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Dynamic Digital Twins for Smart and Sustainable City Planning

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Introduction

Digital Twins (DTs) are the dynamic digital replicas of real-world objects. DTs are updated with real-time data, unlike static 3D models.

Advantages of DTs:
- Evolve with real-world events
- Practical in situations where testing on physical models are not feasible

Works done:
- Developed city-scale DTs within the EU-funded "DIDYMOS-XR"[1] project
- Developed two use cases - *DT creation* and *City planning* for XR applications
- Developed 3D city model using state-of-the-art methods (NeRF[2], 3D Gaussian Splatting[3]) and tools (e.g., Blender[4])
- Developed localization techniques using both non-visual and visual sensor data for the DT
- Developed visualization and rendering pipeline for the DT using cutting-edge tools (Unity3D[5], Carla[6], WebGL)

Developed technology and pipeline for the DT

Figure 1 shows an overview of the processes and technologies that have been in development and incorporated to bring the city-scale DT into reality. Below, a brief summary of these technologies are presented.

Data Acquisition:
- 3D data collected via drones, LIDAR sensors, and cameras.
- Integration of non-visual sensor data (GPS, Odometry) and GIS databases.
- Refining initial point clouds to create high-fidelity 3D assets.

3D City Model Creation:
- Methods: Combination of automatic AI methods (3D Gaussian splatting, NeRF) and further refinements using tools like Blender.
- Incorporation of textures, vegetation, and road networks for realism.

Data Updates:
- Periodic updates using vehicle/drone sensors (cameras, GPS, odometry).
- Techniques: Sensor fusion for 3D reconstruction, 2D segmentation, object detection.

Localization of vehicle in DT: Using a combination of -
- Non-visual sensor data (GPS, Odometry) and Monte Carlo Localization[7]
- Visual sensor data using Image-based localization (IBL) and HSLAM[8] for high-accuracy self-localization.

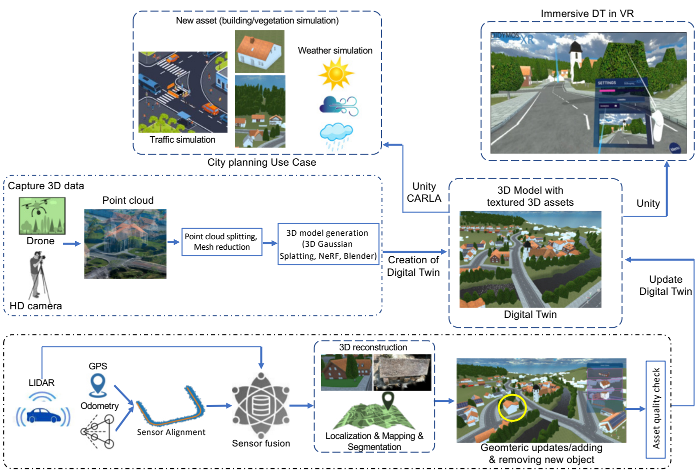

Figure 1 Overview of the processes and underlying technologies incorporated into the creation and update of the DT, City planning use case (weather, traffic simulation), and immersive DT in VR setup.

Simulation aspects and outputs

Below a brief description of the simulation aspects and selected outputs are presented.

Simulation Frameworks:
- Unity3D and Carla to integrate DT into urban simulation environments.

Scenario Simulations:
- Analyze weather, traffic patterns, and smart infrastructure elements.
- Manipulate parameters like vehicle speeds, traffic densities, and environmental conditions.
- **Figure 2** shows sun and rain simulation – with options to simulate sun and rain intensity variations and historic weather data visualization

Figure 2 Weather simulation in the DT – left image shows sun simulation and the right image shows rain simulation with various parameters to change.

Testing and Evaluation:
- Evaluate "What if" scenarios and assess impacts of adding or removing assets (e.g., building, vegetation), traffic lights, and such.
- Evaluate impacts on traffic flow and urban infrastructure.

VR Integration:
- Immersive pedestrian-level DT exploration via a VR framework.
- Facilitates deeper insights and enhanced decision-making for city planners.
- **Figure 3** shows immersive DT in VR setup.

Figure 3 Incorporation of immersive navigation of the DT in VR. Here, functionalities like weather simulation (left), taking snapshots (right) are included to provide a feeling of immersion while checking out various effects such as change of weather conditions.

Conclusion

In this work, we have been developing technologies using cutting-edge AI techniques and tools towards a **comprehensive urban planning approach**, where:
- the DT enable data-driven decision-making for urban planning.
- the DT support the exploration, evaluation, and optimization of city planning scenarios.
- the DT can be explored and experienced in immersive extended reality, e.g. in VR

The inherent benefits of the DT are, among others,
- Enhanced efficiency, resilience, and sustainability of urban environments.
- Support for city planners in making informed decisions on infrastructure development.

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