# Crowded event management in smart cities using a digital twin approach

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***Abstract*—One challenge of any smart city is the management of crowded events (concerts, protests, marathons, etc.). For civil servants in charge of management, in-advance attendance prevision, real-time situational awareness and its evolution forecasting are crucial to resource assignment. These massive events put under stress public resources, organization and safety of smart cities. In this paper, we describe an ongoing effort to model urban layout, sensors deployed, and citizen information (from social networks and smartphone application) to deal with these situations. We use the concept of a digital twin applied to a city by modelling different flows of information which are integrated with a 3D virtual representation with forecasting possibilities. The main contribution of this paper is the architecture proposed and GUI using the augmented virtuality concept. The main purpose of our proposal is to facilitate the knowledge of the situation and the management of this type of event.**

***Index Terms*—smart city, digital twin, augmented virtuality, crowded event management.**

## I. Introduction

Traditionally, massive event management has been mainly focused on disaster response, normally comprising a static set of rules that establish how to proceed in case of abnormal events [1]. The major objective of any plan of emergency is to prevent the loss of life. Smart emergencies intensively use ICT technologies and IoT to train the staff for those evacuations in the most efficient way and under the occurrence of a wide spectrum of events such as natural disasters (e.g. earthquakes, tsunamis, climatic change effects), incidents in crowded events (e.g. marathon, concerts), and evacuation under fires, explosions, or flooding. Just to cite two tragic examples: the Boston Marathon terrorist attack in 2013, which left 3 people dead and 264 damaged and the Love Parade electronic music festival in Germany, which caused in 2010 the death of 21 people from suffocation and at least 510 more injured. Focusing on crowded events, our initial hypothesis is that an exact 3D representation of the urban area where the event is located, showing real-time information coming from different sources, will support efficient management of these types of events. Additionally, simulation can help to forecast the evolution of the event and also help to the organizational issues. 3D representation and simulation capabilities are the base of the digital twin concept. A digital twin [2] is a digital asset, which looks and behaves as the physical counterpart to which it is connected. Both assets are bidirectionally connected. Any change in the state of the physical asset is shown in the virtual counterpart and any action in the virtual asset is translated to the physical asset. As the virtual asset shows similar behaviour to the physical one, it can be used to simulate actions and consequences, as well as state evolution forecasting of the physical counterpart.

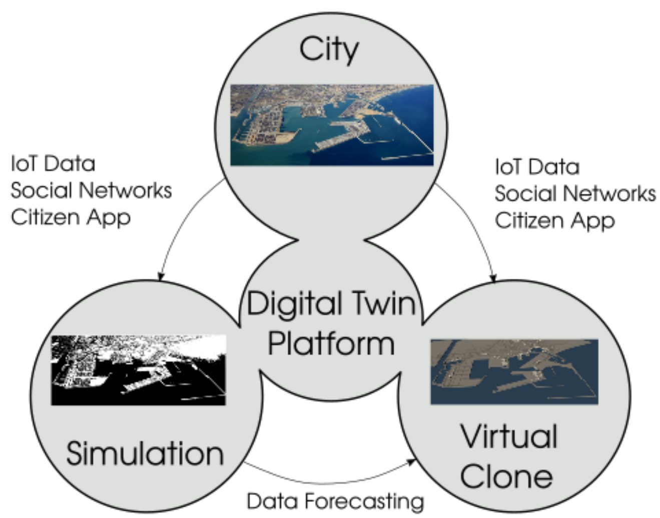


Fig. 1. Digital Twin of a smart city

The main advantages of a digital twin are easy situational awareness, analysis of anomaly situations, testing the consequences of actions and forecasting future states of the physical asset by simulation tools. The main domain where the digital twin concept is being applied is industry 4.0 for applications such as predictive maintenance, incident response, operational optimization, etc.

One of the main challenges of the digital twin applied to the smart city domain is information representation and situational awareness (Figure 1). We need to apply the last techniques related to information representation.

Our approach to implementing the digital twin approach is augmented virtuality. Augmented virtuality [3] is a concept for information representation in which, you add information, coming from real-world (sensors, cameras, drones, social media, citizen's reports, etc.), to an exact 3D virtual representation of that real world. This concept supports situational awareness since you can see in 3D, from any point of view, what is happening in the real world. When you are controlling in real-time a massive event, the feasibility of navigation for the virtual world analysing what is happening could support the tactical decision and basic forecasting of the evolution of the situation.

The advantages of augmented virtuality are:

- Easy positioning in the virtual world using "fly" mode.
- All information geolocated on its origin but placed in the virtual world
- 3D makes easy situational awareness.
- multirole privacy management by information layering privileges. It is easy to define who can access to what type of information since all access are using a 3D client.

The main contributions of this paper are two. First, by building an application based on the digital twin approach and using an augmented virtuality interface, we identify the requirements for these types of platforms that will drive the future of smart city platforms. Second, regarding massive event management, we introduce a new perspective and a tool, which can improve the assignation of resources, minimize reaction time under special circumstances, and improve user experience.

## II. State of Art

### A. Smart city platform

Platforms devoted to support the smart city concept come originally from IoT platforms due, mainly, smart cities are one application of IoT. Fiware [4], Snap4City [5], are examples of platforms originally designed for IoT with direct application to the smart city domain.

As the evolution of this type of platform, researchers and companies have been adding services related to citizens in the specific subdomains of a smart city (traffic management, parking, security, pollution, waste management, etc.).

The great number of platforms proposed for smart cities have become necessary to work on standards to homogenize protocols, layers, and interfaces. Standards like ISO 37100 defining common vocabulary, ISO37120 for key performance indicators, ISO/IEC 30182 for data interoperability and IEC 63205 ED1 defining a smart city reference architecture are examples of standards developed to boost interoperability of smart city solutions.

There are several challenges open regarding smart city platforms. First, the massive amount of information generated makes difficult easy visualization and situational awareness about what is happening in (almost) real-time. The other challenge is the prediction of the evolution of specific situations due to the complex systems that a smart city is composed. The concept of digital twin, coming from industry 4.0, could solve information visualization and situational forecasting.

### B. Digital Twin: 3D and simulation

The concept of digital twin is starting to be introduced in smart city platforms. The ongoing H2020 research project DUET[1] [6](Digital Urban European Twins for smarter decision-making) is working to provide virtual city replicas which makes it easy to understand the complex interrelation between traffic, air quality, noise and other urban factors. Another example, briefly described in the United for Smart Sustainable Cities document [7], is the city of Shanghai. The council has created a complete virtual clone using Unreal Engine (a video game development platform) with the purpose of supporting planners and operators in monitoring traffic flows. No further details are provided about this platform.

## III. The platform

In Figure 2, we summarize our proposal for a digital twin platform for a smart city. Over a binary Remote Procedure Call framework, we define a set of APIs/communication procedures to interconnect the different modules defined.

Directly connected to the physical city, we collect:

- IoT Data: from sensors and security devices, we distribute, using event broker and logical event channels, all IoT geolocated data.
- City Social is a social network analysis tool which monitors social network looking for activity related to smart city activities.
- Citizen App: A smartphone app specifically designed to provide citizens and civil servants with a tool to collaborate in the management of smart city activities.

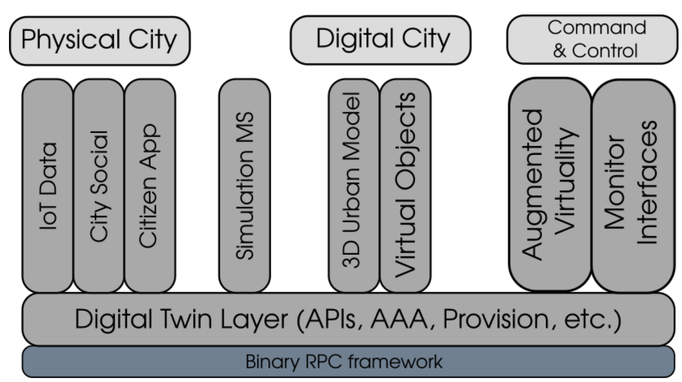


Fig. 2. Overall architecture proposed

[1] https://www.digitalurbantwins.com/

The digital city has two key modules. First, the 3D Urban model, which it is a repository with the urban layout (building's perimeter, pedestrian walkways, bicycle lanes, traffic paths, etc.) of the smart city. The data are downloaded mainly from OpenStreetMap project[2]. An API exposes the repository to enable simulations and GUI to access to different layers of information. The other module is a service running virtual objects representing physical asset status. This module defines a software object for each device, logical event and person representing a simplified, virtual clone of each one. Each software object has metadata, current status, geographical information and specific information relevant for simulations.

Simulation microservices (Simulation MS in figure 2) are modules devoted to simulating, under specific situations, the consequences of some actions and/or forecast situations. With the capability of generating data as real data would be. The simulation interface depends on the application. For example, in a marathon, if you want to forecast the position of the runners, it can be as simple as simulating GPS position for the best/worst runner according to the best/worst time of the last year. In case of complex people flow (e.g. concert evacuation), it is necessary to integrate a specific simulator. These simulations can be very simple or complex, as we will see later.

To monitor a smart city, the command and control layer is composed of a set of graphical user interfaces devoted to monitoring specific information (Monitor interfaces modules in figure 2). The other module is the interface of augmented virtuality, which it is, from our point of view, a novel approach to smart city management.

## IV. Use case: massive event management

As a use case for the first implementation of our digital twin platform, we choose massive event management. From an engineering point of view, it is one of the most demanding scenarios for a smart city management platform. In Figure 3, we use a simplified process of a massive event organization as the starting point.

The lessons learned from past incidents and their responses have become the emergency management guidelines [8]. This standard is an iterative process, including four phases: preparedness, response, recovery, and mitigation. In each phase, the use of ICT and smart systems to simulate, predict and acquire knowledge before the occurrence of the events is a very valuable tool.

We define a massive event as any event that:

- Occupies public space temporally
- Requires from public services
  - Security
  - Clean
  - Traffic/pedestrian management
  - Infrastructure (electricity, mobility delimitation, etc.)
- includes citizen participation.

[2] https://www.openstreetmap.org/

So, we identify sports events (e.g. marathons), concerts, street markets/fairs, parades and protests as key events to be supported by our tool.

Of course, each type of event has specific needs, but we can extract also some common characteristics and needs which are our high-level requirements [8]:

- forecasting people's attendance helps to mobilize appropriate resources.
- public servant localization (policemen and organizational supporter) at real-time helps to easily manage the event.
- Overall, information collecting and shows help with situational awareness.

## V. Platform Implementation

As base middleware for our proposal implementation, we use the open source software Internet Computing Engine[3] (Ice). Ice is a remote procedure call middleware, very efficient and specifically designed for networking tasks on massively multiplayer video game programming [9]. Ice has evolved to a full service set, suitable for large-scale distributed systems. Over Ice we implement our digital twin layer.

### A. IoT Data

As a basic IoT platform, we use Home Assistant[4] project. Home Assistant is an open-source automation platform with multiple equipment already integrated. Our contribution here is about geolocated information. We need to represent:

- The position of the device (e.j GPS coordinate)
- The rotation and orientation of the device (e.j Quaternions). this information is relevant in some devices.
- The area/volume covered by the device (e.j Volume delimited by the angle of view, distance, etc.).
- For each type of device, the data representation.

For example, a security camera is represented by an emplacement, rotation, orientation and a vision camp. The vision camp is represented by a cone volume with the angle of view of the focal lens of the camera, and the distance of the optic with the quality required. A mobile phone's camera picture, as we will see later, is represented by an emplacement, rotation, and orientation.

The position of a device in the real world is provided mainly by GPS coordinates in outdoor. In indoor, the position is a little more tricky since GPS is not available. In the virtual world, the position is usually characterized by X, Y, Z position in relation to a fixed origin position (0,0,0). As data model, we are using our previous work with indoorGML [10] standard extended to outdoor spaces [11].

### B. Social media

Social media represents the heartbeat of any smart city. Citizens share on social media what it is relevant to them at each instant, generating valuable information about what is happening, what is interesting and providing, by comparing

[3] https://doc.zeroc.com/
[4] https://www.home-assistant.io/

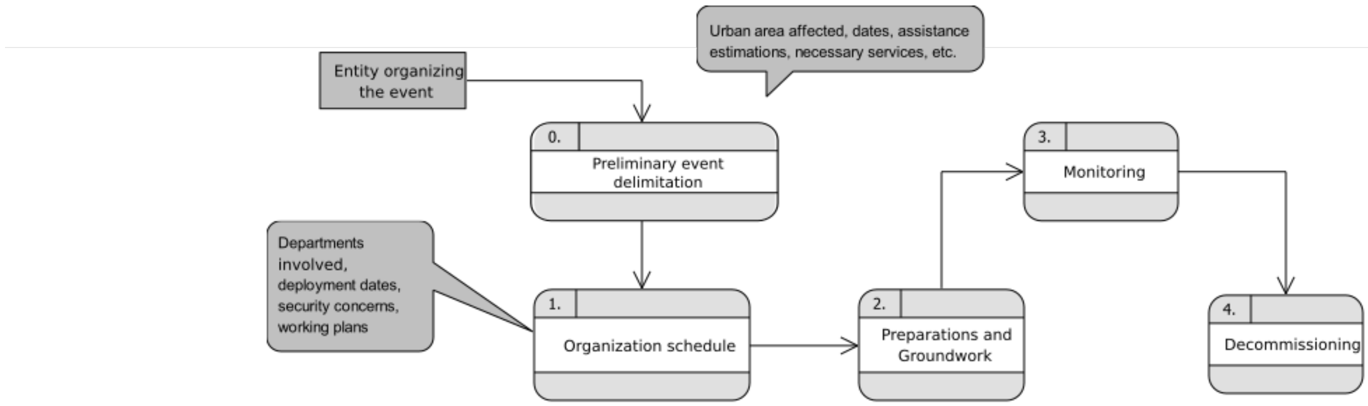


Fig. 3. Simplified organization process of massive events

with historic data, the success of any event in advance. Our approach to this source of information is filtering the information using the hashtags associated with the event. Our tool, Citisocial (Figure 4), monitors in advance the hashtags associated with the organization of the event in the publicity actions. During the event evolution, those social event publications related to the event are represented in the 3D map to provide real-time feedback.

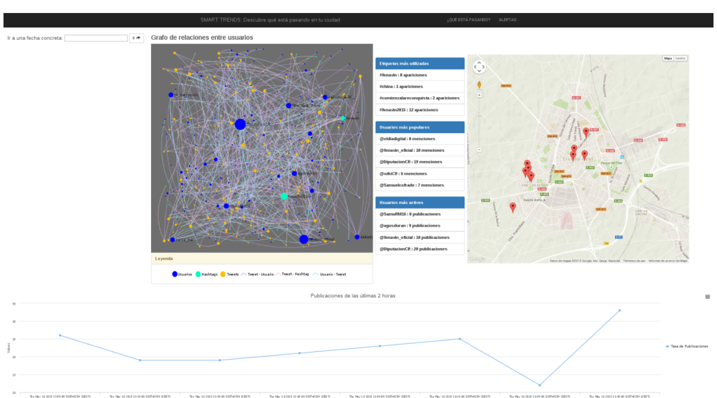

Fig. 4. Our tool, city social analysing wine trade event in Ciudad Real (Spain)

Citisocial web interface shows a graph where:

- Each dark blue vertex represents a user. The larger the node, the more relevant its tweets are (number of retweets, likes, etc.).
- Each light blue vertex represents a hashtag. The larger the node, the more is used in tweets.
- Each orange vertex represents a tweet. The larger the node, the more popular is the tweet.

With this model of visualizing, those vertexes with relevant info are getting bigger, so it is easy to filter the "noise" from the useful info. In the top right of the web interface, a 2D map shows the position of the tweets. At the bottom, we can see the evolution of the number of tweets stored containing the hashtags in the last few days. Historic data stored in periodic events will help us predict attendance. Also, by integrating this information in the 3D tool during event celebration, we can have an idea about the info that citizens are sharing by social networks to minimize reaction time in case any action is necessary.

### C. Citizen smartphone application

We have implemented an Android application with three roles: citizen, civil servants (Police, firefighters, etc.) and organizers, which can use to report incidents. We are focusing on picture-based reports, sending the position and orientation of the picture taken with the mobile phone.

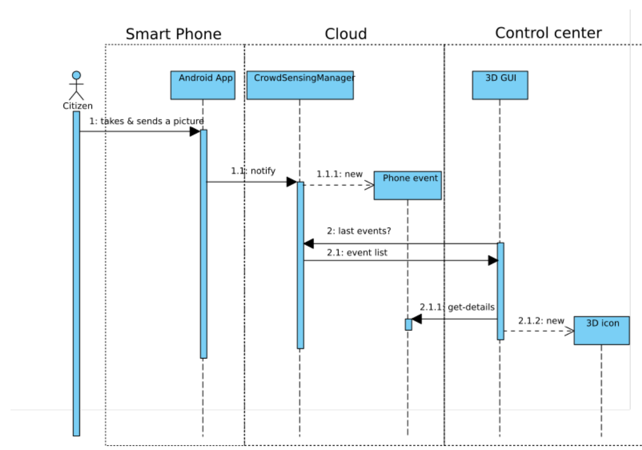


Fig. 5. Simplified sequence diagram of phone event data flow

Figure 5 shows a simplified version of the sequence diagram followed by a picture since is taken in the physical world until is shown in the same position and orientation in the virtual world. The actor who triggers the event can be a civil servant showing an organizational issue, police informing about a security weak point, a citizen reporting any type o incident, etc. In any case, the actor takes a picture and sends it to our platform using an app. Login and security details are omitted by simplification.

This application takes the picture, GPS position and accelerometer data/gyroscope and sends it to a component, the

*CrowdSensingManager*, running in the cloud. The *CrowdSensingManager* is one of the services of the Virtual Objects module in figure 2.

The *CrowdSensingManager* creates a "phone event" with all information related (userID, timestamp, etc.). The Unity 3D Client is the augmented virtuality interface in figure 2. In the diagram is tagged as 3D GUI. This GUI periodically asks the *CrowdSensingManager* for new events. The refresh period and time of life of events shown in the 3D GUI are configurable. If new events are found, the 3D GUI will create a 3D icon per each new event, and It will show them in the right position from GPS data and according to virtual world coordinates.

The picture taken by a mobile phone in the real world, represented in the virtual world, needs to be showed in the same position, with the same rotation and orientation, to boost situational awareness. In Figure 8, step 2, the reader can see a screenshot of the mobile phone application showing how a user sends a picture.

### D. 3D Urban model

This module offers urban information as a service. The urban information of a smart city is the base layer for different advanced services, so if we model the information to be provided through an interface, a lot of services can dynamically load that information.

As data model for IoT devices, as we mentioned before, we are working with indoorGML [10] standard. The smart city layout including buildings perimeter, pedestrian walkways, bicycle lanes, traffic paths and physical fences are downloaded from OpenStreetMap project and exposed through an API.

### E. Simulation and forecasting

The most powerful feature of the digital twin concept is simulation/forecasting possibilities, so you can plan/anticipate in the organization of events. A smart city is a complex system and simulating its interactions (people, traffic, pollution, etc.) is challenging in scalability, accuracy, etc.

We identify two relevant simulation needs in the case of temporal massive events. First, crowd simulation helps to plan checkpoints, evacuation routes, temporal fence's emplacement, etc. Second, real-time simulation supports resource emplacement (organization staff, security forces, etc.), operational decisions (traffic cuts, reallocating of staff emplacement, etc.) and, in general, minimize the time it takes to attend a potential incident during massive event duration.

In Table I we summarize relevant features identified for each type of event according to police needs. A relevant characteristic to help in the management of all of them is the expected attendance that, as we mention before, we are predicting using social network activity.

Crowd simulation in delimited areas has been challenging for research [12], and several tools have been developed for that purpose [13]. Integrating these types of tools is a problem of simplification of use to provide estimations of the capability of people flow, evacuation time, bottlenecks, etc. The use of a game engine for GUI implementation provides us with interesting capabilities for this type of simulation (e.g. Crowd Simulation API[5] for Unity 3D), however, real simulation tools, with validated accuracy, are more appropriate for this type of events.

TABLE I
FEATURES TO BE IDENTIFIED BY TYPE OF EVENTS USING SIMULATION

| **Massive event** | **Simulation** | | |
|---|---|---|---|
| | ***Tool*** | ***Key feature 1*** | ***Key feature 2*** |
| Marathon event | Agent | Head/Tail position | Assistance time |
| Concerts | People flow | Evacuation time | Bottlenecks |
| Street market | People flow | Capacity | Bottlenecks |
| Street fairs | People flow | Capacity | Bottlenecks |
| Parades | Agent | Head/Tail position | Assistance time |
| Protests | People flow | Possible trajectory | Attendance |

Other types of events, like marathons, parades, etc. where the citizen inscription process provides a good estimation of attendance, and the event is distributed along a well-known path have different needs. For example, according to police requirements, if they know an estimation of where the head/tail is of a marathon in real-time, they can move the resources according to that position. These types of requirements are easy to provide, for example, simulating position according to best/word times of the last years by mean an agent.

## VI. AUGMENTED VIRTUALITY INTERFACE

To support our vision of augmented virtuality as visualization proposal for smart city massive event management, we are implementing a prototype with Unity 3D[6] video game engine. As a scenario, part of the university campus in Ciudad Real (Spain) has been modelled in 3D (Figure 6). For scalability reasons, the buildings are modelled as simple grey boxes. Pedestrian paths, fences, roads, etc. are exactly modelled according to OpenStreetMap[7] layout using the urban model API.

The tool currently supports four types of information:

- It shows the last GPS position sent by police patrols (red icon in Figure 4) using the Citizen mobile phone application.
- It shows the position of the security camera (green icon in Figure 7). By clicking on a green icon, a browser with the camera control and video stream is shown.
- It shows a social network event (Twitter) if the tweet has geo-localization associated (blue icon in Figure 7). By clicking on the icon, the tweet is shown.
- It shows pictures captured by citizens, organization staff and security servants with its mobile phones (orange icon in Figure 7). By clicking on the orange icon, the picture is shown in the same position and with the same orientation that it was captured in the physical world. Figure 8 shows an event of this type with the picture

[5]https://memecs.org/crowdsapi/
[6]www.unity.com
[7]www.openstreetmap.com


Fig. 6. Proof of Concept scenario, University campus

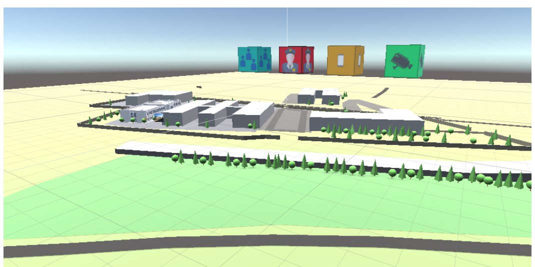

Fig. 7. Icons associated to the four types of information managed by the tool

showed in the same position/orientation that was taken in the physical world.

So for each piece of information shown, a 3D icon is presented in the scenario, with its position in the virtual world, according to the position in the real world, so the controller can easily understand what is happening.

The implementation strategies to connect the game engine with the real information changes in function of the information associated. In any case, the communication is between the augmented virtuality interface and the virtual world (Virtual object's module), which takes the information from the real smart city.

For each security camera, a 3D icon is associated with an URL link to a web where controls and video streaming of that camera is shown. The number of 3D icons of this type are added in a setup procedure before operational deployment, associating and configuring a green 3D icon with each security camera present in the physical world.

In the case of social media events, an entity Social Media Manager connects to the data collector in the virtual object module and, for each tweet geolocated in the area delimited for the event, it shows a blue 3D icon in the corresponding position in the virtual world. Under special conditions, e.g. an accident, if several publications fell in the same area (currently defined by 100 meters x 100 meters), the blue 3D icon increase its size to call the attention of controlling staff.

In the case of security staff position, there is a set of configured 3D icons associated by ID to real security staff which using GPS mobile service sends its GPS position to the digital twin manager. The Citizen application is used by security staff and sends periodically its GPS position. Each 3D icon has associated a Zeroc Ice script which every minute consult if the GPS position of its physical counterpart has changed. If so, it changes the 3D icon according to the new position. Again, a service in the virtual object module has the last information collected.

As stated, the tool offers three key advantages:

- The advantage of having a virtual world is the mobility of the perspective, emulating a drone flight, but also having a set of strategic prefixed positions with virtual cameras. This freedom of visualizing the real information, geolocated in a virtual world, boost situational awareness about what is happening.
- Forensic analysis tool. From the first impressions of talking with civil servants, the capability of reproducing how information flows in an event can be precious in analysis post-event. Therefore, implementing a temporal line about who sent what picture on each moment showing in the world could easier to understand what was happening in each moment. This could support new policies on massive event management.
- Optimization of resources and time-reaction reduction under incidents is a direct consequence of situational awareness improvement.

Finally, simulation info right now is only supported by an agent showing the head/tail of the marathon/parade. This is the simplest simulation case, so it is configured in a simple simulation service which updates the head/tail agent (represented by 3D grey icon) according to a route and timestamp. The simulation service, in this case, only follows a KML/GPX file, generated in the same way that Android applications simulate mobile phone movement.

## VII. Conclusion and discussion

Smart city management in real-time is, basically, a situational awareness issue. Understanding what is happening is the first step toward the correct allocation of resources and making the right decisions.

In this paper, we propose a platform for a digital twin of a smart city. As a reference use-case for requirements, we are using massive event management, one of the most exigent use-cases of a smart city. Our proposal is the first to deal with this issue using a digital twin approach. Additionally, we are also originals on how information is fused by using the augmented virtuality concepts.

Our initial hypothesis needs to be validated by putting under control of our platform a crowded event. We are on this path right now, our tool Citisocial is taking information about specific events yearly. The two immediate targets are Fenavin,

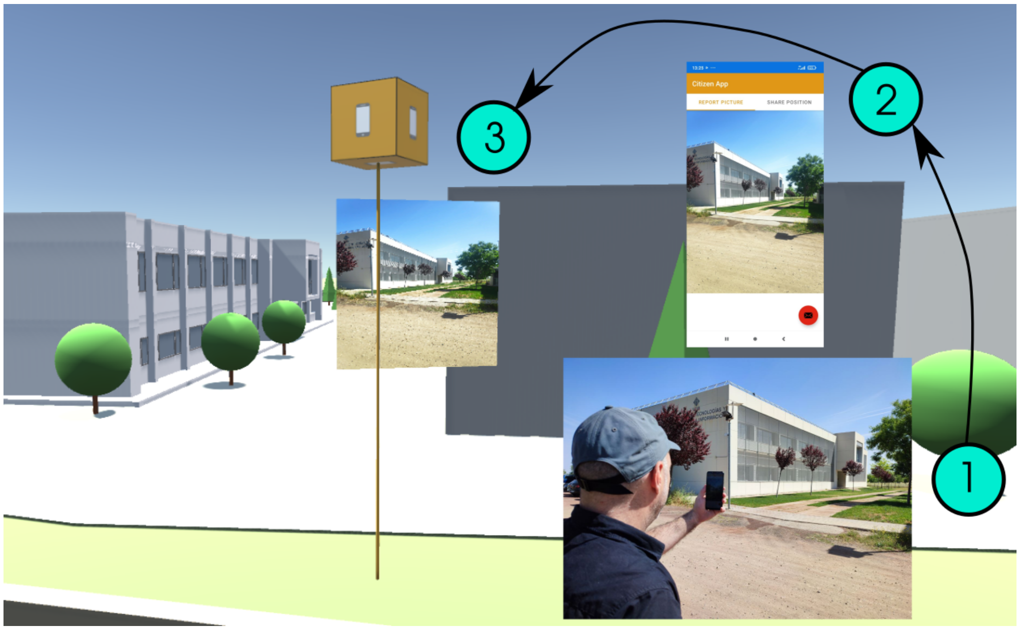


Fig. 8. Taking the picture (1) with the app (2) originates a mobile phone event in the virtual world with the picture associated (3)

one of the biggest wine trade events, and the local marathon. Civil servants of the local council have supported augmented virtuality tool requirements and they are optimistic about our initial proof of concept scenario. Our first approach to the validation is to monitor next year local marathon. A set of volunteers with our citizen application will be distributed along the path of the event, so we can test the accuracy of simulation capabilities, scalability issues and information fusion results. Citisocial will monitor social networks related with the event.

After this initial validation, we will show a report to the council, if they validate the results, we can support officially the organization of the local marathon 2024. The initial idea is to put our tools in parallel with the current state-of-the-art method of crowded event management.

Digital twin presents challenges and opportunities for smart city platforms. Information fusion, simulations setup and scalability of 3D GUI are examples of challenges of future digital twins platforms in smart city domain. However, a digital twin perspective is a keystone toward a future metaverse ecosystem around smart city.

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