ITUPublications

International Telecommunication Union
Standardization Sector

ITU-T Technical Report

(02/2023)

YSTR.BP-DTw

Best practices for graphical digital twins of smart cities

Technical Report ITU-T YSTR.BP-DTw

Best practices for graphical digital twins of smart cities

Summary

This example-based report focuses on how emerging technology solutions can best address environmental issues within cities. The data used is based on information gained from the United Nations "United for Smart Sustainable Cities" reports [b-U4SSC 2020]. Industrial Internet of things (IoT) and smart cities gather a lot of data in data lakes and present the insights generated by machine learning or artificial intelligence in custom proprietary dashboards or in open application programming interfaces (APIs). It is a tedious task for stakeholders with low data literacy to apprehend so much information and in so many data formats in a way that helps them bend their decisions and adapt their behaviours towards a more sustainable future. In light of the United Nations' 2030 Agenda for Sustainable Development and the European Commission's Fit-for-55 programmes, there is a critical need for a visualisation tool which can help visualise and compare, in a consistent manner, the sustainability of smart cities in such a way that priorities can be identified and anchored at all decision-making levels and best practices can be scaled-up and replicated to other cities. The purpose of this document is thus to identify the emerging technologies which allow a prompt comparison between different cities and help detect low hanging fruits and areas of high priorities. For the sake of convenience and reproducibility, attention is drawn to potential universal data formats.

Keywords

Digital twins, emerging technologies, graphical, KPIs, replication, scalability, sustainability, U4SSC, visualisation.

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.

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Best practices for graphical digital twins of smart cities

1 Scope

This example-based report details how emerging technology solutions can be used to address environmental issues in an urban environment. The data used is based on information gained from the United Nations "United for Smart Sustainable Cities" [b-U4SSC 2021] reports. This Technical Report focuses on comparing results from different cities around the world and looking at the areas where cities gained low results. The report attempts to answer the following questions: What are the emerging technologies that could improve these results? How should the data be structured to improve results?

2 References

None.

3 Definitions

3.1 Terms defined elsewhere

This Technical Report uses the following terms defined elsewhere:

3.1.1 Internet of things (IoT) [b-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.

NOTE 1 – Through the exploitation of identification, data capture, processing and communication capabilities, the IoT makes full use of things to offer services to all kinds of applications, whilst ensuring that security and privacy requirements are fulfilled.

NOTE 2 – From a broader perspective, the IoT can be perceived as a vision with technological and societal implications.

3.1.2 smart sustainable city (SSC) [b-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.

NOTE – City competitiveness refers to policies, institutions, strategies and processes that determine the city's sustainable productivity.

3.1.3 big data [b-ITU-T L.1390]: A term that describes the large volume of data – both structured and unstructured – that inundates a business on a day-to-day basis. Big data can be analysed for insights that lead to better decisions and strategic business moves.

3.1.4 digital twin [b-ITU-T Y.4600]: A digital representation of an object of interest.

NOTE – A digital twin may require different capabilities (e.g., synchronization, real-time support) according to the specific domain of application.

3.2 Terms defined in this Technical Report

This Technical Report defines the following terms:

3.2.1 graphical digital twin (GDT): A graphical digital twin superimposes spatiotemporal data, information and insights on a 3D model representative of an object of interest.

NOTE 1 – Graphical digital twins are used to present the data and their insights in a way that can be contextualised and more easily understood by all the stakeholders.

NOTE 2 – Figure 3 shows such a 3D model in AugmentCity's Lollipop data visualisation.

3.2.2 smart city stakeholder: Any person involved in the development of a smarter and more sustainable city.

NOTE 1 – Smart city stakeholders include, but are not restricted to citizens, interest group representatives, businesses, civil servants and urban planners, politicians and researchers.

NOTE 2 – Figure 1 shows smart city stakeholders collaborating in a digital twins solution.

4 Abbreviations and acronyms

This Technical Report use the following abbreviations and acronyms:

AI	Artificial Intelligence
AIS	Automatic Identification System
API	Application Programming Interface
BIM	Building Information Modelling
CAD	Computer Aided Design
CSV	Comma-Separated Values
GDPR	General Data Protection Regulation
GDT	Graphical Digital Twin
ML	Machine Learning
HDF5	Hierarchical Data Format 5
ICT	Information and Communication Technology
IoT	Internet of Things
JSON	JavaScript Object Notation
NETCDF	Network Common Data Format
PM	Particulate Matter
REST	Representational State Transfer
SSC	Smart Sustainable City
U4SSC	United for Smart Sustainable Cities
KPI	Key Performance Indicator
GDT	Graphical Digital Twins

5 Conventions

None.

6 Best practices for graphical digital twins for smart cities

6.1 Introduction

Smart cities are associated with big data, growing concerns about sustainability and climate change, and participative intelligent decision-making solutions. In this context, the challenges of citizen engagement in decision-making include data-privacy and the fact that the sheer amount and heterogeneity of insights from various domains make it extremely demanding for non-experts to understand the situation and communicate priorities and solutions. As high-quality 3D graphical digital twins (GDT) of cities are becoming more widespread and affordable, we propose the introduction of 4D visualisations of geo-localised time-series in the twins. The method, applied in a city council, uses off-the-shelf hardware and game engine software, and creates immersive environments to convey multivariate spatiotemporal data in a data-agnostic manner.

Cities are complex systems of systems which are currently facing major challenges such as accelerating population concentration, increasing congestion and air pollution, and climate change. Indeed, they are now home to a growing number of the world's population; for example, 70% of the European population was urban in 2018 [b-Eurostat] and 75% to 80% will be urban dwelling by 2050. According to the World Health Organization (WHO), 4 to 8 million people die prematurely because of air pollution every year. Two thirds of the world's biggest cities are coastal and will be impacted by rising sea levels and more frequent and devastating extreme weather. Sea level rise threatens the lives of between 150 to 200 million people worldwide [b-Kulp & Strauss]. The problem is thus systemic and cannot be solved by only optimising or upgrading the already existing cyber-physical infrastructure. A series of independent smart city initiatives have mapped the high-level UN sustainable development goals (SDGs) to concrete key performance indicators (KPIs) to assist city councils in understanding the challenges, setting the policy priorities, and communicating them to stakeholders. One such initiative, United Nations for Smart Sustainable Cities [b-U4SSC 2020] has been adopted by a growing number of smart cities worldwide.

Sustainability is the balance between economic growth, social equality, and environment preservation; the U4SSC KPIs are a set of 91 indicators from these three areas and serve as a compass for smart and sustainable city-level decisions. It has proven complicated and demanding to communicate with stakeholders on the current situations, actions to take, and on progress made. Visualisations in 4D can help tackle such challenges.

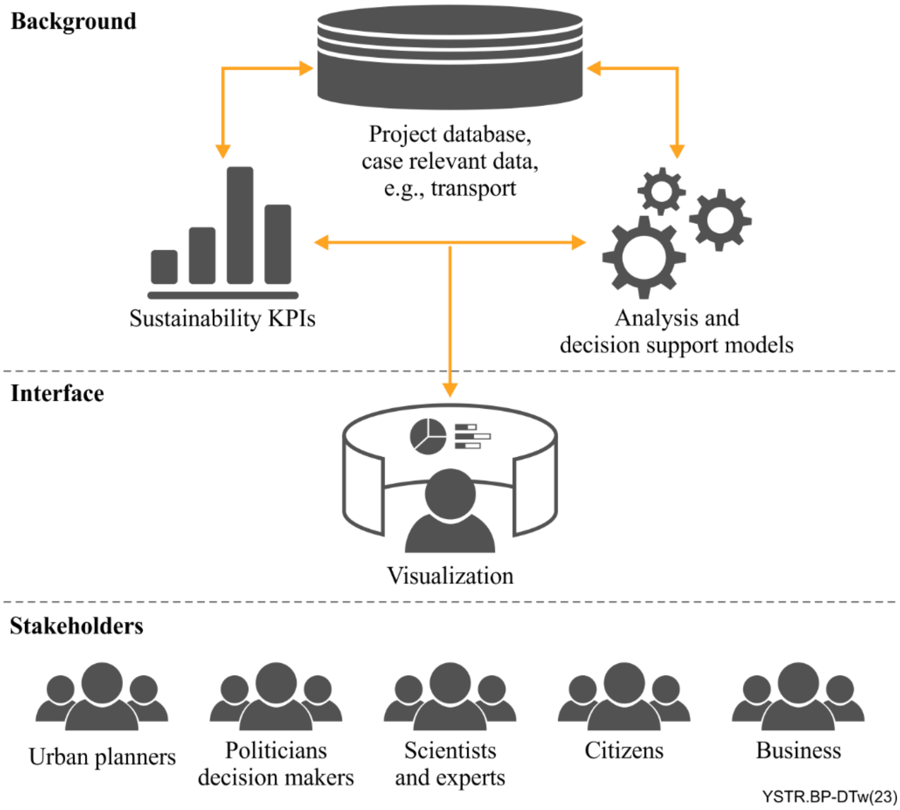

Figure 1 – Smart city stakeholders in a digital twins solution [b-Major, Hildre & Zhang]

6.2 Overview of big data and AI-ML generated insights for smart cities and earth observation: Formats, structure, storage, challenges

This clause will present a short overview of the state of the art in the domain of big data for smart cities and earth observation and conclude with a list of unsolved challenges relative to the stakeholders' involvement in the behaviour change and decision-making processes. Table 4 provides a non-exhaustive list of data and use cases relevant to smart cities.

Smart city data provide data and insights in the form of geo-referenced time series which are multivariate data. High-level decisions, priorities, and measurements must be interpreted in their spatiotemporal context. Instrumentation and measurement are hardly conceivable without a graphical representation of the values. The main challenges of big data are:

– Accessing the unfathomable amount of data, identifying which is business-critical, and presenting it in a human-friendly way through quick response-time, intuitive interaction, and understandable visualisation.

– Finding a balance between high-quality data and data privacy. General data protection regulation (GDPR) is taken very seriously in Europe, especially when the trust of the citizens in local authorities is at stake.

– Determining the reliability of data from sensors and insights given from predictions during the decision-making process.

– Domain knowledge is a requirement for understanding the underlying data, but not all the stakeholders have the necessary literacy to grasp the insights without additional help.

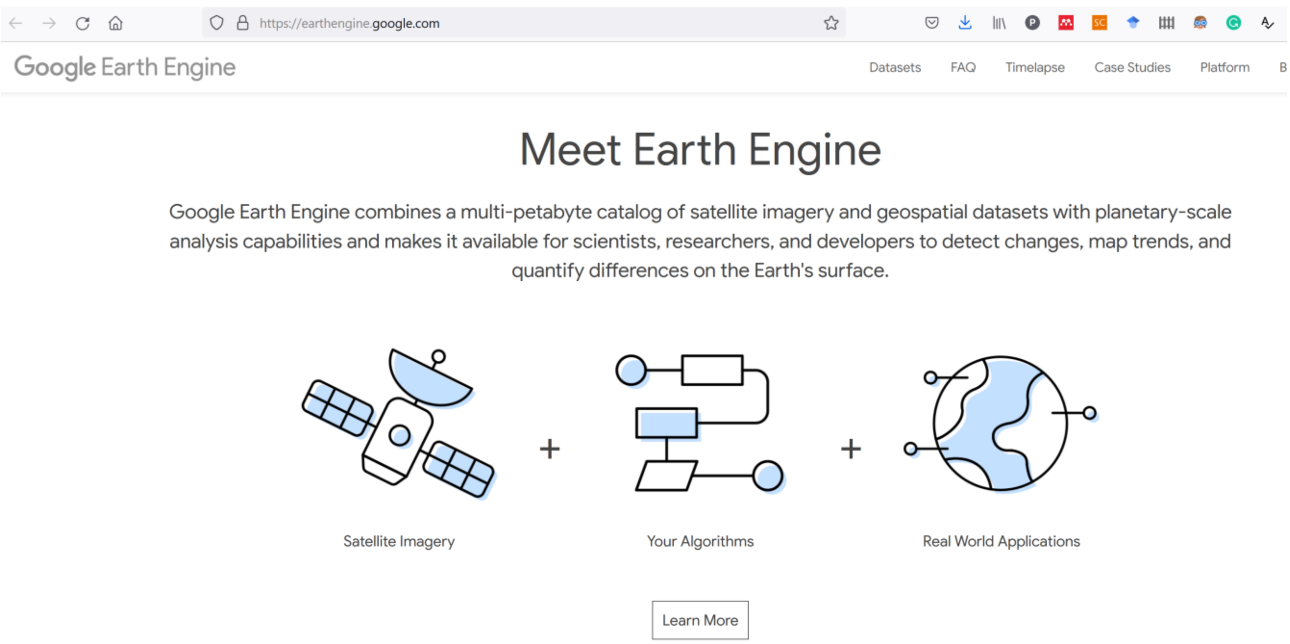

Figure 2 – Google Earth Engine

Figure 2 illustrates the big data process pipeline and value chain offered by Google Earth Engine: collecting petabytes of earth surface data in various catalogues, processing the data thanks to machine learning (ML) and artificial intelligence (AI), then make useful human understandable stories that engage a wide audience and trigger decisions.

Such data-driven approaches are instrumental when trying to understand past geographical processes at Anthropocene scale. But scenario-driven and insight-driven approaches are necessary to nudge stakeholders towards more sustainable high-level decisions.

Intuitive traffic-light-inspired colour-scheme visualisation, as depicted in Figure 3 easily communicates progress on key issues within the city or community. Such visualisations offer a high-level easy to grasp insight which can be drilled down, if necessary, by showing the underlying data set in a spatio-temporal manner. As such, it combines both an intuitive visualisation and a user interface allowing the user to interact with the data.

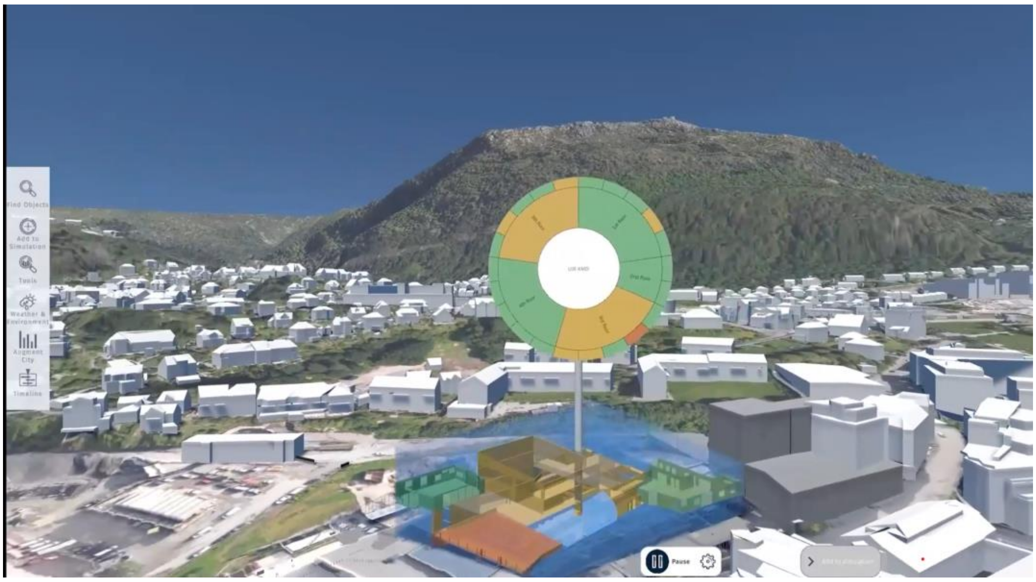

Figure 3 – AugmentCity's Lollipop data visualisation (courtesy of AugmentCity)

6.3 Limitation of current dashboards for Smart Cities and Earth Observation

This clause presents a short overview of the state of the art in the domain of dashboard solutions of smart cities and earth observation and concludes with a list of unresolved challenges relative to stakeholders' involvement in the behaviour change and decision-making processes.

Figure 4 depicts one of the views of the Amsterdam Smart City Dashboard. Geo-localised information can be viewed with a number of widgets displaying real-time trends. Table 1 presents a short analysis of the pros and cons of current dashboard solutions. To summarize, a dashboard is a tool to show the current situation, much like a car's dashboard. They can help decide on short term decisions but not on macro trends or multi-generational decisions.

Table 1 – Analysis of current dashboard

Pros	Cons
• Gather all dynamic real-time (IoT) information in one place. • Engage users through 3D visuals. • Provide historical and real-time data or can provide short term trends such as overnight or 15-minute traffic surges or energy demand. • Some provide possibility to interact remotely with actuators such as emergency valves for flooding, lighting.	• Expert-centric: require a high level of literacy to grasp the many visualisations and make correct decisions. • Expert-centric: information is in the hands of a few people in operational centres. • Seldom provide long term scenarios that are necessary for planning sustainable cities. • Seldom provide long term Anthropocenic analysis of cities. • Very often proprietary protocols. • Provide information but no insight. • Narrative is challenging to engage citizens. • Limited collaboration possibilities.

6.4 Overview of graphical digital twins for smart cities and earth observation

This clause addresses how graphical digital twin solutions of smart cities and earth observation can solve the aforementioned challenges and also investigates the scalability and replicability of such methods.

As shown in Figure 4, graphical digital twins (GDT) of cities helps contextualise geo-referenced information. Virtually any kind of data can be related to a location by joining and merging datasets. Furthermore, the datasets are very often dynamic and historical. There are numerous solution providers which have developed a smart city platform for their main and only client on a project basis. The GDT are thus not replicable and scalable to other countries and cities. International smart city standards, such as U4SSC, should be supported as a minimal requirement of GDT. This will ensure the scalability, portability, and comparison of the standard solution.

Furthermore, many GDTs solutions, such as that shown in Figure 4, focus on Internet of things (IoT) and thus lack the flexibility to show different datasets that are softer such as quality of living or citizen wellbeing and or outcomes of hydrographic simulations (storm surge impact, storm flooding, etc.).

Figure 4 – GeoDan/Huawei Amsterdam smart city platform

6.5 Data formats for graphical digital twins for smart cities and earth observation

This clause addresses how data needs to be structured in order to be intuitively presented in graphical digital twins. Table 2 shows an overview of the data formats. Figure 6 shows an example of a hybrid approach using a dynamic representational state transfer (REST) API to create a CSV based heatmap. CSV files are the best candidates for a wide variety of users. They allow showing data in various case studies (see Table 4) in digital twins and prototype solutions. Integrating static and dynamic REST APIs can be seen as the next step to automating manual work and guaranteeing interoperable solutions.

Table 2 – Data formats

Standard name	Description	Use
CSV	Excel (See Figure 5 for an example)	Broad audience
NETCDF	Multivariate scientific raw low level data	Scientific
HDF5	Multivariate scientific raw low level data	Scientific
OpenStreetMap	Road network description	Mobility visualisation and simulation
GeoTiff via WMS	Raster pictures	Textures picture of terrain
Lollipop	Hierarchical structured high level data	Showing high level KPIs
Static data REST API (arcgis, azure, google, AWS)	Access to datalake	Commercial, productive use, too complex for wide audience, but best way to automate servcices and visualisation
Dynamic data REST API (JSON)	On demand calculations	Mobility simulation and information see Table 4

time	value	lat	lon
07/06/2021 13:02	600	59.901845	10.645841
07/06/2021 13:02	600	59.902192	10.645841
07/06/2021 13:02	600	59.902540	10.645841
07/06/2021 13:02	600	59.902887	10.645841
07/06/2021 13:02	600	59.903235	10.645841
07/06/2021 13:02	600	59.903582	10.645841
07/06/2021 13:02	600	59.903930	10.645841
07/06/2021 13:02	600	59.904277	10.645841

Figure 5 – Spatiotemporal time series

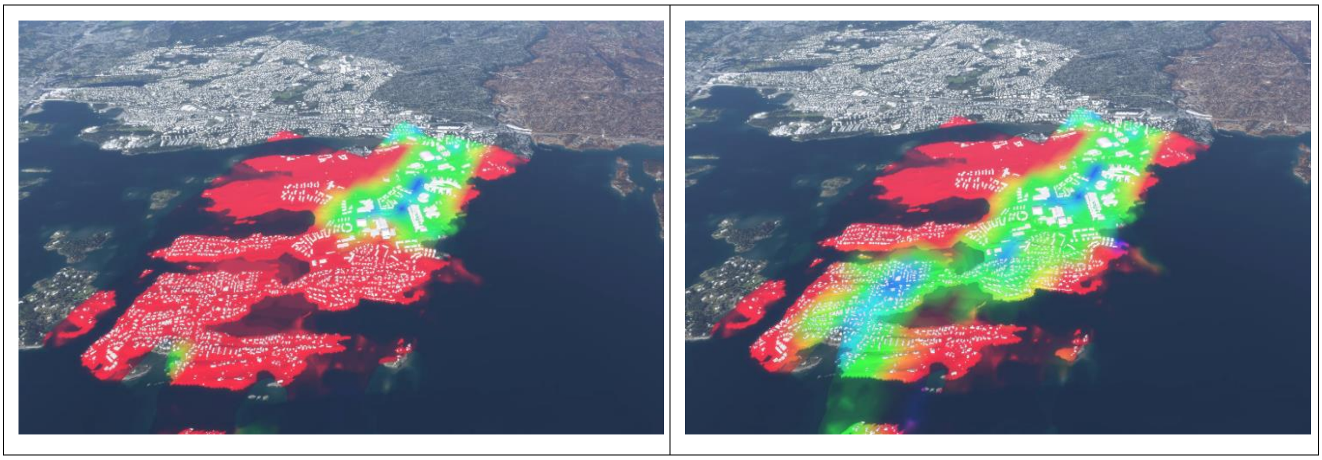

Figure 6 – Heatmap of distance to bus stops (high frequency lines left, low frequency lines right) (courtesy of AugmentCity and Entur)

Table 4 – Smart city data analysis [b-Major, Hildre & Zhang]

Type	Description	Relevance	Scalability	Privacy
BIM	Building and Road Information CAD, Timed BIM	Current and future city Contextualise energy consumption, infrastructure needs	Local and private data, international standard format	Occasionally critical
Energy & Water	**Energy and Water Usage in districts** **KWh/day/hour, m^3/day** **Geo-localised time-series**	**Civil defence** **Current and future infrastructure needs**	**National database**	**Critical**
Weather	Historic and Forecast Geo-localised time-series	Contextualize outdoor activities Civil Defence	Worldwide Service	Irrelevant
Air Quality	Historic and Forecast Geo-localised time-series PM10, PM2.5, PM1, NOx, SO4	Health and environmental consequences	National Service	Irrelevant
Mobility	**Inductive Loop Data** **Geo-localised time-series** **Vehicles/hour/day, etc.**	**Network utilisation of vehicle and bike infrastructure, Emissions, congestion**	**National Service**	**Occasionally critical**
Public Transport	**Automatic Passenger Counting** **Per bus, ferry line and stop** **PAX, revenue**	**Monitoring and planning of infrastructure**	**Regional Service**	**Critical**
Demographics	Historic and Forecast Geo-localised time-series (age, gender, wealth, school pupils)	Contextualize and plan infrastructure needs: schools, roads, bus lines	National Service	Irrelevant
U4SSC KPIs	**91 sustainability KPIs**	**Identify priorities for sustainable planning**	**Worldwide Service**	**Irrelevant**
Emergency Response	Fire and -ambulance Response Time Minutes to destination Geo-localised time-series	Identify areas with poor coverage Plan infrastructure	National Service	Critical
AIS	Automatic Identification System Geo-localised Time-Series	Air quality correlations Traffic planning	Worldwide and National Service	Occasionally critical
Outdoor Activity	Geo-localised Time-Series Outdoor activities with Strava Outdoor Path	Contextualize outdoor activities Identify preferred routes	Worldwide Service	

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