# AI-supported Digital Twins in applications related to sustainable development goals

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**Abstract**

A number of successful AI-supported Digital Twin (DT) applications that foster sustainable development goals in three main areas are summarized. Finally, a standardized conceptual framework for leveraging AI-supported DT federations is identified as future work.

Fostering Sustainable Development Goals (SDGs) is an urgent requirement in every application scenario. Digital Technology provides powerful tools that aid in this regard. This work focuses on AI-supported DT applications, describing their main conceptual architecture and approaches and providing a short sample list of successful, relevant applications in manufacturing, smart cities, and earth systems. From this review analysis, we can conclude that almost all the applications reported are implemented as siloed DT, that despite their efficiency in fostering SDG, they can become even more impactful when interacting and cooperating among them. The work presented here is an extended abstract of the first step, state-of-the-art analysis of relevant works, toward our more ambitious goal: define a standardized conceptual framework for leveraging AI-supported DT federations.

## Sustainable development goals

The United Nations Brundtland Commission widely introduced the definition of sustainable development in (UN 1992): “development which meets the needs of current generations without compromising the ability of future generations to meet their own needs”. In general, making development sustainable is a challenging and complex task involving many factors such as technology and engineering, economics, environment, health and welfare of people, social desires, and government strategies, procedures, and policies. Thus, sustainability has three pillars: environmental, economic, and social (including political). The broad Information Technologies (IT) set provides key tools for enforcing SDG. AI is one such approach that has already shown impactful applications in this regard. The great potential of AI is being harnessed in today’s applications by combining it with other powerful approaches, such as Big Data and IoT. In this work, we review the combination of these three IT approaches under the AI-supported Digital Twin label in applications related to SDGs. Our goal is also to focus on DT applications that collaborate/interact with other DTs.



## Digital Twins

DT approach is not new, but AI is supercharging what it can do. Together, they are transforming how problem-solving is designed, developed, and maintained in order to provide better-suited and optimized services, highly smart, reactive, and proactive control for processes and phenomena, and singularly tailored products. These technologies provide unprecedented insights into our increasingly complex, interconnected, and rapidly changing world.

There are numerous definitions of DT (Negri, Fumagalli, and Macchi 2017). According to Grieves (Grieves 2014), DT contains the following principal components: (i) physical objects in the Physical World, (ii) digital objects in the Digital World, and (iii) the set of connections that ties the digital and physical elements with each other. A DT conceptual architecture that is widely used by most specialized scientific literature and industrial development so far (Juarez, Botti, and Giret 2021), is a three-layer AI-supported DT architecture. The Data layer combines data from different sources (IoT technology is mainly used in this layer to capture data from sensors) with physical system model simulations to derive an estimate of the state of the physical object, system or phenomena that is being mimicked. Starting with a model prediction of what the state could be, the Model layer acts as a physically consistent integrator of the information from the previous layer in four dimensions, namely space and time. Finally, the Decision Support layer can infer future actions, events, and status by combining the output(s) from the Model layer with advanced simulation engines, expert knowledge, and integration with external systems. In AI-supported DT applications, AI plays a first-class citizen role at every layer providing capabilities for (i) advanced preprocessing and post-processing, hybrid simulation, augmentation and data fusion, and mining and discovery for the Data Layer; (ii) hybrid AI physics-based modeling, data assimilation, downscaling and integration of downstream models among others for the Model Layer, and; (iii) recommendation, reasoning and scenario generation under uncertainty, digital assistant and visualization, among others for the Decision Support Layer. The power of the couple DT+AI resides in the way the different AI supporting approaches can be combined for implementing the DT layers; with no fixed rule on how this should be done, the developers can combine the approaches that better suit the particular needs to solve the problem at hand (in the particular DT Layer) and connect them in order to compose a set of AI supported modules for a given DT configuration. Moreover, AI approaches, such as Multi-agent Systems, can equip DTs with social capabilities, such as interaction and collaboration, in order to boost their computation capabilities beyond the single physical or social entity or phenomena the DT is representing. Allowing to interconnect different DTs into an organization.

## DT applications that foster SDGs

In this section, we summarize a number of AI-supported DT applications that, among other functionalities, include as main objectives to foster SDGs.

One of the first application areas of DT is manufacturing. In industrial settings, digital twins provide manufacturers with a way to understand how to optimize their operations and improve sustainability (Giret, Trentesaux, and Prabhu 2015) (Giret et al. 2017). For example, the simulation (Ruiz, Giret, and Botti 2007) can identify potential pain points, highlight where energy loss occurs, and highlight opportunities to reduce consumption. The AI algorithm can process data, recognize patterns and predict future outcomes far beyond human cognitive abilities. In addition, the virtual simulation reduces the waste and power associated with building physical prototypes. In (He and Bai 2021), an extensive review of DT applied to sustainable intelligent manufacturing is presented. Finally, no relevant work on collaborative DTs was reported in these works.

Digital twins and AI are playing a vital role as cities strive to reduce their environmental impact. DTs can help city developers create a real-time "test model" within a virtual twin to proactively test different scenarios of the city. Escenarios include urban planning, policy decisions, resource arrangements, public safety and health, energy management, and transport system optimization. Cities pioneering this approach, for example, Las Vegas[1] and Amsterdam[2], use the technology to model future energy needs, emissions, parking, traffic, and emergency management. IoT sensors collect data from cars, charging networks, and municipal infrastructure to model and scenario plan. For a review of DT applied to smart cities, see (Wang et al. 2023). In this area, we have mainly found isolated DT applications.

Another area where digital twins are aiding sustainability efforts is Earth Observation Systems. In Europe, this approach is led by the European Commission's Green Deal Strategy to develop the next-generation decision support systems to aid the understanding of the consequences of human activity and guide informed decisions. To this end, the "Destination Earth" (DestinE)[3] initiative brings together European scientific and industrial excellence to develop very high-precision digital models of the Earth, or Digital Twin of the Earth (DTE)[4], aimed at offering a digital modeling platform to visualize, simulate, monitor and forecast impacts of natural and human activity on the planet in support of decision making for sustainable development. A number of developments associated with this initiative have already demonstrated potential with scenarios such as food, water resources, climate, forest, and oceans. Whereas one goal of DestinE is to develop organizations of DTEs, the works developed so far are still isolated DTEs. In the US the Advanced Information Systems Technology (AIST) program leads NASA's Earth System Digital Twins (ESDT) efforts[5], developing novel technologies for integrating diverse Earth and human activity models, continuous observations and information system capabilities to provide unified, comprehensive representations and predictions that can be utilized for monitoring as well as for developing actionable information and supporting decision making. Moreover, the National Oceanic and Atmospheric Administration (NOAA) is leading the initiative Digital Twin for Earth Observations (EO-DT) Using Artificial Intelligence[6].

## Conclusions

In this work, we have presented a set of AI-supported DT applications that foster SDGs in three key areas: manufacturing, smart cities, and earth observation. Despite the list presented in this work being representative, it is relatively short since many other areas have also successfully applied AI-supported DT to the different pillars of sustainable development: environmental, social, and economic. As ongoing work, we are compiling a more extensive review that includes more areas in which we survey the associated most impactful results. In future work, we recognize the usefulness of a standardized conceptual framework that might aid in the development of these systems in order to leverage the power of AI-supported DT federations that can combine different solutions for different vertical scenarios (earth systems, agriculture, manufacturing, cities, health system, etc.) into a holistic and interconnected system. Picture, for example, a future digital scenario in which we can interconnect DTs from the Earth with a given smart city DT and the set of manufacturing plant DTs that belongs to the city in order to better understand the current and future situation combining all these DTs SDGs optimization capabilities.


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[1] $https://www.renewableenergymagazine.com/energy_saving/the-city-of-las-vegas-unveils-advanced$ − 20220107

[2] $https://living-in.eu/groups/solutions/local-digital-twin$

[3] $https://digital-strategy.ec.europa.eu/en/policies/destination-earth$

[4] $https://ec.europa.eu/commission/presscorner/detail/en/IP_22_1$977

[5] $https://esto.nasa.gov/earth-system-digital-twin/$

[6] $https://www.nesdis.noaa.gov/events/digital-twin-earth-observations-eo-dt-using-artificial-intelligence$

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