DIGITAL TWIN MODEL FOR ZERO-ENERGY DISTRICTS: THE CASE STUDY OF ANZIO PORT, ITALY

SOFIA AGOSTINELLI
CITERA Research Centre, Sapienza University of Rome, Italy

ABSTRACT

A digital twin (DT) for a built environment is able to predict performances and behaviours across the life cycle through the implementation of predictive models and the real-time monitoring systems. In the present paper, a DT application is described in order to transform port areas in zero-energy districts (ZED) in Italy. The project case study is the port of Anzio, as it is a particularly representative sample of a port in the Mediterranean Sea. The study focuses on energy management strategies for the existing structures integrated with production systems through renewable energy systems (RESs) for sustainable mobility. The energy analysis of the area highlights the potential of DT, combining building information modelling (BIM) and geographic information system (GIS) to evaluate different multi-scale scenarios maximizing benefits of energy efficiency strategies. The proposed DT framework of the Anzio port acquires energy data, presence data, projection of displacements and accesses, among others, together with the data acquired by the distributed sensors allowing elaborations, correlations, scenario simulations and providing insights through dashboards and data visualization.
Keywords: digital twin, renewable energy systems, zero-energy district, digital transformation, BIM.

1 INTRODUCTION

There is a solid and positive relationship between operational efficiency and energy efficiency in port areas, as the increase of energy optimization results in significant energy efficiency. In this regard there is a direct connection between energy and operational efficiency in complex infrastructures such as port areas, as operational efficiency of sources reduces energy consumption [1] as electricity or fossil fuel.

According to policies for air pollution reduction in recent years, the progressive electrification of relevant port areas leads to the integration of renewable energy sources supported by the increasing advances in electricity generation and storage technologies [2]. In addition, a local electric smart grid can be installed to enhance network intelligence and new devices for efficient energy storage using machine learning (ML) to increase energy management.

A smart approach to the monitoring of built environment (e.g., fault detection and diagnostics system using sensor networks and AI-based modern technologies), generates benefits such as reducing maintenance costs, energy consumption and related costs, increased productivity, and extended equipment life [3].

The main objective of the strategy proposed in this paper is the realization of a digital twin (DT) model as a data base able to collect and analyse data coming from sensors, offering a system interface allowing control and monitoring capabilities and enabling predictions about future states [4]. Moreover, the digitization process oriented to digital twin technologies is an opportunity to rethink the approach to urban areas and related infrastructures in a circular economy and sustainability perspective. The proposed framework is intended both for facilitating facilities management operation and for enhancing space management purposes in a sustainable city perspective, according to post COVID-19 pandemics requirements, as occupancy detection is an important part of the facility management to ensure users' safety [5].

www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/SC220291

Digital twins (DTs) are virtual replicas of physical assets in operation supporting managers and technicians, enhancing decision-making processes as well as predictive/ adaptive scenarios. DTs are developed as integrated multi-physics, multi-scale, probabilistic simulations, using the best available physical models and sensors to mirror the lifecycle of their real twins [6].

2 MATERIALS AND METHODS

The Regione Lazio project started in 2020, was funded by the department "Mobility Infrastructure and Transport Area" and aimed at developing and enhancing a digital twin model for four different ports, namely, Anzio, Formia, Ventotene and Terracina based on collecting data from different sources through IoT and 5G.

The present research is restricted to the Anzio port (Fig. 1), an area of over 84,022 m^2 characterized by different activities and uses. Its current configuration is the result of a process of urban regeneration that began essentially in 1960 and still continues today because of the design of a new part of the port. In this changing configuration the DT could be the digital platform where the administration can accurately simulate and plan activities in a healthy, safe, comfortable and sustainable way for visitors.

Figure 1: BIM model of the port of Anzio.

In order to design an optimal DT architecture, policymakers (Regione Lazio and Municipality of Anzio) have been involved in order to support their decision-making processes and optimize the port system management. The result of this participate design has been the implementation of a platform, as shown, for instance, in Fig. 2, in order to make available IoT, geo-referenced data, as well as processed and produced data [7].

In fact, the management of the input data coming from different sources, devices and layers for each type of data, will allow the manager to keep under control the performance of the systems, as well as of goods and people flows [4]. Moreover, using energetic simulation tools, it is possible to evaluate different energy-based scenarios coming from an optimization of actual power loads and form the possible integration of renewable energy systems (RES). IoT devices are essential to make every object, person or building a real time data source; and algorithms, through artificial intelligence approaches, make an energy management system more accurate; all the advanced smart sensors are able to collect a large amount of information while data storage is inserted in a common data environment, secure and reliable in Cloud [8], [9].

A prototype has been developed by Sapienza University of Rome for the Lazio region and visualization capabilities were implemented through augmented reality (AR) supporting a

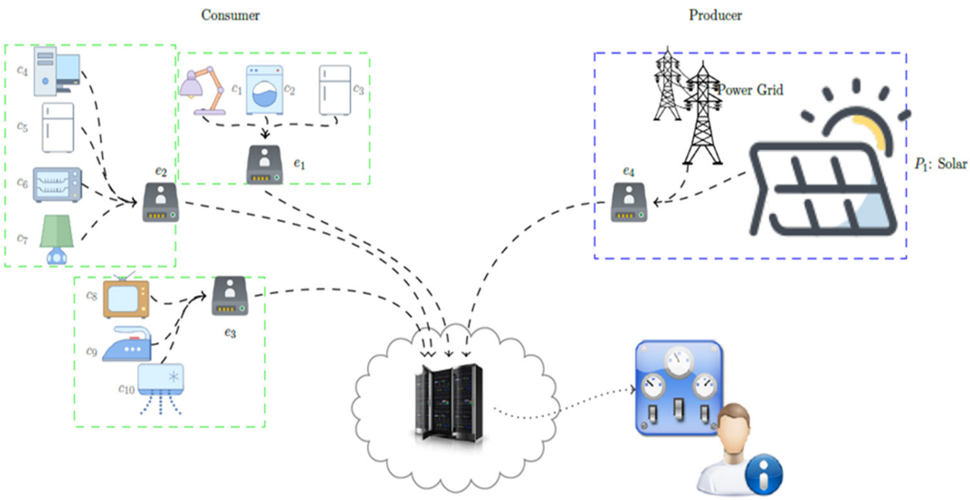

Figure 2: Integrated and multi-layer platform for the port management.

collaborative management approach; starting from a 3D model of the built environment, data are collected from an heterogeneous type of sensors (mobile devices, sensors, video content analysis), and inserted in a multi-layer platform for aggregate data exposure and management.

The collection of data for monitoring are disposed on three main different domains:

- the first one is the installation of smart meters for energy production and consumption, air quality, weather forecasts, sea level, water consumption;
- positioning of security cameras;
- mobile applications receiving from users alerts about faults on the built energy systems with geographical localization.

The inclusion of appropriate shared parameters in the BIM model allows the evaluation of a predictive description of energy consumption associated with the different loads in the port area. The load associated with lighting terminals is about 67% of the total electrical consumption.

In addition, in the north pier area, there are some charging devices for private and public boats. These devices are divided into double charging stations and simple interlocked sockets. The overall electrical consumption of all the devices of the Anzio port area is 90,155 + 129,600 = 219,755 kWh for a year. This is the target of implementing the RESs local grid production in the same place to reach a zero-energy district as described in the result section.

All the data coming from smart meter devices (electrical loads) and an RES production system, such as inverter Fronius, are transmitted by sensors to the platform, and they can be visualized through dashboards able to report and analyse data in real-time as reported in Fig. 3.

3 RESULTS AND DISCUSSION

The realization of a zero-energy district in a port area requires the integration of different RES using available areas. For this project the combination of two different solutions have

www.witpress.com, ISSN 1743-3541 (on-line)

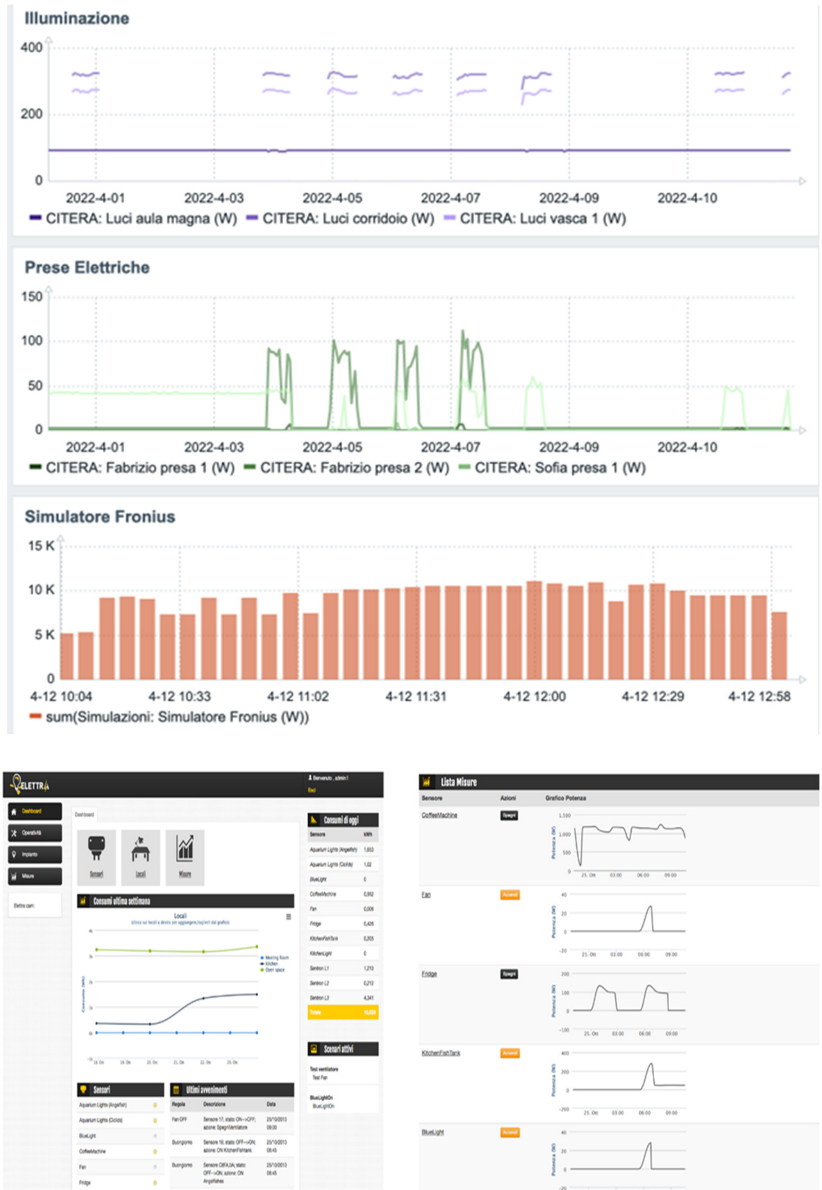

Figure 3: DT energy consumptions: dashboards.

been considered to reach the needed production of 219,755 kWh for a year: photovoltaic panels and micro wind turbines. In fact, the combination of different RES ensures about 40% of energy supply even in unfavourable climate condition. Moreover, wind conditions combined with technical requirements in terms of minimum distance between microturbines did not allow the increase of the supplied wind power, despite the fact that no regulatory constraints are introduced in the area, as the port is subjected to military harbourmaster authorities.

Fifteen micro wind turbines are located in external port areas, south pier, as shown in Fig. 4; the obtained value from each turbine is approximately 2,420 kWh per year. Therefore, it is possible to produce 36,300 kWh per year with fifteen turbines located in all the free area on the entire north pier.

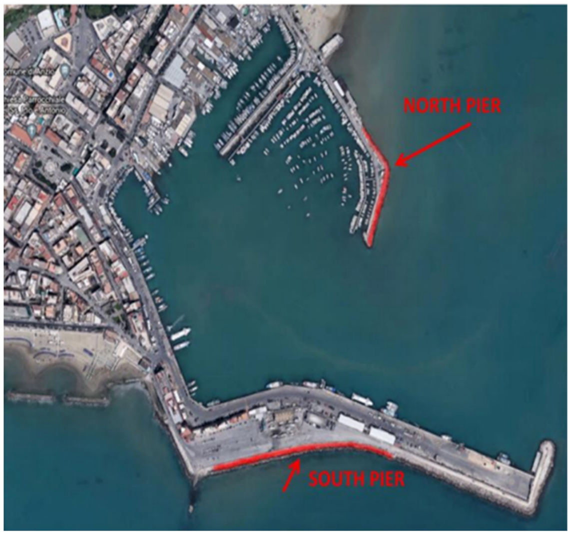

Figure 4: Pier area for RES installation.

In order to install the photovoltaic modules, the area at the end of the Southern pier was chosen. It is a large area, characterized by good exposure and without shading (there are no buildings nearby), as shown in Fig. 4. As shown in Fig. 5, it is possible to evaluate the area covered by the modules, which is much smaller than the available area, that is, about 2,663 m^2.

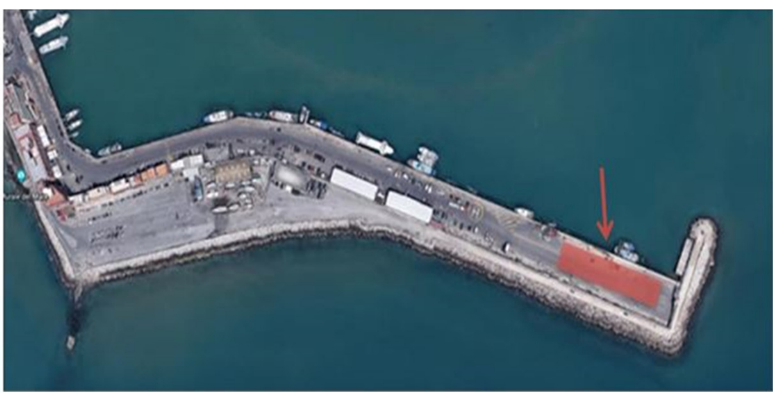

Figure 5: Positioning of photovoltaic models.

The port has a good potential, due to its geometric characteristics and location, and a maximum of two-level buildings is easily transformable into ZEB buildings. A further implementation of the DT and extending the harbour representation can improve its environmental and economic management.

In order to achieve this implementation, the following phases must be considered:

- A primary phase concerns the issue of interoperability between system platforms and languages (middleware) where the system architecture must establish an appropriate shared model for collecting data from the various sources (sensors, inverters, smart meters, etc.).
- The second phase concerns the implementation of smart systems that must be updated and increased over time and always adapted to the changing functionalities required by new operating conditions and/or new emerging technologies.
- Finally, the third phase concerns the correct and adequate installation of connection infrastructures, such as mainly the power supply lines (which must reach every single sensor that needs power) and obviously the network connection (both wired and wi-fi).

4 CONCLUSIONS

The DT of Anzio port project proposes a holistic view of real/virtual spaces acquiring energy data, presence data, projection of displacements and accesses, among others, together with the data acquired by the distributed sensors which allow carrying out elaborations, correlations, scenario simulations that are made available in the dashboards dedicated to the area manager.

The proposed project represents the first phase of a digital transformation process of the coastal cities of the Lazio region, starting from their infrastructural centre. The implications of this transformation directly concern the environmental, economic and social domain, setting the port area as the epicentre and extending to the rest of the city.

Consequently, the digitalization of the area, through this first implementation of the DT for the Port of Anzio, allows the possibility to start from the epicentre of this digital and ecological transformation, to spread throughout the territory, studying the exchange flows with the surrounding territories, linked to transport by sea, land, road and rail [10], [11]. It would also replace economic and environmental costs of electricity production for public lighting and electricity supply to moored boats by switching from carbon to renewable energy sources.

REFERENCES

[1] Wilmsmeier, G. & Spengler, T., Energy consumption and container terminal efficiency. *FAL Bulletin*, **10**, pp. 350–356, 2016. https://www.cepal.org/en/publications/list/date/2016

[2] Parise, G., Parise, L., Malerba, A., Pepe, F.M., Honorati, A. & Ben Chavdarian, P., Comprehensive peak-shaving solutions for port cranes. *IEEE Transactions on Industry Applications*, **53**(3), pp. 1799–1806, 2017. DOI: 10.1109/TIA.2016.2645514.

[3] Brunone, B., Meniconi, S. & Capponi, C., Numerical analysis of the transient pressure damping in a single polymeric pipe with a leak. *Urban Water Journal*, **15**(8), pp. 760–768, 2018. DOI: 10.1080/1573062X.2018.15477.

[4] Grieves, M. & Vickers, J., Digital twin: mitigating unpredictable, undesirable emergent behavior in complex systems. *Transdisciplinary Perspectives on Complex Systems*, Springer: Cham, pp. 85–113, 2017.

[5] Zheng, C., Yuan, J., Zhu, L., Zhang, Y. & Shao, Q., From digital to sustainable: A scientometric review of smart city literature between 1990 and 2019. *Journal of Clean Production*, **258**, 2020. DOI: 101016/j.jclepro.2020.120689.

[6] Glaessgen, E. & Stargel, D., The digital twin paradigm for future NASA and U.S. air force vehicles. *53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, April, Honolulu, Hawaii, 2012. DOI: 10.2514/6.2012-1818.

[7] Nuzzo, A., Tan, C.O., Raskar, R., De Simone, D.C., Kapa, S. & Gupta, R., Universal shelter-in-place versus advanced automated contact tracing and targeted isolation: A case for 21st-century technologies for SARS-CoV-2 and future pandemics. *Mayo Clinic Proceedings*, **95**(9), pp. 1898–1905, 2020.

[8] Hauashdh, A., Jailani, J., Rahman, I.A. & AL-Fadhali, N., Strategic approaches towards achieving sustainable and effective building maintenance practices in maintenance-managed buildings: A combination of expert interviews and a literature review. *Journal of Building Engineering*, **45**, 103490, 2022. DOI: 10.1016/j.jobe.2021.103490.

[9] Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J. & Aharon, D., *Unlocking the Potential of the Internet of Things*, McKinsey Global Institute, 2015. https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/the-internet-of-things-the-value-of-digitizing-the-physical-world.

[10] Olivotti, D., Dreyer, S., Lebek, B. & Breitner, M.H., Creating the foundation for digital twins in the manufacturing industry: An integrated installed base management system. *Information Systems and e-Business Management*, **17**, pp. 89–116, 2019.

[11] Tao, F., Zhang, H., Liu, A. & Nee, A.Y.C., Digital twin in industry: State-of-the-art. *IEEE Transactions on Industrial Informatics*, **15**, pp. 2405–2415, 2019.