French Institute
of Science and Technology
for Transport, Development
and Networks

Networked micro and nanosensors for sustainable cities: from research to real-life deployments

Project Sense-City
Ifsttar, ESIEE, LPICM, CSTB, Inria, UPEM

Overview

July 4th, 2014

IFSTTAR

IFSTTAR ESIEE LPICM CSTB Inria UPEM

Over 40 people throughout France

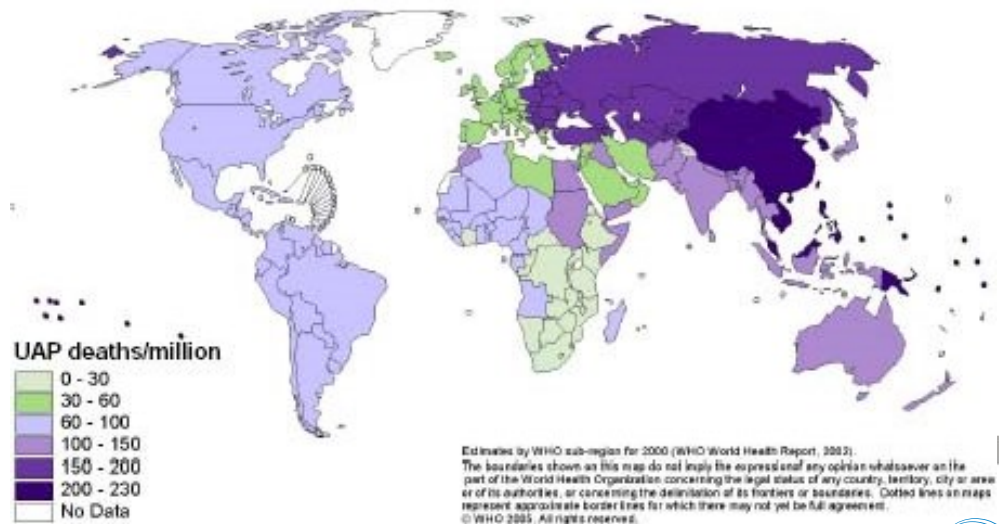
- Covering the whole chain of values for nanosensors prototyping
- From Nanomaterials to Big Data

Goals

- In 2050, cities will *welcome* 75% of the World population
  - Degradation of everyday life conditions
  - Variety of nuisances (pollution, traffic...)
- **Toward Sustainable Cities** we propose

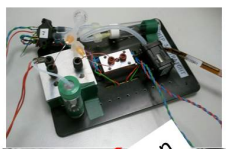
  Decision-support tools based on micro&nano-sensors, physical models, data management and representation

- *Environmental quality*
- *Eco-building & Ecodistrict*
- *People exposure & health*
- *Infrastructure and network durability*

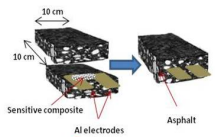


Decision-support tools: from sensors to users

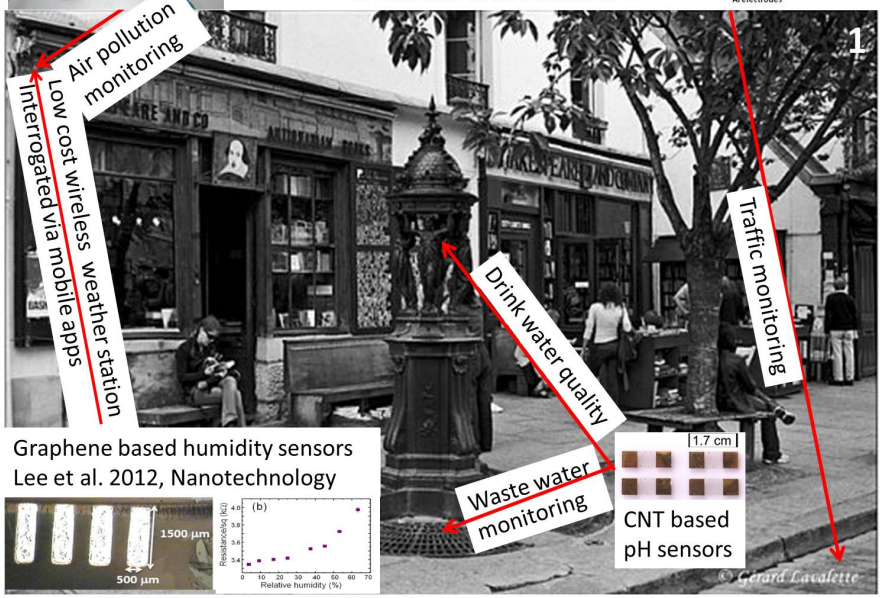
1. A repertoire of *novel micro&nano-sensors*
2. COMBINED with *advanced modeling* (inverse methods)
3. COMBINED with *contextualized visualization* (awareness of needs)



Microchromatograph
Cesar et al., IEEE MEMS 2013

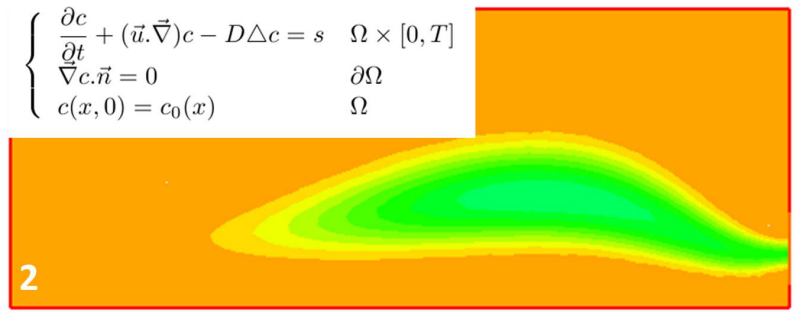


Smart asphalt
B. Lebental et al. Patent 2014



Graphene based humidity sensors
Lee et al. 2012, Nanotechnology

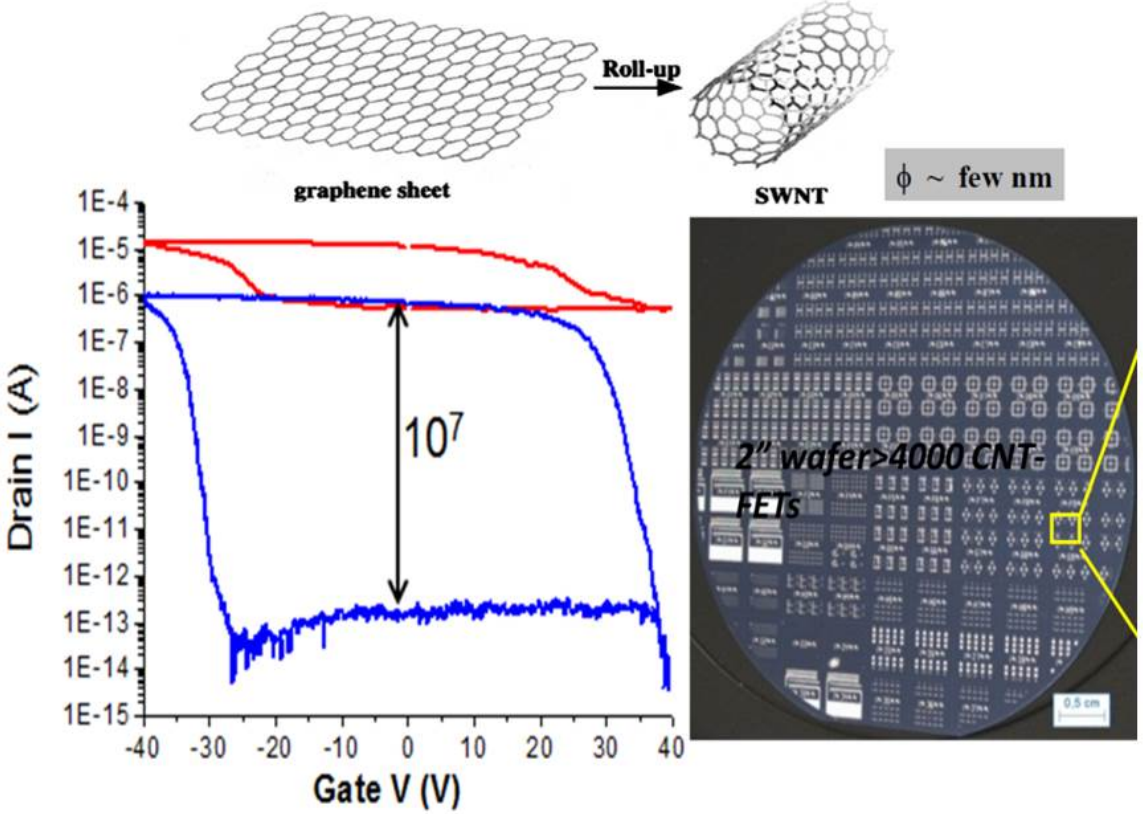
$$\begin{cases} \frac{\partial c}{\partial t} + (\vec{u}.\vec{\nabla})c - D\triangle c = s & \Omega \times [0,T] \\ \vec{\nabla} c.\vec{n} = 0 & \partial\Omega \\ c(x,0) = c_0(x) & \Omega \end{cases}$$

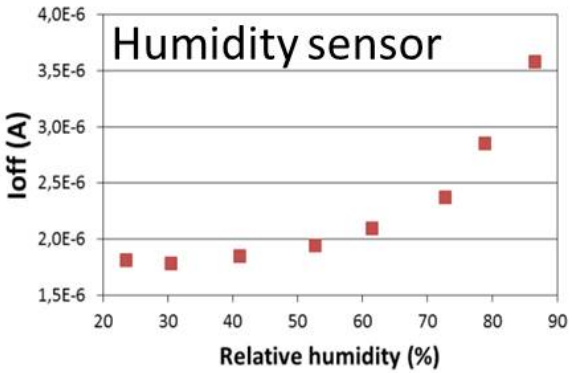


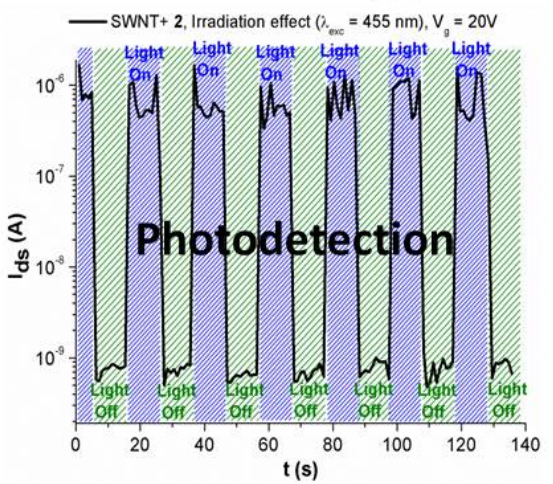
New sensors for sustainability

- Why do we need new sensors?
  - Progress in sustainability relies on **Big Data** analysis
  - Data provided by the **Internet of Things**
  - IoT addresses only few parameters at **affordable costs** (temperature, humidity, GPS data, accelerometers...)
  - **What about next generatation observables? improved quality of data? lower device cost?**
- Two routes for sensor prototyping
  - **Silicon route**: innovative technologies building upon traditional, silicium-based electronics; low cost in mass production, high cost in development; high accuracy and complex observables
  - **Low-cost route**: innovative material on low cost substrates (paper, plastics, glass...); printing, roll-to-roll technologies; moderate accuracy and simple observables

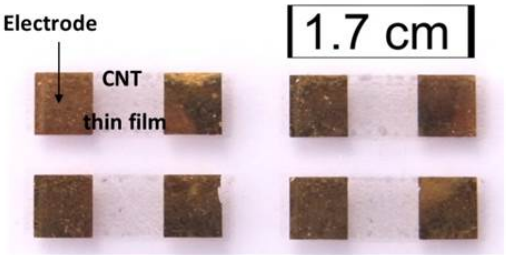
High performance CNTFET for sensing



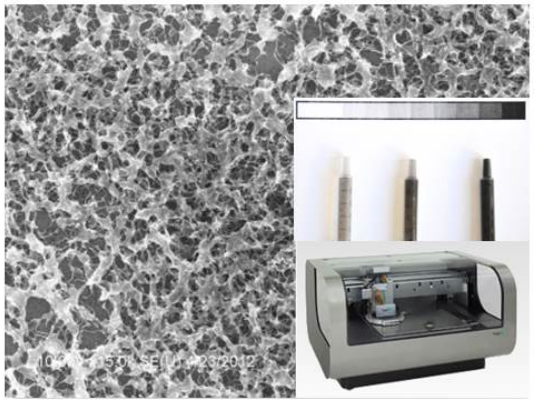


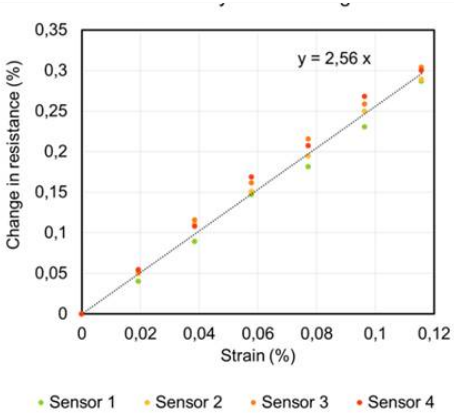


Highly reproducible CNT network strain sensor

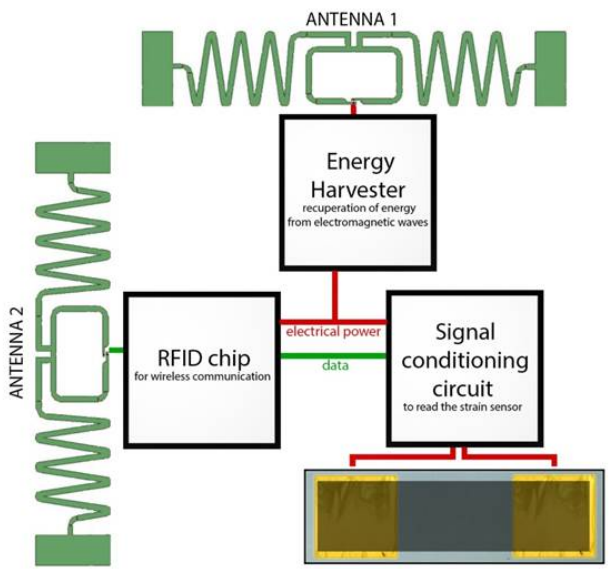


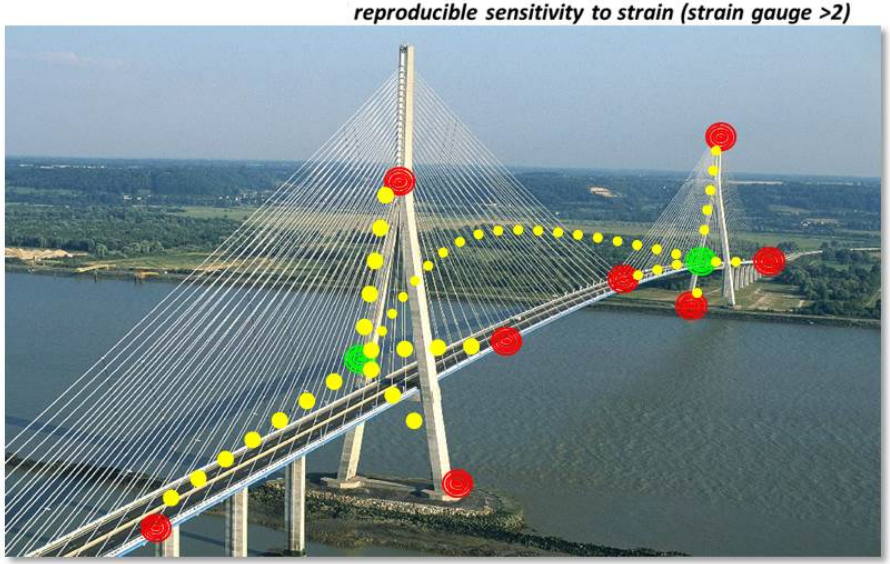
Resistive devices batch-fabricated by ink-jet printing of CNT



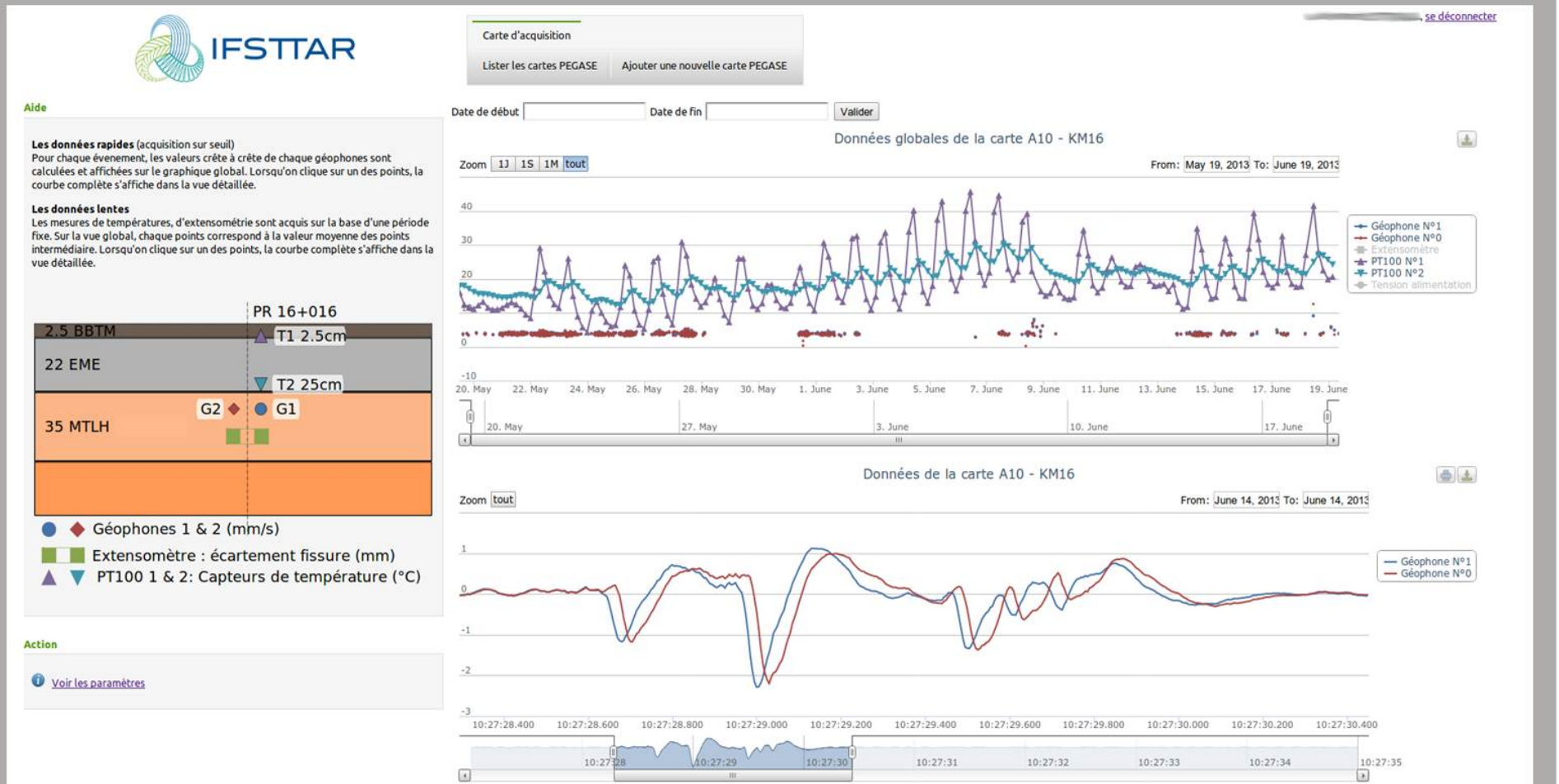


reproducible sensitivity to strain (strain gauge >2)





Wireless sensor network for infrastructure monitoring



Real time reconstruction of flows in water pipes

- Hypothesis: Laminar flow - parabolic velocity in pipes: $f(\underline{x})$
- Unknown velocity boundary conditions: $\underline{v}_c(\underline{x}, t) = V_c(t) f(\underline{x}) \underline{n}$
- Direct problem: Navier-Stokes + incompressibility

$$\rho \frac{\partial \underline{v}}{\partial t} + \rho \underline{\nabla} v . \underline{v} + \underline{\nabla} p - \mu \Delta \underline{v} = \underline{0} \quad \text{in } \Omega \times [0, T] \tag{1}$$

$$div(\underline{v}) = 0 \quad \text{in } \Omega \times [0, T] \tag{2}$$

$$\underline{v} = \underline{v}_c \quad \text{on } \partial_c \Omega \tag{3}$$

$$\underline{v} = \underline{0} \quad \text{on } \partial_d \Omega \tag{4}$$

$$\underline{v}(t = 0) = \underline{v}_0, \quad \text{in } \Omega \tag{5}$$

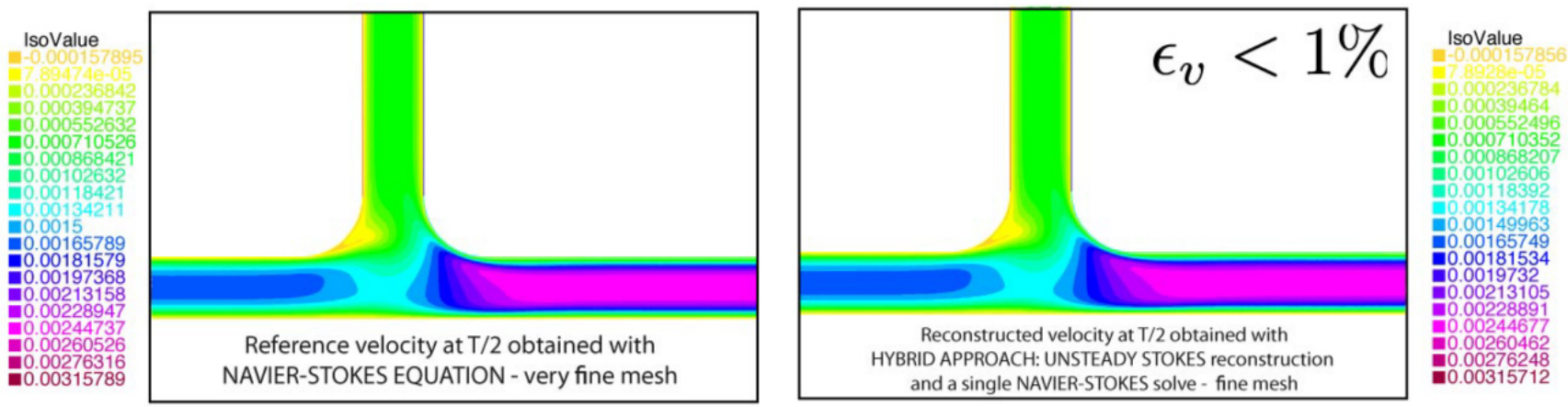
- Find bondary conditions minimizing data misfit functional:

$$\min_{V_c \in \mathcal{V}_c} J(V_c) = \frac{1}{2} \sum_{j=1}^{n_s} \int_0^T \left(\int_\Omega \psi_j^r \underline{v}(V_c) . \underline{d} \; d\Omega - v_j^{mes} \right)^2 dt$$

Real time reconstruction : hybrid approach

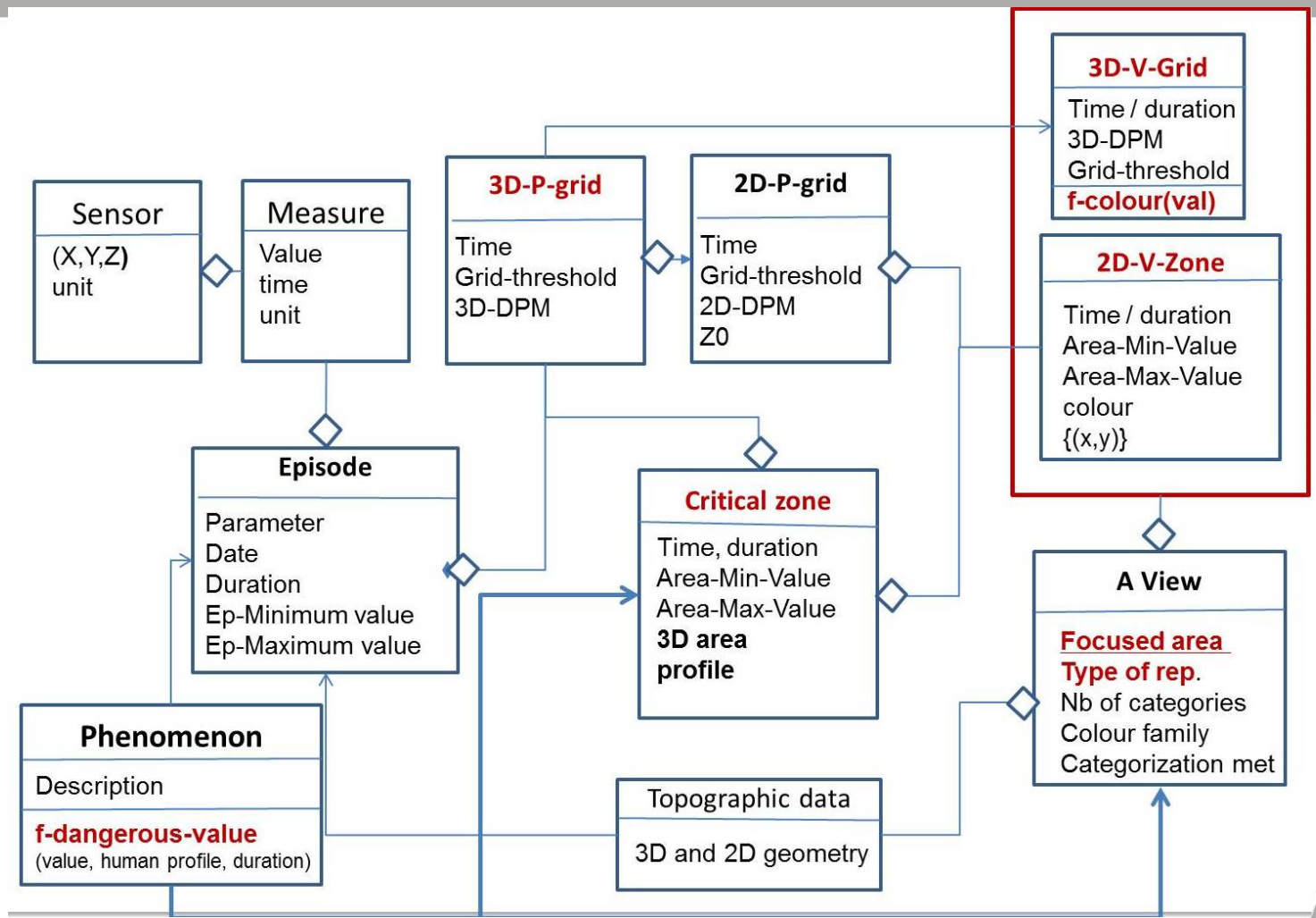
1. Determine the boundary control velocities using **unsteady Stokes reconstruction**
2. Reuse this boundary control velocities in a **single Navier-Stokes direct solve**.

→ Obtention of the velocity field



Data analysis and showcasing

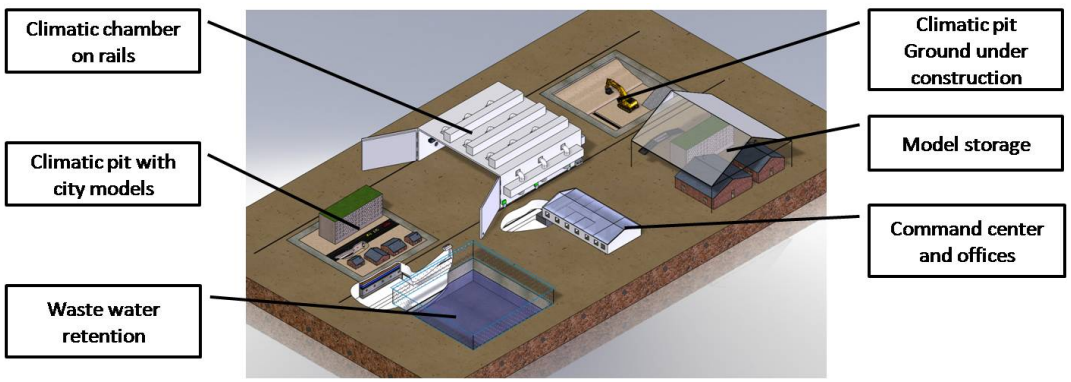
Data models for visualization



Urban deployments for nanosensors

- What next? Real life is way more complicated than the lab...
- Urban deployments essential to demonstrate industrial readiness
  - provide accurate benchmark for new devices
  - debug small series and develop deployment strategies
- But always **slow going process**
  - legal issues and access to infrastructures
  - reluctance from urban managers
  - highly complex, uncontrollable loadings

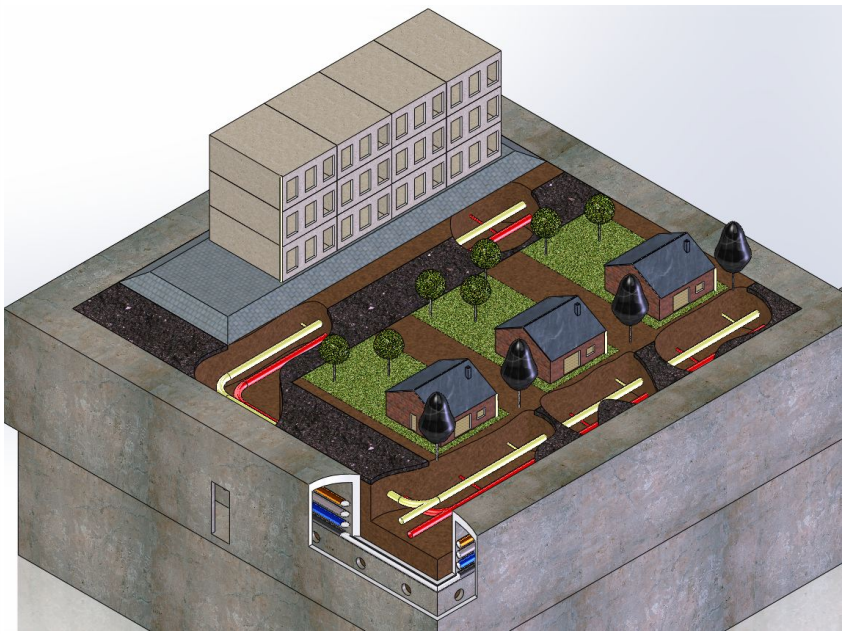
$\Rightarrow$ Sense-City mini-city: 400 m^2 for model urban deployments



Sense-City mini-city

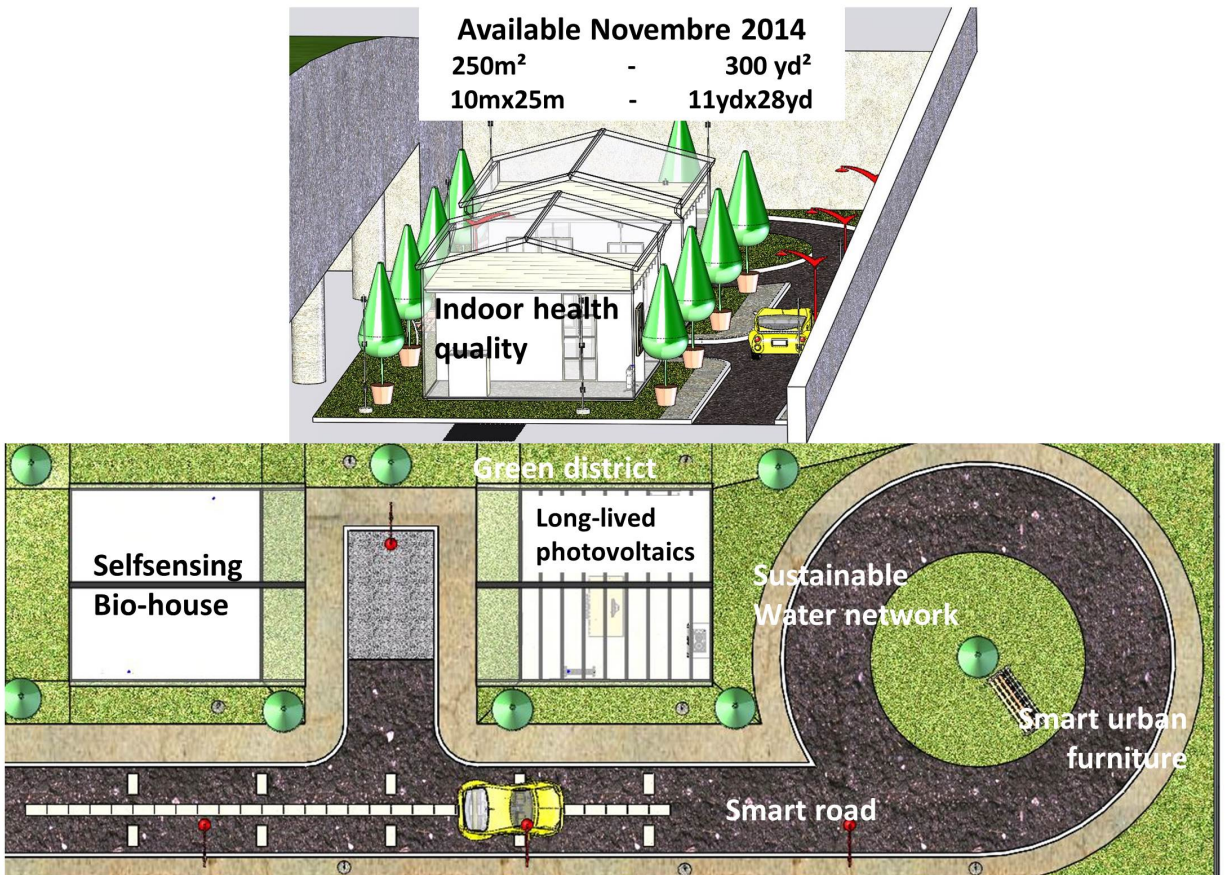
- 400 m^2 mobile climatic chamber with 3m-deep pit
- A tunable district with typical urban features
- From humid winter conditions to dry heat wave to rainstorm

$\Rightarrow$ Time-to-market accelerator



Sense-City mini-city

- First models available by end of year 2014
- Multidisciplinary initiatives
- Additional experiments are welcome



Summary

- Decision-support tools for Green Cities
- An **open** platform for urban deployments
- Contributors
  - IFSTTAR: F. Derkx, F. Bourquin, H. Van Damme, A. Ruas, J. Dumoulin, E. Merliot, S. Buttigieg, F. Bouanis, J. Waeytens, R. Chakir, V. Le Cam, A. Nassiopoulos, E. Merliot, D. Siegert, W. Moujahid, F. Michelis, B. Ghaddab, W. Cesar, R. Kuate, W. Martin, L.-L. Sorin, H. Wu, M. Berbineau, W. Martin, S. Marceau, C. Chevalier, J.-M. Auberlet, F. Vienne, N. Hautière...
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  - UPEM: Jean-Marc Laheurte, Odile Picon
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