Toward phygital agent-based interactive simulations to support urban planning

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Abstract. To support urban planners in assessing and comparing various alternative scenarios, this paper provides a novel methodological framework for phygital agent-based simulation, *i.e.* simulations with which the user can interact through the usage of a physical 3D model and visualize in augmented reality (digital).

Keywords: urban planning · agent-based model · phygital interaction · 3D animation

Urban planning practices have changed deeply over the last 50 years requiring now to consider the whole complexity of the urban area before planning a new development [5]. Indeed, planning the construction of a new building is not limited to ensuring the possible access to the building for people, vehicles, electricity, water... The city needs to be considered as a complex system and many other factors (material or immaterial, qualitative or quantitative...) and feedback loops need to be taken into account and understood. In addition, evolution of the individual behaviors (*e.g.* in terms of mobility mode) and institution regulation (*e.g.* the Local Urban Plan (PLU)) are key factors that can influence the impact of an urban planning. Finally making all these aspects more easily exploitable by different stakeholders is crucial.

Agent-based modeling and simulation has become a tool of choice to simulate such complex socio-environmental systems [6]: it is suitable to take into account very diverse dynamics from various fields and their feedback loops. Thanks to its expressivity, an agent-based model can become a very powerful virtual laboratory to experiment and understand the effects of alternative urban plans. A key challenge is now to make such tools available and usable by any user to help understanding and thus improve the acceptability of urban plans, but also by planners to provide insights and support their decision. This requires innovative approaches in terms of visualization of simulation and interaction with them.

Much recent effort has focused on extending the limited input/output interaction capabilities of desktop computers through the use of interactive tabletops, augmented reality [2] or tangible interaction [1]. In our context, we explore an original interaction mode that we called "phygital interaction": it depicts the use of a physical 3D model, representing the physical location to which a data set is related. The use of 3D physical referent 1) provides support for tangible interaction, which ensures a better memorization through proprioception, and 2) allows for a more situated data analysis, which provides a physical anchor for data facilitating large data sets exploration and understanding [4]. Rendering of the data is then performed using a Head-Worn Display (HWD), such as the Hololens, which provides a large immersive display area to augment the 3D physical model.

Along with the physical 3D model, there is a need for a digital 3D model which will hold all the simulation information. This model would be superimposed on the physical 3D model to enhance the user's understanding of the impact of urban planning on ecology or traffic through the visualization of pollution clouds or pedestrians movement. Furthermore, urban planners use 3D representations to design new infrastructures. These models often consist in a static description of the different parts of the buildings, using classical file formats like CityGML or IFC. Such a single visualisation, even with high level of details needs to be integrated into a huge area to have a more precise vision of the project. In our approach, we propose to visualize not only the 3D model of the project but the environment that is directly impacted. The next step is then the animation of all the movable elements like pedestrians, cars, buses.

The objective of this work is to provide a methodological framework for **phygital agent-based simulation**, *i.e.* simulations with which the user can interact through the usage of a **phy**sical 3D model and visualize in augmented reality (di**gital**). Through different scenarios, we aim to test the impact of the urban project on road traffic and more. In the following, we introduce the three main components of the framework (Simulation, Interaction and 3D animation) and the way they interact.

Simulation component. The *Simulation* component is in charge of computing evolutions of the system and providing information about the current simulation state to the Interaction and 3D animation components. Four simulation use cases have been identified to provide an optimal phygital simulation experience: (i) step-by-step simulation allowing to visualise and interact at runtime with the simulation, (ii) visualisation of recorded simulations, in this case interactions will be limited to query the 3D model to display information (no modification is possible), (iii) comparison between 2 (or N) alternative simulations, and (iv) interaction with the simulation at its initial state, to modify deeply the environment (*e.g.* create a new building). Visualisation and interactions with simulations in real-time (cases (i) and (iii)) require fast (and thus reactive) simulations. In these cases, the model or some of its dynamics will be simplified to preserve this execution time constraint. The designed model should thus be modular enough to adapt these constraints. The GAMA platform [6], an agent-based modeling and simulation platform providing powerful tools to develop spatial models, has been selected to implement the models and run the simulations. GAMA provides a multi-simulation feature, allowing to run several synchronized simulations. It has already been used in several projects coupling simulation and tangible interface, in particular to study urban planning and the impact of new mobility [3].

Phygital interaction component. Two major interaction forms has been identified: exploring the simulation results and tuning the intrinsic simulation parameters. To explore the simulation dataset, users' inputs on the physical 3D model trigger the visualization of the data charts associated with the physical referent (building, street, red light). The chart is displayed above the model using the HWD and can be configured using different physical features (point, edge, surfaces) of the physical referent, *e.g.* a touch on the edges of a building allow to configure the axes of the 3D chart. The adjustment of the intrinsic simulation parameters corresponds to a modification of the physical environment's topology, or a digital modification of a parameter of the simulation engine. For example, a physical floor can be added to the desired building, using a 3D printed pluggable floor, to analyze the impact of higher population density on traffic. Another example is when the speed of a red light requires adjustments to streamline the traffic. To do so, the user may select the red light using a touch on the physical 3D model, then slide on its pole to change the light switching speed.

3D animation component. The main role of this component is to run pre-computed simulations in 3D realistic environments. Visualization is the last step of validation for urban planners. Each element of the scene (building, road, tree, street furniture) is rebuilt from open source data (OpenStreetMap, IGN) providing information about coordinates, height, name, function... We here focus on the buildings which is the most complicated part. To generate realistic buildings, we need accurate data. The first step is preprocessing to recompute the coordinates to make right angles and parallel sides. Then the set of GPS coordinates defines a polygon (footprint) that is extruded regarding the number of floors. The second step is for missing data, we use default values, hierarchically organized by areas, to provide two main characteristics: texture and roof. Then the roof is added and the textures are applied for each wall. Similar algorithms are used for each type of object (road, vegetation...). Finally, we can add 3D models proposed by urban planners.

Overview of the interactions between the three components. The *3D animation* component is in charge of reading the input OSM data and to augment them with additional metadata (*e.g.* obligations and constraints from the PLU). This augmented file is then used for visualisation, to initialize the *Simulation* environment or, once transformed into an augmented STL file for the *Interaction* component. The *Simulation* initialisation is completed by demographic, synthetic data. During its run, the *Simulation* will transmit to the two other components updates of the simulation states (*e.g.* location, state...), to allow

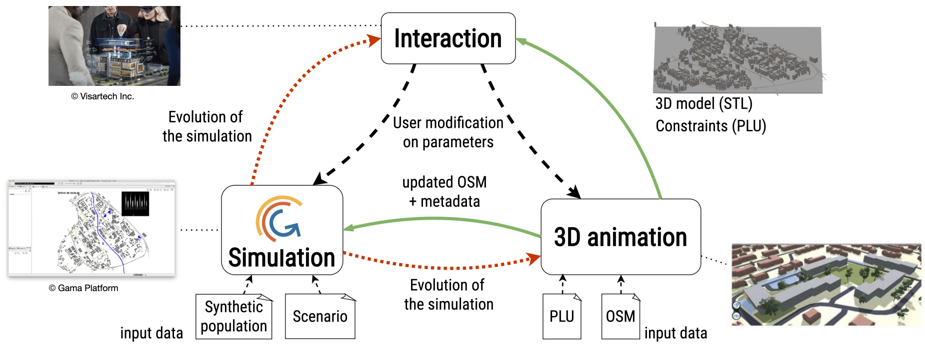

Fig. 1. Workflow of our phygital simulation approach. (*Interaction* will use Hololens by Microsoft, image credit: https://www.visartech.com/blog/)

them to visualise the simulation. When an interaction occurs, either the environment is modified (*e.g.* add a new building), in which case the *3D animation* will regenerate a new 3D model for the 2 other components, or the parameters of the simulation or agents' states are updated and only transmitted to the *Simulation*.

Coupling agent-based simulations with a tangible interface has demonstrated its benefits in terms of communication, but the improvement of the interactions is mandatory to let it become part of the urban planner toolbox. The project goal is thus to apply this approach to support Toulouse Metropole in its planning of a new ward.

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