On building support of digital twin concept for smart spaces

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***Abstract*—Inherited from industry 4.0 domain, digital twin concept will represent an important step forward in what we have understood as smart city concept. In this paper we present our ongoing work on extending a monitoring smart city middleware to a digital twin platform for smart cities. The reader will learn some key issues of this new concept in the field of smart cities including some open questions that need to be investigated about the user interaction with digital twin concept.**

***Index Terms*—smart spaces, ambient intelligence, digital twin, 3D representation.**

I. Introduction

The digital twin [1] concept is taking importance in several domains (Industry, Cyber Physical System, Simulation, etc.) due its important advantages for fostering IT service development, simulation, testing, reduce maintenance issues, user's privacy, etc. As a general concept, a digital twin is a digital representation of a physical asset. So, with different level of accuracy, a digital twin can:

- show users the state of the physical asset at real time.
- interact with the physical asset.
- model the behaviour of the physical asset/space.
- simulate the response of the physical asset to different events.

In the smart space domain, a digital twin is useful at different vertical domains (maintenance of buildings, forecasting anomalous situations, to support emergency situations, etc.) but we have to deal with several challenges to pass from labs to real scenarios.

The project Citsim (ITEA3 European project)[1], recently finished, put the keystones for building smart city digital twins (3D visualization, IoT middleware, citizens services, etc.). In this paper we explain our ongoing efforts to extend Citisim platform to modelize/building a smart city's digital twin.

Two are the main contributions of this paper, first we propose an overall data model to provide support to digital twin building of a smart space from an engineering approach, second we provide a 3D toolchain for automatic smart city 3d model generation from LiDAR/openstreet map data set. We also describe our first experiences on building a digital twin of a smart space, first with a mock-up and currently with a building.

II. State of Art

Currently, Geographic Information Systems [2] (GIS) and Building Information Modelling [3](BIM) are broadly used in smart city planning, management, etc. Both type of systems are working mainly with statistical information.

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[1] http://www.citisim.org/

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In the other hand, 3D visualization is a natural way to visualize information for non-specialize people, it helps to improve situational awareness so the next step have been join GIS/BIM systems providing 3D visualization.

For us, a digital twin of a smart city is a one or more simulating models that are monitoring the real city using sensors/actuators at real-time. This system should have the capability of forecasting anomalous situations, evaluating the impact in citizens of tactical decisions (e.g. traffic, pollution, security, etc.) and to provide a sandbox for smart service testing and developing (e.g to test a new traffic light algorithm).

There are several 3D models of cities due it is a natural way to represent information. Most of the models charges handmade buildings without having into account the level of the terrains and/or how the building fits the ground.

In [4] we have a 3D representation of solar potential of buildings in a city on Finland, as the authors states, an API for feed the system with real-time data from sensors will be developed so at this moment, it could be considered as a GIS system about solar energy potential with a 3D representation.

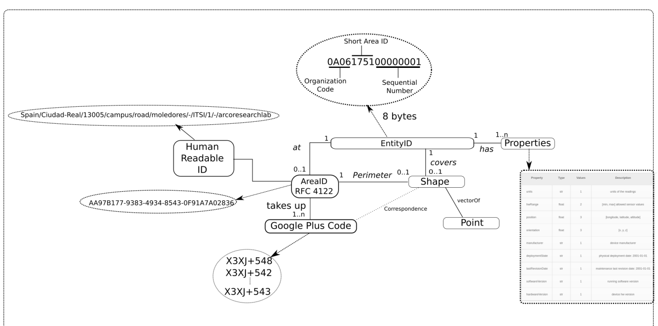

Fig. 1. Reference system for digital twin concept

III. Smart space digital twin architecture proposal

Citisim uses 3D for data monitoring using web technology for showing information to users/citizen in a fashion way. The digital twin concept needs for a step beyond and to use more advanced tools. In our case we propose to extend a game engine, in our current implementation the 3D Unity game engine, to directly interact with:

- IoT domain, i.e, real devices deployed in the real world
- Modelling domain which model the behaviour of the smart space according to a defined model (energy in our current prototype)

The game engine exports a digital-twin interface where a user can create predefined set of virtual device and to attach them to a real device physically deployed in the city. Both virtual object/real device are linked so any type of interaction in the real world is represented in the virtual world using the game engine, and vice versa. Additionally, there is a model of the smart space which also creates a software object representing the link among the virtual object and the real object. This model will be used for simulation/forecasting purposes.

1) Data model: The reference system used in our digital twin platform is devoted to represent correctly IoT devices emplacement and IoT device's area of influence (e.g the area covered by a CCTV camera, motion detected perimeter, etc.) so, as starting point, we attach to each entity a unique 8 bytes length identification number (entityID).

An entity is an IoT device or smart service. In this entityID, the first two bytes is to identify the organization which provides/owner the entity, the next two bytes are a short area ID (e.g. building or neighbourhood) and the last 4 bytes is a sequential number.

This EntityID will help us to relate IoT domain and geo-relate all the information in the virtual and real world. It is specially short to deal with low-power wide-area wireless technologies for connecting IoT devices LPWAN (e.g. Lorawan technology [5]). The maximum transmission unit of this type of wireless technologies are few bytes, so we have to be careful in the amount of information that we sent. For example, in LoraWan technology, one of the most used technologies in smart cities, the MTU of a package is around 200 bytes in the best scenario.

Each entity is located at one areaID (physically, this area is inside the short area identified in the entityID). This areaID follows the RFC 4122 [6] format and it could be related with a string with sense for humans. In the figure 1 we can see a scheme of this data model.

The properties related with an IoT device deals with information regarding manufacturer, type of device, units, digital asset (e.g. icon), orientation, deployment date, revision date, indoor reference point, etc.

IV. 3D smart city representation

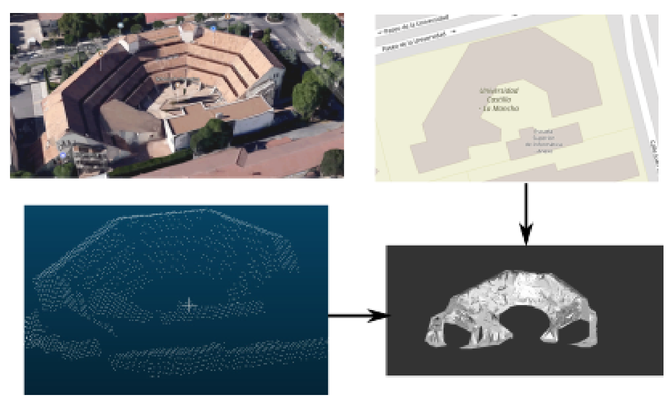

Fig. 2. School of computer science (top-left), Openstreetmap project perimeter of the building (top-right), LiDAR cloud point (down-left) and the 3D model (down-right)

An accurate smart space 3D representation is a useful tool for a lot of different services (robot navigation, UAV navigation, information representation, easy interaction, situational awareness, virtual reality, etc.)

Algorithm 1 Automatic generation of 3D shapes of buildings

```
Input: OSMlayoutfile, LIDARfile
Output: 3Dvector
LOOP Process
for each BuildingPerimeter in OSMLayoutfile do
    for each lidarpoint in LIDARfile do
        if lidarpoint in BuildingPerimeter then
            VectorPoint[BuildingPerimeter]=+lidarpoint
        end if
    end for
end for
for each Building in VectorPoint do
    3Dvector=ConcaveHull(VectorPoint[Building])
end for
return 3Dvector
```

Inherited from Citisim domain, our first approach is to analyse the feasibility of creates 3D representation in an easy semi-automatize way of a whole smart city. For prototypes, hand made 3D buildings/areas is a reasonable approach but for large-scale pilots and/or real world we should semi-automize this task. Currently, we focus on mixing LiDAR data with Openstreetmap project data. As the reader can see in figure 2 and Algorithm 1, we extract building perimeter from waypoints tagged as "building" label from Openstreetmap project after that we get all LiDAR points which are inside the perimeter. After this point we have, for each building in the area to be modeled in 3D, a cloud point of the building. After this phase we are studying now which algorithm can give us a more accurate model to take as starting point to model the building. The figure 2 has been generated using Concave Hull algorithm [7].

The building of the school of computer science (figure 2) is a complex one in its shape but the model captures the key points in form and the distances. Despite the result of this processing is far away to be perfect and hand made work need to be done to integrate in our digital twin platform, the results save hours of work. The scale of the figure, form, distances, key areas of the building, etc are correctly captured so it is a good starting point to model the building. We will continue working on this tool to improve the model generated correspondence with the ground truth.

V. Human interaction on digital twin

Of course, a 3D model of the city visualizing real-time information open the door to virtual reality glasses based applications.

A digital twin can be visualized by the user (e.g. a public servant) as an augmented virtuality world, i.e. the user visualizes a virtual world augmented with real information. The human interaction on digital twin is a direct application of virtual reality principles, but we have to carefully think how the user:

- realizes if it is interacting with the real city or with the simulated/modelled counterpart.
- would like to change from/to testing capabilities with the digital twin to/from real smart city interaction.
- Launches forecast simulation models of the digital twin. This type of interaction involves the use of different approaches to visualize the real information and the simulated one.
- avoid mistakes in the model of interaction.

To deal with these issues, we have taken the following design considerations according to the research in colour feelings:

- When the user is interacting with the real city the background of all visualized scenario is blue light to increase subjective alertness and performance on attention-based tasks [8].
- Actions which has a real result in the city has a red context before the user confirm the action in order to increase caution [8].
- When the user is interacting with a simulation, the background of all visualized scenario is grey light.

The basic interaction following this design guidelines is already implemented, but we have doubts about the fatigue in the user in long-term.

VI. Results

Our first approach is to build a mock-up to analyse the data-flow that we need for building a smart city's digital twin. In the figure 3 we can see the result of this first work.

The mock-up represents several streets joining in two roundabouts and four intersections in the middle of the mock-up. The mock-up has been equipped with nine led based street lamps and six traffic sensors. All the electronic equipment are arduino based and it is connected under the board.

In the screen we can see the 3D visualization of the digital twin created for this mock-up. This scenario is built using the 3D game engine Blender. In the representation we can see the digital twin counterpart of each physical asset. So we have nine digital representations of street lamps and six traffic sensors.

Regarding implementation details, a software object is instantiated in the Arduino board using our picoobject technology [9], a picoobject is a low-footprint software object which implements a simple interface and it is devoted to embed distributed object technology in IoT domain. So we have a picoobject per each physical street lamp and physical sensor. Each picoobject share its state through an event broker, in the current implementation we are using Zeroc Ice middleware [10]. So, a picoobject is listening/publishing in a logical event channel where it publishes each modification of its state. In that event channel there is another software object listening/publishing, the digital twin counterpart. This software object currently is running inside of blender game engine and, by configuration, has a skin associated (e.g. street lamp icon) representing the physical asset.

The reader should note in the figure 3 that not only the set up of the street lamps has been modelled but also the influence area so the lights that are on in the real world also modify the virtual world with the light.

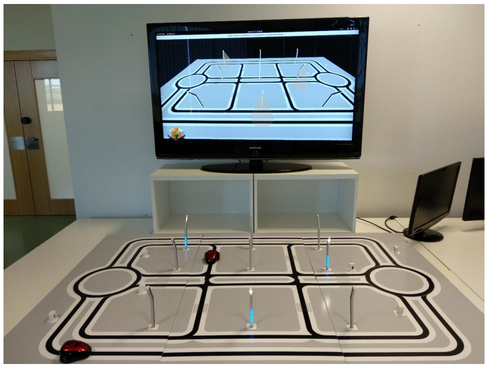

Fig. 3. A mockup concept of smart space's digital twin

Fig. 4. Our smart space's digital twin on action

The problem with Blender game engine is the scalability, on testing scalability performance, with around 200 hundred software objects, the game engine starts to perform badly in 3D interaction. For testing purposes is a reasonable scalability but going further of lab 200 hundred objects shouldn't be enough.

In the current implementation we are implementing the same concept of the mock-up but with a building(figure 4).

As we can see in the figure 4, we have developed a detailed 3D model of a real building (hand made 3D model in this case). This 3D model is not only about structural buildings but also the infrastructures (water and energy) are modelled. This 3D model is loaded in our platform which instantiate each virtual object (counterpart of physical asset controlled by a picoobject) from a configuration file.

To deal with scalability issues we have migrated to Unity Game Engine. In the current implementation we have integrated energy sensors monitoring energy consumption and the digital twin is checking continuously that the consumption at each moment fits with energy consumption model. Under a variance of energy consumption the digital twin generates an alarm. This system is being implanted in the institute of computer science at Ciudad Real (Spain). The energy consumption model is a simple interpolation function of historic data from the last 3 years.

The hololens application (figure 5) interacts with the digital twin using the Unity game engine and following the previously mentioned design guidelines. The application needs to be tested in long term to evaluate user fatigue, mistakes, etc.

Fig. 5. Hololens visualization of energy info (left) and evacuation simulation(Right). Aplication developed by Answare-tech partner.

VII. Conclusions

In this paper we have described two ongoing works extending a smart city monitoring platform (Citisim project) towards a digital twin platform. We have identified the need to define a reference system to model areas, spaces and to set up virtual/physical assets and its area of influence.

We have built a mock-up to test information flow of our digital twin platform and a building to start monitoring/simulating real data. The next step is to implement a digital twin of a real smart city. For this purpose we need and accurate 3D model of the buildings and layout. We are exploring to generate in automatic way the 3D building shapes taking as starting point openstreetmap project files and LiDAR cloud points. The next step is to work to fit 3d building shapes generated in a representation of the city layout to capture the whole 3D model of the city (buildings, streets, squares, etc). By going to a real smart city we will have to deal with scalability/privacy/security issues that our previous work (i.e. the mock up and the single building) have omitted. User interaction with digital twin concept in long-term interactions also will focus our future research work.

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