International Telecommunication Union

ITU-T Technical Report

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

(05-2022)

ITU-T Focus Group on Environmental Efficiency for Artificial Intelligence and other Emerging Technologies (FG-AI4EE)

FG-AI4EE D.WG1-10

Guidelines on the use of digital twins of cities and communities for better climate change mitigation solutions

Working Group 1: Requirements for AI and other emerging technologies to ensure environmental efficiency

Focus Group Technical Report

Technical Report ITU-T FG-AI4EE D.WG1-10

Guidelines on the use of digital twins of cities and communities for better climate change mitigation solutions

Summary

Climate change mitigation involves two principal steps leading to actionable information. The first of these is to gather, produce and validate trustable information, while the second involves conveying this information in a format that is understandable for all stakeholders. As part of this Technical Report, use cases involving the implementation of United for Smart Sustainable Cities (U4SSC) Key Performance Indicators (KPIs) and simulations in graphical digital twins have been performed in real-life experiments to showcase the validity of the method. This Technical Report offers a set of use cases and project testimonials which demonstrate the actual and potential benefits of digital twins for energy-optimization and climate-change-mitigation solutions in an urban context. These project testimonials have been gathered and listed on an online video sharing platform. A summary of digital twin applications, their benefits and results are offered in this report.

Keywords

AI, AR, climate change mitigation, digital twins, ML, U4SSC.

Change Log

This document contains Version 1 of the ITU-T Technical Report on "*Guidelines on the Use of Digital Twins of Cities and Communities for Better Climate Change Mitigation Solutions"* approved at the FG-AI4EE meeting held in Vienna, Austria, on 4 May 2022.

Editor:	Joel Alexander Mills AugmentCity Norway	E-mail : jam@osc.no
Editor:	Pierre Major, PhD AugmentCity Norway	Tel: +4794035960 Email: pierre.major@augmentcity.no

Note

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Table of Contents

List of Tables

Technical Report ITU-T FG-AI4EE D.WG1-10

Guidelines on the use of digital twins of cities and communities for better climate change mitigation solutions

1 Scope

This Technical Report provides guidelines on how to use the United Nations 'United for Smart Sustainable Cities (U4SSC) KPI system [ITU-T Y.4903] in a digital twin city or community, to identify high impact climate change mitigation solutions. This Technical Report includes a set of use cases showing examples of projects where emerging technologies, such as machine learning (ML), augmented reality (AR) and artificial intelligence (AI) have been or could be used to reduce the negative impact of climate change in cities and communities. It lists a set of online videos and testimonials to illustrate those examples.

2 References

[ITU-T Y.3600] Recommendation ITU-T Y.3600 (2015), *Big data – Cloud computing based requirements and capabilities.*

[ITU-T Y.4000] Recommendation ITU-T Y.4000/Y.2060 (2012), *Overview of the Internet of Things.*

[ITU-T Y.4900] Recommendation ITU-T Y.4900/L.1600 (2016), *Overview of key performance indicators in smart sustainable cities*.

[ITU-T Y.4903] Recommendation ITU-T Y.4903/L1603 (2016), *Key performance indicators for smart sustainable cities to assess the achievement of sustainable development goals.*

3 Definitions

3.1 Terms defined elsewhere

This Technical Report uses the following terms defined elsewhere:

3.1.1 big data [ITU-T Y.3600]: A paradigm for enabling the collection, storage, management, analysis and visualization, potentially under real-time constraints, of extensive datasets with heterogeneous characteristics.

3.1.2 Internet of things (IoT) [ITU-T Y.4000]: A global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies.

3.1.3 smart sustainable city [ITU-T Y.4900]: A smart sustainable city is an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental, as well as cultural aspects.

3.2 Terms defined in this Technical Report

This Technical Report defines the following terms:

3.2.1 artificial intelligence (AI) and machine learning (ML) input and output: Independent of the definitions of AI and ML, mathematical algorithms can be developed and/or trained on input data in order to provide actionable knowledge.

3.2.2 input data: Can be timeseries of Internet of things (IoT) sensors (temperature, CO_2 level, humidity, noise, particulate matter (PMx), nitrogen oxides (NOx), sulphur oxides (SOx), pressure, power consumption etc.); remote pictures of satellites; video streams of online, closed circuit television (CCTV); light detection and ranging (LIDAR) footage; tagged or untagged pictures; handwritten text; structured and unstructured online accessible text; natural language soundtracks of songs; phone calls; home assistant devices; and so on. Most of the input data is geolocalizable with some degree of precision and can thus be displayed and visualized for human inspection.

3.2.3 output data: The purpose of ML and AI algorithms is to solve complex problems by providing recommendations with uncertainty range and/or actionable information. The recommendations and information are thus the outputs of the algorithms. The outputs can be smoother and filtered timeseries showing short-term and long-term predictions; IoT commands to controllers such as video game controllers or house automation and heating ventilation air conditioning (HVAC); synthetic images, video streams and soundtracks; chess or go game steps; probability contours of sea level rise, deforestation or avalanche; heatmaps of urban heat islands; urban, industrial and traffic pollution prediction, and so on. Most of the output can be geolocalized with some degree of precision.

4 Abbreviations and acronyms

This Technical Report uses the following abbreviations and acronyms:

AI	Artificial Intelligence
AR	Augmented Reality
CCA	Climate Change Adaptation
CCM	Climate Change Mitigation
CCTV	Closed Circuit Television (monitoring cameras)
EV	Electric Vehicle
GAN	Generative Adversarial Network
GDT	Graphical Digital Twin
GHG	Greenhouse Gas
HVAC	Heating Ventilation Air Conditioning
IoT	Internet of Things
KPI	Key Performance Indicators
LIDAR	Light Detection and Ranging,
ML	Machine Learning
NOx	Nitrogen Oxides
PMx	Particulate Matter (2.5,10, etc.)
SOx	Sulphur Oxides
U4SSC	United for Smart Sustainable Cities
VR	Virtual Reality

5 Guidelines on the use of digital twins of cities and communities for better climate change mitigation solutions

5.1 Background

Climate change mitigation (CCM) and climate change adaptation (CCA) are two of the six environmental objectives established by the European Taxonomy Regulation [b-EU Reg 2020/852], which is closely aligned to the UN SDGs. Examples of CCM mainly address the reduction of greenhouse gas (GHG) emissions. While cities span only 2% of the earth's area, they shelter more than 50% of the world's population and represent 80% of global GHG emissions. It is thus imperative to prioritize CCM for cities and communities. Furthermore, 100 million people living in coastal regions are at risk of being affected by the sea level rise caused by climate change [b-Kulp]. CCM solutions for cities and communities include but are not limited to:

- Decarbonizing energy in general by using biofuels, green hydrogen, electric vehicles (EV), and solar and wind energy
- Decarbonizing transport by:
  - Transitioning to electric or hydrogen vehicles;
  - Promoting active transport (walking, cycling, public transport);
  - Providing and incentivizing the use of carbon-free public transport.
- Exploiting energy-saving potentials with:
  - Low-carbon insolation materials for new buildings and by retrofit existing buildings;
  - Smart grids of interconnected energy sinks and sources during circadian rhythms;
  - Re-greening cities and communities;
  - Promoting denser cities independent of passive transport.

Multisector and holistic solutions are known, but have social and economic costs. CCM and CCA demand behavioural change from the population. To promote a smoother green transition, it is critical to engage and involve citizens in explanatory and consultative processes to guarantee adherence to the solution. However, these consultative and decision-making processes have a tendency to be very slow and, in the face of the climate urgency and the ambitious goals for 2030 (COP2627), they need to be accelerated to raise awareness of the urgency and necessity of systemic and societal changes.

This sets the stage for the use of new technologies such as AI, ML and AR in environmental efficiency. These technologies are already in use to improve business efficiency, e.g., by using AI to find the short-term local minima of cost functions of operative costs. These emerging technologies also can potentially steer decision-makers and a wider audience of non-experts towards a more sustainable mindset and thereby find optimal global solutions in the long run.

The examples below illustrate how technologies can contribute to improving reality and de-risk sustainability projects in the long run.

5.2 Advantages of using graphical digital twins for climate change mitigation

Graphical digital twins (GDTs) are visual platforms that represent big data, scenario base model data and AI-generated insights and recommendations. Clearly, the solutions have interconnected advantages and disadvantages which can only be comprehended by a holistic analysis of the city and community; hence, they must be addressed on platforms that display multiple formats and simulation outputs, such as GDTs. Table 1 provides examples of how GDTs help find CCMs for the categories mentioned above.

Table 1 – How Graphical Digital Twins can help find Climate Change Mitigation Solutions

CCM Solution	GDT use
Decarbonizing energy	• Visualizing new energy real estate projects in citizen consultations. • Showing the environmental impact of offshore/onshore windmills, hydropower, solar panel projects. • Showing the AI-based/model-based solar or wind potential of buildings in the city to help developers and cities identify the best solutions or spots.
Decarbonizing transport	• Identifying and localizing future electric charger hotspots (AI-based/model-based). • Showing the needs and location for new high voltage lines and high energy mega-battery packs. • Visualizing in a 3D map the decarbonization impact of active transportation and public saving in terms of traffic demand, CO_2 and air pollution reduction.
Exploiting energy-saving potentials	• Representing spatiotemporal time series to visualize the energy-saving potential of old buildings, including upfront costs and heating savings over their lifetime. • Computing such savings by AI and/or more simple models. • Offering a platform for entrepreneurs, the financial sector and building owners to co-create and make the best decisions. • Offering a simulation platform for testing agent-based (AI-controlled) smart-grid simulations, modelling the circadian rhythms of cities: battery/EV car charging or delivering back to the grid, better planning of heating, smarter consumption/battery saving. • Visualizing explorable 3D models of city re-greening projects [b-Willsher] (generative Adversarial Network (GAN) models can show greener cities as well as burning or flooded houses [b-Knight]. • Post-second war, car-driven urban planning has proven to be an unsustainable city model. City models are incredibly complex systems, and GDTs are useful to explore solutions and pathways to build socially fair, economically thriving and environmentally friendly cities, including agent-based and scenario-based simulations which can compute the CO_2 emissions cuts, time savings and financial benefits of building denser and more vibrant cities.

Big data (input and output data) represents an endless stream of information that is extremely challenging to grasp. KPIs are often used to reduce the domain complexity of systems and provide a comparable ground between peer systems on a temporal and spatial level. The human brain is unique in perceiving patterns in a visual format. GDTs of cities and communities can bridge the gap between big data provided by AI, ML and the human brain. Furthermore, by using KPIs together with the underlying data, it can help stakeholders in trusting the data, information and insights presented by the KPIs.

[ITU-T Y.4900] gives general guidance to cities and provides an overview of KPIs in the context of smart sustainable cities (SSCs). This set of KPIs was developed by United for Smart Sustainable Cities (U4SSC) to establish the criteria to evaluate ICT's contributions to making cities and communities smarter and more sustainable and to provide them with the means for self-assessment.

GDTs allow for these indicators to be visualized in a 3D wheel or lollipop to contextualize the information in space and time. The KPIs can be linked to the underlying dataset and provide more explanations to foster the understanding of stakeholders of smart city and community development projects. Table 2 shows how high-level KPIs can be drilled down to activate the underlying layer of information, and Table 3 shows project testimonials that highlight how digital twins can be deployed and what their environmental benefits on the city and community scale are.

Table 2 – KPIs drill-down and insights

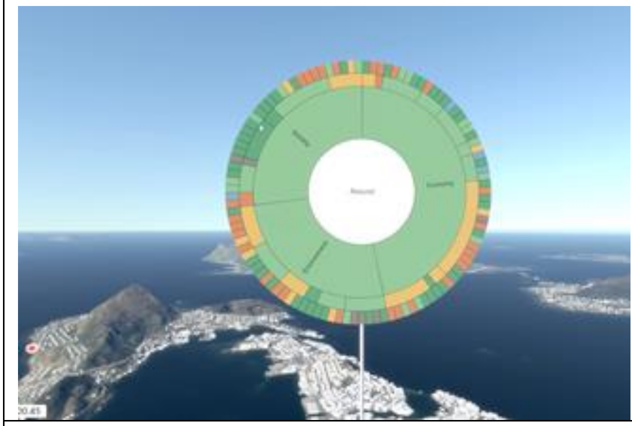
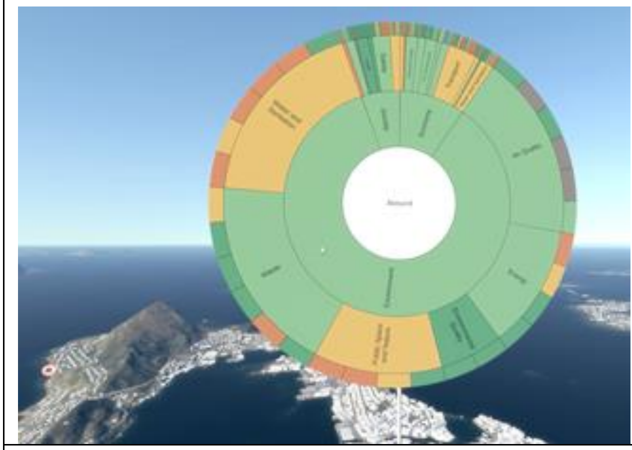
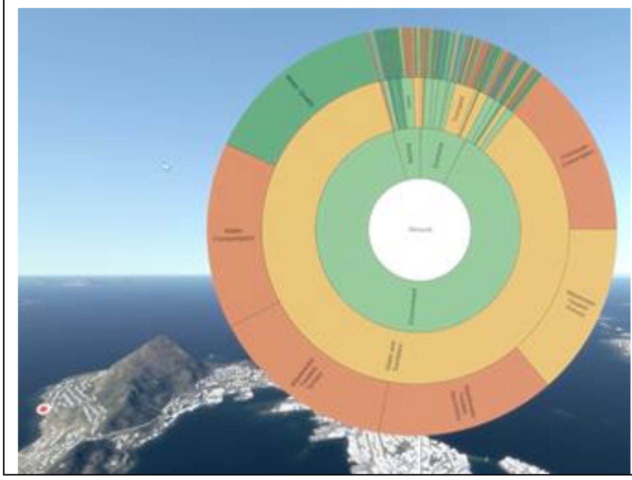
U4SSC KPI view in GDT	Comment
	High level KPI categories: social, environmental and economic. Pressing one of the categories activates the underlying KPI layer.
	Middle level KPI subcategories: Inspecting the economic KPIs. Pressing one of the sub-categories activates the underlying KPI layer.
	KPI: Inspecting the water and sanitation KPIs. Pressing one of the KPIs activates the underlying information layer.

Table 2 – KPIs drill-down and insights

U4SSC KPI view in GDT	Comment
	From KPIs to water system and infrastructure: Understanding the situation with the historical data from the water sanitation site.

5.3 Project testimonials

Project testimonial 1 illustrates different visualizations a drill-down feature can open, stressing the importance of the intuitiveness of the plotting and trackability of the aggregated KPIs (outputs) into raw and localized data (inputs). When providing insights based on big data and simulations, it is essential to provide accountability and to verify that the results are plausible and realistic. It is therefore vital to have a possibility to link outputs with inputs in the GDT.

Project testimonial 2 exemplifies the use of virtual digital visits in domes to engage multiple stakeholders.

Project testimonial 3 shows how planning operations in 3D help understand the future of operations and their environmental profile.

Project testimonial 4 shows how urban planners and civil servants can use GDTs for cross-sectoral city planning (schools, infrastructure, sustainability).

Project testimonial 5 show how visualization in a 3D digital twin brings a higher understanding of the influence of COVID-19 lockdowns on the traffic situation in a small city by utilizing an open IoT/big data gathering vehicle.

Project testimonial 6 sheds light on how roaming SIM-card data of cruise ship passengers in a city centre brings invaluable information on the flow of tourists in a city.

Project testimonial 7 presents the extent of the sea level rise in the San Francisco Bay, visualized in a 3D GDT. The visualization could be used to show areas of concern [b-Kulp].

Project testimonial 8 invites users of GDTs to explain why visualizing climate change challenges, and their solutions, via scenario-building in GDT, is a catalyst of understanding and a game changer in fighting climate change.

Project testimonials 9 and 10 illustrate how the virtual city visit process operates for small- and medium-sized cities.

Project testimonial 11 reports on the monitoring and optimization of heating, ventilation and air conditioning (HVAC) in municipal buildings, thanks to IoT, simulation and visualization.

Project testimonial 12 explores the use of wheel KPIs for the overview of schools in a Norwegian city, showing the number of pupils, teachers and budget per child.

Finally, project testimonial 13 attempts to explain what one tonne of CO_2 means and represents.

5.4 Project testimonial videos

The project testimonials below serve to showcase the applications of digital twins for better climate mitigation solutions. On the one hand, urban planning processes can take decades before reaching a decision and completing project execution. On the other hand urban planning processes carried out without involving stakeholders to "accelerate the process" present a high risk of rejection from citizens in the final project phases, which is very costly. Digital twinning offers a tool to balance the process and help stakeholders understand the environmental goals, CCM and CCA, and the pathways to reach them.

Table 3 – Project testimonials videos[1]

Number	Observation	Link
1	Application field: This video offers a representation of simulated and dig data using a palette of 3D visualizations, each of which is more suited to a particular data format or semantics: – KPI wheel for aggregation of data to KPI; – Ribbon for traffic and water infrastructure, e.g., CO_2/PMx/NOx produced along motorway or water leakage; – Heatmap for high-density spatiotemporal values, e.g., air/noise/light/toxic grounds pollution, heat-island simulation; – Coloured cadastre/building register (e.g., a measure of energy consumption or efficiency of buildings); – Bar graphs for low-density spatiotemporal values (e.g., traffic, noise, air pollution measure at the sensor's placement).	Digital Twins: Palette of visualizations
2	Simulation dome: This video demonstrates how using immersive environments to perform virtual visits helps smart city stakeholders immerse themselves in a given location and better understand the existing environmental challenges.	Digital City Visit in Simulator
3	Visualizing the environmental impact of offshore wind park commissioning and production. The KPIs can provide information on CO_2 savings, AI-based remaining useful timely production of information and ML-estimated number of birds killed during the lifetime of the windmill.	Digital Twins: Impact of Offshore Wind Farm
4	**Use case 1:** This video shows how digital twins can help compare three alternatives for setting up a new school in a district, visualizing population density, walking distance to school, impact on traffic and	Digital Twins in Urban Planning 1 Digital Twins in Urban Planning 2

[1] Please note that the full Project Testimonials Videos playlist used in this deliverable can be accessed here.

Table 3 – Project testimonials videos[1]

Number	Observation	Link
	building shadow testing for neighbours. It shows how AI-based and fact-based information can help inform decision-making in a 3D environment. **Use case 2**: Showing spaciotemporal big data (air quality, soil pollution, noise level, traffic density) to citizens in local digital twins and building the future of their city and community in a simulated environment according to the wishes expressed during citizen consultations.	
5	Norwegian Road Authority visualization showing big data gathered by the authority and the actionable knowledge they bring when visualized in a simulator. One of the findings was that there was 30% reduction of traffic and 11% increase of use of green recreative areas due to the Covid-19 lockdown.	Big Data & Graphical Digital Twins
6	Use case showing the flow of tourists in a city, based on SIM-card information aggregated at a GDPR compliant level. AI algorithms can propose the placement of tourist services accordingly.	Digital Twin Cities: Flow of Tourists
7	Use case showing how sea level rise affects coastal cities in the San Francisco Bay area affecting key infrastructure such as airports, residential and industrial areas.	Digital Twin Cities: Sea Level Rise in the SF Bay
8	This video highlights customer testimonies applied to: – Simulation of mobility; – Future-proofing active mobility; – Coastal planning for the next Generations.	Digital Twin Cities: Customer Testimonies
9	Virtually inspecting the KPI of a small Norwegian coastal city, showing potential AI-based propositions of coastal planning on where to place fish farms and windmills close to the city. It offers a detailed view on the U4SSC KPIs.	Virtual City Inspection
10	Virtual visit to a megacity in a simulator, showing how building information models can be displayed with future buildings.	Scaling up AR Visualization Domes for Megacities
11	Energy consumption is a demanding concept to convey and communicate. The testimonial shows how the KPI wheel can visualize what energy is consumed in buildings and when ,and the impact of simple measures to save energy while improving comfort.	Using KPIs for enhanced building energy control

Table 3 – Project testimonials videos[1]		
Number	**Observation**	**Link**
12	Education is one of the Sustainable Development Goals, and environmental efficiency depends on knowledge being disseminated to the next generations. Furthermore, a significant amount of IoT is measured in schools. This testimonial concerns a virtual city visit with a focus on education. It shows school placement with KPI wheels. The KPIs (cost per pupil, employee per pupil, yearly energy consumption) can be downloaded from the central education agency and combined with other datasets such as socioeconomic district information and various forms of pollution.	Digital Twins: Visualizing School Performance with KPIs
13	CO_2 is an invisible and odourless gas that is challenging to communicate about. Using spheres to convey what a tonne of CO_2e means, the testimonial compares the greenhouse gas equivalent emissions, by source, for two cities of the same size.	Digital Twins: Comparing cities CO2 emissions

5.5 Cost-benefit analysis of graphical digital twins

Table 4 outlines the costs and benefits of GDT.

Table 4 – Cost-benefit analysis of graphical digital twins

Costs	Advantages and/or cost mitigation
The upfront cost of building a digital twin	Capitalizes on the already existing and poorly utilized GIS information and democratizes the digital assets.
Demanding expertise to combine the data sets into a visualization	IoT and AI models are expert-demanding, so GDTs help communicate the insights to decision-makers and all the stakeholders in a common platform.
Demanding expertise to combine the various insights into a single visualization	Supposing AI models and expert knowledge are provided, GDTs offer a holistic view of a city, community or region by contextualizing the insights in time and space. Thus, they are more helpful for citizens and civil servants than pdf reporting.
Demanding expertise and time to combine IoT data	Big data is very often not instrumentalized (data sleep in cold storage; unused), and GDTs can provide a possibility to capitalize on the hidden assets of the cities (their data).

Table 4 – Cost-benefit analysis of graphical digital twins

Costs	Advantages and/or cost mitigation
Digital twins are reserved for rich, smart cities	Regional governments often have the capacity, authority and mandate to perform GDT projects, thus exploiting economies of scale and breaking the vertical and horizontal silos experienced by many urban planning projects around the world.
Digital twins involve many stakeholders and are therefore slowing down the decision-making process	Environmental and Societal change temporality's order of magnitude is in the domain of tens and hundreds of years. The feedback loop of environmental decisions and indecisions, i.e., the time we taken to travel along the wrong path, also has this temporal magnitude. Using GDTs unleashes the potential of AI and simulation to identify sustainable and liveable pathways. Moreover, errors in virtual reality are less costly and less time-comsuming than making the same errors in reality. In the shorter term, using GDTs de-risks projects since the errors can be visualized early on in the design and concept phase.

Bibliography

[b-EU Reg 2020/852] European Parliament and the Council (2020), *Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852

[b-Knight] Knight, W. (2019), *AI can show us the ravages of climate change*. MIT Technology Review. https://arxiv.org/abs/1905.03709

[b-Kulp] Kulp, S.A., and Strauss, B.H. (2019), *New Elevation Data Triple Estimates of Global Vulnerability to Sea-Level Rise and Coastal Flooding*, Nature Communications, Vol. 10, No. 4844, October, pp. 1–12. https://doi.org/10.1038/s41467-019-12808-z

[b-Willsher] Willsher, K. (2021). Paris Agrees to Turn Champs-Élysées into "extraordinary garden". *The Guardian*. https://www.theguardian.com/world/2021/jan/10/paris-approves-plan-to-turn-champs-elysees-into-extraordinary-garden-anne-hidalgo

____