Creating Cities of the Future with Digital Twin Technology

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INTRODUCTION

Our world faces mounting challenges in ensuring safe and efficient energy and water services to cities around the world. From maintaining and upgrading aging energy and water infrastructure to adopting emerging technologies to improve the human condition, new technology is entering the stage to imagine new possibilities for solving public health, safety and environmental issues across the globe. Adopting emerging technologies such as augmented reality, machine learning, digital twin platforms and spatial intelligence in new ways may help to meet the zero emissions goals that are shaping tomorrow's cities and utilities of the future.

THE BATTLE AGAINST AIR POLLUTION

In 1967, the cover story of the January edition of *Time Magazine* was "Ecology: Menace in the Skies." The article examined a tragic 1948 industrial pollution disaster in Pennsylvania. A lethal build-up of toxic exhaust from a zinc plant and steel mill in the borough of Donora (southeast of Pittsburg) became trapped by a cold front that parked itself over the region for five days, killing 20 people. For the first time, the public realized that air pollution could kill.

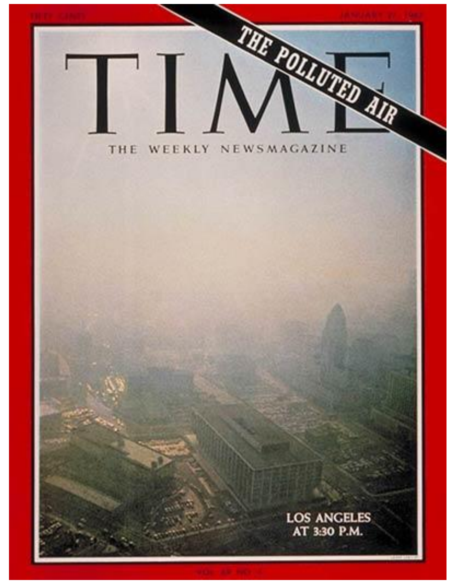

Figure 1: Time Magazine Cover, January 1967

The same year as the Pennsylvania disaster, Arie Haagen-Smit, a Caltech biochemist, set about to discover the root cause of Los Angeles's smog. By 1960, he had conclusively identified car emissions as the culprit, founded California's pioneering Motor Vehicle Pollution Control Board (the predecessor to the California Air Resources Board (CARB)) and initiated research to mitigate the pollutants in automobile exhaust. In less than a decade, Haagen-Smit's investigations resulted in the adoption of key pollution mitigation strategies, standards and policies. [1]

The Pennsylvania smog deaths and Haagen-Smit's research contributed to the passage by Congress of a federal law to control air pollution at the national level. Dubbed the Clean Air Act of 1963, it was heralded as the most comprehensive air quality legislation in the world at that time. The purpose of the

[1] Caltech. April 25 2013. https://www.caltech.edu/about/news/fifty-years-clearing-skies-39248

Clean Air Act was to establish a federal program to research into techniques for monitoring and controlling air pollution. Significantly enhanced by a series of subsequent amendments, the Clean Air Act evolved from monitoring and controlling to limiting sources of pollution by setting air quality standards and thorough enforcement actions.

Despite technology advancements in auto emissions, regulations and policies intended to drive compliance, poor air quality continues to affect almost every aspect of our health, from decreased lung capacity in children[2] to inflammatory skin conditions[3] and even physical changes in facial features such as thickening of the skin around the mouth and nose.[4]

Fossil fuel-based energy generation is a major source of air pollution in many communities. The World Health Organization has linked emissions from fossil fuel with 43% of lung cancer deaths and 25% of heart disease deaths.[5] The deleterious effects of air pollution are not limited to our skin, our hearts and our lungs. Air pollution and other byproducts of our continued reliance on fossil fuels[6] is also warming the earth, changing weather patterns and shortening lives.

In 2018, the Intergovernmental Panel on Climate Change[7] sparked an impassioned international conversation on the urgent need to address climate-change risks to our environment. As a result, cities around the world are seeking to decarbonize their energy systems as quickly as possible. Swift adoption of renewable energy, however, can have unintended consequences. Without a measured approach to the potential network impacts of distributed energy resources (DERs), some early adopters have experienced a number of issues related to the reliability and power quality of renewables.

For example, the amount of energy that can be produced via solar depends on weather conditions and time of day. With this type of variation, the amount of power from renewable sources that enters the electricity grid fluctuates. Since most rooftop solar Photovoltaics (PV) generation is not visible to power grid control rooms, this variation in power production leads to load forecasting errors which, in turn, require additional generation reserves to cover the load

[2] US National Library of Medicine. March 24 2005. https://www.ncbi.nlm.nih.gov/pubmed/15356303

[3] US National Library of Medicine Dec 29 2015. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5916788/

[4] ResearchGate. May 2014. https://www.researchgate.net/publication/266850972_Air_Pollution_and_the_skin

[5] World Economic Forum. June 5 2019. https://www.weforum.org/agenda/2019/06/10-facts-about-air-pollution-on-world-environment-day

[6] Pacific Standard. Apr 17 2019. https://psmag.com/environment/air-pollution-is-killing-more-people-than-smoking-and-fossil-fuels-are-largely-to-blame

[7] Intergovernmental Panel on Climate Change. Oct 2018. https://report.ipcc.ch/sr15/pdf/sr15_spm_final.pdf

uncertainty. These fluctuations stress the local grid infrastructure and overpower the system. To overcome the negative impact of the intermittency of renewable power and to enable more accurate load forecasting, material scientists are urgently and actively exploring methods to cost effectively bank power from renewable energy resources.[8]

All involved in the effort to decarbonize the grid agree that time is limited for designing a practical and reliable solution to mitigate the environmental impact of pollution. Progressive government leaders including the C40 mayors, a coalition of mayors from cities around the world, are setting policies and sending market signals to technologists and private entities. Scientists are urgently focused on material science research toward developing a cost-effective solution for storing and dispatching several days' worth of renewable energy, and public and private partnerships are being established to promote adoption of clean energy across all socioeconomic groups.

A component still missing from all these efforts is an adaptable and user-friendly open planning tool that enables the leadership in a given community to incrementally add renewable resources to the energy system in a technically, operationally and socially feasible manner.

Making the Switch to Renewable Energy

When communities generate and use renewable energy, the demand for fossil fuel energy drops. This means that less fossil fuel gets burned and fewer pollutants are emitted into the atmosphere. Reducing the burning of fossil fuels reduces nitrogen oxides which contribute to air pollution through the formation of smog and acid rain. Transforming the energy system of an entire region can be intimidating. Exactly how should a mayor or city planner close the gap between ambitious goal setting and the actual work of transforming the energy system? While the desired metrics are clear and infrastructure solutions exist, the path to successful implementation could be straightforward if made from scratch, but it isn't as obvious when we need to transform an existing infrastructure. Adding renewable energy to existing grid infrastructure poses a unique set of challenges. In addition to the significant load balancing and power forecasting considerations, expanding renewables requires planning, permitting and program and policy design—particularly given a key goal for C40 mayors is providing renewable energy resources equitably across all income households, but especially focusing on underserved groups. Inadequate or ineffective network planning could derail a city's renewable electricity future.

Though the task seems daunting, industry innovators recognize a number of advancements in technology that may be

[8] NPR. July 22 2019. https://www.npr.org/2019/07/22/744206049/a-new-battery-could-be-key-to-cutting-carbon-emissions-slowing-climate-change

used to identify, classify and predict the impact of renewable resources and climate mitigation efforts to neighborhood grids in cities, including rooftop solar systems, public electric vehicle charge station placement and battery storage. These same tools may be used to conduct what-if scenarios for infrastructure changes to traffic patterns on major thoroughfares, identify inefficiencies in fresh and wastewater infrastructure and educate citizens on impacts of civic programs and incentive programs. This article explores how the combination of an open digital twin marketplace, artificial intelligence, geographic information system and open data sources will enable researchers, private entities, policy makers and the public to take effective and timely action to reduce the sources of air pollution and accelerate the transition to increased renewable energy generation.

WHAT IS A DIGITAL TWIN IN THE CONTEXT OF A SMART CITY?

The concept of a digital twin is generally accepted as a software representation of a physical system that behaves in virtual space identically as in the real world. To create a digital twin of elements in an urban neighborhood for example, a library of devices such as transformers, streetlights, energy meters, solar panels, EV chargers and bus and rail systems is necessary. Each urban "twin" is programmed to behave as its physical counterpart and incorporates associated performance characteristics such as maximum and minimum load, operating temperature characteristics, directionality in the case of automobiles, network messaging, water and electrons and other operating environment specifications. The digital twins feature preloaded attributes in a spatial graph to facilitate training of machine learning models. These discrete twins may be arranged in a virtual network and communicate with each other and draw upon each other with spatial awareness as they do in a real deployed network. Using such a system, a neighborhood planner may conduct "what if" scenarios to optimize conditions (i.e., traffic flow), pump efficiencies, grid resiliency improvements and see the potential impact of these assets on existing and planned infrastructure elements. Once assets are deployed, the digital twin platform serves as an operational tool to monitor and service the area.

The Itron digital twin concept arose from examination of the use of digital twins in smart building energy management. Our team sought to discover whether this approach may be used for smart city planning and management. What if we expand the application of a digital twin from commercial real estate to municipalities and non-governmental organizations (NGOs)? Would it be possible to model, validate and optimize sensing networks before deploying assets?

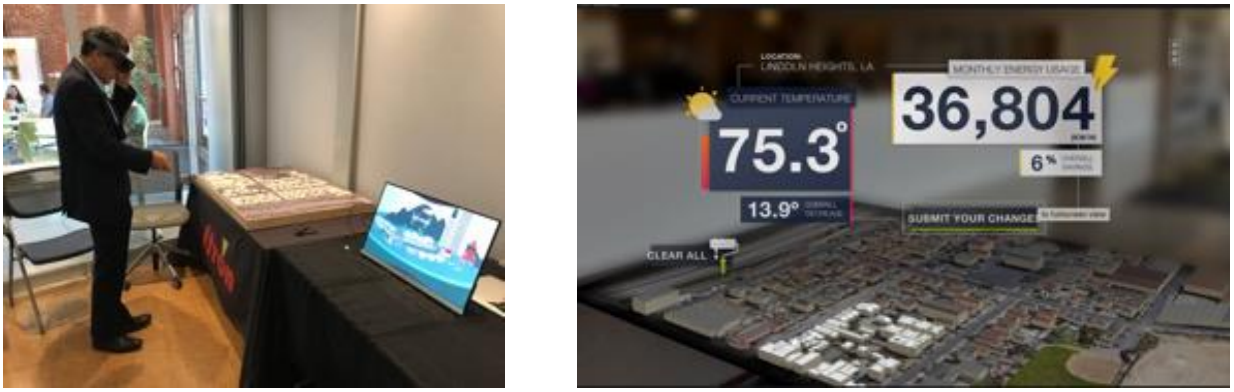

Figure 2: Itron's "Three Degrees" Mixed Reality Digital Twin Demonstration

Rather than a "venue, floor, area" ontology, the general ontological model that describes the relationship between the various elements in a smart city context features a regional hierarchy and draw from state, district and utility service area maps, to name but a few sources. A commercial digital twin platform concept necessarily includes third-party data integrations with geospatial locations of various city infrastructure elements such as streetlights, traffic lights, DERs and fresh and wastewater pumps. The digital twin platform ingests information such as energy consumption, weather information and other sensor information from utility sources as well third-party systems.

While the sheer volume of data may seem overwhelming, a neighborhood-by-neighborhood approach to modeling and deploying a digital twin concept serves to reduce the complexity and reinforces a hyperlocal approach to neighborhood goals and data-driven results.

Another benefit of using a digital twin approach in the context of a smart city is the ability to combine the platform with a mixed-reality element to create a powerful community engagement tool. For example, by combining mixed reality and digital twin technology, a citizen can virtually install infrastructure or alter building materials in a simulated environment that mirrors a real neighborhood. Successfully engaging a diverse audience is in great part achieved due to the use of a mixed reality user interface and encouraged engagement or "gamify" consumer incentive programs.

This approach enables city leaders to conduct community outreach, education and consensus-building. The persuasive value of show *and* tell can be realized when city officials are able to bring the digital twin technology to the neighborhoods that will be impacted by the proposed changes. Using these tools, city officials can address both known and hypothetical concerns and resolve potential community objections by using data and technology to demonstrate real outcomes and public benefits. Whether citizens are concerned about new infrastructure, additional taxpayer burden or privacy concerns, the combined use of mixed reality and digital twin technology allows a citizen to virtually experience the benefits so they can truly envision how proposed changes will improve their own neighborhood.

This digital twin proof-of-concept model focuses on the market demand created by progressive government leaders around the world setting zero emissions goals. Renewable energy planning requires coordinated access to time of use and energy demand data, distributed energy management, load forecasting algorithms and product performance characteristics of existing and emerging renewable energy infrastructure elements. Historically, energy consumption data has remained siloed at the utility. To accurately model and transform the energy system, the digital twin concept leverages these “utility-owned” and “city-managed” data sets such as:

- Historical and predicted power consumption by neighborhood
- Infrastructure mapping and maps of utility assets
- Local environmental data
- Street maps, census data and neighborhood information (what neighborhoods are in a district, city or county and how their boundaries are defined).

While the urgent focus is on decarbonization, a city-focused digital twin platform may also be used to model other city services such as a city’s fresh and wastewater system. In the case of water distribution, a digital twin platform may ingest supervisory control and data acquisition (SCADA) data together with other information such as acoustic signals, temperature and pressure information to identify pump inefficiencies and potential leaks.

This digital twin concept embraces an open architecture whereby a marketplace of digital twins may be made broadly available to facilitate innovation and collaboration among the various stakeholders. By creating an ecosystem of open-data sourced device twins, any city may leverage efforts across multiple sectors to optimize resource allocation across a number of smart city applications. This approach promotes integrated uses of technologies and services that, in the initial use case example of DER planning, provides resiliency, ensures time-of-use electricity signals align with marginal carbon emissions signals and expedites the process from plan to action for zero emissions goals. Using an open digital twin platform approach, city leaders not only make data-driven investments in infrastructure, but avoid having to manage multiple siloed systems as it adds services to benefit its citizens in the future.

A Digital Twin Concept for Distributed Energy Resources

While the value of combining mixed reality with a digital twin drives understanding and education for citizens that will be impacted by the proposed changes, a digital twin platform is an ideal forecasting and planning tool for virtual Smart City pilots by planners and operators of clean energy infrastructure projects such as gas, water and people movement.

To address the emergent clean energy use case, Itron developed a web-based user experience for a digital twin Smart City planning tool featuring DER assets such as solar panels, solar arrays and battery storage devices. A user interacts with the planning tool via a web application that consists of two main screens, a neighborhood map overview and a forecasted results dashboard. The use case under test involves sectionalizing a neighborhood grid or creating a microgrid. The user experience is easily expanded to other use cases such as adding trees, adding cool roof materials, altering traffic patterns and visualizing proposed modifications to the infrastructure that exists below the neighborhood such as wastewater, service water and other subterranean city infrastructure. The next few paragraphs explain the user interaction for the DER planning use case.

In Figure 3, a neighborhood map screen features digital twin representations of renewable energy assets such as solar panels, solar arrays and battery storage devices. The concept relies on an open architecture for those twin objects and anticipates an extensible set of twins such as trees, EV chargers and energy efficient materials. It is envisioned that the platform will feature preloaded algorithms for distributed energy forecasting and planning, as well as plug-in third-party algorithms from climate scientists, material scientists and city planners. Finally, the user interface (UI) is envisioned as role-based and secure.

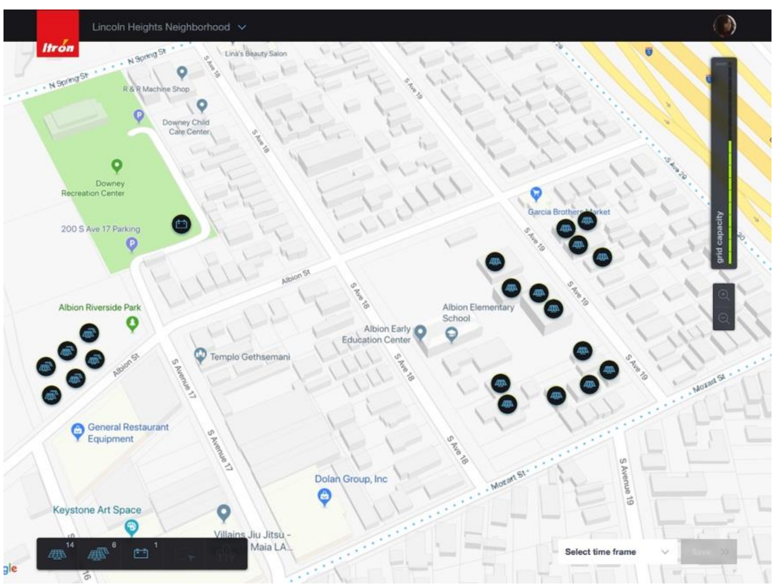

Figure 3: Neighborhood Map

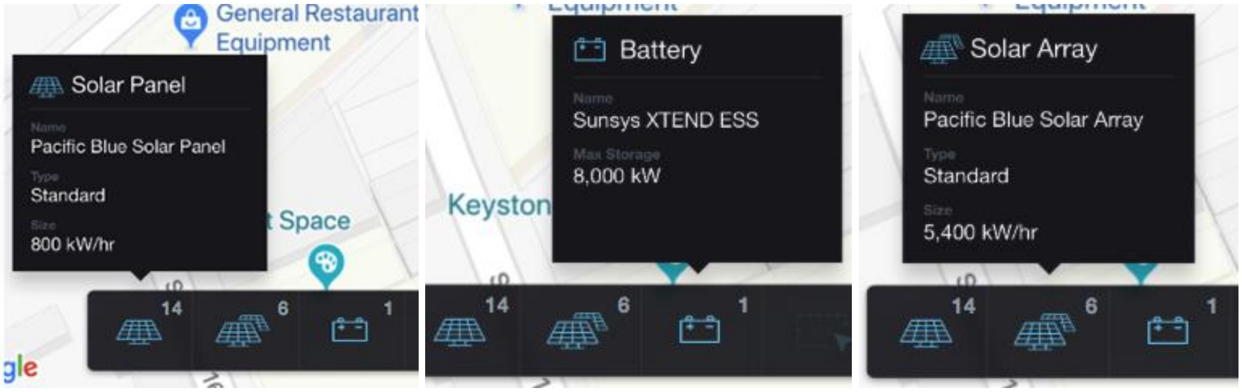

Figure 4: Renewable Energy Asset Identifiers, Enlarged View

Here, the example is an urban six block setting of an actual neighborhood in the city of Los Angeles. It is envisioned that the digital twin mapping function may be changed to feature the geographic coordinates of any area of interest. At the bottom of the screen is a toolbar where the drag and drop enabled objects reside; solar panels, solar arrays and batteries. Figure 4 demonstrates how the details of each digital twin representation can be displayed by a cursor rollover.

These digital twin objects are drag and drop enabled so the user can place them, as needed, on the map as shown in Figure 5.

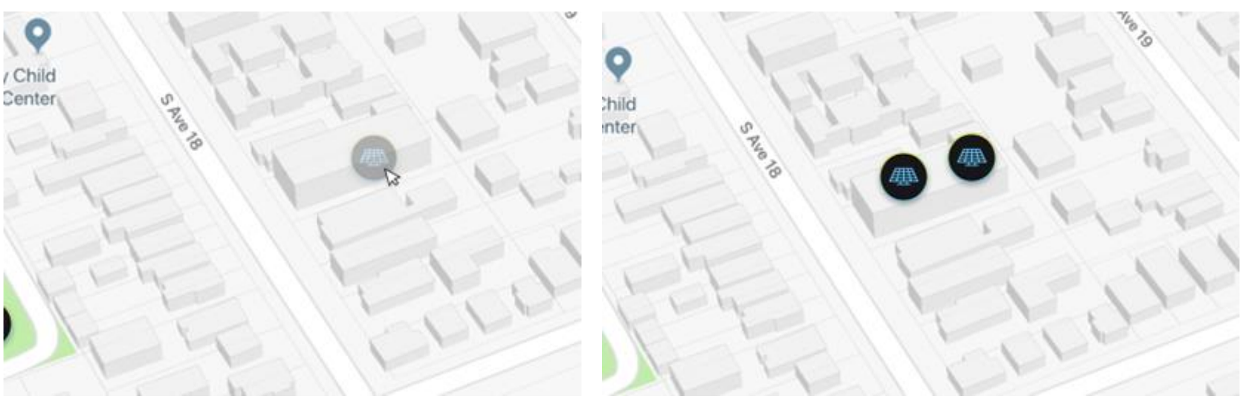

Figure 5: Renewable Energy Assets placed in neighborhood map

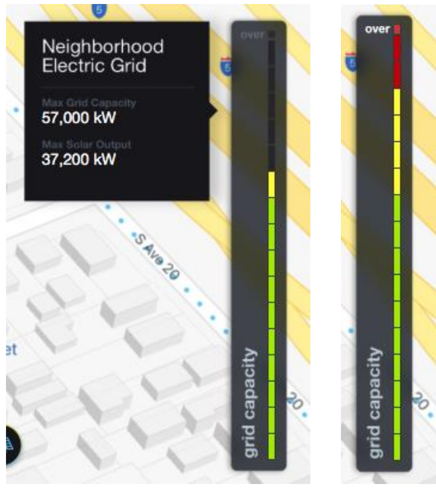

Figure 6: Electric Grid capacity before and after adding panels and arrays

As the user continues to drag and drop, visual feedback regarding grid impact is provided via a temperature-like gauge at the top right of the map overview as shown in Figure 6. If the additions the user makes cause the neighborhood energy system to exceed capacity, either limited by the age or number of transformers or other factors that impact the neighborhood grid system, the user is presented with the warning message seen in Figure 7.

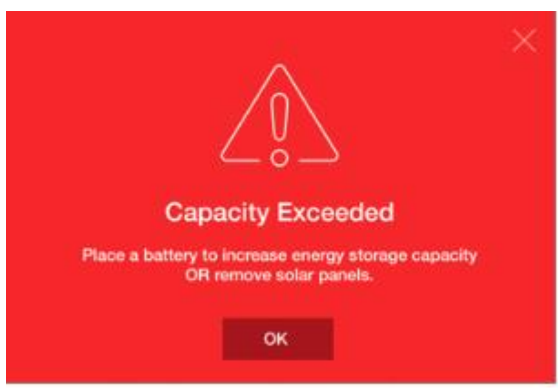

Figure 7: Capacity exceeded warning

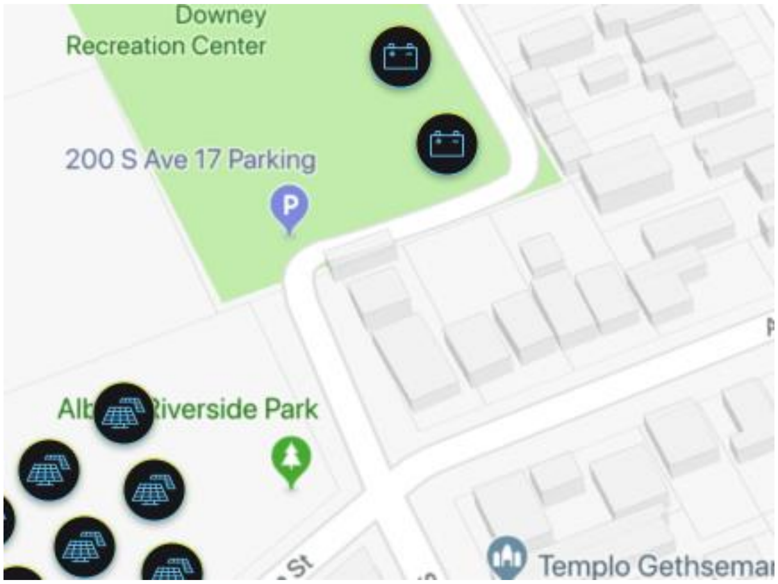

Figure 8: Batteries placed to store excess capacity

The user, after dismissing the warning, can alter the proposed plan by either removing some of the panels and/or arrays, or by placing additional batteries to store the excess energy as seen in Figure 8.The real power of using a digital twin platform in this manner comes from the insights that arise by combining device characteristics, environmental factors and expertise from the various stakeholders. As third-party data is introduced to the platform, the scenarios that may be simulated are more realistic and make for a very useful, flexible planning and forecasting tool, as well as a modeling and maintenance platform as piloted infrastructure scales from virtual to real world deployment.

Addressing the Impact of Renewables with Virtual Pilots

A digital twin is a powerful proxy, not only for a device, but for its function and relationship to other devices and objects in its vicinity. Tuning and optimizing a network of digital twin nodes promises to balance and optimize the lifetime of the endpoints while ensuring key data is monitored.

Similarly, digital twins enable data scientists and infrastructure planners to validate and optimize the impact of new infrastructure before investing and deploying capital equipment. By using digital replicas of the data-producing things and combining their historical behavior and data, an industrial internet of things (IIoT) enhanced network may be tuned and otherwise optimized. Such a tool helps planners simulate the impact of data-driven goals *before* they are implemented and helps operators monitor and maintain smart city services.

Using a neighborhood-by-neighborhood approach and optimizing performance characteristics of IIoT networks, the digital twin concept is a promising new planning and visualization tool for infrastructure planners, scientists and policy makers. A smart city digital twin platform enables utilities and municipal governments to make informed, data-driven decisions for infrastructure investments. This digital twin concept incorporates third-party datasets and expertise in load disaggregation, DER event verification, grid connectivity modeling, advanced load forecasting and data analytics to enable utilities and city planners to confidently and efficiently transform their energy systems by:

1. Identifying and optimizing spatial maps of existing, proposed and planned infrastructure enhancements before investing in equipment;
2. Creating data-driven justifications to invest capital in order to optimize service to the community; and
3. Predicting and effectively managing the required distributed energy resources in a given neighborhood, including managing rooftop solar systems and battery storage.

CONCLUSION

Digital twin platforms can transform infrastructure, engage communities and help smart city planners make informed investments. By coupling augmented reality with a digital twin platform, a powerful community engagement tool can educate citizens and drive awareness of a local incentive program to change rooftop material. It is important to engage with sustainability professionals and demonstrate how to conduct what-if analyses to add clean energy and battery storage to neighborhood grids. We are continuing the virtual journey under the neighborhood where data delivers a baseline visualization of the local water distribution network.

We believe that a digital twin platform coupled with machine learning algorithms and device behavior models may be used to expand the possibilities for anomaly detection, predictive maintenance, infrastructure expansion and clean energy and water planning. Creating a digital twin library of existing and proposed infrastructure elements enables stakeholders to confidently take plans to action, transform cities and improve the quality of life for real people in real places for a more resourceful world.

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