 3-5 September 2025, Lausanne, Switzerland.

The study examines the impact of future climate scenarios on a potential conversion of a residential area into a PED. Simulation-based energy modelling integrates renovation measures and renewable energy systems. The results show a slight increase in seasonal cooling energy demand, partly offset by a significant reduction in thermal energy demand and variations in PV energy production. The insights underline the need to include additional considerations in renovation planning.

3) Malakhatka E, Abouebeid S, Arvanitis T, Eleftheriou O, Naserentin VA, Wästberg D, Thuvander L (2025). Digital Twin for Positive Energy Districts: A Web-Based Viewer for Scenario Simulation of the mixed-use area Jättesten, Gothenburg. *Proceedings of Digital Frontiers in Buildings and Infrastructure International Conference Series*.

Best paper award. Presented at DFBI International Conference on Digital Frontiers in Buildings and Infrastructure, 11-13 June 2025, Delft, The Netherlands.

The article presents a web-based Digital Twin platform, DT4PED, developed to guide the development towards PED through integrated modeling, simulation and visualization. DT4PED serves as a decision support tool that combines urban datasets with parametric modeling. The interactive web DT Viewer, developed with Unreal Engine and distributed via Pixel Streaming, enables real-time visualization of simulation results, comparative scenario analysis and display of performance metrics, without the need to install specialized hardware or software on the user's side.

4) Malakhatka E, Wallbaum H, Abouebeid S, Hofer G, Pooyanfar P, Dursun I, Weber G, Gecer HS, Thuvander L (2025). Fostering Sustainable Urban Energy Transitions: Backcasting for Positive Energy Districts and Digital Twin strategies in a European Context. *Proceedings CIB World Building Congress*. http://dx.doi.org/10.7771/3067-4883.1959

Best paper award. Presented at CIB World Building Congress, 19-23 May 2025, Purdue University, USA.

The study integrates backcasting methods and Digital Twin (DT) strategies to promote PED development through a two-step approach: backcasting workshops to co-create long-term visions and actionable strategies, as well as DT applications adapted to the three Urban Living Labs in Vienna/Austria, Gothenburg/Sweden and Sakarya/Türkiye. The back casting process identified pathways to energy efficiency, integration of renewable energy and reduction of climate impact. These were translated into operational tools and the DT functions Digitize, Visualize, Simulate, Predict and Orchestrate. The results underline cooperation between actors to align with local priorities. Challenges such as scalability, resource intensity, and maintaining long-term commitment remain.

5) Malakhatka E, Wästberg D, Wallbaum H, Pooyanfar P, Dursun İ, Hofer G, Thuvander L (2024). Towards Positive Energy Districts: Multi-criteria framework and Quality Assurance. In *IOP Conference Series: Earth and Environmental Science* (1363, No.1, 012085). IOP Publishing. doi: 10.1088/1755-1315/1363/1/012085

Presented at the World Sustainable Built Environment Conference Innovation Pathways & Partnerships, 12-14 Juni 2024, virtual conference.

The article develops a framework and checklist for quality assurance for PEDs linked to the European project DT4PEDs with Living Labs in Austria, Sweden and Türkiye. Based on a workshop with stakeholders from partner countries and a literature review, the study discusses consolidation of real estate development practices in the three countries including new construction and renovation, it formulates a multi-criteria PED framework for a quality checklist, and proposes recommendations for how a digital twin can support energy-related information flows and stakeholder dialogue.

Reports

Gollner C, Persson J, van Noordt A, Thuvander L, van der Laan M (2025). *Deep-dive #3: Digital Twins and decision-making tools for PED*. DUT report.

Naserentin, V (2025). *DENIM Project Repositories Report Technical Summary: denim-urbanOpt & denim-kfp.* DTCC and Flax & Teal Limited.

Sandoff A (2025). *Affärsmässighet i energigemenskaper. En fasindelad analys av företagsdrivna affärsmodeller i svensk kontext*. Handelshögskolan vid Göteborgs universitet.

Svensson, O (2025). *Lufttäthetsmätning av lägenhet 397, Jättestensgatan 13A, Göteborg*. Rapport RISE

Wästberg D (2025). *Digital Twin Simulation Backend for Energy Modeling – Summary*. Chalmers industriteknik.

Films

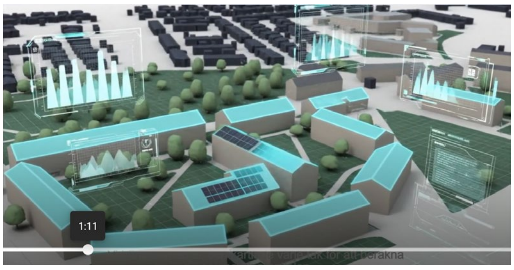
Project, partners, and expectation (Swedish consortium):

241023 DT4PEDs kortfilm SV.mp4

Project, partners, and expectations (international consortium):

www.youtube.com/watch?v=pmhWSi0SGnc

Summary of project results:



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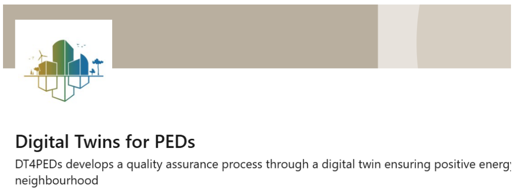
Social media - LinkedIn



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Malakhatka E, Abouebeid S, Arvanitis T, Eleftheriou O, Naserentin VA, Wästberg D, Thuvander L (2025). Digital Twin for Positive Energy Districts: A Web-Based Viewer for Scenario Simulation of the mixed-use area Jättesten, Gothenburg. *Proceedings of Digital Frontiers in Buildings and Infrastructure International Conference Series*.

Malakhatka E, Shafqat O, Sandoff A, Thuvander L (2025). Positive energy districts and energy communities: how living labs create value. *Buildings and Cities*, 6(1), 783–799. doi. org/10.5334/bc.630

Malakhatka E, Wallbaum H, Abouebeid S, Hofer G, Pooyanfar P, Dursun I, Weber G, Gecer HS, Thuvander L (2025). Fostering Sustainable Urban Energy Transitions: Backcasting for Positive Energy Districts and Digital Twin strategies in a European Context. *Proceedings CIB World Building Congress*.

Malakhatka E, Wästberg D, Wallbaum H, Pooyanfar P, Dursun İ, Hofer G, Thuvander L (2024). Towards Positive Energy Districts: Multi-criteria framework and Quality Assurance. *IOP Conference Series: Earth and Environmental Science* (1363, No. 1, 012085). DOI: 10.1088/1755-1315/1363/1/012085

Negri E, Fumagalli L, Macchi M (2017). A review of the roles of digital twin in CPS-based production systems. *Procedia manufacturing*, *11*, 939-948.

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Appendix A Completed workshops and larger meetings

Workshops Swedish project team

WS#	Date/location	Theme	Participants
#1	2023-02-02 Online	System boundaries Definition of PED, concept, energy efficiency strategies, principles for calculating energy use, energy sources	12
#2	2023-03-01 Online	Stakeholders and driving forces Mapping of actors based on degree of interest - core actors, participant, be informed - and their driving forces	12
#3	2023-04-04 Online	Scenarios Coordination of renovation and development strategies between property-managing companies, discussion of energy relationship between buildings, time horizons	10

National workshops

WS#	Date/location	Theme	Participants
#1	2023-10-04 Jättesten Gothenburg	Stakeholder analysis and scenarios Identify and discuss key stakeholders and their potential drivers to contribute to the development of energy and climate scenarios	20 5 Property company 5 Consultants 6 Researchers 1 Municipality 1 Energy company 2 Car company
#2	2024-11-27 AWL Gothenburg	Roundtable Project presentation and discussion PED energy scenarios, energy system innovation, business models, and community engagement. Gather insights from various experts and stakeholders to evaluate preliminary results and discuss future developments of DT4PED methodology.	23 4 Property company 3 Consultants 4 Energy company 2 Municipality 2 Public regional organisation 8 Researchers
#3	2025-06-11 Jättesten Gothenburg	Demo-day, final event Presentation of project results combined with demonstration and testing of the developed DT-Viewer	17 7 Property company 3 Consultants 2 Energy company 5 Researchers

Internationella workshops

WS#	Datum / plats	Tema	Deltagare
#1	2023-10-05 AWL Gothenburg	Business models Discussion of importance, pros and cons of developing and using a digital twin as a product, service and infrastructure	20 3 Austria 15 Sweden 2 Türkiye
#2	2023-10-05 AWL Gothenburg	Quality assurance process Development and discussion of a common PED framework	20 3 Austria 15 Sweden 2 Türkiye
#3	2024-09-19 e7 Vienna	Back-casting Analysis of current situation, identification of long-term vision, mid-term vision and measures for implementation of the visions	16 6 Austria 7 Sweden 3 Türkiye
#4	2025-09-11 Sakarya Sakarya University	Evaluation project Reflection on DT4PED project results and process as a whole	9 1 Austria 2 Sweden 6 Türkiye

Activities international consortium
Kick-off meeting 16–17 November 2022, online
Meeting and study visit Jättesten 5–6 October 2023, Gothenburg, Sweden
Workshop *Lessons learnt*, 3 June 2024, online
Meeing and study visit 19–20 September 2024, Vienna, Austria
Knowledge exchange meeting *Ekodenge Platform, Türkiye*, 23 January 2025, online
Knowledge exchange meeting *Digital Tvilling koncept, Sverige*, 13 March 2025, online
Knowledge exchange meeting *Circularitet, Austria*, 28 May 2025, online
Final meeting and study visit 11–12 September 2025, Sakarya, Türkiye

Active participation in Expert Support Facility
01_Meeting 2023-01-30/31, Copenhagen
03_Meeting 2023-09-05, online
04_Meeting 2024-01-25/26, Brussels
05_Meeting 2024-09-05, online
06_Meeting 2024-12-05, online
07_Meeting 2025-02-18, online
08_Meeting 2025-05-12, online
Final meeting 2025-10-22, online

Project meeting Swedish team
2022 – 2 meetings
2023 – 9 meetings
2024 – 4 meetings
2025 – 2 meetings (less meetings in whole group, meetings in smaller focus groups)

Appendix B Compilation of result dissemination activities

Year 2025

Presentations at conferences

- *Klimat- och energikicken,* 12–13 November 2025, Örebro, Sweden
- *CISBAT The Built Environment in Transition*, 3-5 September 2025, Lausanne, Schweiz
- *First Nordic Energy Informatics Academy Conference*, EIA Nordic 2025, 20–22 August 2025, Stockholm, Sweden
- *DFBI International Conference on Digital Frontiers in Buildings and Infrastructure,* 11–13 June 2025, TU Delft, The Netherlands
- *CIB World Building Congress*, 19–23 May 2025, Purdue University, USA

Presentations at workshops, seminars, and webinar

- *International final event:* JPI Urban Europe PED Call II, 21 October 2025, online
- *Workshop*: Kraftsamling för lokal energiomställning, 4 September 2025, Stockholm, Sweden
- *Webinar:* Digital Twins and decision-making tools for PED, Thematic Deep-dive 3, PED Expert Support Facility, 6 March 2025, online DD#3: https://www.youtube.com/watch?v=AbdvlIMAL-E
- *Seminar*: Area of Advance Energy, Profile urban energy, 28 February 2025, Chalmers, Gothenburg, Sweden

Dissemination information about the project

- *Webinar:* The role of positive energy districts in city transformation - A Swedish perspective (Jonas Persson, Viable Cities), SyC Smart Cities Electrotechnical aspects of Smart Cities, IEC, 10 June 2025, online
- *Blogpost:* ECMI – European Consortium for Mathematics in Industry, 10 September 2025

Year 2024

Presentations at conferences

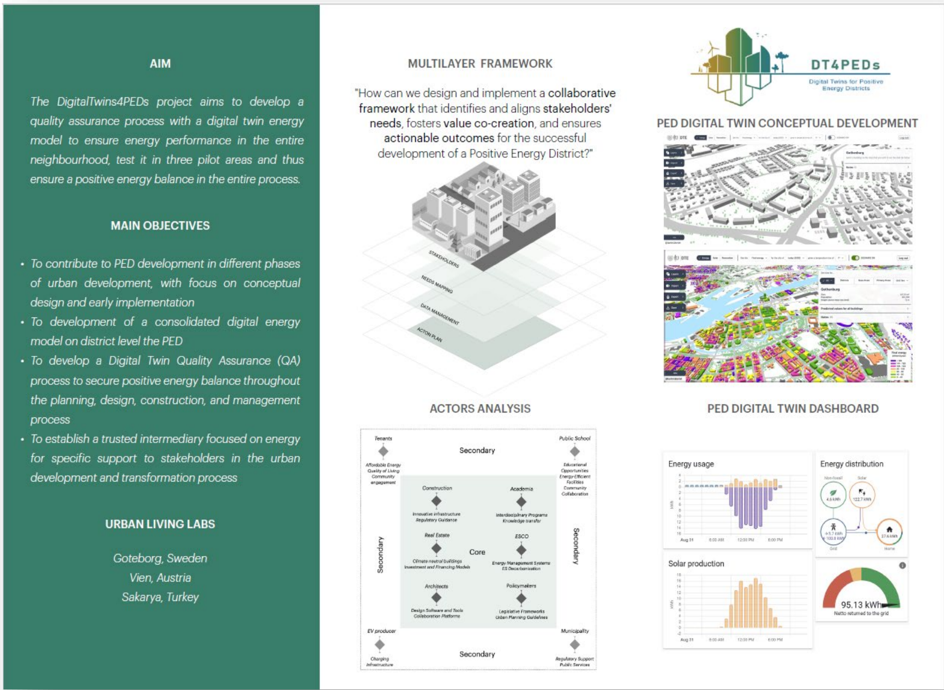
- *WSBE 2024 Innovation Pathways & Partnerships for Sustainable Built and Urban Environments*, 12–14 June 2024, virtual conference

Presentations at workshops and exhibition

- *Exhibition and survey:* Urban Futures: The Better-Cities Event, 5–7 June 2024, Rotterdam, The Netherlands
- *Workshop:* Urban Living Lab Conference Re-inventing the city (urban innovation), 23–25 April 2024, AMS Institute, The Netherlands

Appendix C Posters and other dissemination material

Information brochure DT4PED



DT4PED Poster: Expert Support Facility workshop in Brussels, 2024