Report

Maturity of Swiss public administration in the field of Urban Digital Twin from a GIS perspective.

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Table of contents

Preamble

This document acts as a supplementary introduction, not the main part of the project. It's designed to reference the online application, accessible at https://udt.epfl.ch, which presents the survey results.

Introduction

The objective of this project is to assess and enhance the level of expertise and capability within the Swiss public administration concerning the implementation and utilization of Urban Digital Twin technologies, specifically from a Geographic Information Systems (GIS) standpoint. Urban Digital Twin technologies strive to provide an accurate reflection of city functions and processes, to affect its operability and management (Shahat et al. 2021). Urban Digital Twin approaches are implemented to anticipate challenges in urban planning, assist decision-making processes, and for operation and maintenance by public administrations (Ferré-Bigorra et al. 2022; Shahat et al. 2021).

The evaluation of Urban Digital Twin concepts regarding their potential to develop the Swiss NGDI as a knowledge infrastructure is incorporated in the action plan 2023 of the Swiss Geoinformation Strategy (SGS 2022). A survey was conducted to assess the current maturity level of the Swiss public administration in this domain. The proficiency in integrating diverse data sources, developing comprehensive virtual representations of urban environments, and utilizing GIS technology for effective urban planning and management are canvassed within the survey.

As the implementation of Urban Digital Twin concepts poses a variety of challenges (Lei et al. 2023), the identification of needs and requirements of the Swiss public administration is crucial to enable technological advances within the domain. Thus, this project seeks to identify areas of improvement and provide recommendations for enhancing the Swiss public administration's maturity in utilizing Urban Digital Twin methodologies from a GIS perspective.

Methodology

To analyse the current maturity of Urban Digital Twin technologies in the Swiss public administration, actors of federal, cantonal and municipal institutions or organizations were contacted to participate in the survey.

For this endeavour, it is essential to select a suitable and standardised maturity spectrum. Maturity models are used to assess processes, organizations and systems against a norm to identify the potential for improvements. These models, which originated in the software industry for improving software development and maintenance (Paulk et al., 1993), are a common topic of discussion in digital twin academic and professional literature (Davila Delgado & Oyedele, 2021). By defining a series of progressive phases that outline required capabilities, digital twins' maturity models facilitate tracking, benchmarking and achieving technological advances (Evans 2019). Masoumi et. al (2022) compiled several digital twin maturity models and classifications. The maturity spectrum suggested by the Institution of Engineering and Technology (IET) (Evans et al. 2022) served as a guiding reference in this project, as this model exhibits greater detail compared to other models and has been utilized in numerous scientific publications. This particular spectrum offers a well-defined and industry-agnostic framework that encompasses six development elements, providing clear requirements and desired outcomes. The progression of the six development elements represent a transition from reality capture to an Urban Digital Twin with autonomous operation and maintenance. In the following, the six elements are described briefly (according to Evans et al. 2022):

Element 0 (reality capture for existing physical assets) represents the creation of a precise, as-built data set of the system design or asset geometry, and is thus the foundation for data connection and overlaying.

In *Element 1* (2D map/systems or 3D model, only object-based), the as-built model is created through the entry of new assets and reality capture.

In *Element 2* (connected to persistent (static) data, metadata and BIM Stage 2), persistent data-sets (i.e. material specification or design information) and metadata (i.e. BIM) are connected to the model. The data is connected by tagging the data or pulling it from existing systems and not directly stored or embedded in the model.

The model is expanded with real-time data in *Element 3* (enrich with real-time (dynamic) data) via a one-directional flow from sensors, Internet of Things or connected devices to the model.

The one-directional flow is extended to a bi-directional flow in *Element 4* (Two-way integration and interaction). This implies that the digital twin can change the state and condition of the physical asset. Output and results are fed back to update the digital twin.

In the future, an *Element 5* (Autonomous operations and maintenance) digital twin that learns and evolves autonomously by absorbing experience about the behaviour of the physical asset can be imagined. It is able to react and take corrective action with little or no human interaction.

To assess the maturity spectrum of the Swiss administration, specific challenges per maturity element were compiled. Open issues and key challenges associated with implementing an Urban Digital Twin have been examined and systematically categorized in a previous project (Weil et al. 2023). To leverage the identified challenges, they were categorized based on the maturity elements described above. Certain GIS related challenges were transformed into questions that the actors respond to based on their expertise and the maturity level of their organization's Urban Digital Twin. The set of gathered questions was divided into five main themes: data visualization, data accessibility, data interoperability, data management and data processing.

In total, 33 questions that canvass the five themes and different levels of technological Urban Digital Twin maturity, or that assess the participant's wishes, needs and attitude towards Urban Digital Twin concepts, have been selected. Additionally, 27 follow-up questions were included, to gather more detailed information on the previous questions. Single and multiple choice questions, as well as open text questions are posed. A commentary field allows for the participants to provide remarks and further information to their answers. For clarification, some questions were equipped with additional information and explanations.

To facilitate the completion of the survey to the multilingual actors, the survey was translated into French and German. In the initial stage, the survey was conducted with French and German speaking participants to validate the translations and to ensure the acquisition of desired target information. As a tool, the platform findmind.ch is employed, as it offers survey translations into several languages and thus enables the participants to choose the desired language.

Throughout the survey implementation stage, individual support and assistance for the survey completion was offered. Online meetings were held with various actors to address specific questions and to assist during the process. The result documentation and analysis are described in the following section. The survey questions in English are provided in the Appendix.

Results: Web Application

The results are presented and illustrated in a web application (made with Streamlit v1.27.0). On the interface, results can be filtered by theme and question, as well as by federal, cantonal or municipal actors. For each survey question, the results are displayed in a diagram or as plain text plus corresponding comments by the participants. Additionally, motivation and analysis are provided per question and theme. The web application allows for a print of the results, as well as screencast recordings.

Anonymized results are accessible via https://udt.epfl.ch/, while the raw data is protected with a private login and can be accessed via https://udt.epfl.ch/private.

Analysis

The following section contains an analysis of the survey results per theme.

Data visualization

From the provided survey, a few key trends in geospatial data management emerge. Over half of the surveyed institutions have incorporated 3D visualizations into their GIS platforms, enhancing urban representation, planning, and communication with stakeholders. Additionally, most respondents' web map applications exhibit adaptability, with some having multiple interfaces tailored for different user types. While many platforms also integrate visual elements beyond traditional maps, such as KPIs and charts, augmented reality (AR) remains less adopted. Although AR tools exist and are recognized, challenges in implementation and early-stage exploration inhibit widespread use. Collectively, these findings spotlight the evolving nature of geospatial tools, with growing emphasis on comprehensive visualization, adaptability, and user-centric interfaces, though there's still hesitancy in adopting emerging technologies like AR.

In terms of the level of maturity in the data visualization field, some respondents mentioned using 3D or BIM data in their processes. However, the majority of respondents still do not make reference to 3D or BIM models, despite having the technical capacity to do so. Thus, the current status of Data visualization is early 1.

To increase the maturity level, the following steps should be taken:

- Generalized 3D data collection on the field or processing based on alternative dataset (eg. lidar).
- Promote the usage and best practices of BIM methodology through the use of cases, standardization, knowledge transfer, and promotion within GIS units.
- Promote the usage of augmented and virtual reality through the use of cases, standardization, knowledge transfer, and promotion within GIS units.

Data accessibility

Most organizations are favorably inclined towards open data, offering free access to geospatial and non-geospatial datasets, with some looking to expand these repositories. While many employ diverse tools for this purpose, a significant number lean towards geocat.ch for metadata management and publication. It's notable that the GM03 metadata standard, based on ISO 19115, is predominantly in use, and there's a consistent effort among these organizations to define dataset-specific access rights. On the other hand, only a quarter of them allow individuals to independently publish datasets, reflecting a centralized data management approach, primarily driven by the GIS unit. The concept of 'data mesh' remains relatively less explored, with only 10% being familiar and half being aware of it. Despite its limited recognition, those familiar with it see potential benefits, although apprehensions exist around its implementation, primarily due to technical, political, and economic challenges. Currently, the flow of information involves the data provider taking action to reference or load it onto a publishing platform. However, there appears to be no common access system in place for sharing dynamic information between different levels of the administration.

Data management

The survey captures an intricate landscape of GIS infrastructure and data management practices. When developing new datasets, respondents favor aligning with existing federal or international data models, underscoring the importance of standardization and interoperability. There is a prevailing inclination towards integrating custom data models into standard ones, particularly when higher authorities dictate. Archiving practices reveal varied approaches, emphasizing the need for uniformity, especially given the diverse strategies towards vector, raster, and LIDAR datasets. Crowd-sourced data like OpenStreetMap sees limited use, but there's growing interest, necessitating rigorous quality assurance. There's a significant gap in the readiness of organizations to integrate real-time and elevation data into their GIS systems, revealing potential areas for growth and development. Data generalization strategies hinge on considerations of data privacy, readability, and legal mandates. Real-time data utilization and the ownership of sensor networks for such data exhibit mixed trends, with many leaning towards collaborative efforts between public and private entities. The ability to handle web ontology data like RDF is not widespread, suggesting a domain ripe for exploration. Many experience computational challenges with real-time datasets, pushing them towards enhancing computational power, distributed processing, and outsourcing data processing.

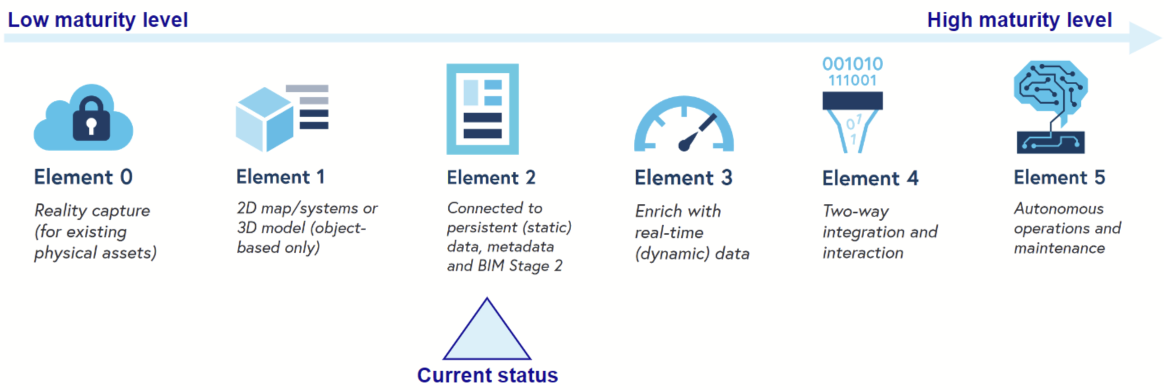
The ideal solutions, as perceived by respondents, revolve around a mix of technological enhancements, edge computing, and strategic outsourcing, reflecting the diverse challenges and solutions in the GIS domain.

In the context of an Urban Digital Twin, data accessibility and management are intricately linked, as the successful operation of the digital twin hinges on the effective organization, maintenance, and availability of data. Data management practices are vital for aggregating, cleansing, and integrating diverse data sources, ensuring data quality, and supporting real-time updates. Simultaneously, data accessibility enables stakeholders such as urban planners, government agencies, and the public to interact with and extract valuable insights from the digital twin. Without proper data management, the digital twin's accuracy and usefulness may be compromised, while inadequate data accessibility could limit its potential impact on urban planning, decision-making, and the overall management of the urban environment.

The survey highlights the respondents' acceptance of the concept of data openness, as most of them provide open data. There is some attention given to metadata, with a nationwide program in Switzerland improving data referencing. However, the means of data transfer are not fully dynamic and mostly rely on regular or manual file transfer. The Urban Digital Twin concept aims to promote a more integrated approach to data sharing.

Additionally, the survey emphasizes the importance of standardization in data management. The majority of respondents clearly indicated that they would not develop a new data model without considering what already exists in the field.

Within the organization, data accessibility is currently, most of the time, centrally managed by the GIS unit. This limits the flexibility of business specialists to implement new data services or updates. In an Urban Digital Twin concept, both spatial (geo) and non-spatial (non-geo) data should be transferred and exchanged between systems. However, the current silo approach may prioritize non-geo data at the expense of pure geo data. This approach may not be sustainable, and a more integrated data management approach, such as a Data Mesh, should be implemented.



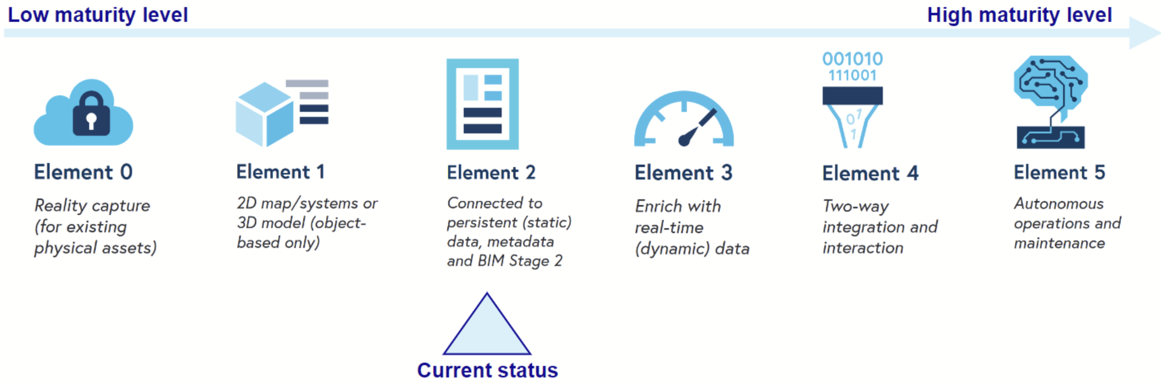
To increase the maturity level, the following steps should be taken:

- Promote the real-time transfer of data within and outside organizations based on web services, as this facilitates timely access to critical information, enabling rapid responses to urban challenges, enhancing situational awareness, and supporting data-driven decision-making for urban planning and management. This can be achieved by implementing some flagship project, use cases and knowledge sharing.
- Explain and illustrate the data mesh principle and how it can address governance needs through "federated computational governance" (a set of policies, processes, and mechanisms that govern how data is managed and used across decentralized organizations). This involves coordination and collaboration among these domains to ensure consistent and secure treatment of data, regardless of its origin.

Data interoperability

The theme offers a comprehensive overview of organizations' readiness and adaptability towards emerging technologies and data formats. A large proportion of organizations have GIS tools that support the OGC vector formats such as GeoJSON or CityGML, but many need additional software to bridge compatibility gaps. While many platforms struggle with processing Building Information Modeling (BIM) data, there is a growing trend towards its adoption, especially using open standards like IFC. Reasons for not utilizing BIM yet vary, including lack of transition, demand, or clear use cases. Most platforms can process a variety of data types like LIDAR, remote sensing, and IoT data, but the capacity to handle social media data or citizen reports remains limited. The ability to manage camera data varies, with many platforms currently not supporting it, though some see potential in its future integration. Lastly, the capability to handle multi-dimensional data is mixed, with some organizations ready and others in early stages or yet to consider it. Overall, the geospatial community appears to be in a state of flux, with an evident push towards adopting new technologies and diversifying data sources, but with varying degrees of readiness and implementation.

This theme highlights the overall inflexibility of geodata platforms when it comes to incorporating new data types. While many respondents mentioned the capability to handle OGC standard file formats, these platforms appear to be limited to traditional forms of geodata and do not include other types such as social media data, IoT, or citizen report data.



To increase the maturity level, the following steps should be taken:

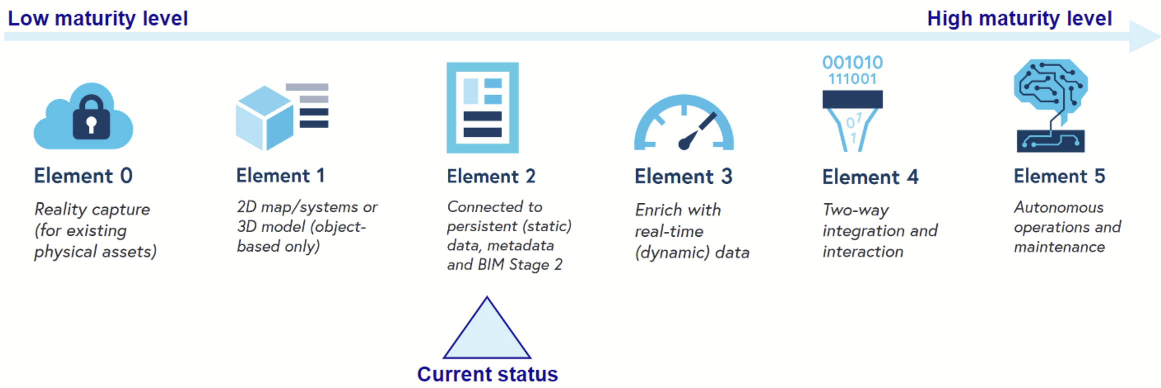
- Promote the usage of new types of data, such as social media or citizen reports, to better include citizens in decision-making and enhance communication. This can be achieved through the use of use cases and technology sharing.
- Promote the usage of other type of non spatial data to add extra context. Adding non-spatial types of data (e.g., demographic, economic, or social data) in an Urban Digital Twin is crucial to provide a comprehensive understanding of the urban environment, enabling holistic decision-making that incorporates not only physical aspects but also the social and economic factors that shape urban life and development.
- Utilize more IoT-type data and on-field sensors to monitor the real-time dynamics of the urban environment. This can be accomplished through the use of use cases and technology sharing.

Data processing

Organizations often turn to more powerful workstations to bypass computational limitations, although cloud and cluster solutions also have their merits. Swisstopo, for instance, transitioned from using distributed computation software for tasks during nighttime hours to relying on individual computing power due to advancements in technology. A significant number of respondents anticipate using virtual machines for data processing, though presently, only a fifth use such infrastructure. Surprisingly, while many use a mix of data processing tools, prominent options like Apache Sedona and Apache Spark are unfamiliar or unused by many. Despite the potential of machine learning (GeoAI) for analysis and planning, its uptake is limited, largely because of perceived knowledge and resource gaps. Still, its varied applications, as demonstrated by SwissTopo and others, span diverse geospatial challenges, from urban planning to environmental monitoring. Moreover, while traffic and transportation simulations are popularly used, other domains such as land use, emergency response, and sustainability show varied or exploratory adoption of simulation techniques.

While the other themes primarily centered around data acquisition and management, this theme now shifts its focus to the potential applications of the data. In an Urban Digital Twin context, effective big data processing becomes essential, enabling the seamless integration, analysis, and utilization of the extensive and diverse data generated in urban environments to guide decision-making, enhance resource allocation, and improve urban quality of life.

This theme brings attention to significant trends and hurdles. To start, organizations frequently depend on more robust workstations to surmount computational constraints, yet there is also an increasing curiosity regarding cloud and cluster solutions. Furthermore, the survey indicates a gap in understanding real-time or big data processing tools, whereas conventional geoprocessing applications seem to be widely recognized. Additionally, the adoption of machine learning (GeoAI) faces obstacles due to perceived knowledge and resource limitations, despite its proven adaptability in tackling various geospatial challenges, including urban planning and environmental monitoring.



To increase the maturity level, the following steps should be taken:

- Clarify and advocate for the utilization of AI and machine learning to illustrate their potential value addition, which can be achieved through sharing code and models, as well as conducting training sessions and workshops
- Encourage the adoption of big data technology and processing to ensure the efficient handling of data, eliminating any potential application bottlenecks by offering efficient tools for processing large datasets.

Conclusion

The survey responses revolve around the intersection of technology, automation, and urban management. Organizations today are increasingly intertwining virtual work with tangible real-world outcomes, as evidenced by applications in flood prediction, forest fire warnings, and traffic control. The "Urban Digital Twin" concept has been met with a mixture of enthusiasm, curiosity, and cautious optimism. Many respondents believe in its transformative potential for urban planning, though some reservations about its practicality and security implications exist. Furthermore, as urban digital technologies evolve, there's a pronounced need for collaboration and knowledge sharing. The call for a Use Case Repository, Standardization Efforts, and Collaboration with Industry underscores the importance of collective learning and adaptability in this domain. Participants express a clear appetite for real-world examples, best practices, and tools that enhance interoperability and drive the seamless integration of digital solutions in urban management.

Survey Conclusion

The survey response rate was very high, as only a few organizations did not have the capacities to complete the survey. This underlines the general interest in the topic by the participants. One major challenge during the survey implementation stage was the different understanding of questions by different participants. To ensure an uniform understanding, assistance via online meetings was provided. Nevertheless, several participants completed the survey without assistance. This and subjectivity in general can lead to incertitudes in the results.

The survey findings shed light on several critical aspects of data management and utilization in the context of Urban Digital Twins. The assessment of data visualization maturity indicates a growing interest in 3D and BIM data, suggesting a potential avenue for further development. However, there remains room for improvement in maximizing the use of these technologies. Data accessibility and management emerge as fundamental components, with the importance of data openness and standardization highlighted. The transition toward real-time data transfer and the exploration of the data mesh principle present opportunities for enhanced data governance and collaboration. Furthermore, data interoperability faces challenges in incorporating new data types, emphasizing the need to broaden data sources to include social, IoT, and citizen report data. Lastly, the theme of data processing underscores the growing interest in AI, machine learning, and big data technologies, suggesting the potential for significant advancements in urban data analysis and decision-making. To advance the maturity levels across these themes, it is imperative to promote knowledge sharing, training, standardization, and technology adoption, ensuring Urban Digital Twins can reach their full potential in shaping the future of urban planning and management.

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Appendix: Survey

3 - Does your organization maintain a spatial data infrastructure ?
5 - Can your GIS online platform provide 3D representations of the territory?
6 - Can the display of your organization's web map application be adapted to different types of users ?
7 - Is the GIS online platform provide visual representations beyond maps, such as KPIs, charts, and other graphical elements?
8 - Is the use of augmented reality (AR) integrated in your organization's GIS data platform?
10 - Does your organization provide open data that users can freely access (without any login or fees) ?
11 - Why does your organization not provide free open data access to the users ?
12 - Which tool does your organization utilize to provide free open data access to the users?
13 - Does your organization possess a conventional method for sharing or presenting metadata ?
14 - What type of metadata standard do you emploi?
15 - Which tool do you utilize to manage and publish metadata?
16 - Can your organization's geodataset be selected temporally?
17 - If a user wants to access a historical dataset (e.g. LIDAR data from 2010), what is the process for providing such data?
18 - Can your geospatial dataset be queried remotly via an API?
19 - What level of data granularity can be obtained through this API?
20 - Can you explain why your organization does not use APIs?
21 - Do you define different access rights per dataset?
22 - Why are there no different access right defined per dataset?
23 - Which tool do you use to set different access rights per dataset?
24 - If somebody would like to publish a new dataset, can he/she do it alone ?
25 - Are you aware of the datamesh principle?
26 - Do you think the datamesh principle would be implementable within you organization?
28 - Are all of your relevant GIS tools capable of importing and exporting OGC vector formats, such as GeoJSON or CityGML?
29 - Can your current geodata platform be fed and process BIM data?
30 - Which type of BIM data can your geodata platform work with?
31 - Could you briefly explain why you are not using BIM data yet?
32 - Can your current geodata platform be fed and process the following data?
33 - Can your current geodata platform use camera data?
34 - Can your current geodata platform be fed and process and display multi-dimentional data?
36 - Imagine that your organization needs to create a new dataset to describe a new feature. Which strategy do you consider while defining its data model?
37 - When developing your own data model, would you consider providing an interface to translate your data model into a standard one, even if it results in a loss of information?
38 - Could you please provide an explanation of your archiving policies for the following datasets, if any exist?
39 - Do you work with crowd-sourced type of data (e.g. Open Street Map)?

40 - Could you please provide insights into how your organization ensures crowd-souced data quality?
41 - Imagine that your organization's data will be used in an Urban 3D digital model. Can you estimate the percentage of your datasets that have a 3rd dimension (elevation).
42 - Does your organization manage accurate data that is published at a lower level of detail?
43 - Could you explain in which case you would publish a dataset with lower levels of detail?
44 - Can your GIS infrastructure effectively utilize, display, and establish links with real-time data?
45 - Does the sensor network for real-time data transfer belong to your organization or does it rely on private firms?
46 - Can your GIS infrastructure effectively handle web ontology data, such as RDF and linked data?
47 - Could you please provide further details regarding the nature of the data and the infrastructure that has been established to handle web ontology data (what technologies,software, quering languages)?
49 - To overcome computational limitations (e.g. extended processing time), is providing more powerful work machines a current/future solution?
50 - To overcome computational limitations (e.g. extended processing time), is accessing a virtual machine a current/future solution?
51 - To overcome computational limitations (e.g. extended processing time), is utilizing a cluster infrastructure a current/future solution?
52 - If your organization has to process a very intense data stream on a regular basis, what solutions can you imagine without having access to a virtual computational capacity or cluster?
53 - Does your organization use one of these processing tools :
54 - Are you experiencing any computational limitations or challenges with handling realtime and frequent datasets?
55 - What solution or approach is being considered to address the challenges in handling realtime and frequent datasets?
56 - In your opinion, what would be the ideal solution or approach to address the challenges in handling realtime and frequent datasets?
57 - Do you use machine learning (GeoAI) approach for analysis, planning and support decision making?
58 - Why does your organization not use machine learning yet?
59 - Could you describe in which context your organization uses machine learning (GeoAI)?
61 - Does your orgnisation run simulations (AI or standard) with these topics :
62 - Are there any automatic processes in your organization that can generate an output that directly affects the real world? In other words, can virtual work have a tangible impact on reality?
63 - How do you feel about this "Urban Digital Twin" concept?
64 - What would you need/wish to have in order to progress towards future uses of digital urban technologies?