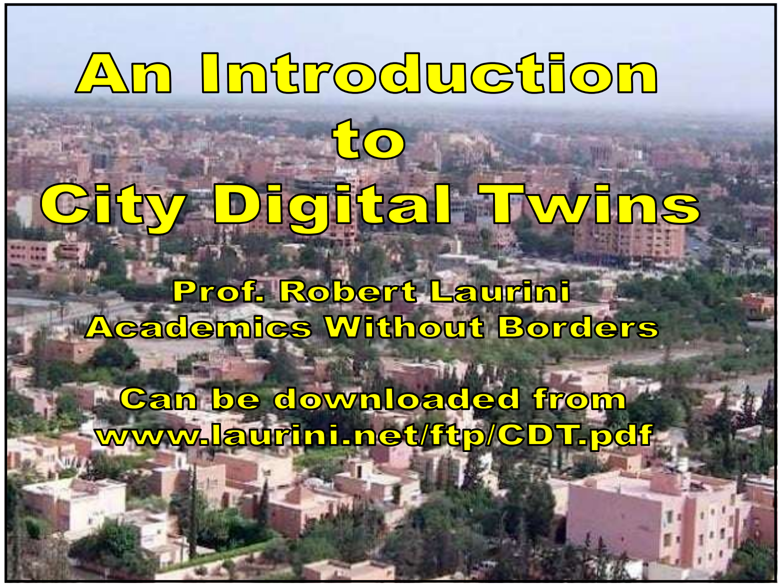


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## Dr. Robert Laurini

- Doctorates in computing (1973 and 1980),
  - University of Lyon, France
- Distinguished professor at INSA-Lyon
- Extra positions
  - University of Cambridge, UK; University of Maryland CP, USA; University of Venice, Italy.
- Research specialty:
  - computing (AI) for urban planning
  - 10+ books, 250+ papers
  - (co)-supervisor of 44 PhD; Member of PhD committees in 19 countries
- Now,
  - Professor Emeritus at KSI,
  - IARIA fellow
  - Honorary president of « Urban Data Management Society »
  - Honorary president of « USF/Academics Without Frontiers »

2

2

## City Digital Twins

- The aim is to build a digital model of the city on which analyses and simulations can be carried out according to certain assumptions and conclusions for planning purposes.
- This is a new concept, although intuition (precursors) has existed since the 1970s with minor scopes
  - Urban data banks and databases
  - Development models
  - Geographic information systems
  - 3D digital models

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## Contents

- 1. Introduction, objectives
- 2. Technologies
- 3. Conclusions

4

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# 1. Introduction, objectives

- There are many definitions of city digital twins
- Common purposes
  - Have a vivid digital image in all its complexity
  - Control it in real time in an optimal way



# Different meanings of city digital twins

**Table 1** Different understandings of "digital twin"

| | Part of Understanding | Ideal Characteristics | Digital Twin Cities | Dimensions |
|---|---|---|---|---|
| 1 | a. Digital twins are 3D models<br>b. Digital twins are copies of physical entities<br>c. Digital twins are virtual prototypes | Multi-dimensional/multi-space-time/multiscale<br>Dynamic/evolutive/interactive<br>High fidelity/ Highly reliable/high-precision | Accurate Mapping | Model |
| 2 | a. Digital twins are data/big data<br>b. Digital twins are PLM (Product Lifecycle Management)<br>c. Digital twins are digital thread<br>d. Digital twins are digital shadow | Total factor/all-service/ complete flow scheme/full life circle<br>Virtual-real fusion/ multi-source fusion/heterogeneous integration<br>Real-time update/real-time interact/real-time respond | | Data |
| 3 | a. Digital twins are Physical union platform<br>b. Digital twins are industrial Internet platforms | Bi-directional connection/interaction/driving<br>Cross-agreement/interface/platform | Virtual-real Interaction | Connection |
| 4 | a. Digital twins are simulation<br>b. Digital twins are virtual verification<br>c. Digital twins are visualization | Model driven + Data driven<br>Simulation verification/visualization/control/predict/optimize | Software Definition | Services/ Functions |
| 5 | a. Digital twins are pure digital representation or virtual bodies<br>b. Digital twins are irrelevant to entities | models vary from object to object/data vary by feature/services and functions vary according to needs | Intelligent Feedback | Physical |

Deren, L., Wenbo, Y. & Zhenfeng, S. Smart city based on digital twins. Comput.Urban Sci. 1, 4 (2021). https://doi.org/10.1007/s43762-021-00005-y 6



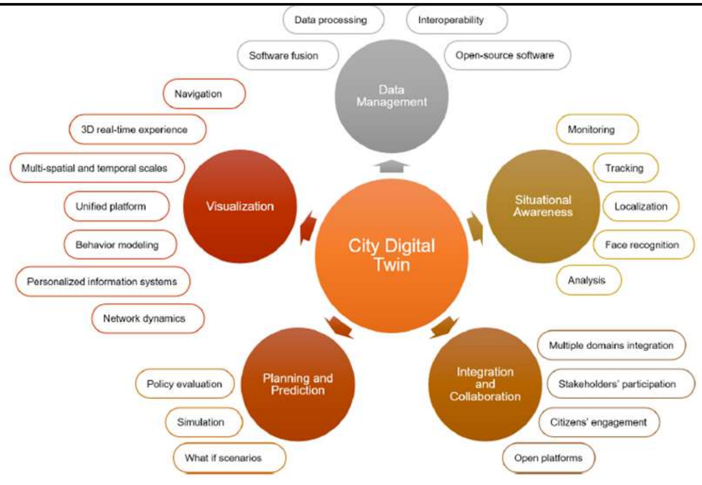



**Figure 2.** City digital twin potentials.

Shahat, E.; Hyun, C.T.; Yeom, C. City Digital Twin Potentials: A Review and Research Agenda. Sustainability 2021, 13, 3386. https://doi.org/10.3390/su13063386



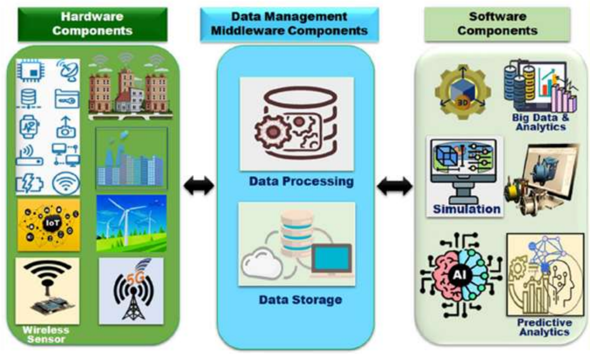
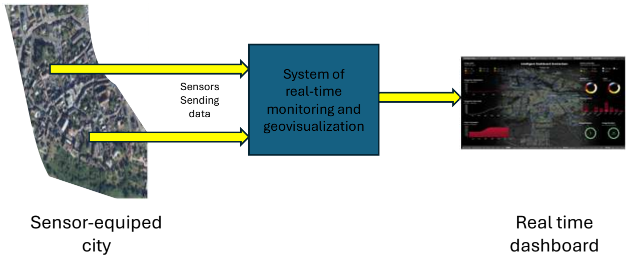



**Fig. 1** Digital twin system structure. This diagram illustrates the essential components of a Digital Twin system, showcasing hardware with IoT sensors, middleware for data management, and a software analytics engine

Rasha F. El-Agamy, Hanaa A. Sayed, Arwa M. AL Akhatatneh, Mansourah Aljohani, Mostafa Elhosseini (2024) Comprehensive analysis of digital twins in smart cities: a 4200-paper bibliometric study. Artificial Intelligence Review (2024) 57:154 https://doi.org/10.1007/s10462-024-10781-8

## Principle of real-time monitoring and geovisualization systems

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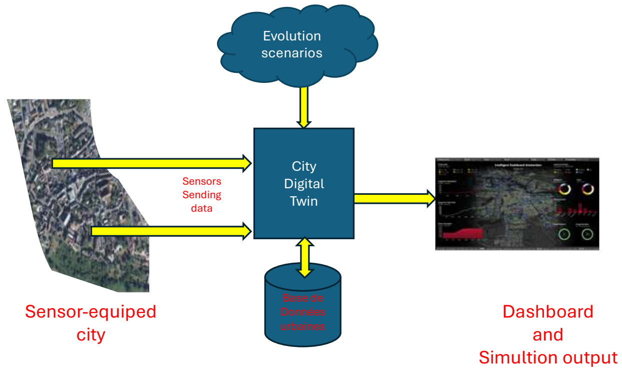
## Principle of digital twin systems

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## 2. Technologies

- 2.1 Sensors
- 2.2 Urban IoT
- 2.3 Urban development models
- 2.4 3D Models
- 2.5 Geovisualization and dashboards
- 2.6 GeoAI
- 2.7 Digital Sovereignty

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## 2.1 Sensors

- Depending on their function, they send signals
  - Often regularly
- Some have local storage options
- Particular type of distributed databases
- Often linked to the Internet of Things

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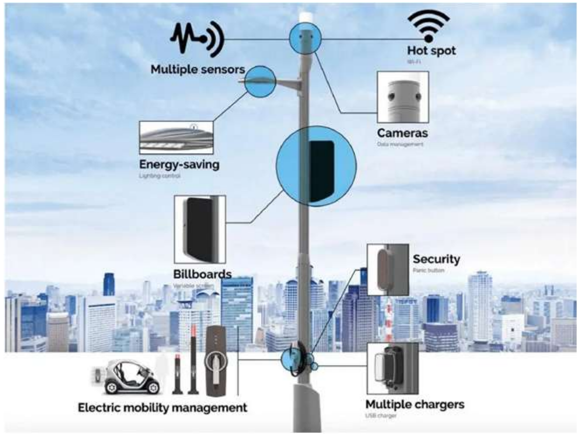
## Intelligent lamppost

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## Intelligent streetlighting

- Principle: streetlights along the streets light up when a vehicle passes
- They send an order to the following streetlights to illuminate thus a light wave is created allowing the vehicle to move quickly.
- Need to manage multiple vehicles in both directions
- Sensors are installed in the streetlights
- They detect vehicles and their speed
- They inform the following streetlights according to the vehicle speed

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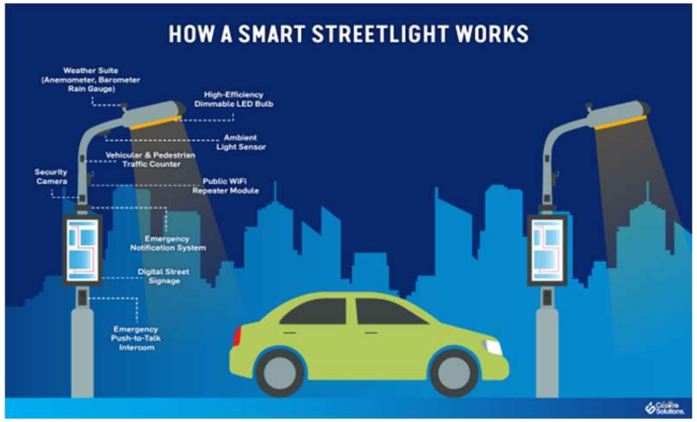
## Intelligent streetlighting

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## 2.2 – Urban IoT

- Common street furniture
- Fixed urban connected objects
- Connected mobile urban objects

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## Common street furniture

- Street furniture includes various equipment installed in public spaces to serve and embellish the daily life of residents.
  - Benches
  - Streetlights
  - Garbage cans
  - Bus shelters
  - Decorations on the squares (sculpture, etc.)
  - Charging stations for electric vehicles road signs
  - etc.

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## Common street furniture





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## IoT in urban areas

- Some objects can be connected
- Need to organize a specialized fiber network
- Sometimes linked to moving objects

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## Connected benches


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## Variable display panels


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## Connected Trash Containers


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## Crossroad lights


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## Videosurveillance

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# Connected mobile objects

- Public vehicles with specific missions
- Embedded systems
  - Equipped with sensors
  - Positioned by GPS
  - Linked to various information systems (including GIS)
  - Often connected to fixed furniture

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# Bus and shelters




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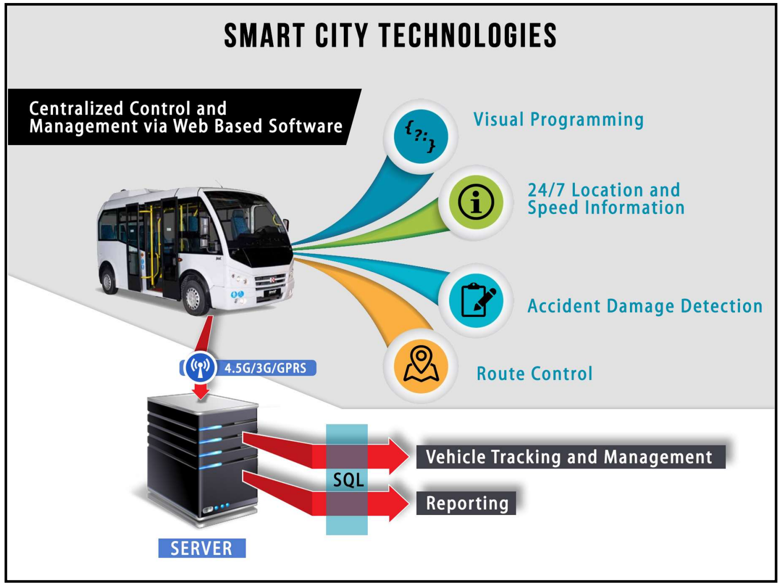


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# Bus Shelters

- Features
  - Waiting time for the next bus/tram
  - Viewing the schedules
  - Problems with connections
- Prior
  - Each bus is connected - on-board equipment
  - GPS positioning
  - Monitoring centre
  - Awareness of the positioning of all buses

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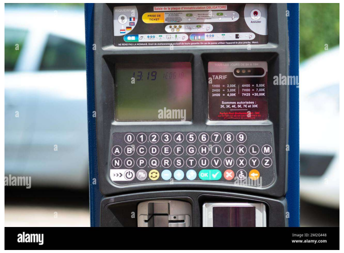
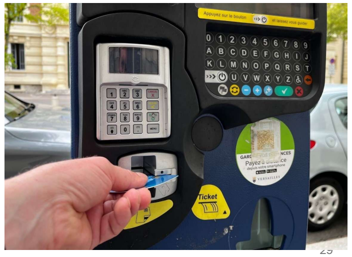
## Connected parking meter



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## Automatic reading of licence plates


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## Automatic reading of licence plates

- Automatic scanning of parked vehicles
- Verification
  - Whether vehicle stolen
  - Payment for parking
  - Compulsory insurance
  - Technical inspection
  - Etc.

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## Connected Urban Furniture

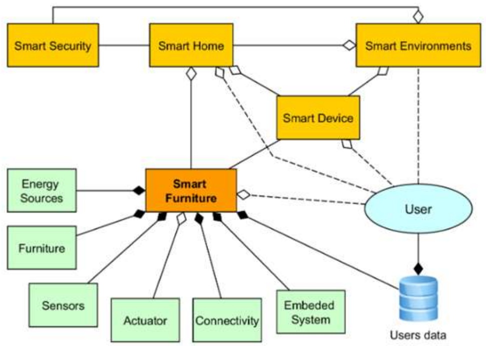


FIGURE 5. Role and position of Smart Furniture within the Smart City umbrella according to the UML design.

Ondrej Krejcar et al. « Smart Furniture as a Component of a Smart City - Definition Based on Key Technologies Specification »

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# Connected street furniture

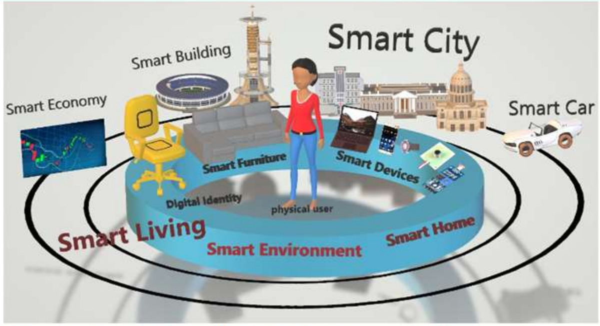


FIGURE 7. A user in a digital world of smart concepts (living, furniture, devices, home, environment, car, building, city, economy, etc.).

Ondrej Krejcar et al. « Smart Furniture as a Component of a Smart City - Definition Based on Key Technologies Specification »

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# 2.3 Urban development models

- Very fashionable in the 70s-80s
- Winter for 30 years
- Back on the critical path of research
- Two types
  - **Static** (to understand and analyze the static relationships between urban components)
  - $\vec{V}(t) = f(a, b, c,)$
  - **Dynamics** (to understand and analyse developments)
  - $\vec{V}(t+1) = f(\vec{V}(t), e(t), d(t))$

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# Example: home-work commuting

- Commuting $T_{ij}$
- Model by A.G. Wilson
- City divided into *n* zones
- Knowing (where $C_{ij}$ is the interzone distance)
  - $\sum_i^n T_{ij} = O_i \quad \sum_j^n T_{ij} = D_j$
  - $\sum_{ij}^n T_{ij} C_{ij} = C$
- It is enough to maximize the entropy under constraints
- $H = -\sum_{ij}^n T_{ij} ln T_{ij}$

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# Static example (cont'd)

- The Lagrangian is written
- $L = -\sum_{ij}^n T_{ij} ln T_{ij} + \sum_j^n \alpha_j \left(\sum_i^n T_{ij} - D_j\right) + \sum_i^n \delta_i \left(\sum_j^n T_{ij} - O_i\right) + \beta\left(\sum_{ij}^n T_{ij} C_{ij} - C\right)$
- To obtain the optimum, we put to zero he partial derivative of the Lagrangian
- $\frac{\partial L}{\partial T_{ij}} = 0$
- The solution is:
- $T_{ij} = A_i B_j \exp(-\beta c_{ij})$

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## About $C_{ij}$

- Distance interzone at bird's eye view
- Distance on the road network
- Distance taking into account track capacity

- If new route, change the concerned $C_{ij}$
- And make the calculations again

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## Dynamic model example

- Population growth in an area
- Vector $\overrightarrow{P(t)}$ population by age and sex

- Next year:
- $\overrightarrow{P(t+1)} = A\vec{P}\ (t) + \overrightarrow{E(t)} + \overrightarrow{S(t)}$

- With
  - $\overrightarrow{E(t)}$ are inputs (new comers)
  - $\overrightarrow{S(t)}$ are outputs (Those who left)

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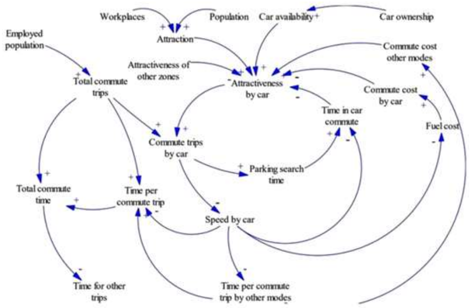
## Example of interactions




Jing Wang, Gengze Li, Huapu Lu, Zhouhao Wu (2024) Urban models: Progress and perspective Sustainable Futures 7 (2024) https://doi.org/10.1016/j.sftr.2024.100181

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## What-if models

- Model calibration based on real data

- Presentation of development scenarios

- Compare the results of various alternatives

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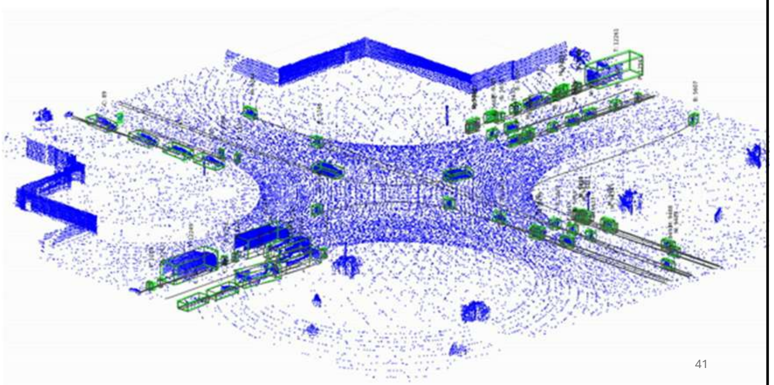
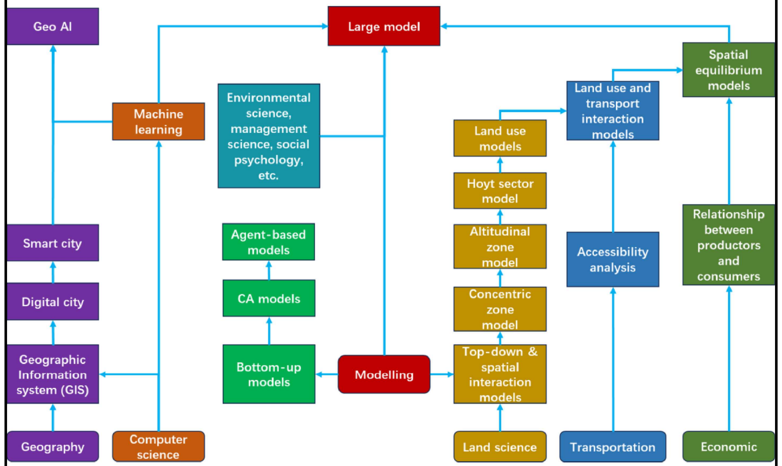
# Example of simulation










Jing Wang, Gengze Li, Huapu Lu, Zhouhao Wu (2024) Urban models: Progress and perspective Sustainable Futures 7 (2024) https://doi.org/10.1016/j.sftr.2024.100181





# 2.4 3D Models

- For some authors, 3D representation is the heart of digital twins
- Uses
  - Overall vision of the city
  - Visualization of urban projects
  - Visualization of risk consequences
  - Integration of new buildings
  - Simulation of wind effects
  - Location of photovoltaic panels
  - Location of rooftop gardens
  - Etc.





# Example: Amsterdam

https://aecmag.com/digital-twin/five-types-of-urban-digital-twins/

## 3D Example

https://www.artstation.com/artwork/JeQAr0

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## 3D of the underground

- Metrolines
- Engineering networks
- Subsoil car parks
- Underground City (Montreal)
- Underground galleries (catacomb, etc.)
- Geology
- Etc.

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## 2.5 Geovisualization and dashboards

- Global visualization

- Ben Schneiderman's Mantra
- *"Overview, zoom and filter, details-on-demand"*

- Geovisualisation
- Chorems
- Data landscape (datascape by Nadia Amoroso)
- Dashboards
- https://placesjournal.org/article/mission-control-a-history-of-the-urban-dashboard/?cn-reloaded=1

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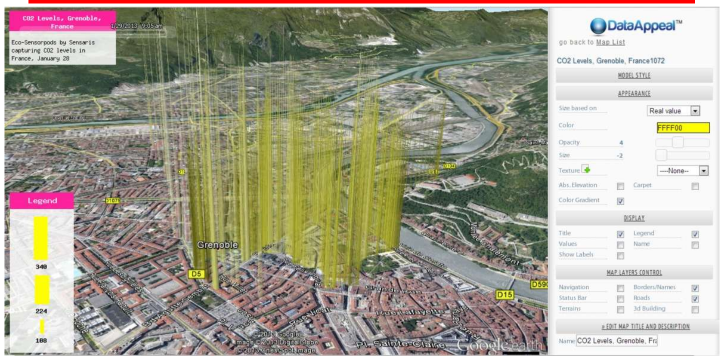
## Air pollution




https://www.nadiaamoroso.com/creative-cartography

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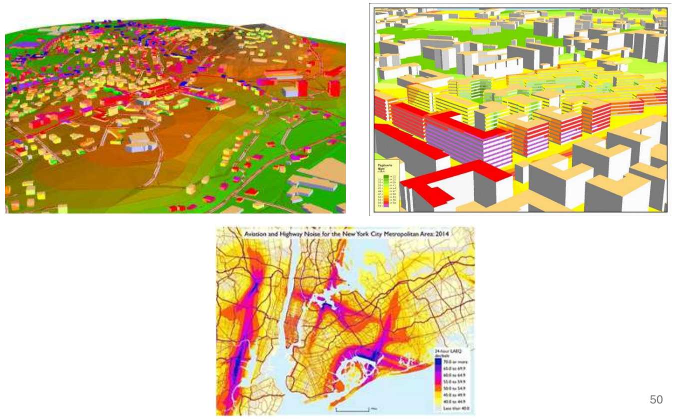
## Examples of noise visualization



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## Example: Zurich

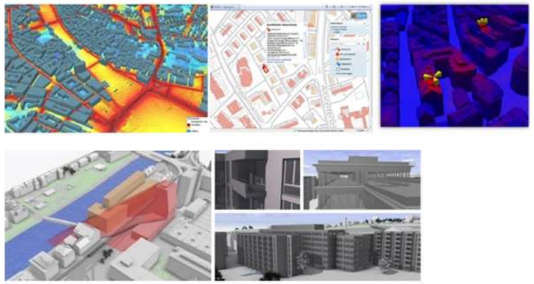

Fig. 7 Established applications: noise (upper left), air pollution (upper centre), mobile phone radiation (upper right), solar potential (lower left), visualization of construction projects (lower right) (source: City of Zurich)

Gerhard Schrotter · Christian Hürzeler (2020) The Digital Twin of the City of Zurich for Urban Planning. PFG (2020) 88:99–112 https://doi.org/10.1007/s41064-020-00092-2



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https://www.sciencedirect.com/science/article/pii/S1071581920300331#:~:text=City%20dashboards%20use%20a%20suite%20of%20visual%20analytics%20-%20dynamic



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## 2.6 GeoAI

- Little AI work for urban planning
- Rules-based systems
- Geographic knowledge graphs (GeoKG)
- Deep learning
- Generative AI;
- Large language models
- LLM ↔ GeoKG ?

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## Definition of geographic knowledge

- Knowledge = information that can be used to solve a problem or facilitate decision-making
- For a territory, geographic knowledge is information potentially useful for: explain
  - Manage
  - Monitor
  - simulating the future
  - and plan

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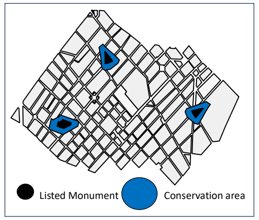
## Example of rules around historical monuments




$\forall T \in Earth,\ \forall B \in PROJECT,\ \exists M \in Geo\text{-}Objects,$

Type ($B$) = "Building",

Type ($M$) = "Listed_Monument",

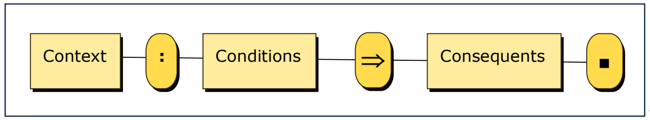
$\models$ *Inside* (*Geom* ($B$), $T$), *Inside* (*Geom* ($M$), $T$)

:

*Disjoint* (Geom($B$), *Union* (*Buffer* (*Geom* ($M$), 100)))

$\Rightarrow$

*State* ($B$) = "LM_Approved"

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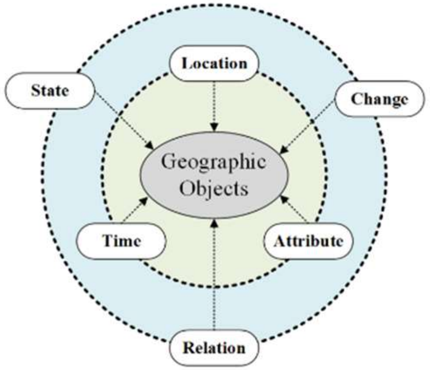
## Geo-KG (Shu Wang 2019)

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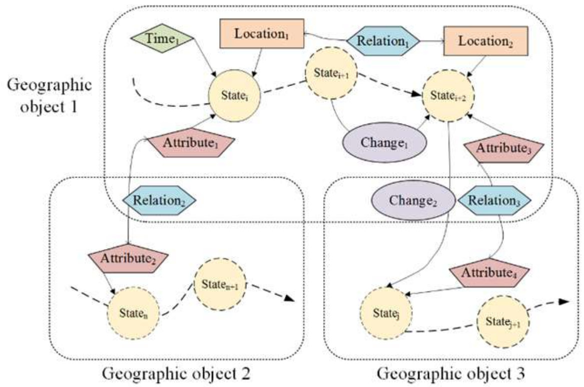
## Large interactions between urban objects with Geo-KG (Shu Wang 2019)

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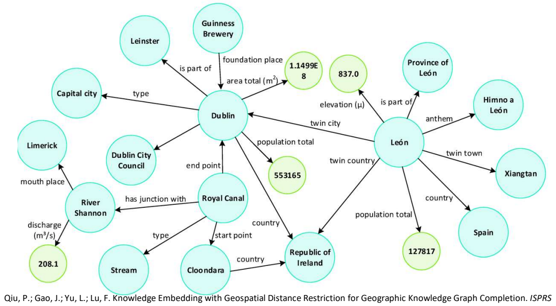
## Knowledge Graph for Dublin




Qiu, P.; Gao, J.; Yu, L.; Lu, F. Knowledge Embedding with Geospatial Distance Restriction for Geographic Knowledge Graph Completion. *ISPRS Int. J. Geo-Inf.* **2019**, *8*, 254. https://doi.org/10.3390/ijgi8060254

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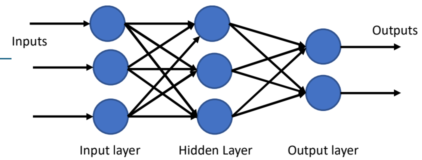
## Learning
## Ex: Mass plan




Request input
Shape of the plot of land
Number of buildings
Other services

Response to the request
Proposal for
several mass plan

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## Foundation Models

- Chatbots based on large models
  - Large sets of training texts
  - Token (part of a word) (*N*-gram)
  - Statistics between tokens
  - Well-suited for text, images etc.
- What about space?
  - Raster: aerial photos and satellite images
  - Vector: 2D and 3D

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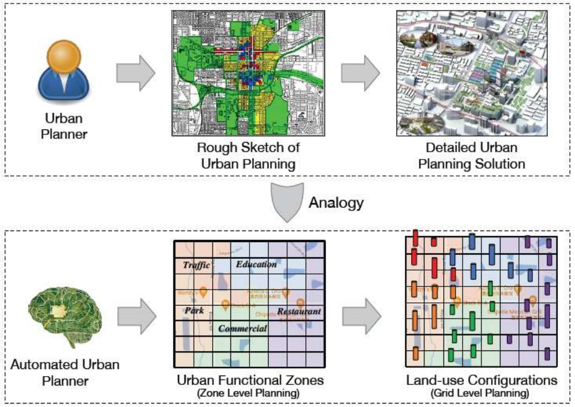
## Approach from Dongjie Wang et al. (2023)

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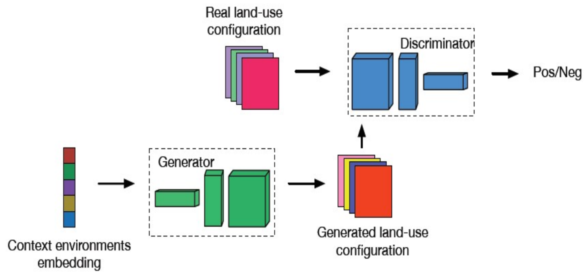
## Automatic land use configuration planner




- Wang D., Fu Y., Wang P., Huang B., & Lu C.T. (2020). Reimagining City Configuration: Automated Urban Planning via Adversarial Learning. In 28th *International Conference on Advances in Geographic Information Systems* (SIGSPATIAL '20), November 3–6, 2020, Seattle, WA, USA. ACM, New York, NY, USA, 10 pages.

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Confidential Internal

**After YOUSEF KHALILI, Tonomos**

*CCO / President Professional Services Unit*

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## 3. Conclusions

- Promising new concept
- Intuition for several decades
- Assembly of technologies
- Lack of a comprehensive conceptual framework
- Multiple acceptions of the concept
- Several ways of achieving
- No success story yet

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## Two possible evolutions

- In the filiation of "enlightened despotism"
  - Techno-authoritarianism
- In the democratic filiation
  - Tools for participation

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## Special issue of the "AI Journal" RL Guest Editor

**Special Issue**

**AI-Powered Smart Cities: Towards Sustainable Urban Environments**


https://www.mdpi.com/journal/ai/special_issues/40JO81A46V

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