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Abstract. Smart cities utilize the Big Data and IoT to provide better life for citizens. Since, they are the most complicated human artifact, the adoption of such technologies become a complex task, requiring continuous data collection, aggregation and analysis. In order to transform city problems into concrete actions a systematic approach aimed at digital transition needs to be followed. There are huge efforts to build city information models for encoding city objects, their relations and supporting the decision-making. This requires a common knowledge base, supported by rich vocabularies and ontologies that are capable to handle the information diversity and overload.
In this paper a methodological framework and an upper-level ontology for building digital city models are presented. The process of digital city modelling follows the concept of digital twin by providing a data-driven decision making. The proposed upper-level ontology aims to overcome city modeling problems due to data silos and lack of semantic interoperability.

Keywords: Data-driven decision making · Digital twin · methodological framework · Smart city · Upper-level city ontology

1 Introduction

Smart city concept attracts the attention and interest of many cities, authorities, industrial and research organizations at national, European and international level. Big Data is undoubtfully considered as one of the main enablers of the smart cities. By adopting Big Data and IoT technologies, the city stakeholders can push a data-driven processes using a shred data instead only their own data. Unfortunately, the data is spread across different organizations and systems in isolation without common semantics and technology base. The interoperability of data is missing, and it is a target goal of use case scenarios that depend on linking and analysis of heterogeneous data. Therefore, the building of share urban data platform for a deeper insight requires establishment of common data semantics agreed with all city stakeholders.

Nowadays, the smart city's performance is evaluated by different key performance indicators (KPIs) and platforms as well as the effects of smart city initiatives is measured by several assessment procedures. Unfortunately, the current approaches and tools for smart city assessment do not perform continuous monitoring of city processes to collect city data and guide decisions on it. In addition, the smart city interventions are often focused on a single direction such as urban planning, air pollution, mobility, etc. In order to support city monitoring and analysis, to identify problem issues before they arise, to suspend idleness, to find new opportunities and to decide through experimentation, a physical city needs to be paired to a virtual one trough digital twinning.

The concept of digital twin is not new, but now it has different view and is listed by Gartner as one of the top 10 strategic technology trends, since it provides robustness models using the Artificial Intelligence and Big Data potential to find new opportunities and to interact with virtual model to simulate "what-if" scenarios. The City Information Model (CIM) is a core of a digital twin, providing a foundation for semantically integration of data from heterogeneous sources.

The primary contributions of the paper are as follows:

- A methodological framework for building intelligent city models that adopts the digital twin paradigm;
- An upper-level ontology for city information modeling that aligns the ontologies applied in different sectors and facilitate building of city digital twins.

The proposed methodological framework aims to support city authorities to get valuable insight from city processes and to evaluate outcomes from application of novelty solutions. The upper-level ontology provides a description of concepts in a city model in a formal and explicit way and helps to overcome problems such as data silos and lack of semantic interoperability. The framework and ontology are a starting point for development of open data platform for performance assessment of smart cities in transparent and flexible way. The architecture of the platform together with a classification schema of KPIs are presented in our previous work [1].

The remainder of this paper is structured as follows. Section 2 outlines the proposed methodological framework. Section 3 presents an upper-level city ontology for digital twin modelling. Section 4 provides a brief review of the currently available ontologies and standards for information description of cities. Finally, Section 5 concludes the contribution of this paper and suggests considerations for future research.

2 Methodological Framework

The proposed methodological framework adopts the digital twin concept. It proposes building of a virtual city model that supports testing of new solutions prior their deployment to the physical city and to evaluate the results to discover new directions to accelerate the performance. The physical and virtual city are twinned by integration of edge computing to perform data processing close to its source, communication interfaces for data transmission and security mechanisms to ensure confidentially and integrity of data. The interaction with the real world is performed through sensors, which capture data from physical processes and transmit it to the virtual world. The sensor data is enriched with data from different system, operating in the city, like municipality data, base urban plan, social media data, data from utility companies, businesses and citizens. Using the power of machine learning algorithms and other Artificial Intelligence methods and technologies, new evidence about the city is likely to be obtained, which is able to drive concrete decisions. The decisions force processes and actions in the physical world.

The methodological framework prescribes six stages for implementation of digital twin, which can be summarized as follows:

- Create – CIM is created by gathering data from databases in organizations, sensors, cameras, social media, etc. The data form sensor and physical devices falls into two classes: (1) data related to environment in which the city operates and (2) data coming from city operations. The operational and environmental data may be enriched with additional data collected from ERP systems, geographic information systems, and other systems that serve the needs of city authorities, enterprises, utility companies, etc.
- Interact – At this stage, a bidirectional connectivity between the physical city and its digital footprint is established. The collected information is transmitted to the analytical platform by the communication infrastructure. Depending on the type of the communication network (LPWAN, Wi-Fi etc.) and the location and specific characteristics of the sensors, the interfaces for data transmission can vary.
- Aggregate – At this stage, the collected information is structured in a data store and pre-processed using techniques like cleaning, filtering, linking, anonymization and semantic annotation.
- Analyze – The analyze stage relies on variety models of virtual city, which are created on top of CIM. This stage aims to produce insights, driving the decision-making process through application of artificial intelligent methods.
- Insight – The insights from analytics are visualized in multidimensional views during the insight stage. The full potential of 3D and 4D models is exploited to provide better understanding of city processes and patterns.
- Decision – The insights are applied to the physical city to gain an effect from the twining model during the decision stage. The decisions push new processes and actions to accelerate the performance of physical city.

3 Upper-Level City Ontology

Computer science defines the ontology as a formal explicit description of concepts in a domain, properties of concepts that describe attributes and features and restrictions on properties. This section proposes an upper-level ontology for digital twin modelling of smart cities. The concepts of the ontology are presented in Table 1.

Table 1. Concepts of ontology.

#	Concept	Description
1	ENTITY	A particular thing.
2	RECORD	A container of information held by an ACTOR who record data coming from PROCESS that relate to an ENTITY in a role.
3	PROCESS	An ENTITY consisting of EVENTs related to a particular FUNCTION execution.
4	GROUP	A collection of ENITIEs with similar attributed that is defined by an ACTOR.
5	ACTION	An act influenced by a GOAL, taken by an ACTOR.
6	PROCEDURE	A preliminary defined method or series of steps, defined to achieve a GOAL.

7	GOAL	An objective set by an ACTOR.
8	SCHEDULE	A sequence of steps.
9	ACTOR	An ENTITY that could be a PERSON, ORGANISATION or SYSTEM, taking a role in an EVENT or performing a FUNCTION.
10	OBJECT	A physical ENTITY.
11	EVENT	A case that has happened or might happen.
12	LOCATION	A geographic position.
13	INDICATOR	A thing that indicates the STATE of ENTITY.
14	HYPOTHESIS	An assumption for a particular STATE
15	SERVICE	A collection of FUNCTIONs.
16	FUNCTION	An operation performed by an ACTOR using an ASSET and typically targeted at a GROUP.
17	ASSET	An ENTITY used by an ACTOR to achieve a GOAL.
18	REGULATION	A rule or policy governing a PROCEDURE or constraining a SERVICE.
19	PERSON	A human being.
20	ORGANISATION	A group of PERSONs with common objectives.
21	SYSTEM	A set of connected ENTITIEs that operate together to achieve a GOAL.
22	STATE	A condition of an ENTITY at a TIME
23	TIME	A measure to describe observed changes of a STATE.
24	ROLE	A specific behavior of an ACTOR in a PROCESS.

The city consists of ENTITIEs that are described with data coming from different sources. ENTITY has a common unique identifier, which might be referenced by different organizations delivering data. ENTITY could be an OBJECT (e.g. car) or an ACTOR (e.g. driver). The ACTOR could be a PERSON, an ORGANSATION or a SYSTEM. ENTITY might be associated with a LOCATION, describing where an ENTITY is. LOCATION could be geographic position (defined with latitude and longitude) or area (defined with boundaries). ENTITIEs have STATEs over TIME. TIME might be presented with a time value or time interval. The STATE describes characteristics of the ENTITY (e.g. carbon emissions in the air). The smart city decisions are based on the STATES of ENTITIEs. ACTOR can perform ACTIONs to change a STATE of an ENTITY.

ENTITIES could form GROUPS. GROUP contains ENTITIEs from a single class with similar attributes (e.g. family is a GROUP, which consists of PERSONS, namely family members). GROUP is defined by an ACTOR in order to manage a set of ENTITIEs. ACTORs have GOALs to change the STATE of the ENTITIES (e.g. reducing traffic congestions, providing e-services, optimizing energy using, reducing waste). A GOAL can be achieved through series of ACTIONS performed by an ACTOR. GOAL can be quantified using INDICATORs, which asses the STATE of impacted ENTITY after series of ACTIONS (e.g. greenhouse gas emissions per capita). GOAL is identified based on a HYPOTHESES, which represent the future STATE of ENTITIES participated in a PROCESS.

The city performs different FUNCTIONs (e.g. water and energy supply, waste collection, traffic control), which follows different PRODUREs. FUNCTIONs are provided by ACTORS (PERSON, ORGANISATION or SYSTEM). FUNCTION could be used by a GROUP of ACTORS. The FUNCTION is a sub-concept of ENTITY. FUNCTIONs can be grouped into SERVICEs. SERVICE is a sub-concept of GROUP. Each SERVICE provides several FUNCTIONs to a GROUP of ACTORs (e.g. water management SERVICE consists of FUNCTIONs for water supply, wastewater recycling, billing, sewerage maintenance).

SCHEDULE consists of steps and decisions taken to achieve a specific GOAL measured by an INDICATOR defined for it. ASSET is an ENTITY that can be used by ACTORS to take ACTIONS in order to achieve a specific GOAL. ASSET could be applied to a SCHEDULE or FUNCION. ACTOR participates in a PROCESS (e.g. a driver participates in transportation process). PROCESS covers specific city dimension such as transportation, healthcare, education. All ENTITIEs can take a role in a PROCESS (e.g. a PERSON could be a driver or passenger in the transportation process). PROCESS consists of EVENTs that are related to a particular execution of a FUNCTION. For some PROCESSEs, a SCHEDULE could be elaborated to estimate the required ASSETs. ACTOR creates RECORDs when an EVENT happens.

4 Related work

The main goal of city ontologies is to provide data interoperability through data linking and semantic annotation. Several ontologies with a general purpose are available such as the Suggested Upper Merged Ontology, owned by IEEE [2], the Descriptive Ontology for Linguistic and Cognitive Engineering [3], the community initiative Schema.org and the Knowledge Model for City and Mobility ontology [4]. In addition to them, there are ontologies related to specific sectors. For example, the General Transit Feed Specification of Google defines a common format for description of information about the schedule and transit system of public transport [5]. The e-Government Core Vocabularies provides a semantic interoperability among European public administrations though reusable and extensible data models [6]. The Event Recording and Incident Sharing (VERIS) is a vocabulary for security event recording and incident sharing. The Public Procurement Ontology defines concepts appropriate for semantic description of public procurement processes and contracts [8].

The Energy Model, proposed within the SEMANCO project is a formal ontology, specified with the Web Ontology Language 2 [9]. It consists of concepts that are taken from different sources like standards, use cases, urban planning and energy management. The Smart Appliances Reference ontology defines a common data model in the field of smart appliances [10]. It is based on the concept of device as an object that performs tasks through one or more functions in the households and public buildings. CityGML is a widely adopted international standard for 3D city modeling, data storage and transfer [11]. It provides an extra dimension to traditional 2D models based on spatial and registry data through support of semantics in description of city objects.

5 Conclusions

The digital twin modeling allows city stakeholders to better understand, learn and reason city processes using real-time data. This paper proposes a methodological framework and an upper-level city ontology for digital twin modelling. The methodological framework supports decision making along digital transition of cities by providing a virtual environment for what-if scenario analysis. Different actions and processes could be evaluated to predict their effect on the city performance before their application in the real world. The upper-level ontology is a first step towards implementation of city digital twin, overcoming the problems related to semantic interoperability and data consistency, complexity, volume and quality. In such context, the ontologies and standards for information description of cities appropriate for 3D modeling are discussed and a new upper-level city ontology is proposed.

The future work includes application of the proposed methodological framework and upper-level city ontology to a real case using data for Sofia city. The collected data will be organized in information objects following the ontology and a mapping with the objects in the core module of CityGML standard will be elaborated. The goal is to identify the missing objects in the core module and to define new application domain extensions needed to be added to the information model of Sofia city. The application of ontology-based approach will simplify information retrieval and provide a solid base for further development of the digital twin.

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