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Digital Twins for industrial applications

Fernando Cucchietti

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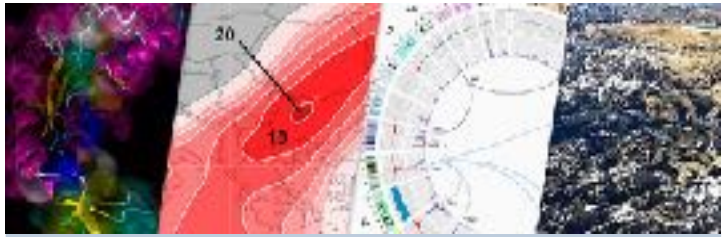
Supercomputing services
to Spanish and EU researchers



R&D in Computer, Life, Earth
and Engineering Sciences

PhD programmes,
technology transfer
and public engagement

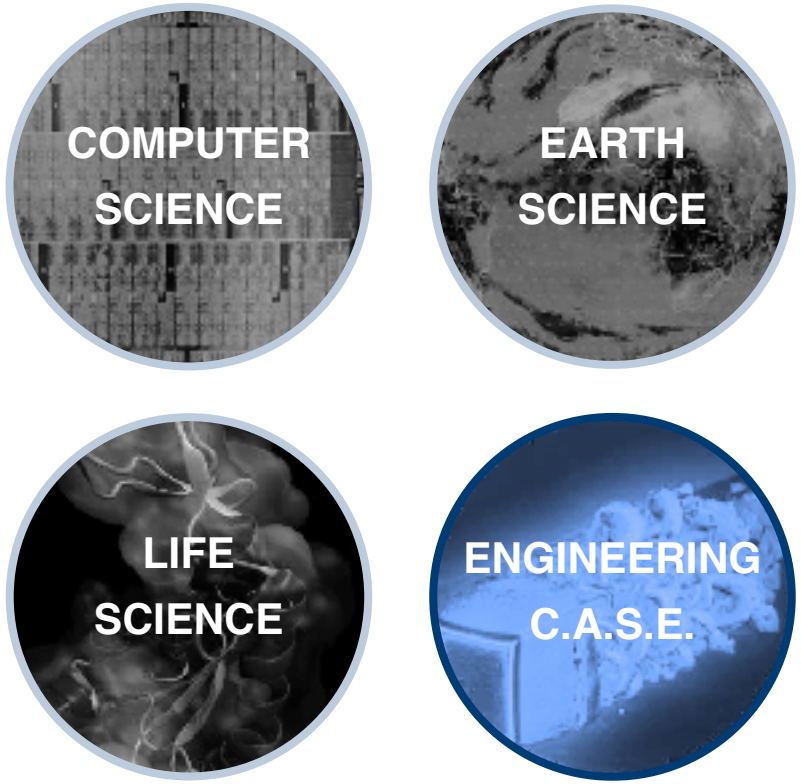
BSC-CNS is a **consortium** composed of

- ➔ Spanish government (60%)
- ➔ Catalan government (30%)
- ➔ Polytechnic University of Catalonia - UPC (10%)

MareNostrum 5

Accelerating science
to 314,000 trillion
calculations per second.

Scientific departments BSC



Computational Applications
for Science and Engineering

Data Analytics & Visualization Group


Fernando Cucchietti


Paula Szewach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Carlos García


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Jerónimo Calderón


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Paula Fernández

BSC
DATA VIZ
.GROUP


Marc Heras

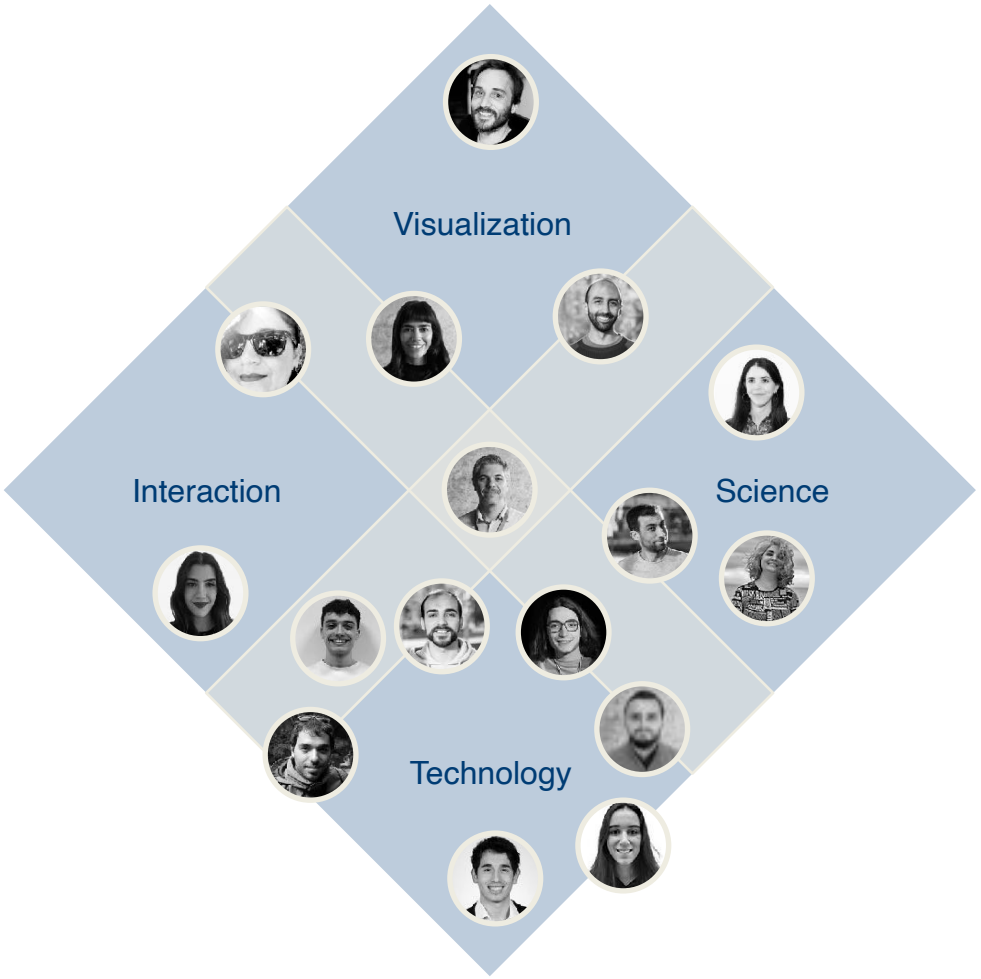

Raquel Barrachina


Adria Espinoza


Roger González

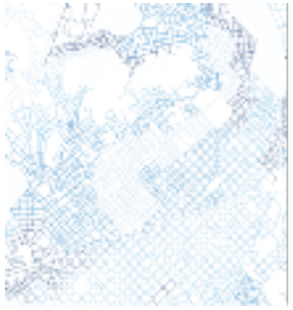

Alex Gil

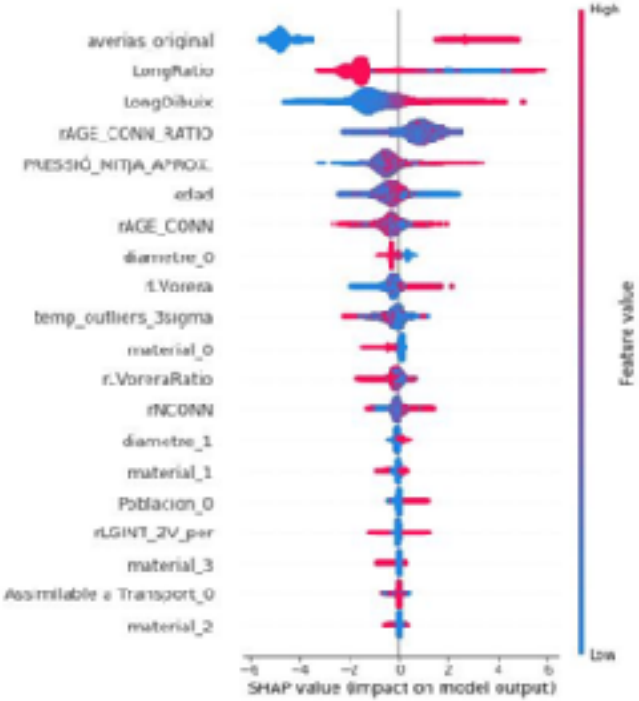
Talent connection



- Scientific Visualization and Storytelling
- Interactive Data Visualization
- Industrial AI and Digital Twins
- Art+Science Driven Innovation
- Urban Data Science

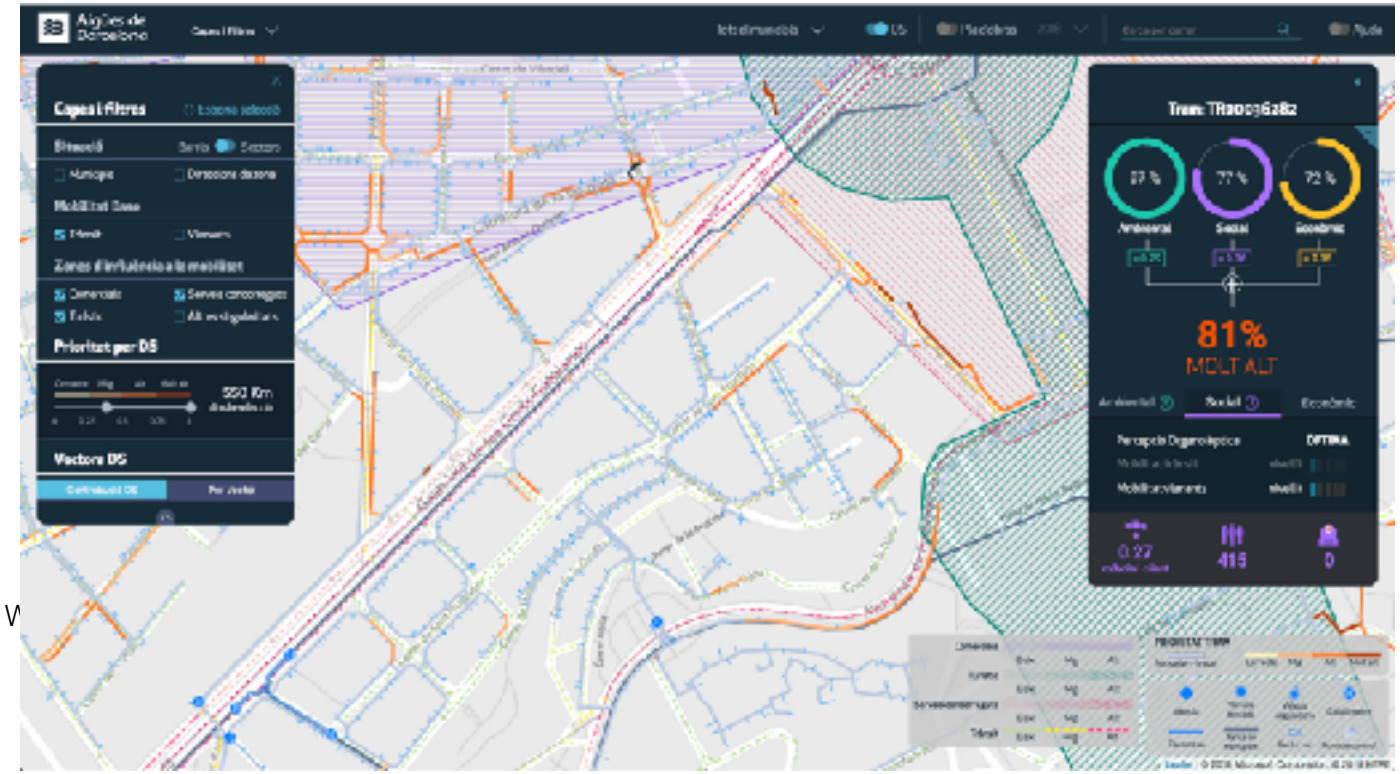
Predictive Maintenance





Predictive importance of features

Result: Hierarchical model with **4x more accuracy** than previous models



Predictive Maintenance: Developed algorithms to forecast yearly probability of failure of elements in water distribution network (all hidden assets), leading to improved renovation investment and better understanding of causes of failure

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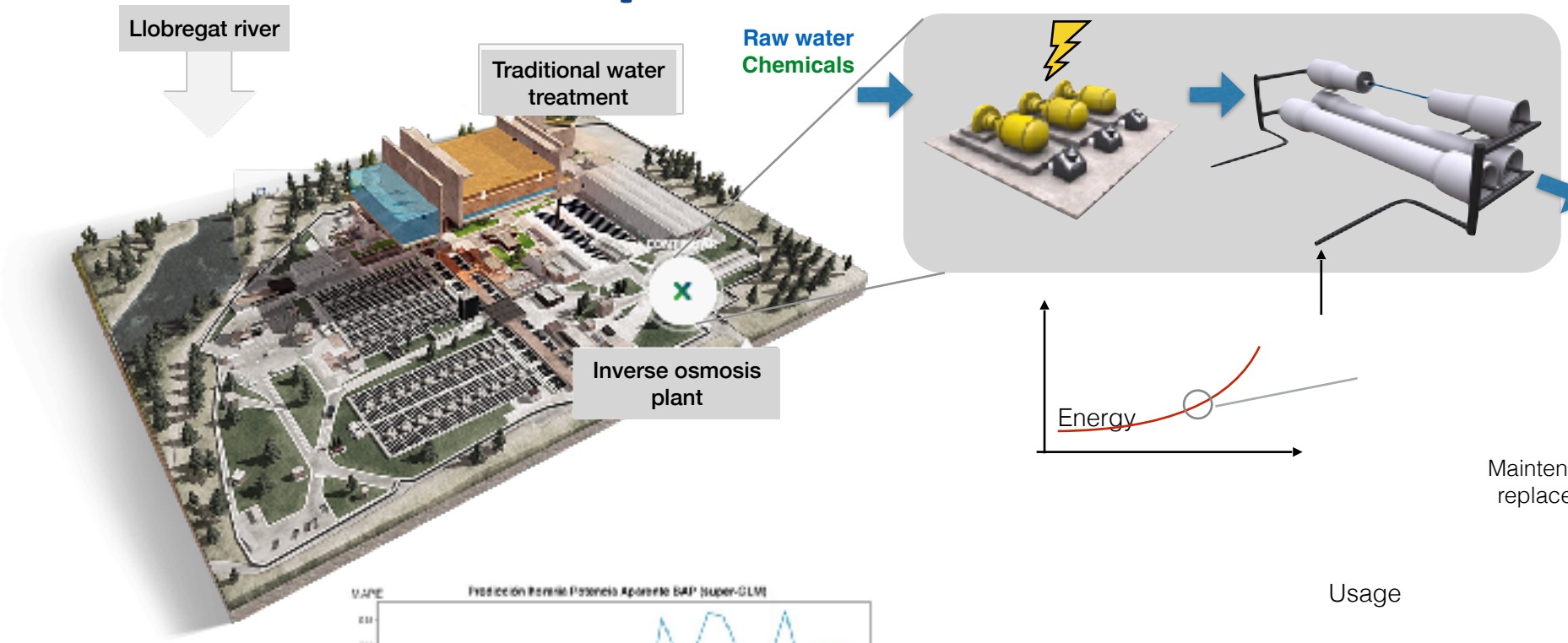
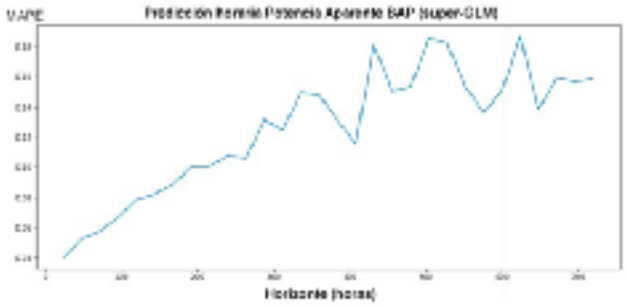
Optimisation of resources



- Replacement is **costly**
- Maintenance **reduces** useful life
- Lack of maintenance **reduces energy efficiency**



Forecast machine evolution up to **30 days** with **<20% error**

Recommendations on maintenance and operation procedures

7.5% reduction of energy consumption

Energy Efficiency: Developed forecasting algorithms of a water treatment plant dynamics, leading to optimisation strategies that reduced total energy consumption

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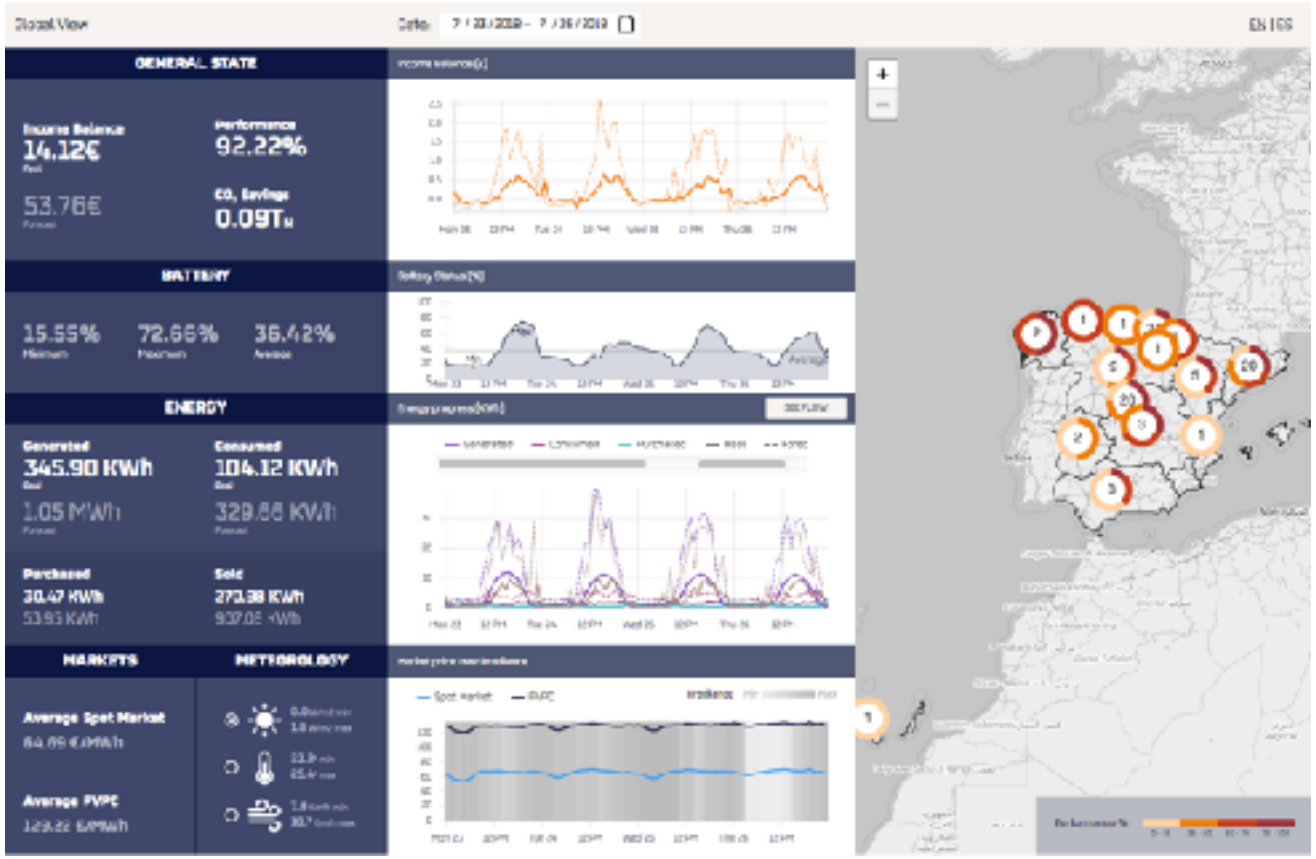
Optimal operation



Control panel of operation of multiple energy plants

Distributed power producing sites coordinated by central AI

Virtual Power Plants: Developed forecasting algorithms (local production and consumption, global energy demand/offer and bid price), optimisation algorithms, a visualisation platform for monitoring, and a digital twin for development and testing.

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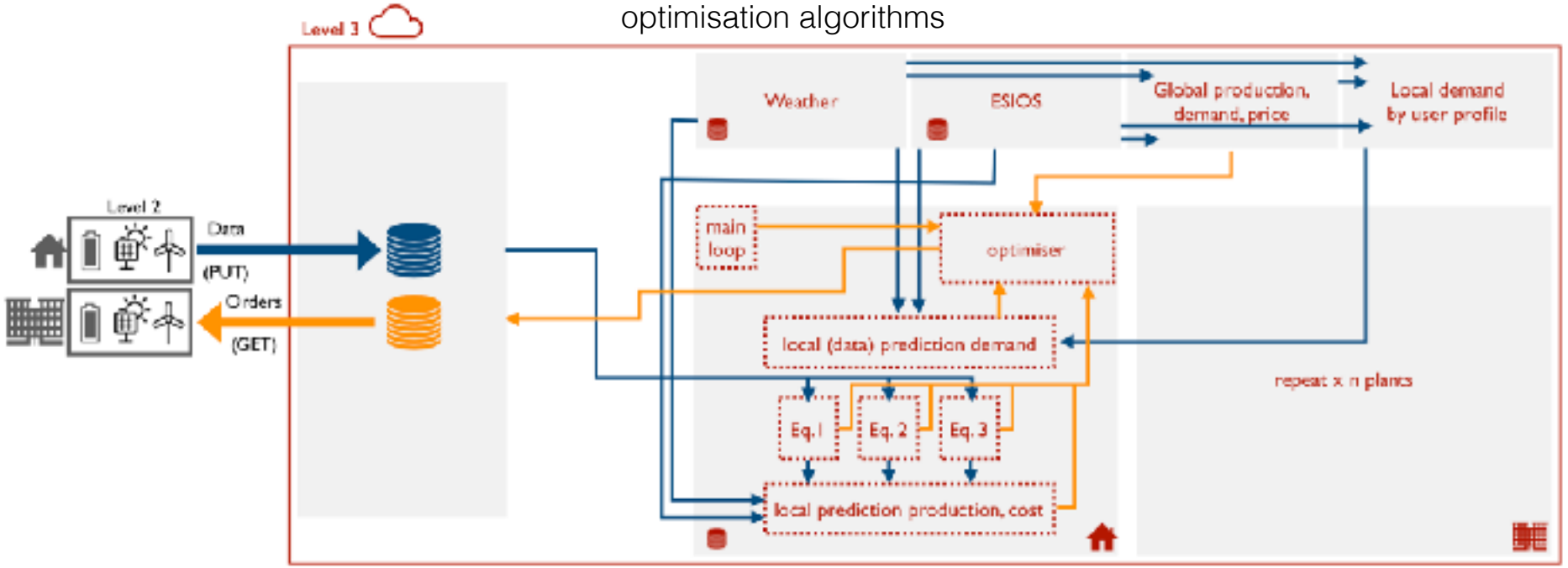
Optimal operation

Central AI relies on forecasts and optimisation algorithms



Global operations (level 3) over **10% gain** compared to local control (level 2)

Virtual Power Plants: Developed forecasting algorithms (local production and consumption, global energy demand/offer and bid price), optimisation algorithms, a visualisation platform for monitoring, and a digital twin for development and testing.

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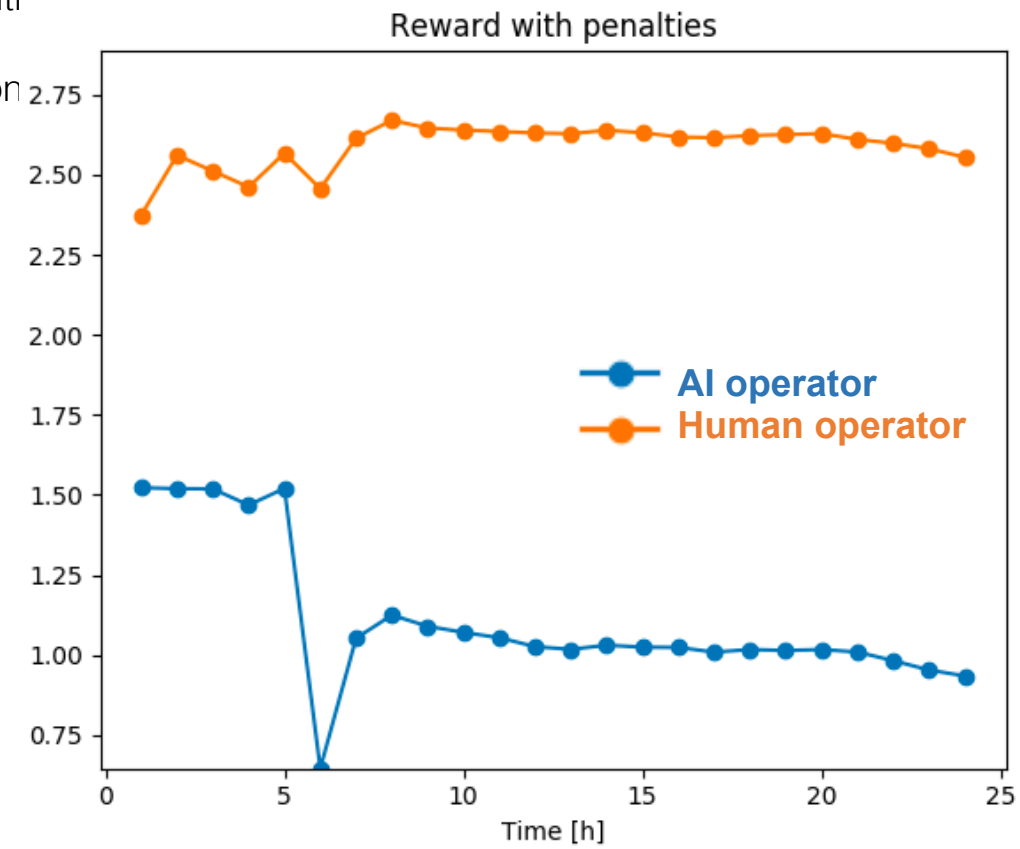
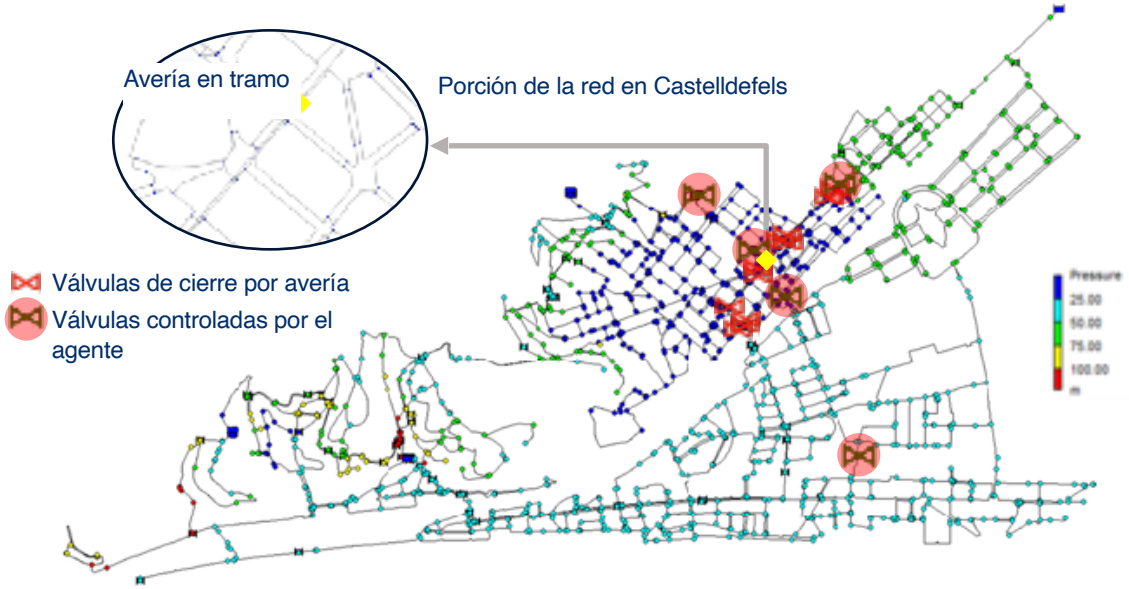
Operator in control room receives recommendation



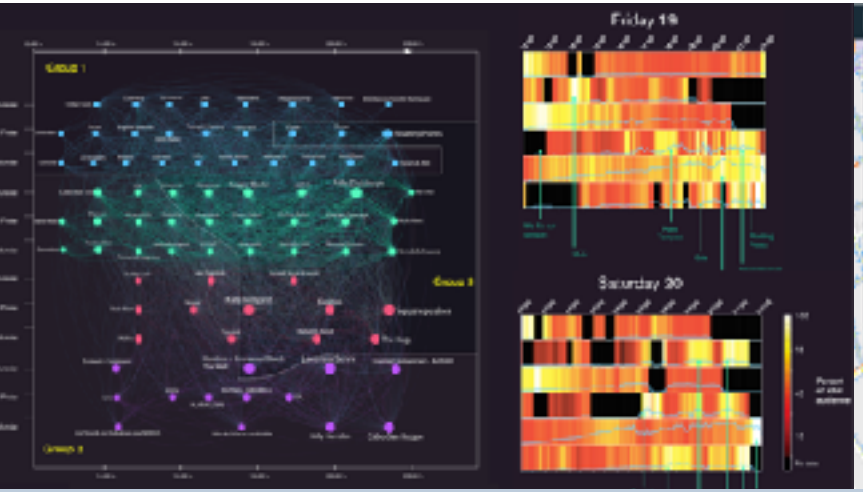


Digital twin simulates behaviour of distribution network

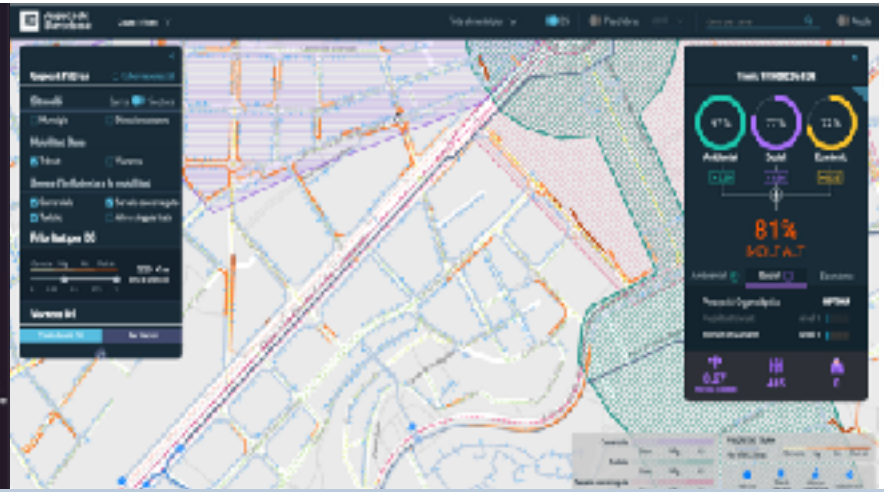
Reinforcement learning based AI controls the network and obtains higher metrics than human designed operation schedule

AI driven automated control: AI control of industrial plants or machinery to optimise sequences of tasks using Reinforcement Learning techniques

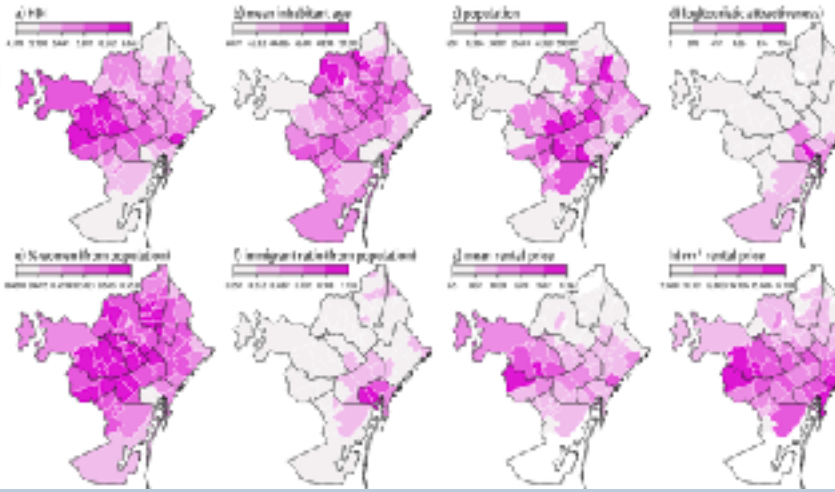
Since 2015: getting started



We know what you did last Sónar

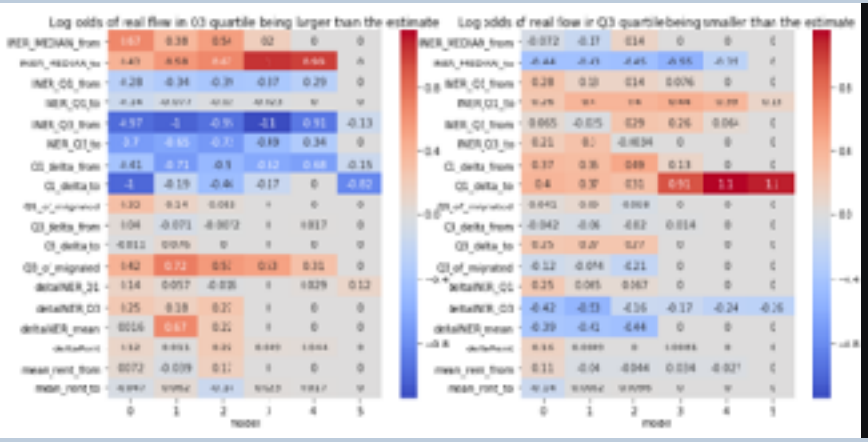


Aguas de Barcelona

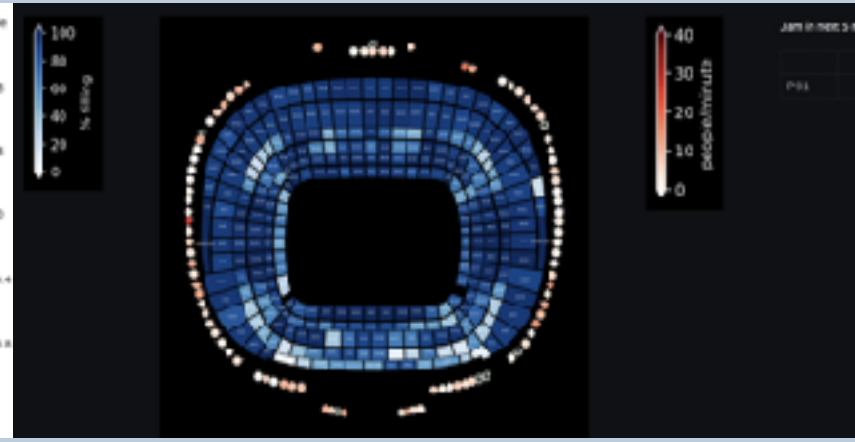


Accessibility

PRECINCT

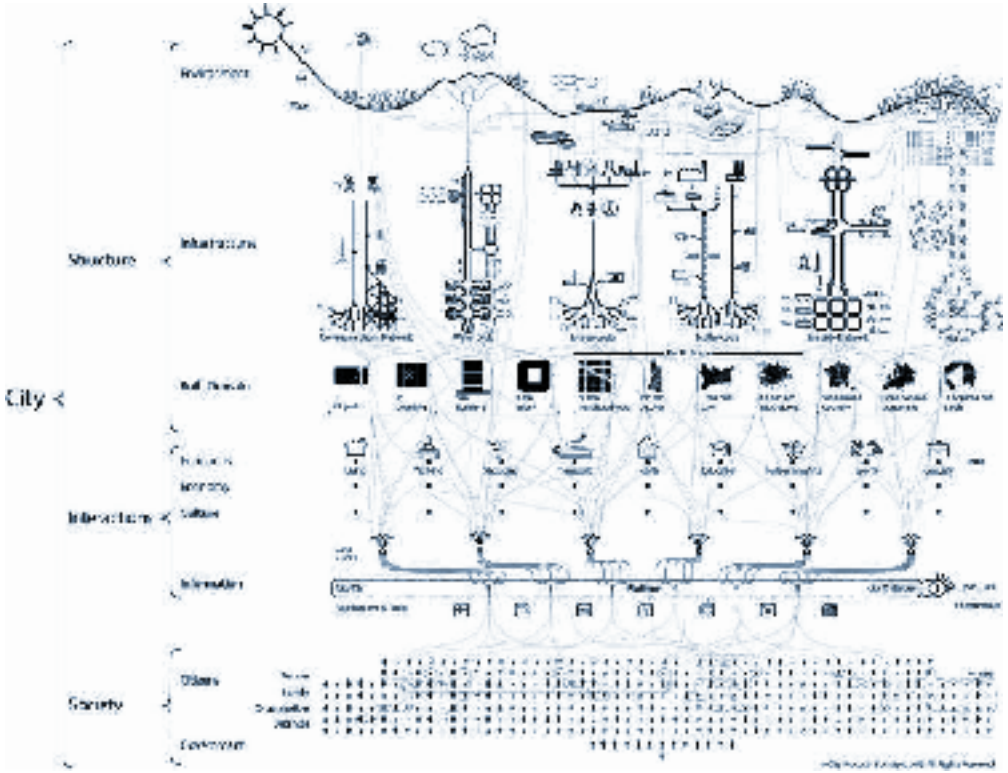


Gentrification



IOTwins

From anatomy to physiology of the city



Theoretical framework on **how** to **simulate** a **complete city**

Meta, I., Cucchietti, F. M., Navarro-Mateu, D., Graells-Garrido, E., & Guallart, V. (2022). *A physiology-inspired framework for holistic city simulations. Cities*, 126, 103553. https://doi.org/10.1016/j.cities.2021.103553

Use Case: The Camp Nou Digital Twin

2 Edge nodes mix w/external data and pre-analyse and transmit stats to the cloud

3 AI models create (anonymous) audience profiles (affecting mobility such as age, gender, and tourist/local)

Camp Nou

Edge nodes
Kiosks
smart cameras
Signaling

IoT devices
Wifi
Turnstiles
Cameras
Ticketing
Vending
smart IoT

External data
4G/5G
Weather
Traffic
Social media
Wikipedia

1 IoT devices measure crowd state in the facility

Cloud

Machine Learning inference and forecast

Metrics

Audience profiles

4 Profiles feed into HPC Agent Based Model simulations

BSC

Mobility simulation:
Agent based modelling

5 Evacuation, entry/exit, and general flow scenarios are optimised with 1000's of simulations and sent back to cloud.

6 Optimal configuration is sent to edge notes to actuate

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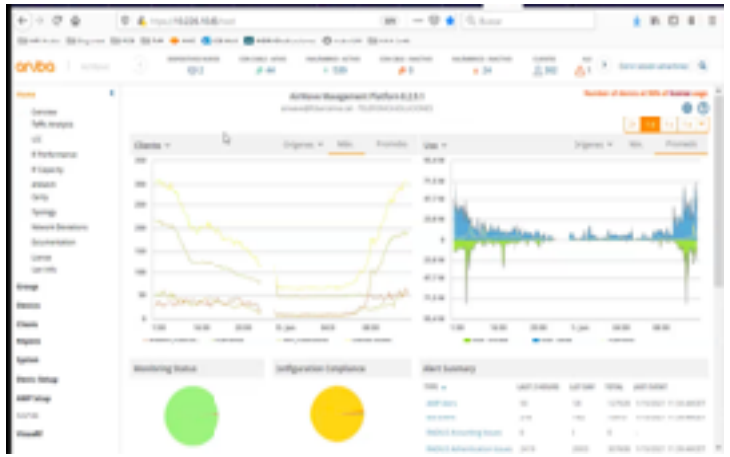
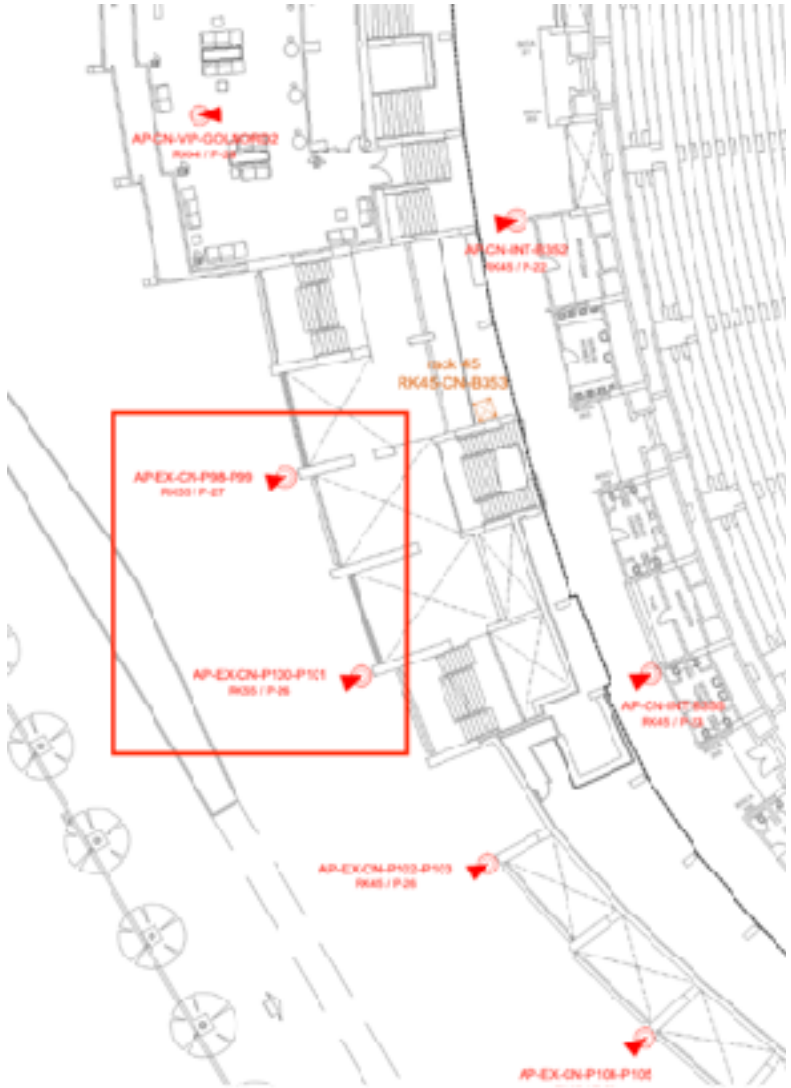
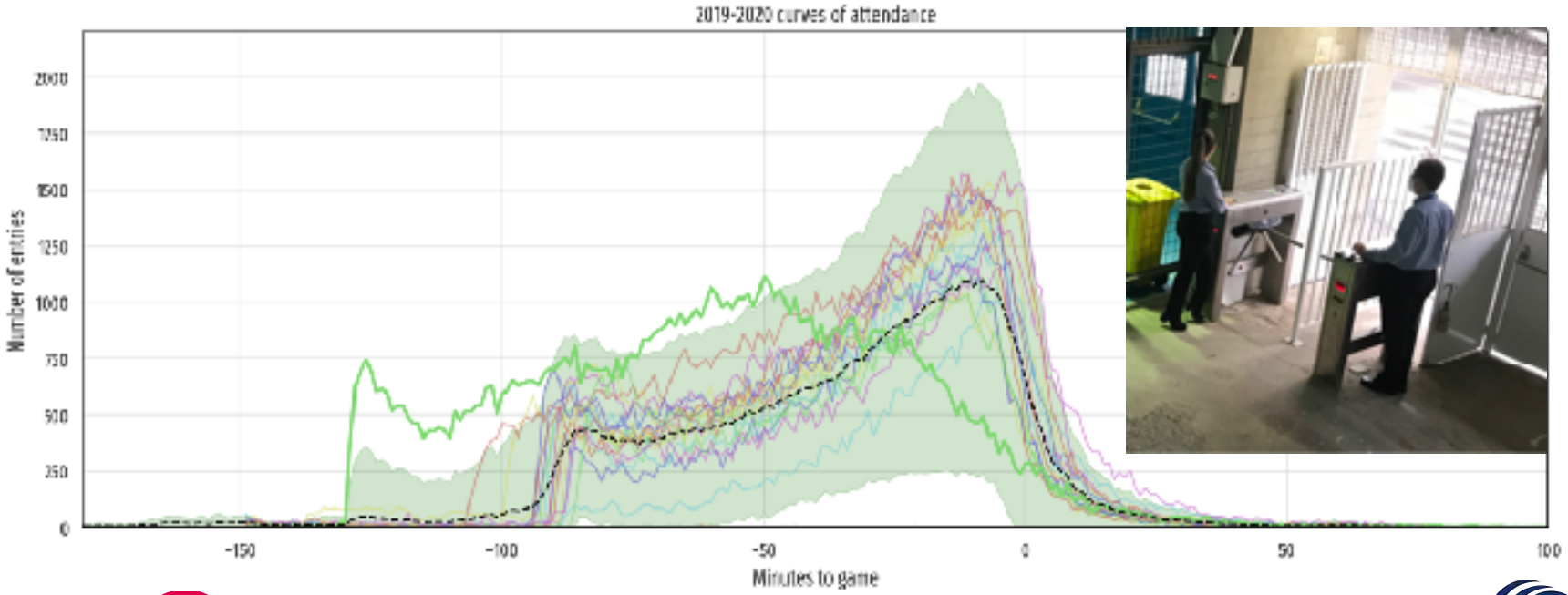
IoTwins

Sensors and IoT devices

- API
  - Coming from FCB edge
  - Anonymised WiFi APs data
  - Sensors (turnstiles etc.)
  - Cameras (delayed)







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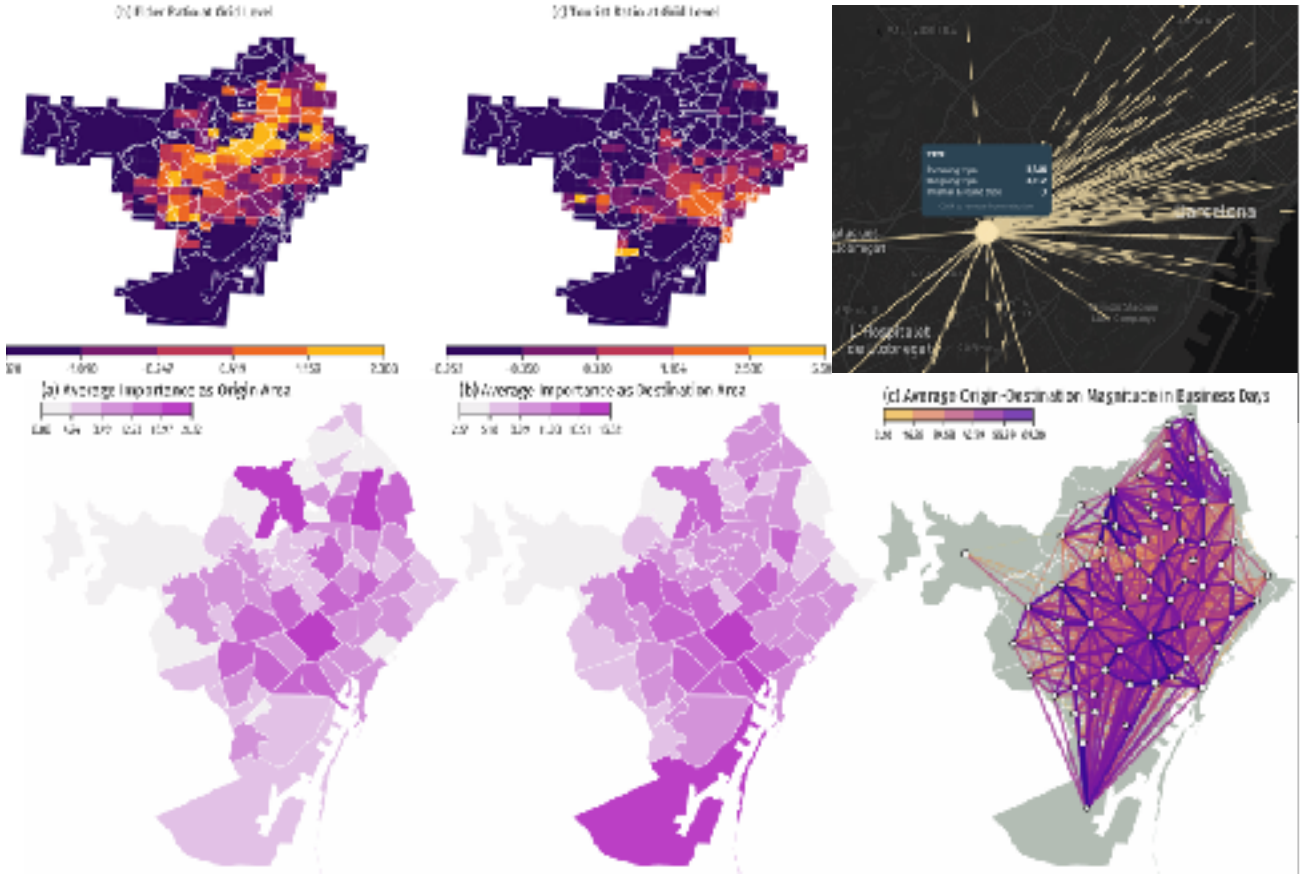
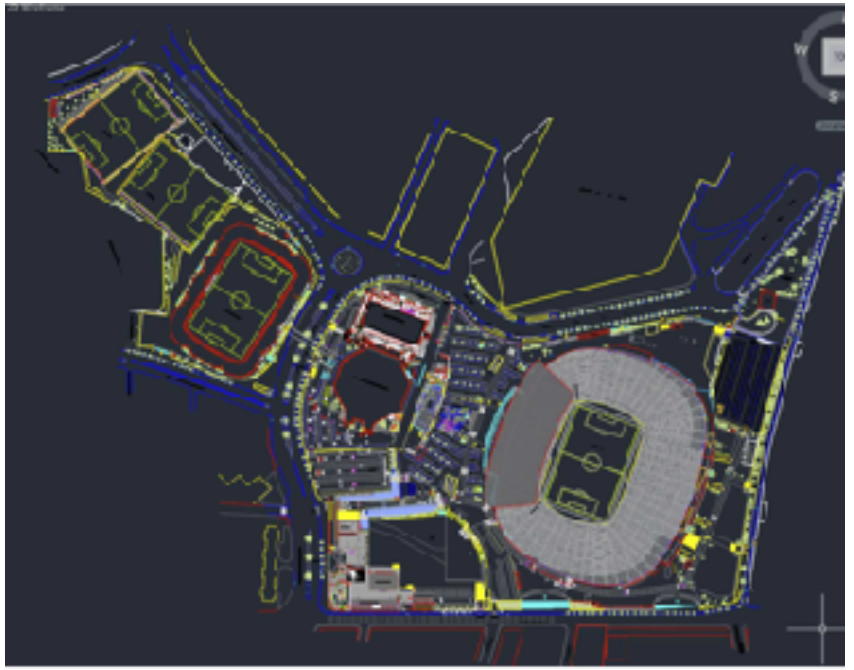
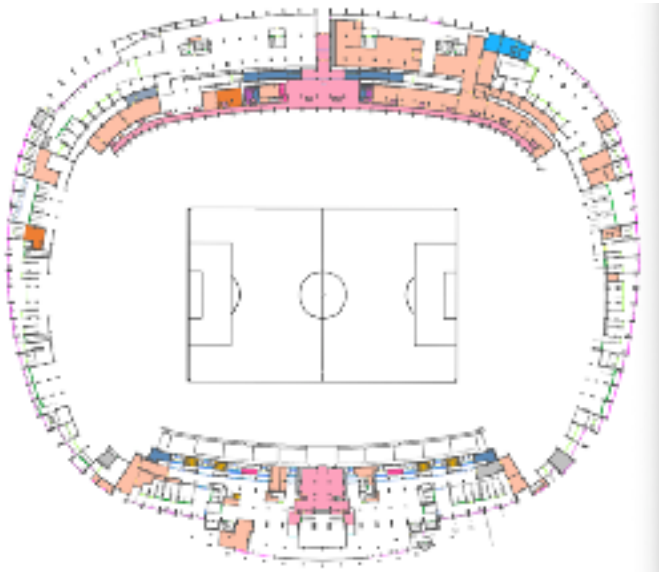
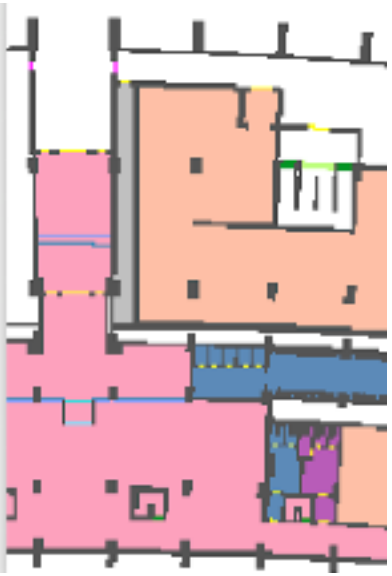
IoTwins

External data input









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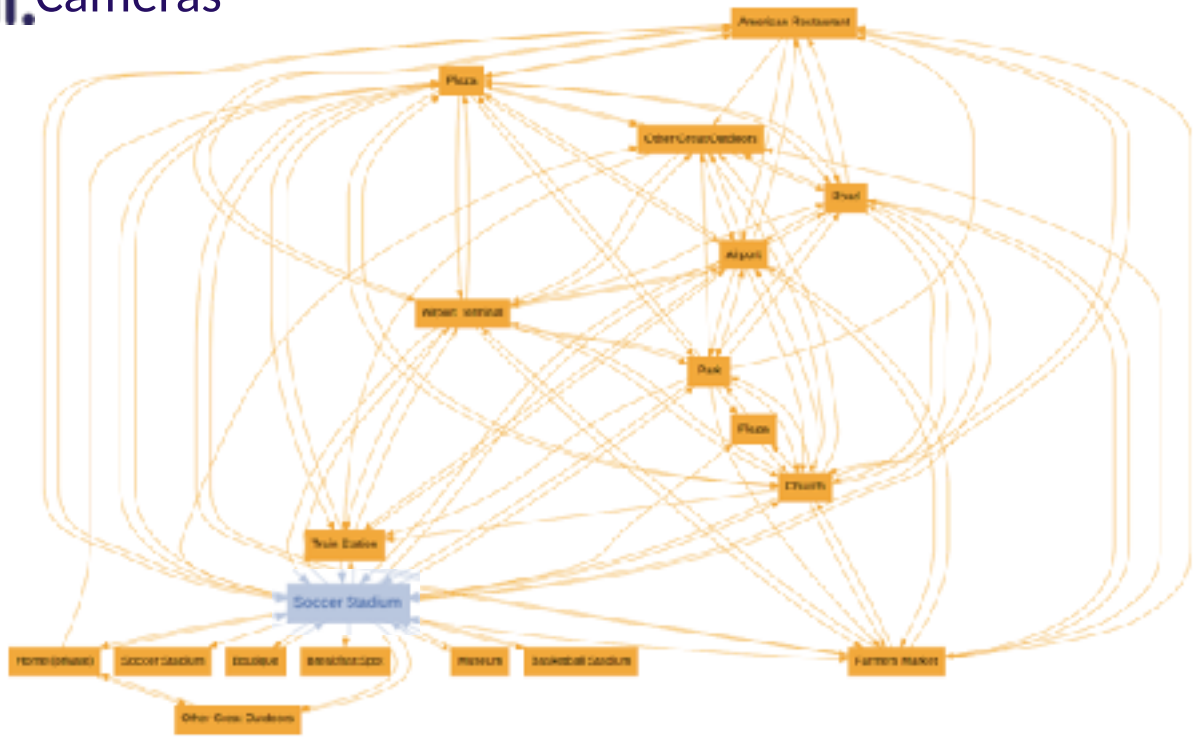
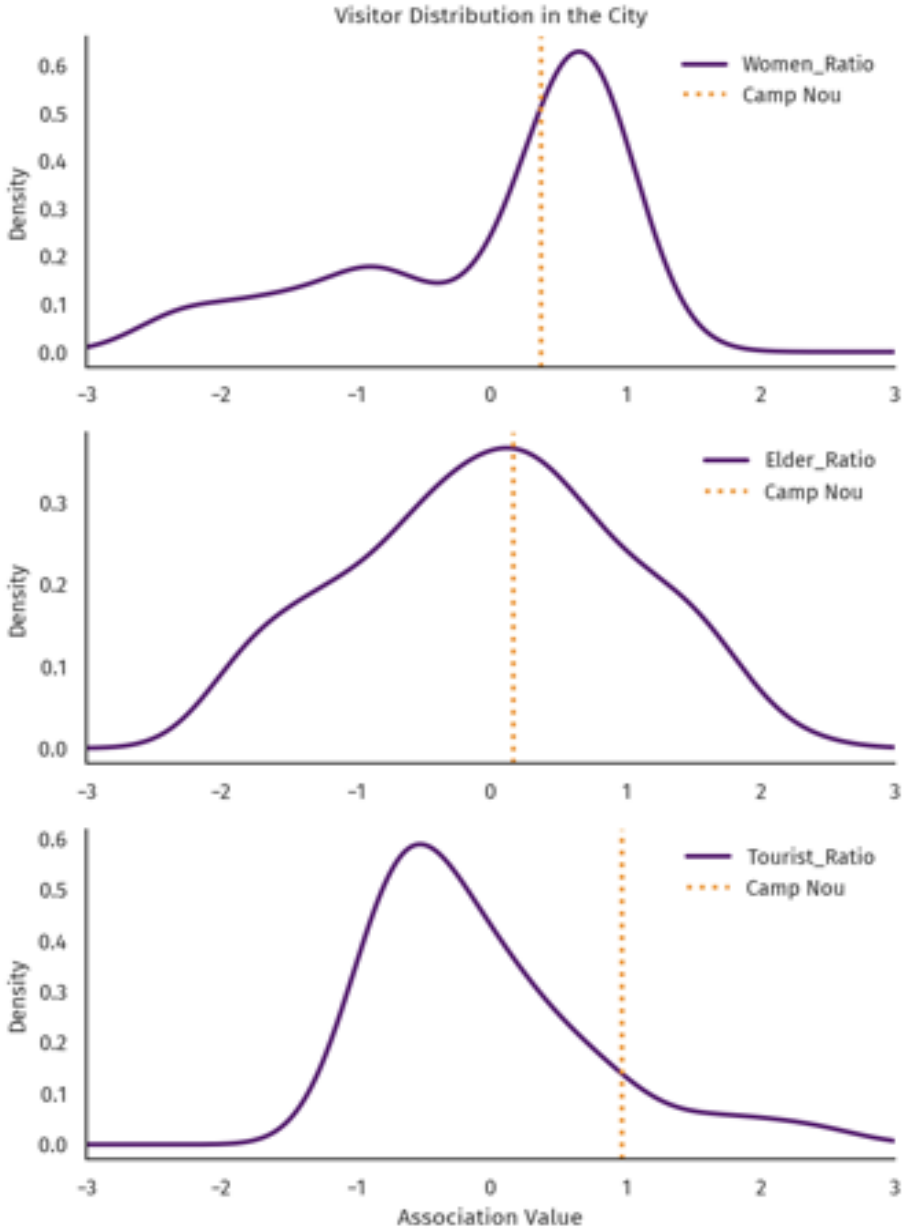
IoTwins

Machine learning models

- Visitor profile (related to mobility)
  - Origin
  - Gender
  - Age bracket
  - Cameras





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IoTwins

Machine learning models

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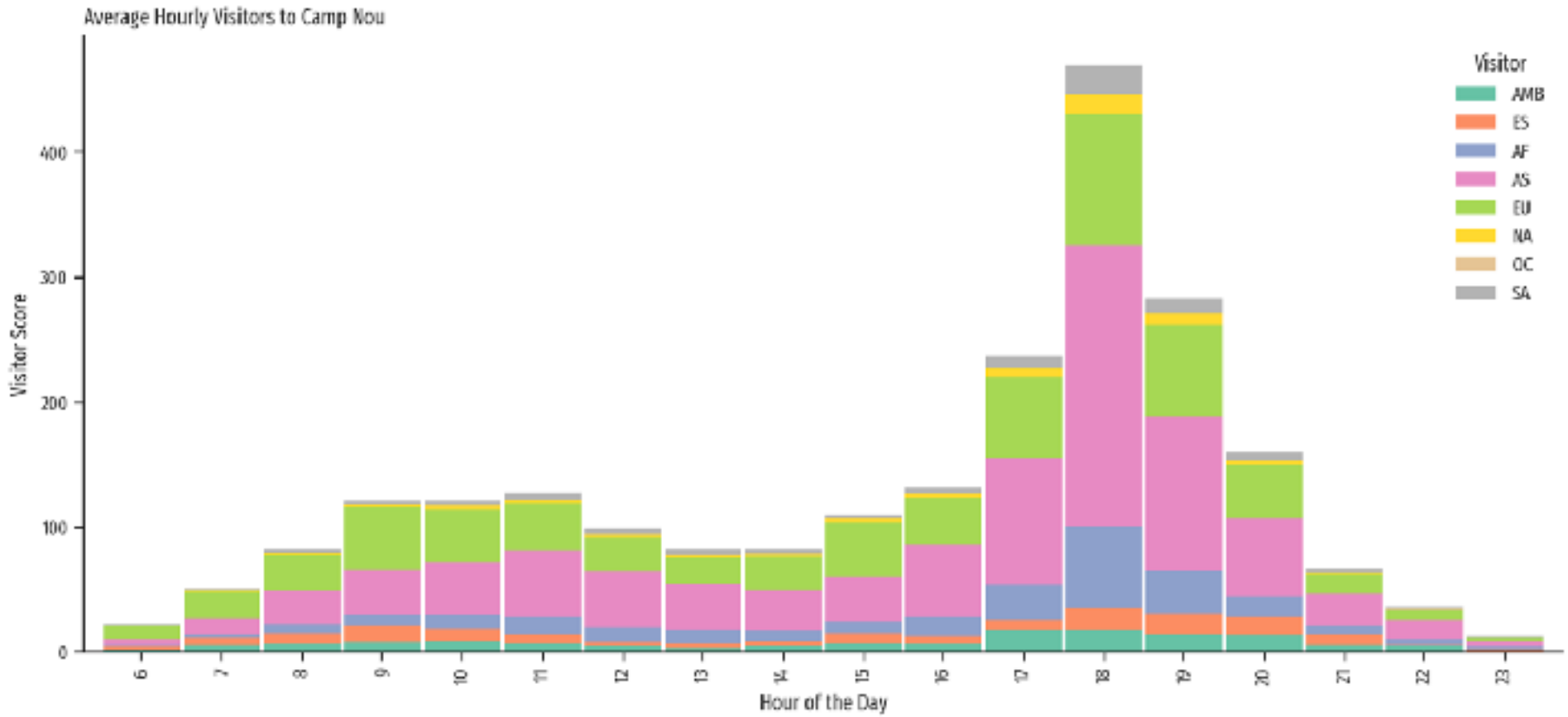

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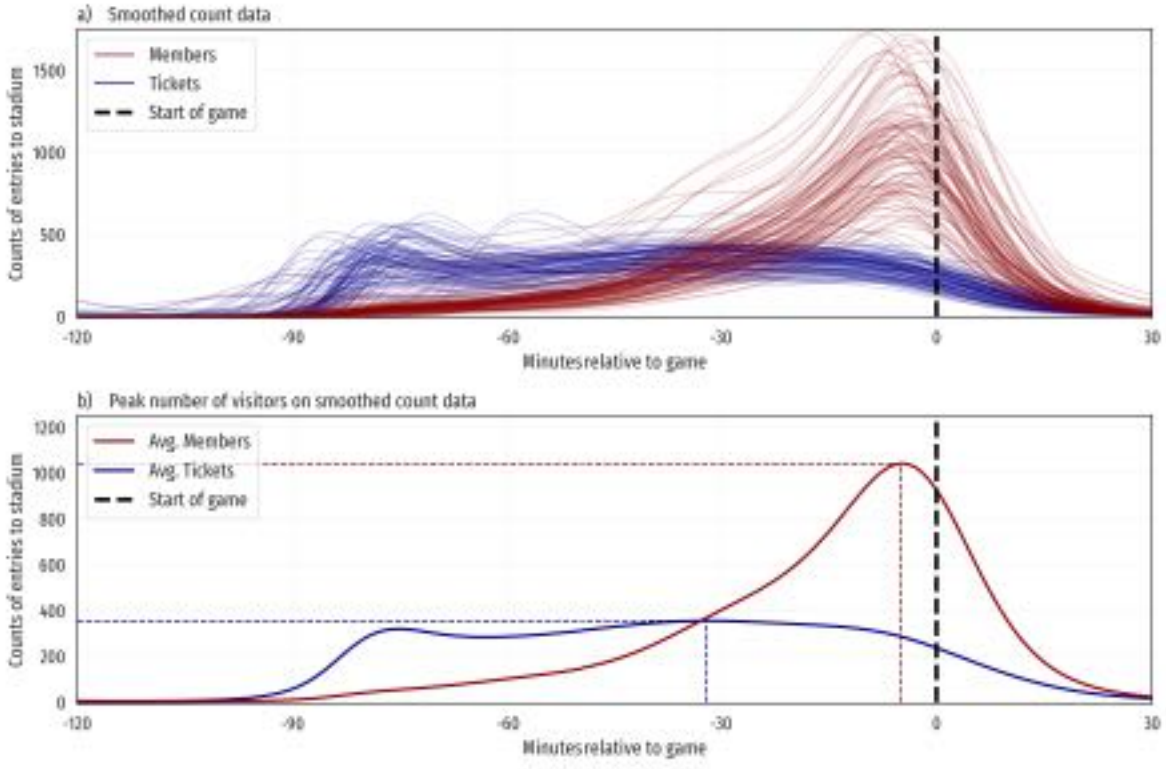
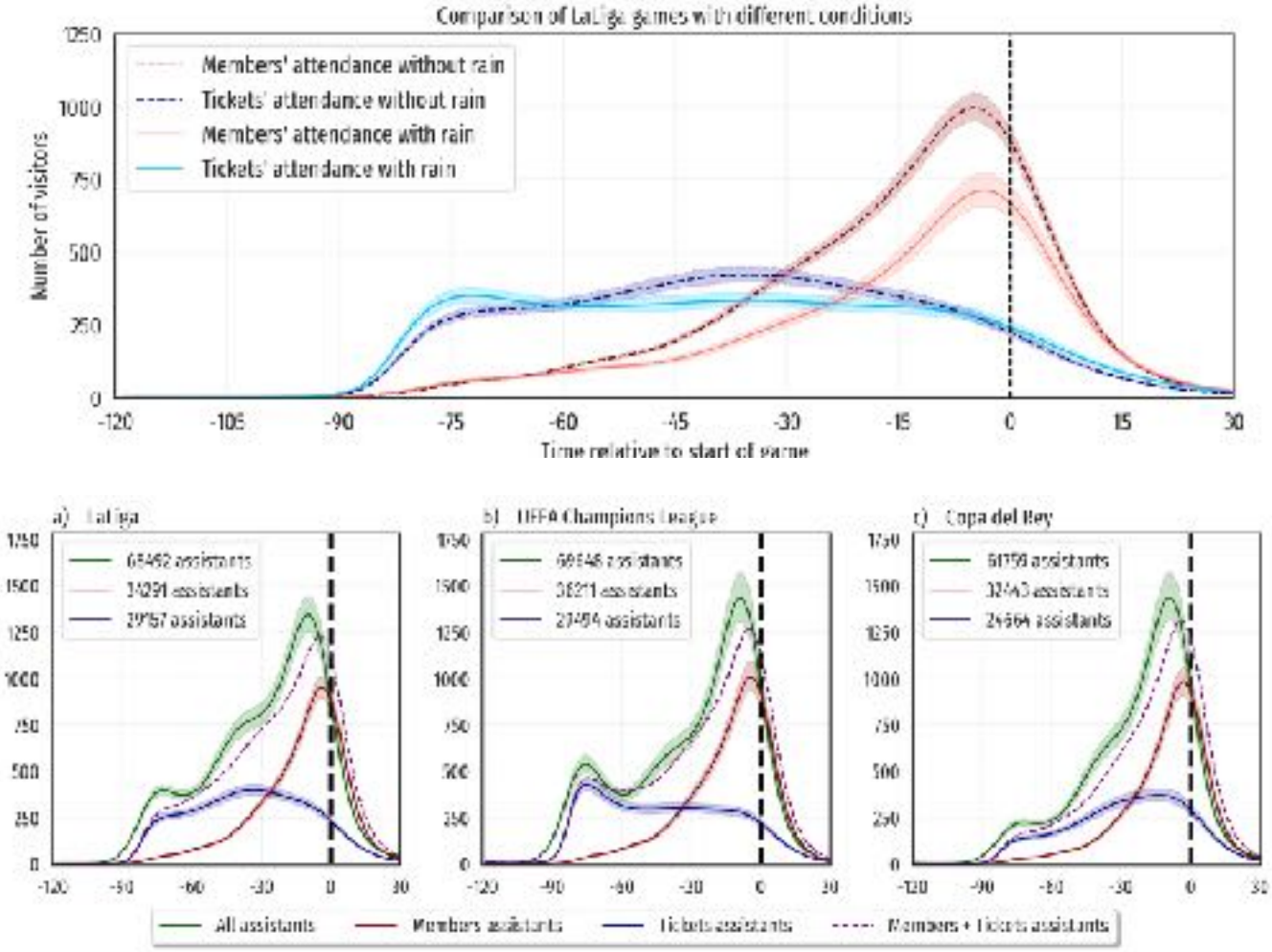
IoTwins

ML models: Predicting attendance

- Attendance influx
  - By gate and by minute
  - Including profile





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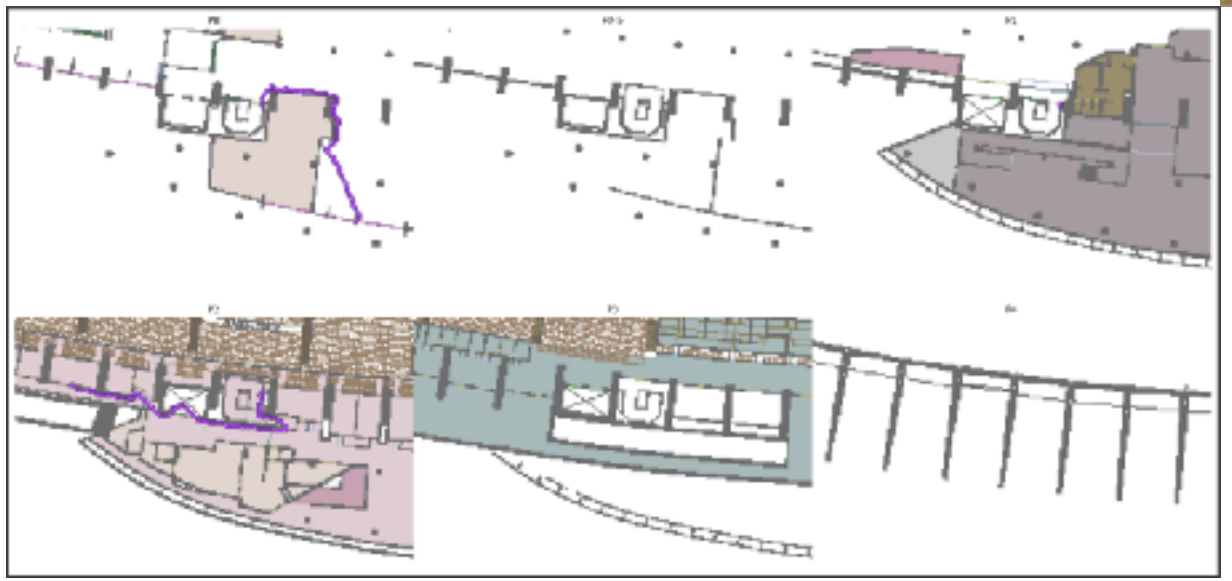
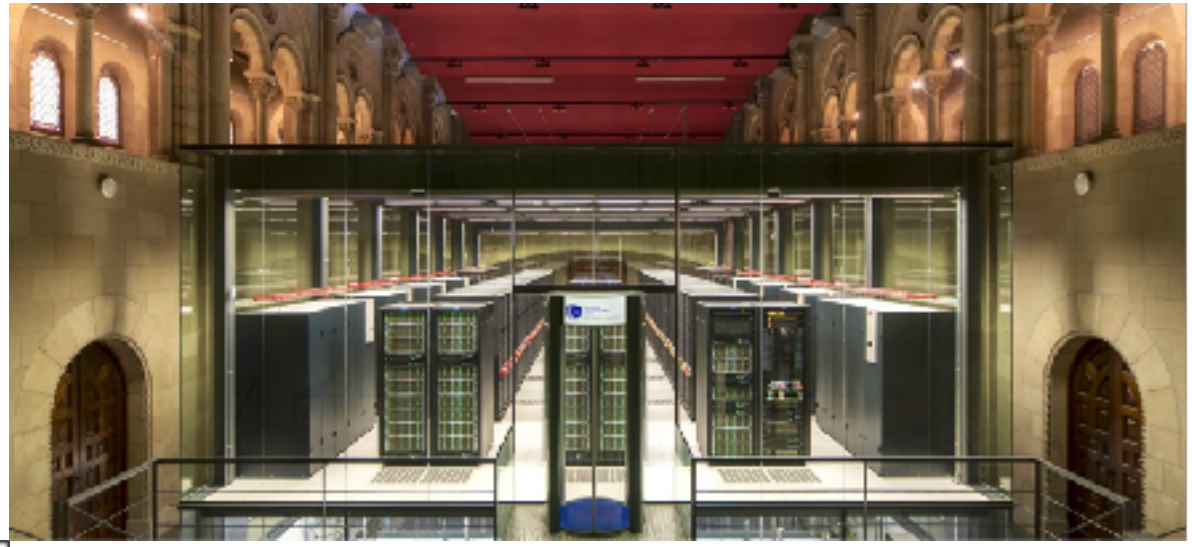
IoTwins

Simulation

- Pedestrian Modeling
  - Collision avoidance
  - Profiles of behavior
  - Path finding with local information





- HPC simulation
  - Marenostrum IV
  - Pandora

P2
P1
P0.5
PB

Urban Data Science

We aim to

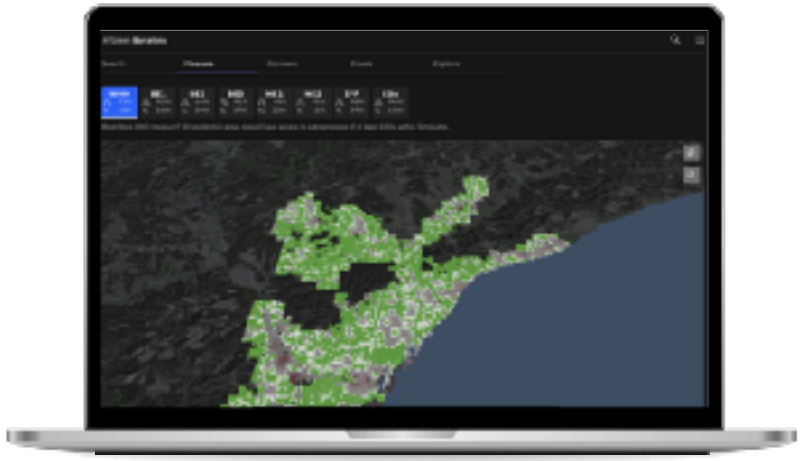
- Influence urban regulations to improve the quality of life in cities.
- Help policy makers make evidence-based and people-centred decisions.
- Help citizens interact with their city by proposing better interventions that respect individual privacy and ethical principles.

We **use data** to **study** the **interactions** that take place in cities: between their **inhabitants** and their **environment**.

Recent projects

Pilots for applicability in different areas

THE 15-MINUTE CITY



AT GREEN (GREEN INDEX)

CIRCULAR CITY INDEX

VCITY

A human-centric platform for Urban Digital Twins

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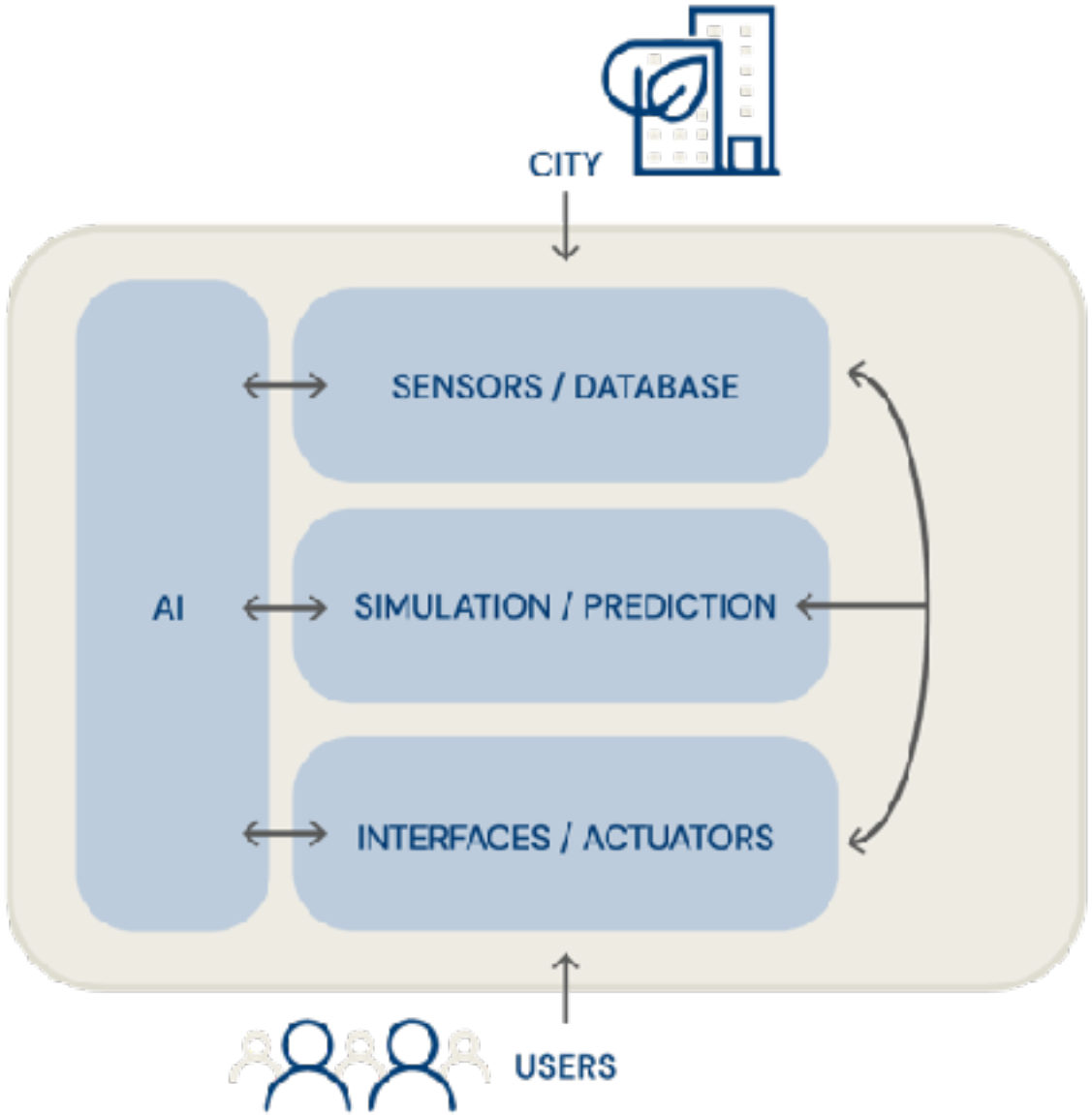
An Urban Digital Twin (UDT) is a tool to improve the process of designing and implementing Urban Policies.

It involves three connected components:

- A data collector and organizer.
- A set of simulators and models of the different parts of the city.
- Interfaces that allow users to visualise and control the results.

Together, the UDT allows for improved city management and planning by analysing the past, monitoring the present and predicting the evolution of future scenarios.



An example of why a GDU is useful

Developing strategies to reduce extreme heat in cities.

Context

- Between 1983 and 2016, exposure to extreme heat in urban environments grew by 200% globally.
- Total urban warming increased by 52% above proportional population growth.

Solution effective, but complex

Different spatial patterns require different local strategies to reduce heat. Multiple factors influence urban warming, often with interrelated effects.

The most effective strategies are those that combine approaches, applying a holistic approach and tailoring policies to the needs of each city.

city

virtual

"vCPU", virtual versions of a physical "CPU”

Mission

To provide a human-centric platform for Urban Digital Twins that supports the growth of fairer and more sustainable cities, ready to adapt to whatever the future brings.

Vision

A growing network of cities developing through data-driven decision making based on the needs of the people who live in them. vCity will be an inspiration and a reference of the potential of the Urban Digital Twins at social, political and economic levels.

Pilares

Human-centric

We adopt a socio-technical approach to developing UDT, incorporating human values into the design process.

Honest

A platform has the potential to influence society must always be transparent, traceable and auditable.

Modular

The software must be compatible with an unknown future; it will be reusable and adaptable to new urban environments and the different actors that accompany them.

Human-centric

- **Designed to address people's problems**
  Focus on impact on people
- **Support for evidence-based policies with participatory democracy**
  Considering that there are different stakeholders
- **Co-designed with end-users**
  Considering that there are different stakeholders
- **Usable/Comprehensible**
  Some knowledge exists,
  but people cannot/do not know how to use it.

Honest

- **Open? Free?**
  Unlimited
- **Transparent**
  Security and joint assessments
- **Traceable and auditable**
  Data lifecycle is key to compliance
- **Respectful**
  GDPR is just the beginning

Modular

- **Adaptable**
  Every city is a universe
- **Reusable**
  Software inspired idea
- **Compatible**
  With other actors in the city
- **Future-proof**
  Simple and open standards

Allows:

- Urban planners to simulate different scenarios and combinations of strategies and visualise the results in a simple way.
- Technicians with specialised knowledge to have a centralised tool to experiment with comparable indicators.
- Politicians and citizens to review the summarised information.

vCity is a **integrated platform** that allows you to **build different scenarios** linked to each other.

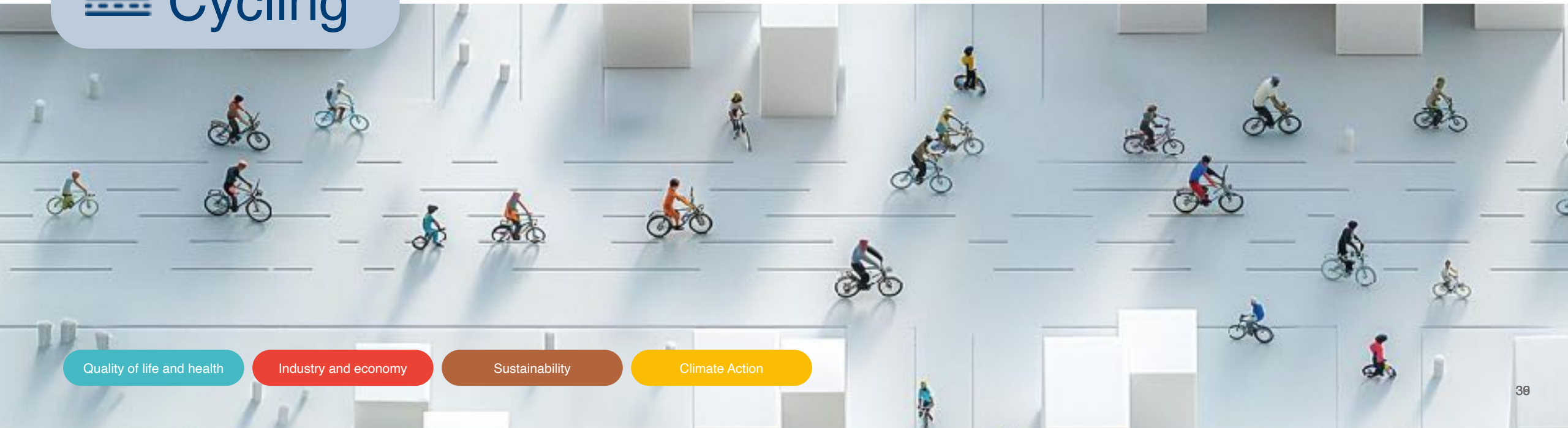
Living Labs

Plan and implement an efficient network of cycle lanes.

To meet the challenge of shifting to more sustainable transport, with a focus on reducing pollution and improving public health, a concerted effort has been made to promote cycling.

This vCity demonstration will provide a system for creating and expanding the cycleway network in an economically efficient way, taking into account people's needs.

Cycling

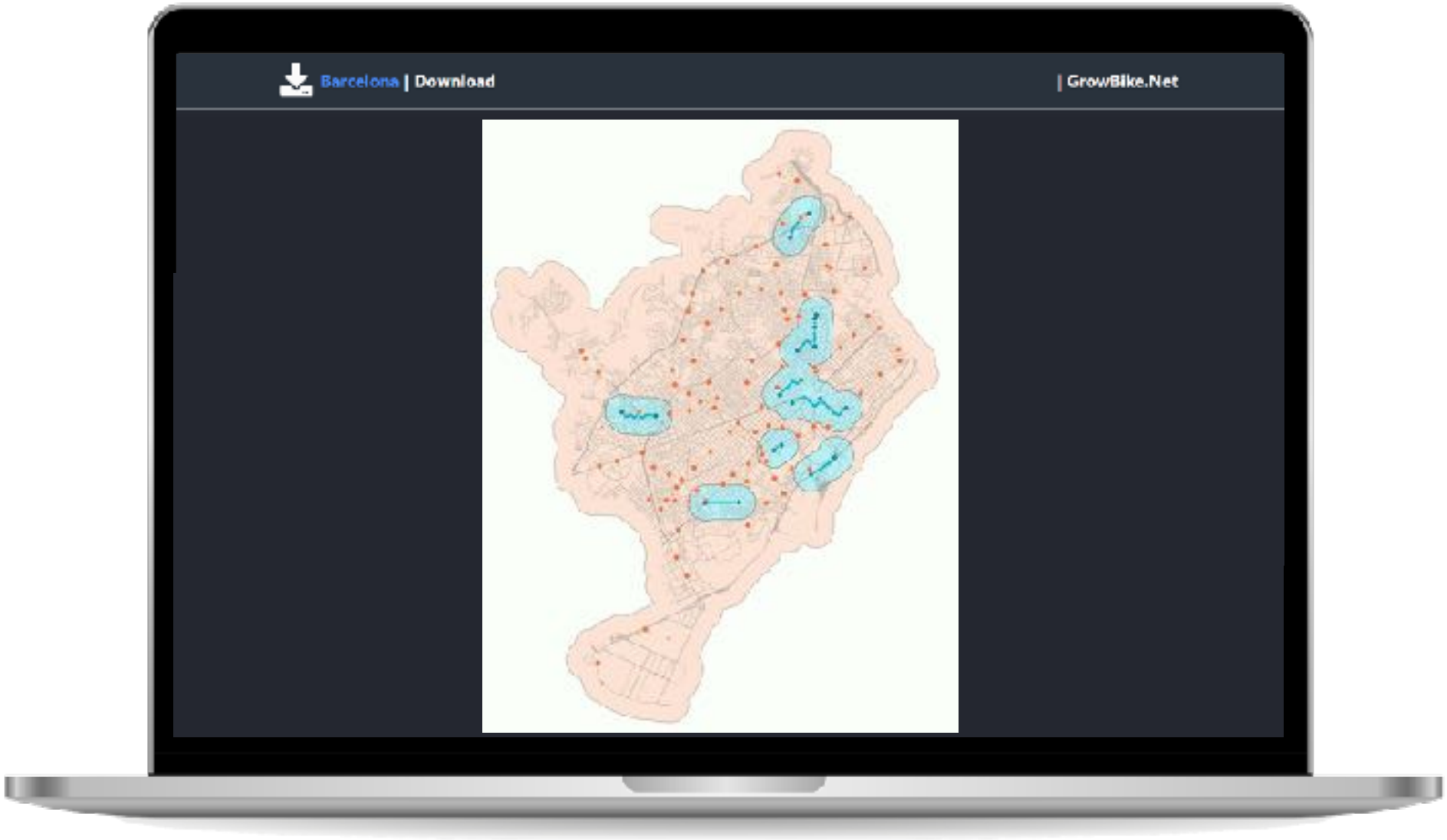


Quality of life and health | Industry and economy | Sustainability | Climate Action

Technical aspects

- What data do we consider?
  - Cycleway network
  - Demographic layers
  - Points of interest
- What functionalities can we develop?
  - Adjust needs and growth constraints
  - Adapt bike system parameters
  - Filter by demographic and/or interest group
- What results can we expect?
  - A proposed new extension and associated costs
  - Impacts on the affected population
  - Calculation and view of global and/or local metrics

Cycling
Example



Source: GrowBike

Rapid prediction of air quality due to urban interventions.

Through simulations, vCity will provide rapid predictions of air quality and, more importantly, how it affects people living and working in the intervention area.

In this way, the application will suggest optimal urban interventions to improve air quality (renaturation).

Breathing

Quality of life and health

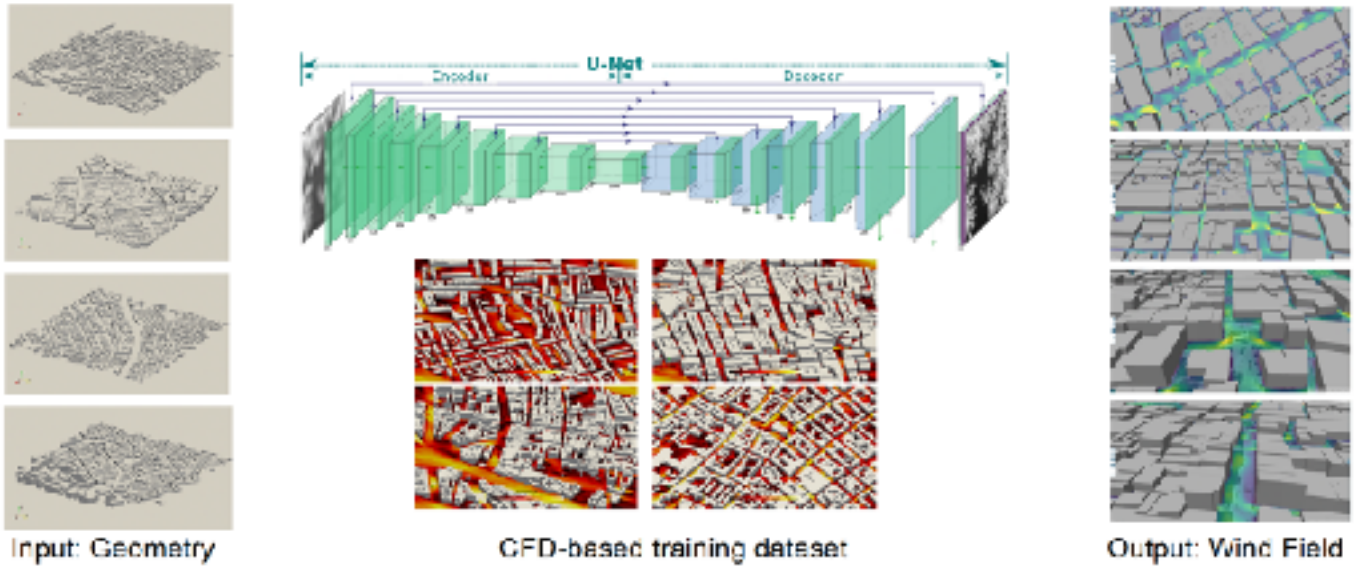
Climate Action

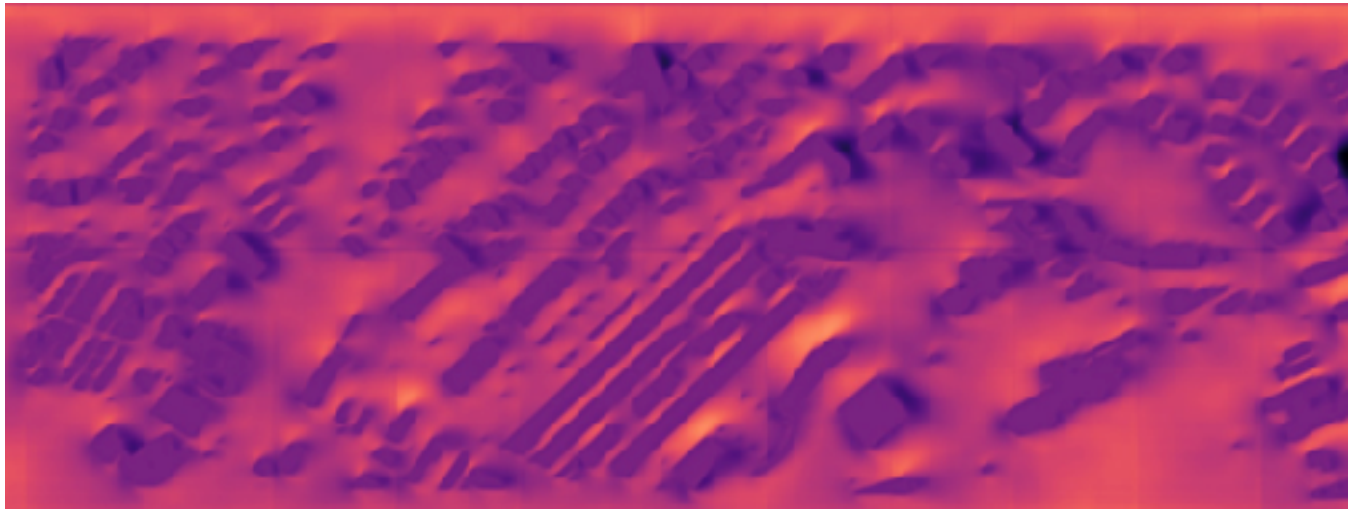
Technical aspects

- What data do we consider?
  - 2D and 3D mapping (height of buildings, trees, type of terrain, etc.)
  - Emission sources
  - Demographic layers
- What functionalities could we develop?
  - Select areas of the city and change their typology.
  - Filter by demographic and/or interest group.
- What results can we expect?
  - A new air quality map, absolute values and differentials with respect to current status
  - Calculation and view of global and/or local metrics

Breathing

Example





Source:
Large-scale Computational Fluid Dynamics (LS/CFD) CASE - BSC.

Investigate the environmental and social impacts of different dimensions of multimodal transport.

The introduction of new, more sustainable modes of transport can have diverse and unexpected social and environmental impacts.

Based on real city data, this application will simulate the complex transport system with its wide variety of mobility modes, allowing city planners to test different changes to the system and choose the best solution for citizens.

Mobility

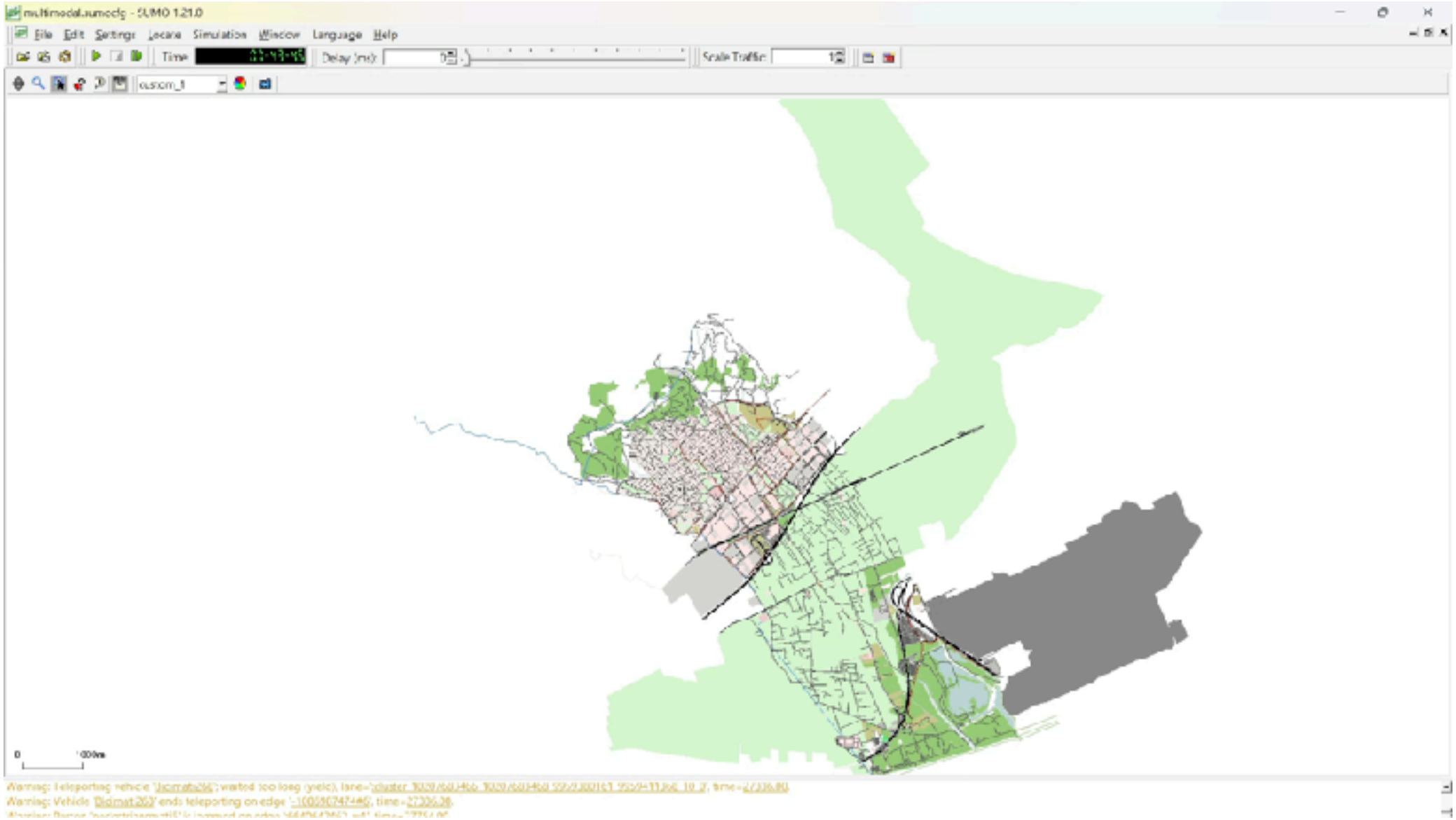
Quality of life and health | Industry and economy | Sustainability | Reduction of inequalities

Technical aspects

- What data do we consider?
  - Traffic on streets
  - Demographic layers
  - Points of interest
- What functionality can we develop?
  - Delineate areas for traffic shifting
  - Adjust incentives/penalties and compare changes in traffic mode
  - Filter by demographic and/or interest group
- What results can we expect?
  - The evaluation of classic mobility metrics (flows) plus the impact on demographic and transport mode layers.
  - Calculation and overview of global and/or local metrics

Mobility

Source:
vCity (own elaboration)



Extend the circular economy index to high resolution for cities.

A city's Circular Economy Index scores components such as digitalisation, energy, climate, mobility and waste.

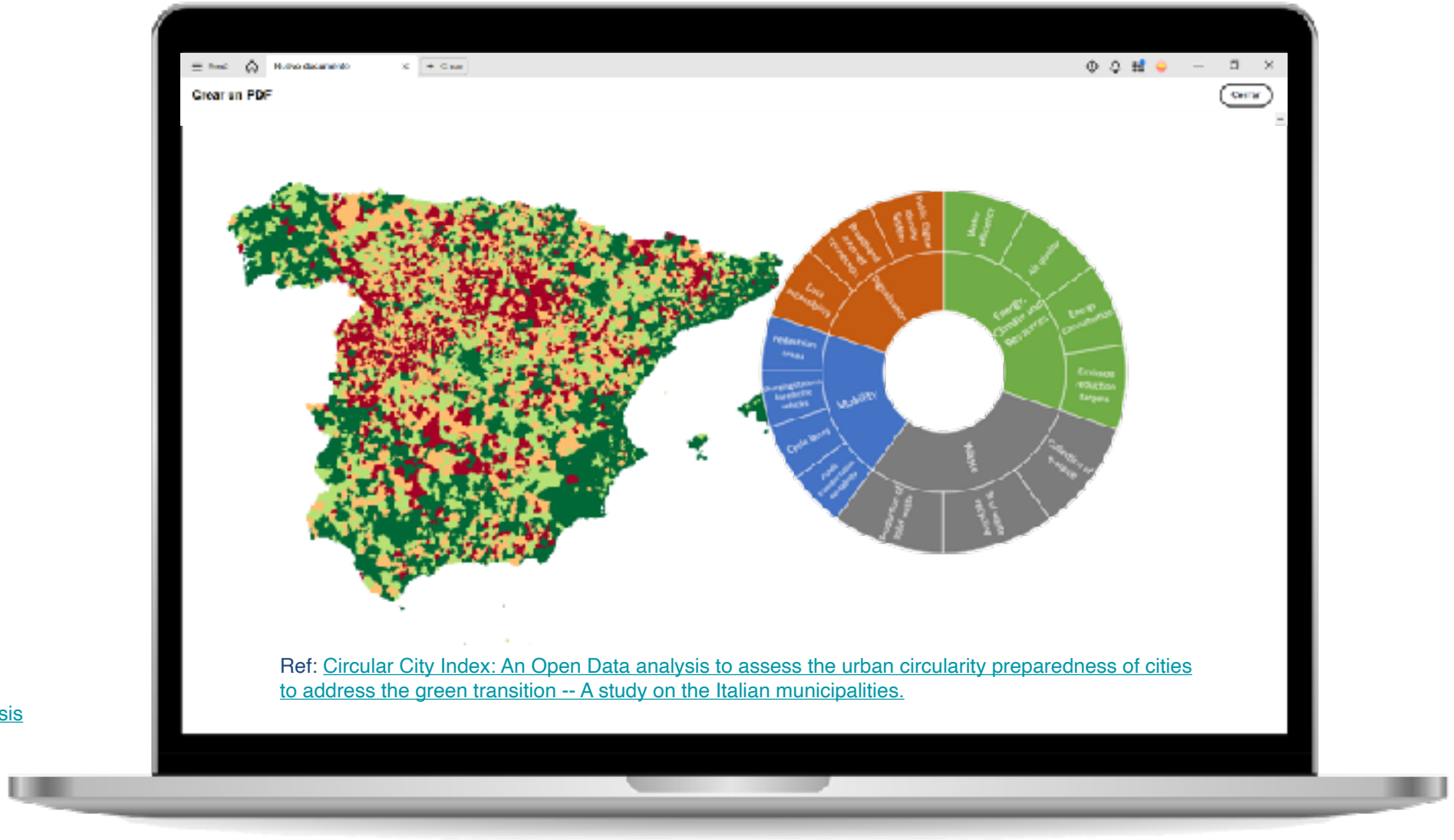
This application demonstrates how the vCity platform can calculate the index score to drive specific strategies for sustainable urban development, promoting circularity and advancing the green transition.

Sustainability

Technical aspects

- What data do we consider?
  - Indicators by region/area
  - Points of interest
  - Demographic layers
- What functionalities can we develop?
  - View the circularity index of each neighbourhood
  - Remove and/or add points of interest
  - Adjust global and/or local parameters of the areas to be analysed
  - Filter by demographic and/or interest group
- What results can we expect?
  - Suggestions on how to improve each neighbourhood index
  - Recalculation of the local index
  - Maps of influence of each area on the global index
  - Calculation and view of global and/or local metrics

Sustainability



Ref: Circular City Index: An Open Data analysis to assess the urban circularity preparedness of cities to address the green transition -- A study on the Italian municipalities.

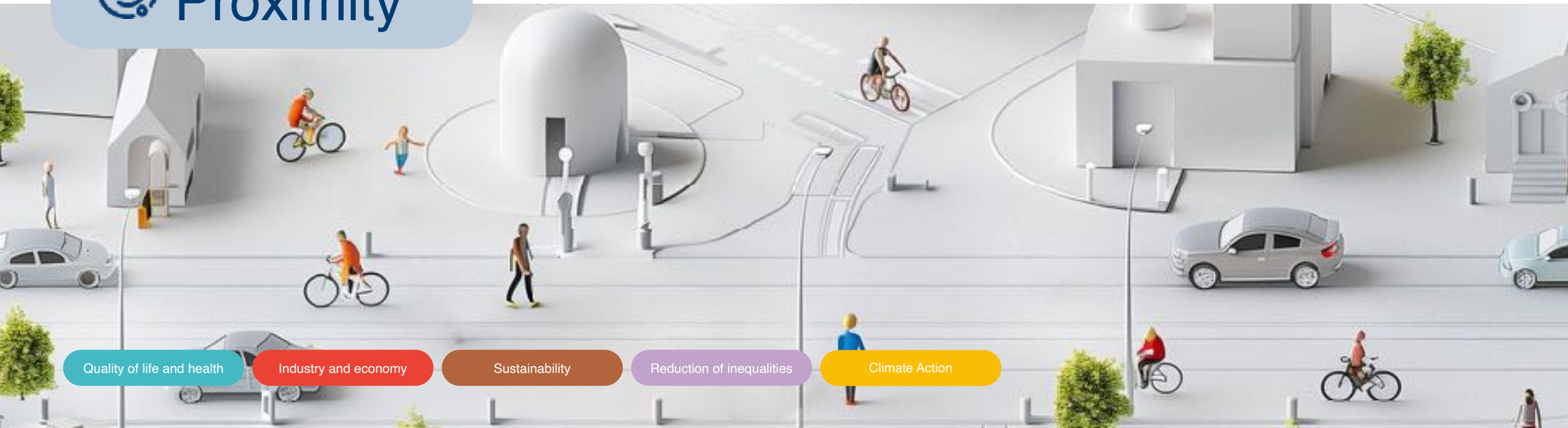
Source:
Rens van Wijk, Master thesis

Promote the proximity of services or points of interest to reduce transfers.

vCity will help to analyse cities from a proximity perspective, visualising the level of accessibility of public services to citizens.

With this tool, urban policy makers can easily identify the need for facilities in each neighbourhood.

Proximity



Technical aspects

- What data do we consider?
  - Points of interest
  - Demographic layers
- What functionalities can we develop?
  - Remove, add and/or move points of interest
  - Adjust global and/or local parameters
  - Filtering by demographic or interest group
- What results can we expect?
  - Recalculation of proximity/accessibility areas
  - Calculate and view global and/or local metrics

Climate shelters in Barcelona

Proximity

Climate Shelters are public spaces that provide shelter from extreme temperatures. This network is particularly important to support the most vulnerable populations (the elderly and children).

This study investigates and analyses a key question: do these groups have adequate access to shelters during heat waves?

https://www.vcity.tech/studies/shelters

08

Partner cities

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PhD in Computer Science

Design of a methodology for transparency in the use of DT

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Data Visualisation Expert

Dashboard design

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Design of bias reduction methodology in DT

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Designing policies and strategies for DT implementation in cities

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Design of applications and interfaces for citizenship

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Support

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Collaborators

300.000 Km/s	ARUP	CARTO	CETAQUA	DECIDIM	DigitalFems	Domestic Data Streamers
Eurocities	Festival Cruilla	Festival Sonar	GeoSolutions	Guadaltel	Guallart Architects	IAAC
Idealista	INTRA	iThinkUPC	LIS Data	Logicalis	MCrit	Memorandum
MongoDB	Taller Estampa	TC-Street	TomTom	Universidad Autónoma de Barcelona	University of Bologna	University of Liverpool
Universitat Oberta de Catalunya	Universidad Pompeu Fabra	University of Torino	Urbanly	Wizzie	Yonder	

Thanks!

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