



UNIVERSITÀ DEGLI STUDI DI NAPOLI  
FEDERICO II

itee<sub>PhD</sub>  
information technology  
electrical engineering



Debora Russo

Synthetic Data Generation for Smart City  
Applications: *From Behavioral to Physical  
Simulation*

Tutor: Nicola Mazzocca

Cycle: XXXIX

Year: Second

# My Background

- **MSc degree:** Computer Engineering
- **DIETI Research group/laboratory:**
  - SECLAB
- **PhD start date:** 1<sup>st</sup> November 2023
- **Scholarship type:** PNRR - Partenariato Esteso PE14 - RESTART

# Summary of Study Activities

- **Ad Hoc PhD Courses**
  - How To Boost Your PhD
- **PhD Summer School:**
  - TAROT 2025 – 20<sup>th</sup> Summer School on Software Testing, Verification & Validation
- **Conferences/Events attended:**
  - RESTART Plenary Dissemination Workshop, Napoli
  - 23rd IEEE International Conference on Smart City (SmartCity-2025)
  - 33rd ACM International Conference on Multimedia (ACMMM2025)

# Research Field of Interest

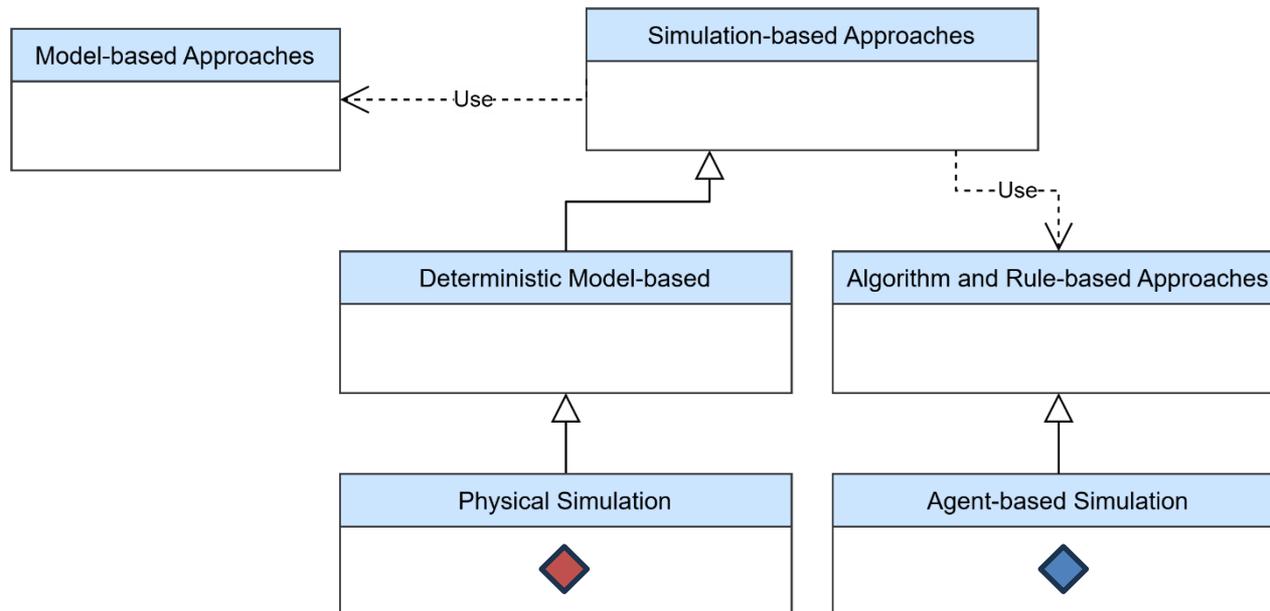
- My research focuses on **synthetic data generation** for **smart city** applications.
- My work explores  $2D \rightarrow 3D$  synthetic generation for **behavioral** and **material-aware** environments.



# From Behavioral (2D) to Perceptual (3D) Data Generation

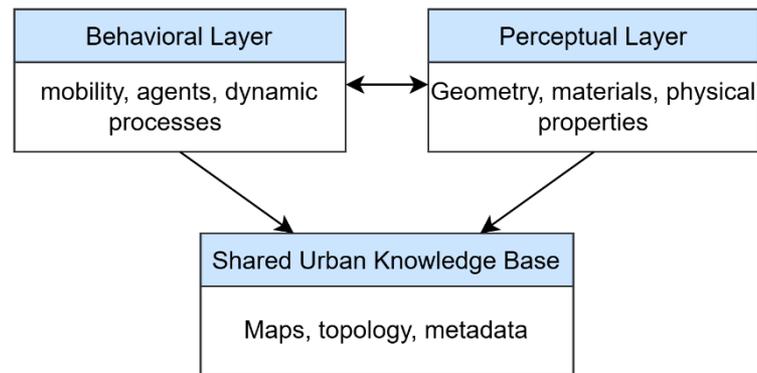
- Guided by our Synthetic Data Generation Taxonomy, we explored different smart city case studies:
  - **Year 1** → 2D behavioral simulation (mobility). 
  - **Year 2** → 3D physical realism (Unreal: geometry + materials). 

Excerpt from the Synthetic Data Generation Taxonomy



# Why Physical and Material Information Matter

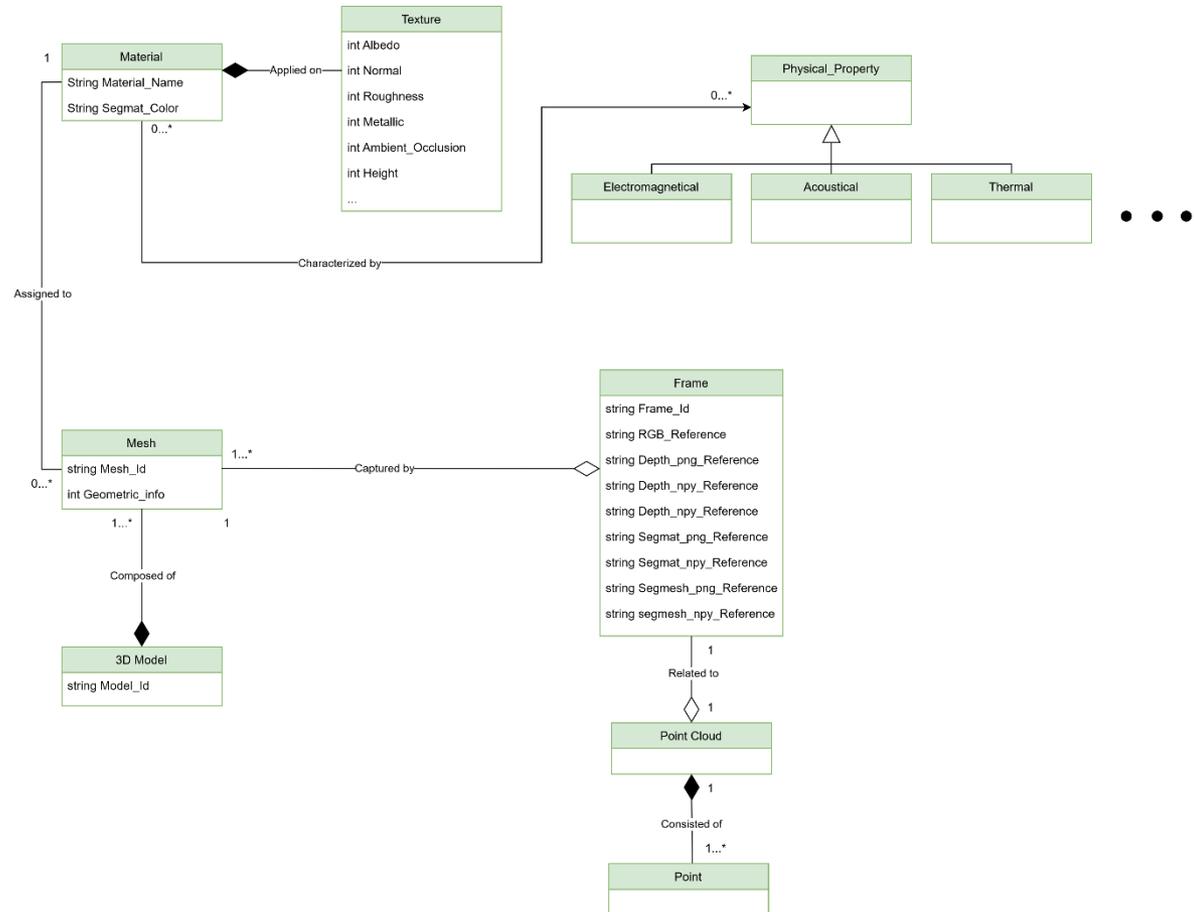
- **Beyond visual realism:** synthetic urban scenes must reproduce not only shapes and colors, but also the physical behavior of surfaces and materials.
- **Physics adds credibility:** properties like reflectance, roughness, and attenuation define how materials interact with light and sensors, making synthetic data closer to real-world conditions.



# Material-Aware Scenario Generation

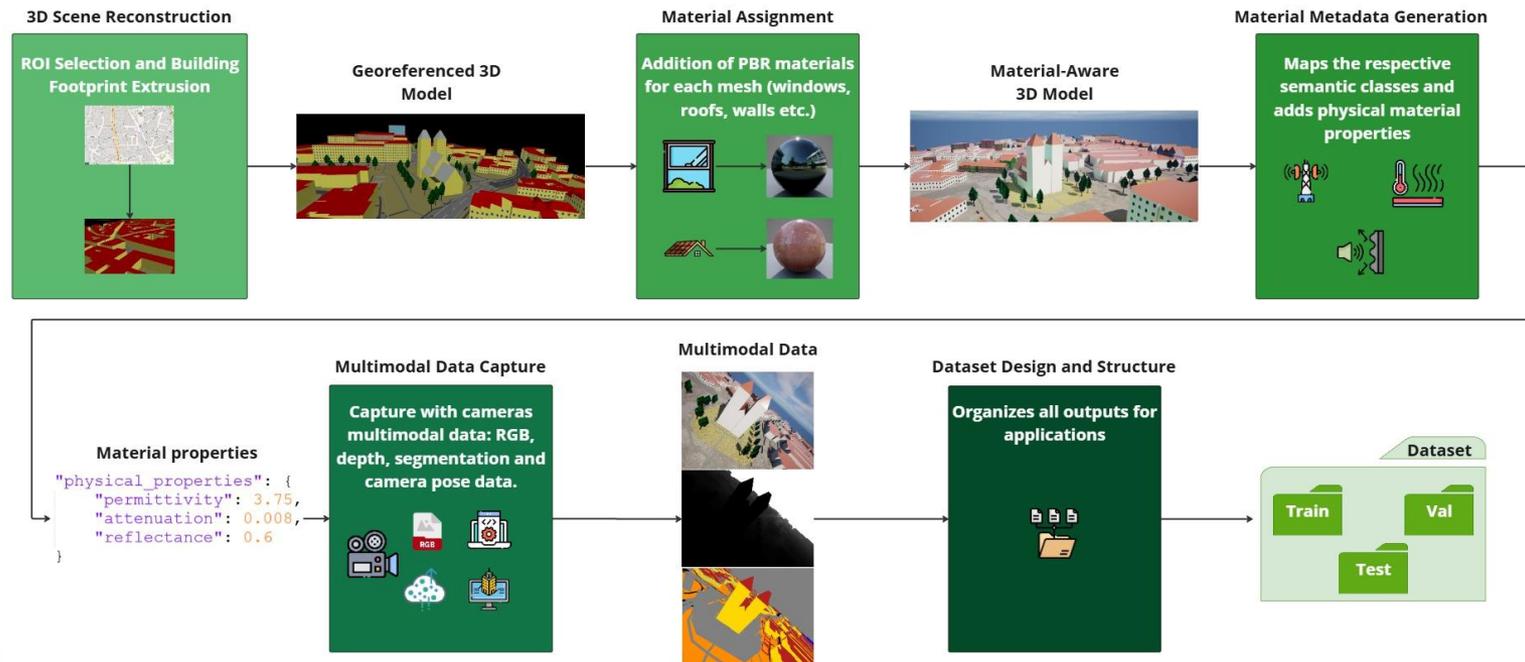
- The class diagram formalizes three levels of abstraction:

- Logical level:** defines entities and relationships (3D Model, Mesh, Material, Frame, Point Cloud).
- Semantic level:** encodes metadata linking geometry, materials, and physical properties.
- Physical level:** Describes the deliverables that instantiate each scene, providing a reproducible representation.



# Material-Aware Scenario Generation

- **Our Process follows three characteristics:**
  - Urban coherence and georeferencing.
  - Material semantics and physical characterization.
  - End-to-end traceability from geometry to metadata

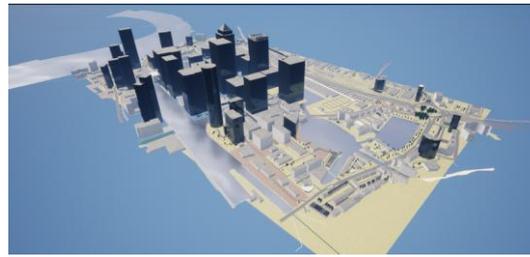


# The UR-MAT Dataset

- **UR-MAT (URban MATerials Dataset)**
  - **UR-MAT integrates 7 European districts and 13 material classes** with full metadata for RGB, depth, segmentation, and **EM properties**.



Bryggen, Norway



Canary Wharf, London



Citylife, Milan



Eixample,  
Barcelona



Trastevere,  
Rome



Louvre,  
Paris



Siemensstadt,  
Berlin

Debora Russo, Nicola Mazzocca, and Valeria Vittorini. 2025. UR-MAT: A Multimodal, Material-Aware Synthetic Dataset of Urban Scenarios. In Proceedings of the 33rd ACM International Conference on Multimedia (MM '25). Association for Computing Machinery, New York, NY, USA, 13164–13169. <https://doi.org/10.1145/3746027.3758314>

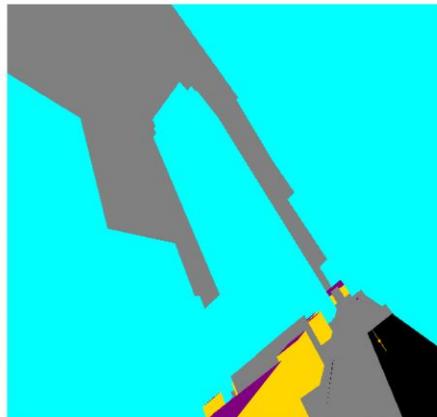
# Use Case: Material-Aware Segmentation

- **RGB → GT mask → Prediction**
  - Our dataset can be used for material segmentation: our model achieved 96% pixel accuracy and over 80% mean IoU, distinguishing well materials such as glass and brick.

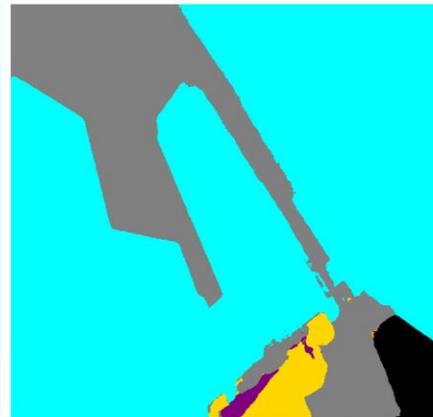
RGB



Ground Truth



Prediction



IoU per class for the material segmentation task.

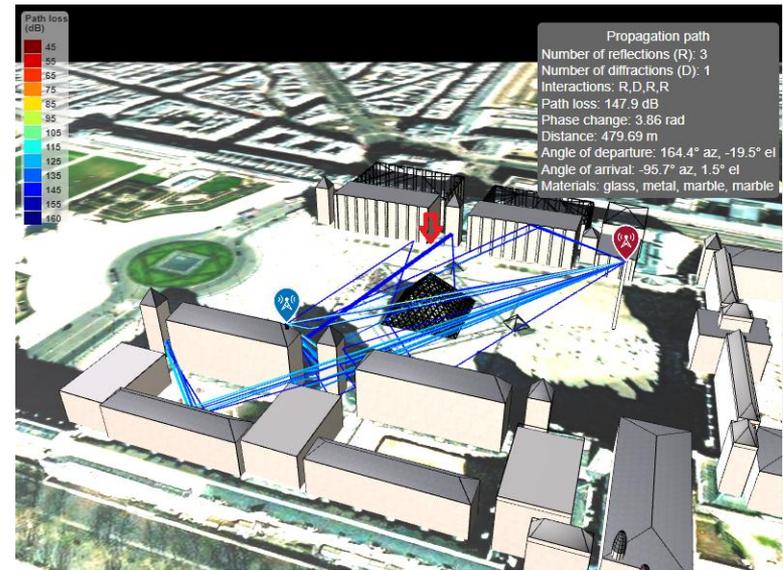
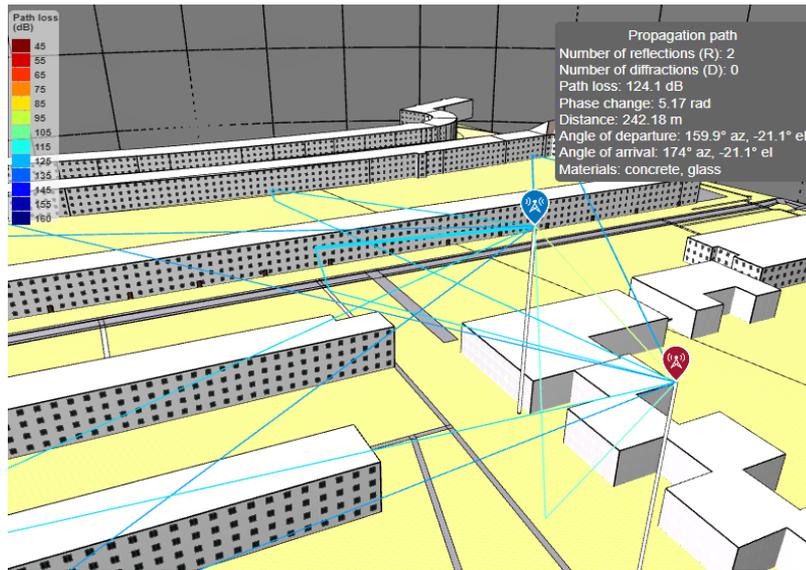
| ID | Material    | IoU    | Color Name   |
|----|-------------|--------|--------------|
| 0  | Limestone   | 0.9674 | Yellow       |
| 1  | Slate       | 0.9261 | Blue         |
| 2  | Glass       | 0.9527 | Cyan         |
| 3  | Steel       | 0.0026 | Orange       |
| 4  | Brick       | 0.9006 | Firebrick    |
| 5  | Cobblestone | 0.8911 | Dark Orange  |
| 6  | Plaster     | 0.9118 | Gold         |
| 7  | Concrete    | 0.8695 | Purple       |
| 8  | Gravel      | 0.9569 | Indigo       |
| 9  | Tiles       | 0.9702 | Dark Red     |
| 10 | Wood        | 0.7029 | Saddle Brown |
| 11 | Asphalt     | 0.7012 | Black        |
| 12 | Plastic     | 0.5318 | Deep Pink    |
| 13 | Unknown     | 0.9541 | Gray         |

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# Use Case: Material-Aware Propagation Simulation

- **5G Ray Tracing Simulation**

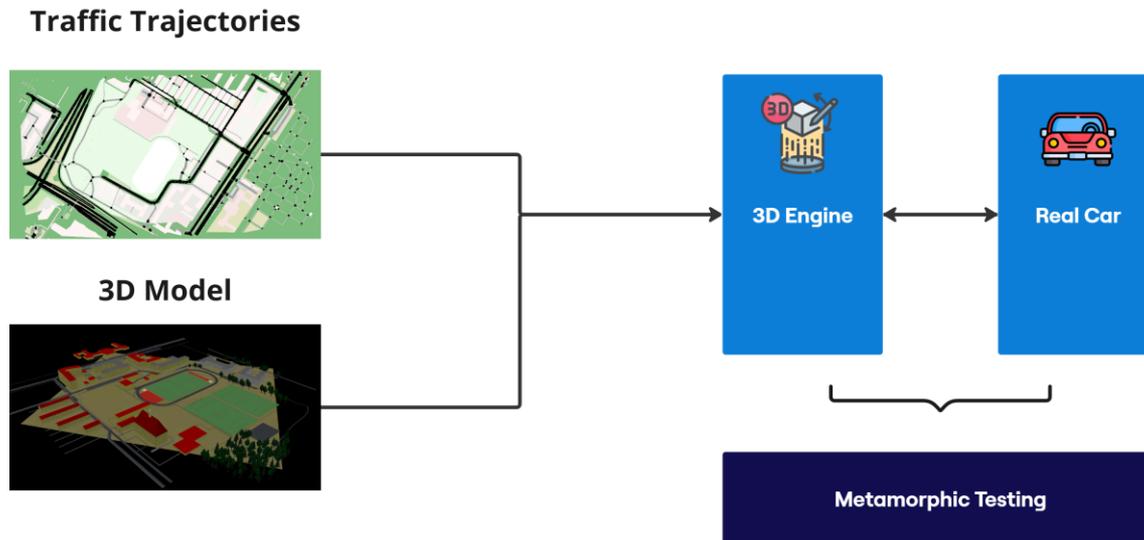
- Using the annotated meshes, MATLAB simulations show how signals reflect on glass and steel and attenuate through wood or concrete



D. Russo, D. Amalfitano, G. Di Martino, N. Mazzocca and V. Vittorini, "Material-Aware Synthetic Data Generation for Smart City Applications," 2025 IEEE International Conference on High Performance Computing and Communications (HPCC), Exeter, United Kingdom, 2025, pp. 1037-1044, doi: 10.1109/HPCC67675.2025.00151

# Upcoming Research Focus

- **Research Objective:**
  - **Integration of behavioral and perceptual layers**
    - The next research step aims to integrate behavioral and physical simulations within a unified synthetic framework.
  - **Reliability through Synthesis (Fortiss/TUM period)**
    - The goal is to enable **cross-domain experiments** where traffic flow and perception models are simulated together.



# Research products

|      |  |
|------|--|
| [J1] | D. Russo, F. Rocco Di Torrepadula, L. Libero Lucio Starace, S. Di Martino and N. Mazzocca, "A Framework for Generating Synthetic Urban Mobility Datasets With Customizable Anomalous Scenarios," in <i>IEEE Open Journal of Intelligent Transportation Systems</i> , vol. 6, pp. 1439-1458, 2025, doi: 10.1109/OJITS.2025.3626948. Published.  |
| [C1] | D. Russo, D. Amalfitano, G. Di Martino, N. Mazzocca and V. Vittorini, "Material-Aware Synthetic Data Generation for Smart City Applications," <i>2025 IEEE International Conference on High Performance Computing and Communications (HPCC)</i> , Exeter, United Kingdom, 2025, pp. 1037-1044, doi: <a href="https://doi.org/10.1109/67675.2025.00151">https://doi.org/10.1109/67675.2025.00151</a> . Published. |
| [C2] | Debora Russo, Nicola Mazzocca, and Valeria Vittorini. 2025. UR-MAT: A Multimodal, Material-Aware Synthetic Dataset of Urban Scenarios. In <i>Proceedings of the 33rd ACM International Conference on Multimedia (MM '25)</i> . Association for Computing Machinery, New York, NY, USA, 13164–13169. <a href="https://doi.org/10.1145/3746027.3758314">https://doi.org/10.1145/3746027.3758314</a> . Published.   |

J – Journal Paper; C – Conference Paper

**Thank you for your attention!**