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Vibrations, Shocks and Noise

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Abstract

A large scale equipment project, the Sense-City Equipex has received support from the French government in the framework of the “Programme d’Investissement d’Avenir”. This project is led by the French Institute of Science and Technology for Transport, Development and Networks (IFSTTAR) with ESIEE-Paris, the Laboratory of Physics of Interfaces and Thin Films (LPICM) and the Scientific and Technical Centre for Building (CSTB) as consortium partners.

Starting in 2012, Sense-City will offer a suite of high-quality facilities for the design, prototyping and performance assessment of innovative, micro- and nanotechnology based sensors devoted to urban instrumentation. Acknowledging the shortcomings of evaluating sensors performances in laboratory conditions only or in the ever-changing environment of our cities, Sense-City will provide a realistic urban test space in climatic conditions, far more complex than clean rooms and far less complex than actual cities.

Sense-city revolves around the “mini-city” concept, a large, fully customizable climatic hall able to host full- and reduced-scale models of essential urban components. The design of the models will allow for the simulation in climatic conditions of numerous scenarios of sustainable cities.

The scenarios to be implemented will correspond to different research topics related to urban sustainability: energy performances in buildings, quality of air, water and soils, quality of fluid distribution networks (gas, sewage, drink water), control of waste disposal areas, durability and safety of infrastructures.

Keywords: Nano-sensors, sustainable City, climatic tests;

1. Presentation of the project

The Sense-City project is a suite of high-quality facilities for the design, the prototyping and the evaluation of performance and risks of innovative micro- and nanotechnology based sensors devoted to measurements in urban environment.

Sense-City will bring together two very promising, yet still highly disjointed topics, nanotechnologies and cities. Introducing nanotechnologies into the city could lead to a more modern, more sustainable and human friendlier urbanization. Economical and social stakes are high, since 90% of the French population is expected to live in cities by 2020. Today’s galloping urbanization impacts heavily on people and environment, whereas tomorrow’s sustainable city is not upon us yet.

Metrology of urban spaces is a landmark toward urban preservation and modernization. Sensors are the first

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interface between the actual and the numerical worlds. As such, they are essential to understand or control our surroundings. Continuous monitoring is already widely used in civil engineering, buildings, housing, and public water, gas, lighting networks. Collecting massively distributed information requires the use of high-performance communication systems as well as the use of low-cost and low-consumption sensors with a very small ecological footprint. Because of their high sensitivity, the wide range of their observables, their energy self-sufficiency and their low-cost, micro- and nano- sensors are particularly well suited to cities.

However, adapting sensors developed in a perfectly controlled, clean room environment to the uncontrollable urban environment is a difficult task: cities are complex systems, with a large number of variable parameters and various sources of sensors degradations, all of which cannot be accounted for in numerical models. Implementation of sensors in an urban environment raises many questions. How can we make sure that sensors measure the observable they are actually designed for? That sensor ageing does not affect measurements? That sensor does not induce any risks for persons nor goods? Where should they be placed in order to give an accurate picture of the local parameters and their gradients? These questions are critical, all the more so since micro- and nano- sensors are more fragile and more sensitive to their environment than macro-sensors.

In order to address these issues, Sense-city will provide a testing facility for micro- and nano- sensors in realistic conditions. Environmental parameters will be much more varied and complex than those of the traditional clean room, but also better controlled and reproducible than urban environment.

This testing facility, which we call “mini-city”, will consist of a unique (Europe-wide) large scale, fully customizable climatic hall dedicated to hosting full- and reduced- scale models of main urban components (e.g. buildings, infrastructures, underground and distribution networks). The design of these models will allow for the simulation in the climatic chamber of numerous scenarios of sustainable cities. These scenarios will be designed to address scientific issues such as energy performances in buildings and cities, quality of air, water and soils, health issues related to air quality in confied spaces, quality and sustainability of all kinds of networks (gas, sewage, water supply), control of waste disposal areas, durability and safety of infrastructures.

Around this facility will be gathered hi-tech equipments essential to the prototyping and performance assessment of the proposed sensors. These equipments will complement those already owned by the partners of this project. They will permit the design, integration and calibration of the sensors. At the end of the fabrication process, prototypes tested in the realistic “mini-city” will be ready to be evaluated in a real environment, and then transferred to the industry.

From the industrial point of view, Sense-city can be viewed as the early basis for a future technological innovation platform. It will help increasing the reactivity of companies involved in sensor development, while reducing sensors’ time-to-market. Presently, design, prototyping and validation of innovative sensors are atomized, which is detrimental to the massive and rapid diffusion of the new technologies into the society. Sense-city has a unique potential for integration in the context of urban applications. By helping companies develop new products, Sense-city will therefore contribute to fostering economic development.

2. Details of the scientific goals

Sense-City is a ten years project built around three applicative programs.

2.1. Environmental monitoring

- Air quality: Gas components of the air are tell-tale signs of atmospheric pollution and of various chemical and biological phenomena [1-4]. We will develop micro-instruments dedicated to the measurement of air-quality with the goal to increase sensor selectivity, sensitivity and durability and to decrease response times. We will address the issue of sensors packaging and integration into wireless sensor networks.
- Drink water quality: To optimize chemical reactions of disinfection, operators of drink water networks are in strong need of systems surveying water quality. We will develop multiplexed sensors for water quality monitoring based on the hybridization of MEMS and microfluidic chips. The sensors being designed to be implemented in water pipes under high water pressure, special care will be given to sensors conditioning,

robustness and durability.
- Waste water networks and water bodies: The metrology of urban lakes and wastewater networks is essential to understand and reduce the impact of urbanization on environment. Sensor concepts developed in the field of drink water monitoring will be adapted to water bodies monitoring.

2.2. Structural health monitoring

- Infrastructures: Sustainable development is tightly related to the concept of structural health monitoring (SHM) of infrastructures [5-19]. Indeed, SHM makes it possible to increase service life time of structures by anticipating degradations and ageing. Downsizing SHM sensors is essential because the durability of cementitious and composite materials is controlled by transport phenomena occurring within the micro and nanoporosity of the materials We will focus on the development of SHM targeted micro and nano-sensors specifically dedicated to the early detection of degradations and the measurement of durability indicators in concrete and composite structures.
- Networks: The measurement of water pipe profiles, pipe wall thickness and the detection of hydraulic abnormalities will allow drink water network operators to localize defects and improve maintenance planning. We will further the development of robust, wireless in-situ acoustic sensors and the associated data technical processing.

2.3. Energy performances monitoring

- Buildings: To reduce energy consumption and green-house gas emissions, energetic performances of buildings need to be improved both in new buildings and via renovation programs. We will develop a sensor-based assessment method for existing buildings which will enable the characterization of their global intrinsic quality and of their independent components. Coupled with studies on the use of buildings (comfort management, energy use and storage), this methodology will contribute to the choice of performing (in terms of energetic performances) construction and renovation solutions. In a first step, we will install massively distributed sensors in buildings.

- City district: eventually, the study of building energetic performances with distributed sensors will be extended from the scale of the individual building to the scale of a city district (multi-buildings). In particular, we will tackle the issue of smart grids, which require the ability to network sensors spread throughout numerous buildings.

2.4. Health and exposure monitoring in enclosed space

- People exposure: Enclosed spaces are riddled with various types of pollutants, physical, chemical or microbiological. In order to assess people exposure to these pollutants, following the “Grenelle” recommendations and laws, there is a need for low-cost, low volume, high sensitivity metrological tools to assess the (even very low) concentrations of typical pollutants.
- Health quality of enclosed spaces: We will also develop and implement sensors solutions 1) for the continuous, real-time monitoring of enclosed space air quality and 2) for the localization of pollution sources.

3. Prototyping equipment

To achieve this ambitious, long term scientific program, prototyping equipment has been awarded to the partners:

3.1. For sensors fabrication and characterization

- An atomic layer deposition system: sensor sensitivity is expected to be significantly improved by the atomically

thin coatings achievable by such an ALD system.
- An ink-jet printer for the fabrication of very low-cost sensors on flexible substrate.

3.2. For sensors packaging

- A wafer bonding system for the development of technology processes aiming at lowering packaging costs.
- An automatic dicing saw for fast and efficient wafer-to-dice separation in low-cost processes.

3.3. For sensors small-scale validation

- A small-scale controlled-environment enclosure with a parametric 8-channel analyzer and a liquid-phase measurement module for sensor gas and liquid sensitivity evaluation.
- An infrared camera for non-intrusive detection of defaults within composite and bonded material.
- A dynamic automatic water-sorption device for the in-situ study of the nano-micro-structure morphology of porous material. This device is specifically designed for automation of the tests.

4. The climatic Mini-City

4.1. Overview

After prototyping and small-scale validation, the sensors have to be validated in realistic, complex conditions similar to urban configurations. That is the purpose of the equipment central to the Sense-city project, the so-called "mini-city". To be designed in 2012 and built in 2013, it should include[1] (Fig. 1):
- a large (25m x 25m x 8m) climatic chamber (1), designed to be mobile (at low speed) on rails (2) This climatic chamber will assure the temperature (heating up to 50°C (8) and cooling down to -20°C (9)) and humidity control (from 0% to 100% relative humidity) of a mini-city built with models (7) representing typical urban situations. Other environmental solicitations will be available: UV radiations, rain, liquid and gas pollutants (injection through pipes (11)). The entire volume of air will be homogenized thanks to fan stirring (10).
- two climatic pits (3) of size 20m x 20m x 5m, designed to be connected to the climatic chamber, will enable to include underground and soils in the environmental tests: the climatic pits will be built with a double partition in which will be installed air-conditioning, fluid injection and water drainage equipment. The content of the pits will feature typical underground structures (embankment, dam, water body, garden, urban underground…), including urban pipes.
- a retention pond (5) for the collection of waste water (especially useful for pollution experiments)
- adjoining buildings: an office building (6) for the technical staff and for the control room, and a hangar (7) for the storage of the models.

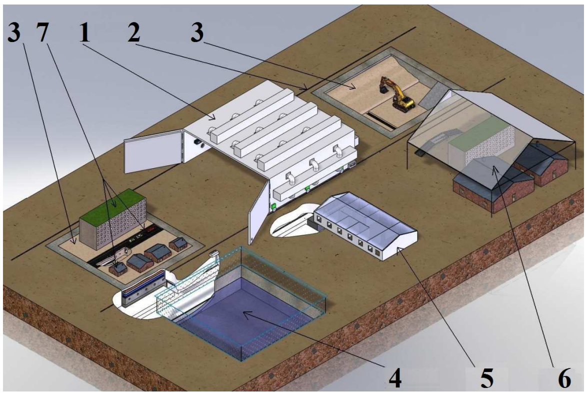
This "mobile chamber/two climatic pits" design was chosen to maximize operation time of the climatic chamber. Indeed, when one climatic pit is being used with the climatic chamber, the other can be prepared for the next set of experiments (soil preparation and models installation) (see Fig. 2).

The innovative design of the "mini-city" makes it a unique equipment in France and worldwide. As a matter of fact, even if a series of climatic chambers exists in France [20-23] and abroad [24-29] none of them allows for the modeling of such a variety of urban situations. The ability to combine the various components of a city is essential to our global scientific project because the global behavior of a city is deeply dependent on the various interactions between its components.

To the best of our knowledge, only the NIED equipment in Japan [29] is designed to integrate undergrounds and soils in a controlled climatic environment. In France, at the CER of Rouen, large surfaces of hangars are dedicated to underground assessment, but this facility does neither offer the possibility to control the local climate

[1] The size and characteristics given here are indicative only, in so far as the detailed design phase is to take place by the end of 2012.

nor to simulate interactions with the emerged parts of a city. Additionally, there are only very few climatic chambers on rails worldwide [29].



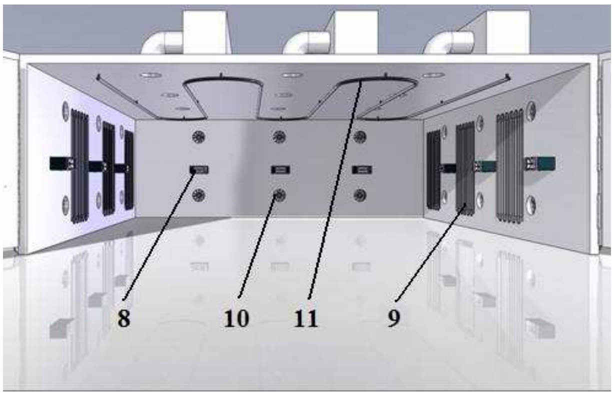
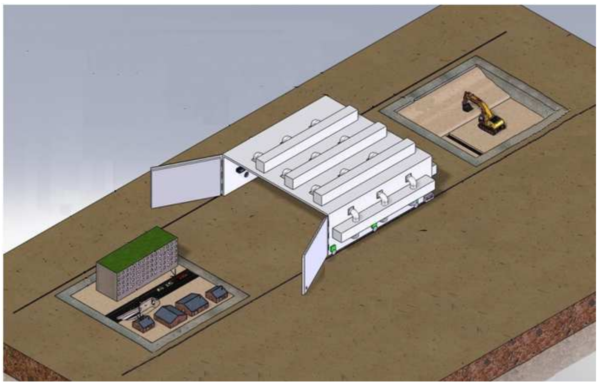


Fig. 1. (a) Artistic view of the “mini-city; (b) Artistic view of the inside of the climatic chamber



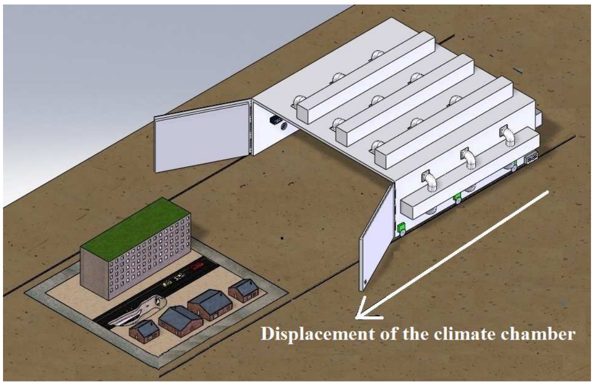


Fig. 2. (a) Climatic chamber betwen the two pits; (b) Displacement of the climatic chamber .

4.2. Instrumentation and control

The climatic chamber will be equipped with reference sensors able to measure continuously, in real time and in several places in the chamber, all climatic parameters (temperature, humidity ...). The outputs of these reference sensors will be used first to regulate these parameters within the chambers, second to benchmark the output of the nano- and micro-sensors prototyped within the project.

The whole facility will be commanded from a control room located in the office building. HMI (Human Machine Interface) will enable to control and monitor all the security and to manage tests remotely.

4.3. City models

The scale 1:1 models will typically include (table 1) large houses with insulation, electrical equipment and automation, small houses to test interaction with the environment, networks and infrastructures, several streetlamps and a street with its sidewalks. The 1:3 scale models will typically include at least one big-size housing block, various detached houses, two streets with their sidewalks and an urban bridge. Models will be designed (see Fig. 3) or adapted along the course of the project according to requirements established along the course of our research programs.

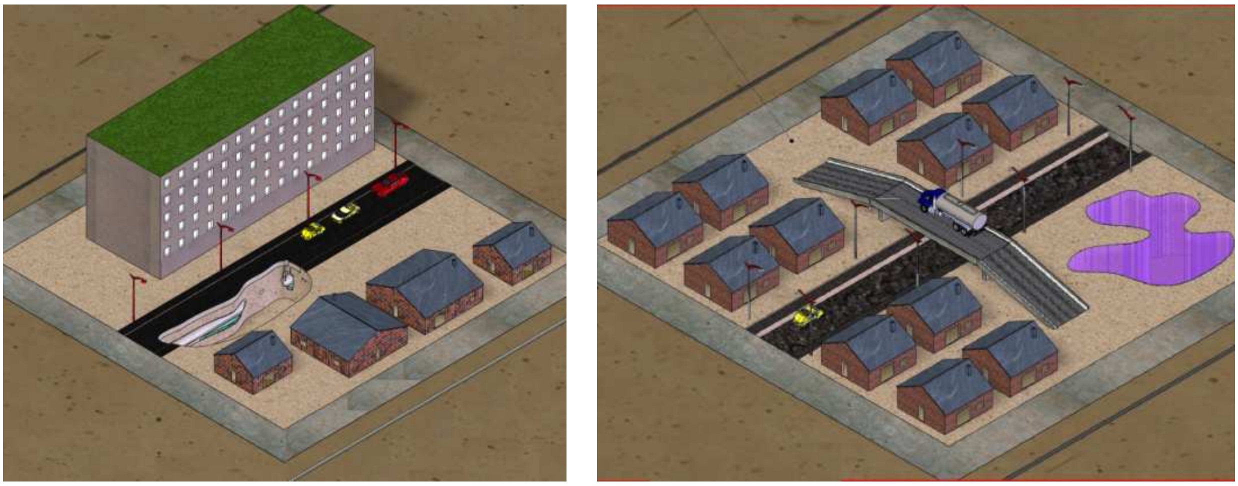


Fig. 3. (a) First example; (b) Second example of “mini-city scenario”

Table 1. Typical scale 1:1 and 1:3 models

Designation	Scale 1:1	Scale 1:3
Large houses	12m x 12m	4m x 4m
Small houses	8m x 8m	2,5 m x 2,5m
Street	width 6m, length 15m	width 2m, length 15m
Sidewalk	width 1,5m	width 0,5m

4.4. Main characteristics of the climate chamber and pit

The main dimensional features of the climatic mini-city are summarized in the tables 2 and 3 and on the Fig. 4 below.

Table 2. Characteristics of the climatic chamber

Climatic chamber	Characteristics
Interior size	25m x 25m
Useful size	20m x 20m
Height	8m
Useful area	400m^2
Useful volume	5 000m^3

Table 3. Characteristics of the climatic pit

Climatic Tip	Characteristics
Useful size	20m * 20m
Useful depth	5m
Useful area	400m^2
Useful volume	2 000m^3

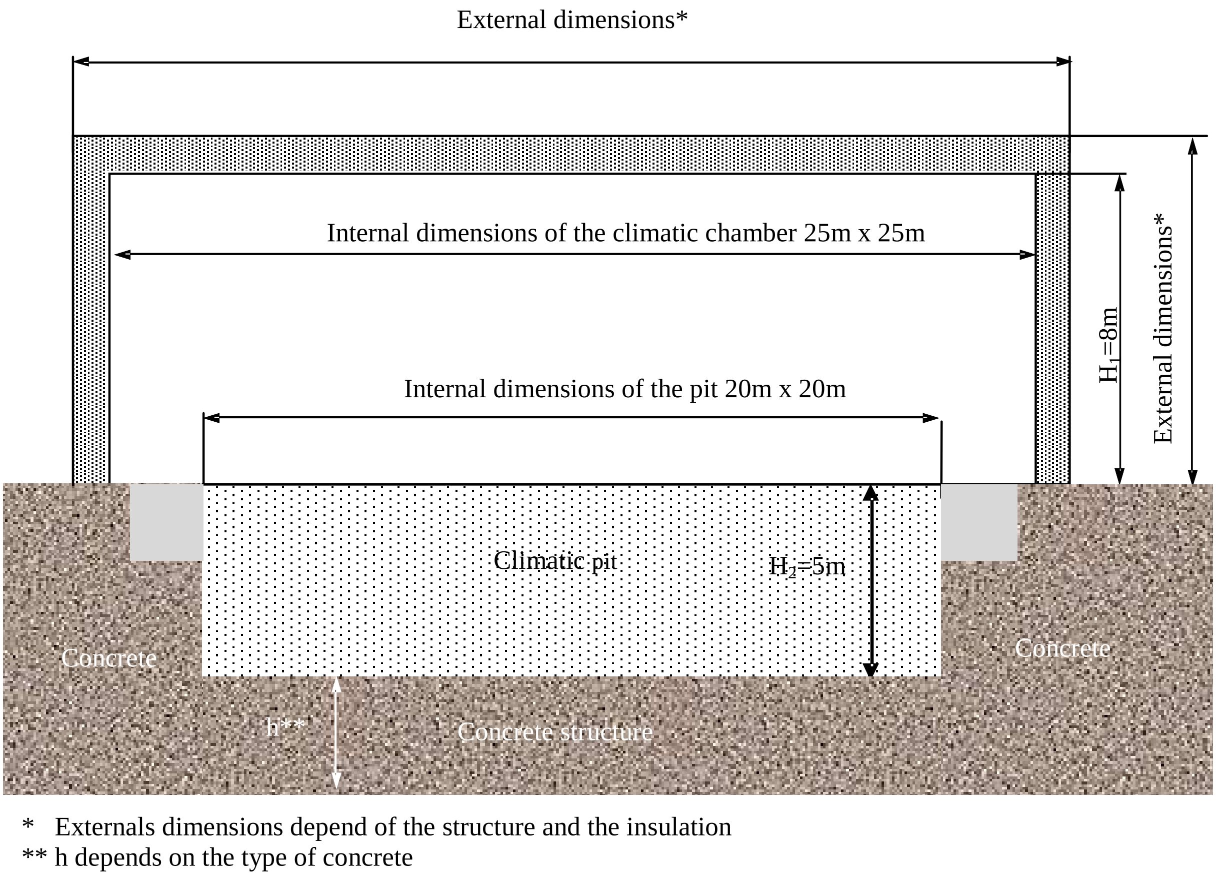


Fig. 4. Sketch of the climatic chamber and pits

The table 4 below summarizes the main climatic characteristics of the equipment.

Table 4. Climatic characteristics of the climate chamber and pits

Designation	Characteristics
Air Temperature	-20°C, + 50°C
Rate of air temperature variations	10°C/hour
Rate of ground temperature variations	5°C/hour
Rain	120 mm/h
Solar radiation	1 000 W/m^2
Controlled hygrometry	0-100%
Injectable pollutants	SO_2, CO, CO_2, NOx

5. Conclusion

The “Excellence” Facility “Sense-city – Nano-sensors for cities: design, prototyping and large-scale validation” – is a unique chain of equipment revolving around the "mini-city" concept.

The “mini-city, to be designed in 2012 and built in 2013, is a 400m² reconfigurable climatic hall unique in Europe, able to accommodate small-scale or real-scale models of main urban components such as buildings, transportation infrastructures, distribution networks and soils. These models are designed to enable the simulation in climatic conditions of a large number of scenarios for the Sustainable City. These scenarios will be exploited to validate micro- and nanosensors prototyped within the project.

Metrology of energy performances, environmental monitoring at the city level (air, soil and water quality, control of waste storage), detection of hazardous events and durability assessment of transport infrastructures, soils and utilities (gas, sewage, potable water) will be of particular interest.

This main facility, dedicated to sensors large-scale validation, will be complemented by selected flagship pieces of equipment which will play an essential role for the prototyping of Sense-City sensors. They will add to the facilities already available to the project partners. They will enable the partners to carry out essential prototyping tasks such as design, characterization, integration and calibration.

At the end of the design chain, prototypes tested in realistic environment will be ready for evaluation in a real environment and then for industrialization.

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