



# SMARTGREENS 2021

10<sup>th</sup> International Conference on Smart Cities and  
Green ICT Systems

## Final Program and Book of Abstracts

28 - 30 April, 2021

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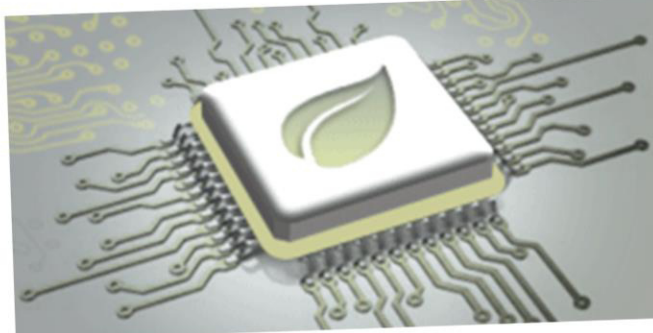
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# SMARTGREENS 2021

10<sup>th</sup> International Conference on Smart Cities and Green ICT Systems

Online Streaming | 28 - 30 April, 2021

## Design of an Urban Monitoring System for Air Quality in Smart Cities

Andrea Marini<sup>1</sup>, Patrizia Mariani<sup>2</sup>, Alberto Garinei<sup>1,2</sup>, Stefania Proietti<sup>2</sup>, Paolo Sdringola<sup>3</sup>

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# Motivations

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- **Pollution** is one of the main problems faced by **cities**
  - increase in **emissions** from anthropogenic sources resulting from economic, industrial and demographic development
- High values of pollutants (*e.g.* atmospheric particulate matter) lead to **adverse effects** on the **environment** and **human health**
  - spread of respiratory, cardiovascular and neurological problems
  - connection between the spread of the **Covid-19 pandemic** and environmental pollution? [Setti et al., 2020] [Wu et al., 2020] [Fattorini and Regoli, 2020]
- **Urban monitoring** of pollutants can allow to evaluate and perform actions aimed at **reducing pollution** in order to safeguard citizens' health

# Overview

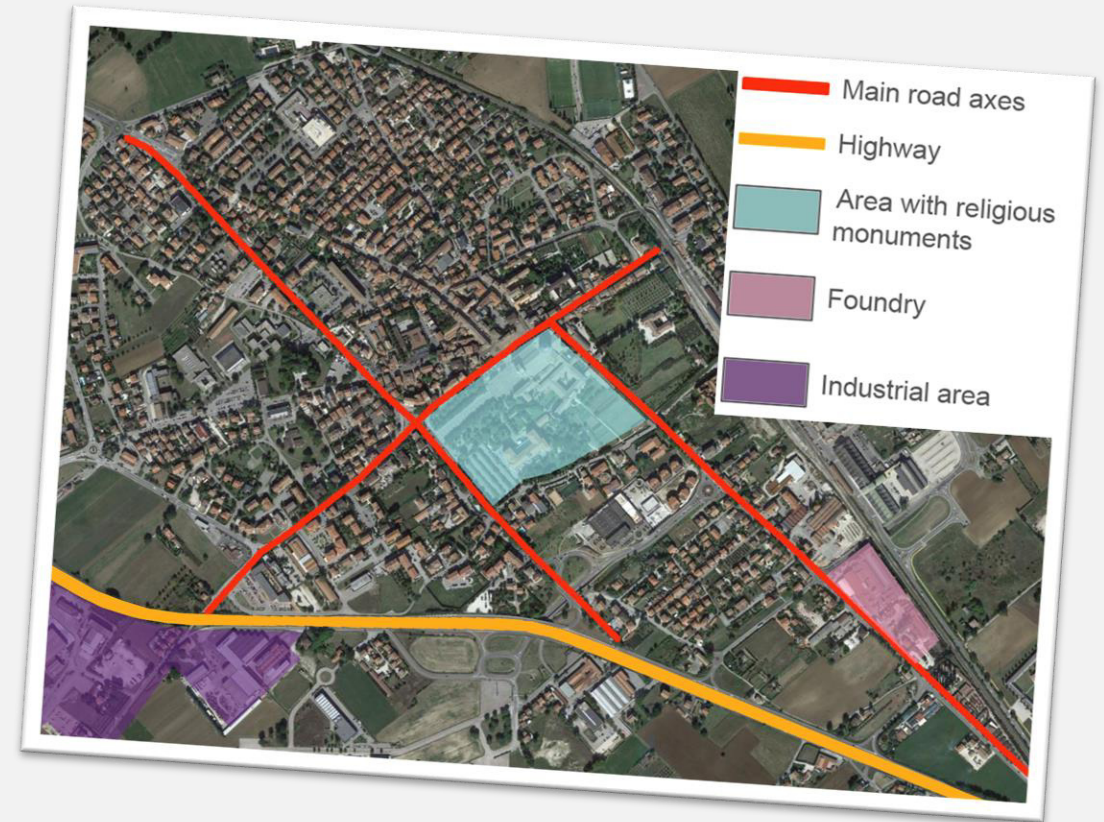
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- This study proposes a method to design a **low-cost urban air quality monitoring system** that can be implemented in any small-to-medium-sized smart city
- The monitoring concerns **atmospheric particulate matter** (PM10 and PM2.5)
- Sensors are connected through a **LoRaWAN network**
- Location of the sensors are determined in two steps
  1. **Analytic Hierarchy Process (AHP)** multi-criteria decision-making technique
  2. **Cellular Automaton** model in order to ensure the best overall coverage of the polluted areas



# Case study

- **Santa Maria degli Angeli**
  - (43°03'32"N 12°34'41"E)
  - Municipality of Assisi (Italy)
  - 8470 inhabitants
- Over the years, the area has experienced an important urban development
  - residential settlement
  - industrial activities (concentrated in the south-west area)
- LoRaWAN network consists of **six sensors**

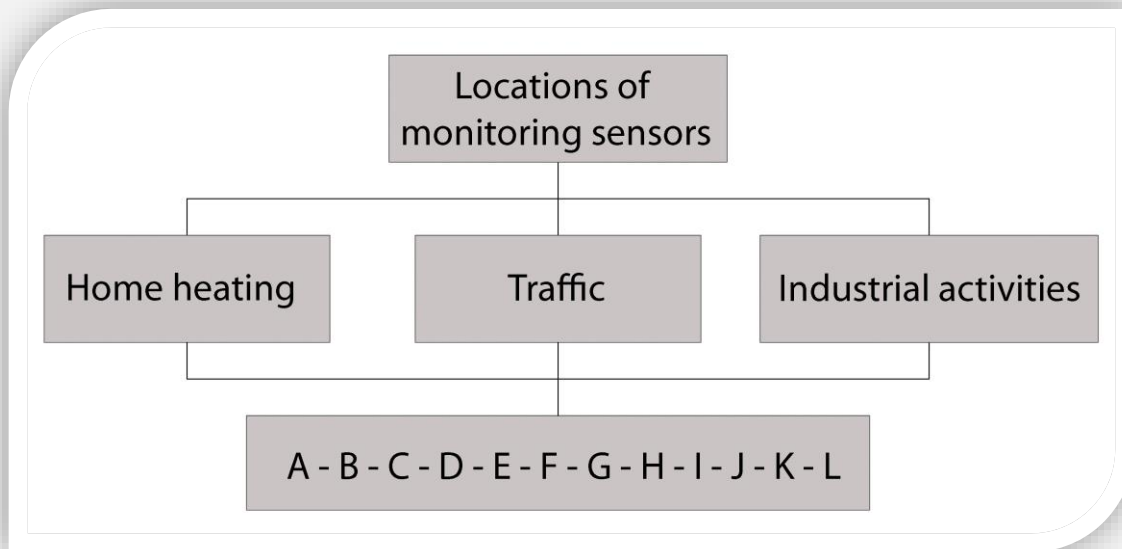


# Analytic Hierarchy Process (AHP)

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- Analytic Hierarchy Process (AHP) is a **multi-criteria decision-making technique** [Saaty]
- AHP allows to assign **priorities** to a series of decision-making **alternatives** and define them on a **single scale**, relating also parameters that are not directly comparable
- The method is made of three steps:
  - definition of a **hierarchy** of the problem (final objective, criteria, alternatives)
  - for each hierarchy layer definition of the matrices of **pairwise comparisons** and computation of the **priority vector**
  - **hierarchical recomposition**

# AHP hierarchy

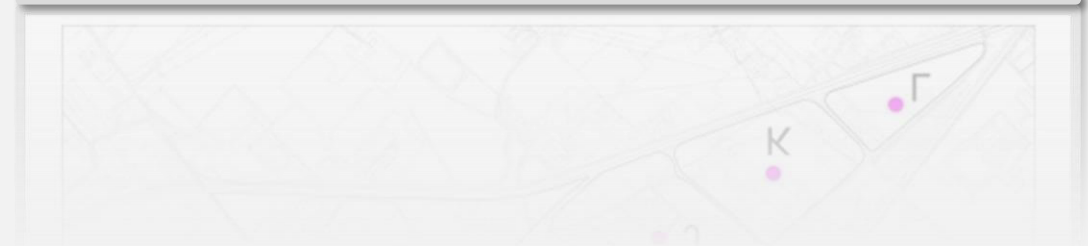
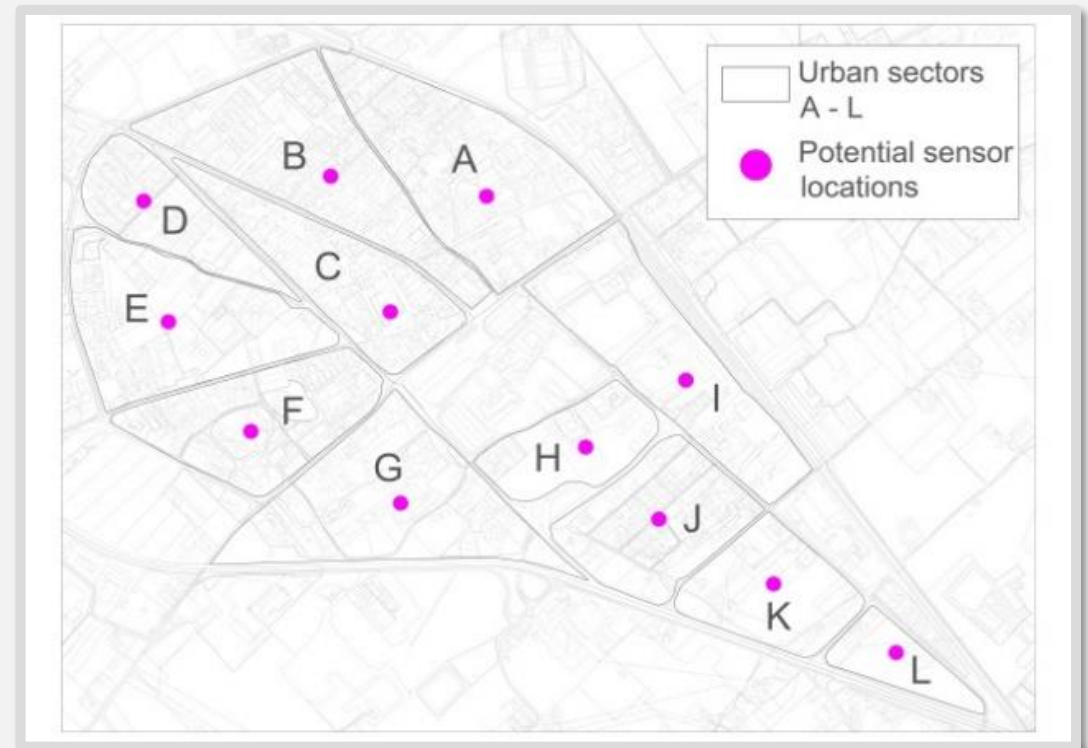


- **Final objective:** locations of sensors for air quality monitoring
- **Criteria layer:** three main sources of pollution [Samad & Vogt, 2020]
  - Evaluation through a **participatory process** with the direct involvement of citizens (survey)
- **Alternatives layer:** twelve candidates locations for the sensors
  - Evaluation through a more objective method using available data



# AHP: candidate sensors locations

- **Twelve urban sectors (A-L)** identified by the three main roads axes and the other main roads



# AHP: questionnaires

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- Questions:
  - which is the **main source of atmospheric pollution** among **home heating, traffic** and the presence of **industrial activities**?
  - **how much** the indicated source of pollution is more decisive than the other two, expressing a value in the **scale from 1 to 9**?
  - **subjective assessment** of the **air quality** in the various areas of the town (polluted or clean?)
- The anonymous **questionnaires** were distributed to a heterogeneous sample of citizens, inhabitants of the study area, of different ages and gender
- 38 questionnaires were collected

# AHP: criteria comparison

- Collected values aggregated by means of the **geometric mean** and approximated to the nearest integer number yielding the **pairwise comparisons matrix**

|                       | Home heating | Traffic | Industrial activities |
|-----------------------|--------------|---------|-----------------------|
| Home heating          | 1            | 1/7     | 1/8                   |
| Traffic               | 7            | 1       | 1/5                   |
| Industrial activities | 8            | 5       | 1                     |

- Priority vector** = normalized principal eigenvector

$$\begin{pmatrix} 0.0545 \\ 0.2331 \\ 0.7125 \end{pmatrix} \begin{matrix} \leftarrow \text{home heating} \\ \leftarrow \text{traffic} \\ \leftarrow \text{Industrial activities} \end{matrix}$$

# AHP: alternatives comparison

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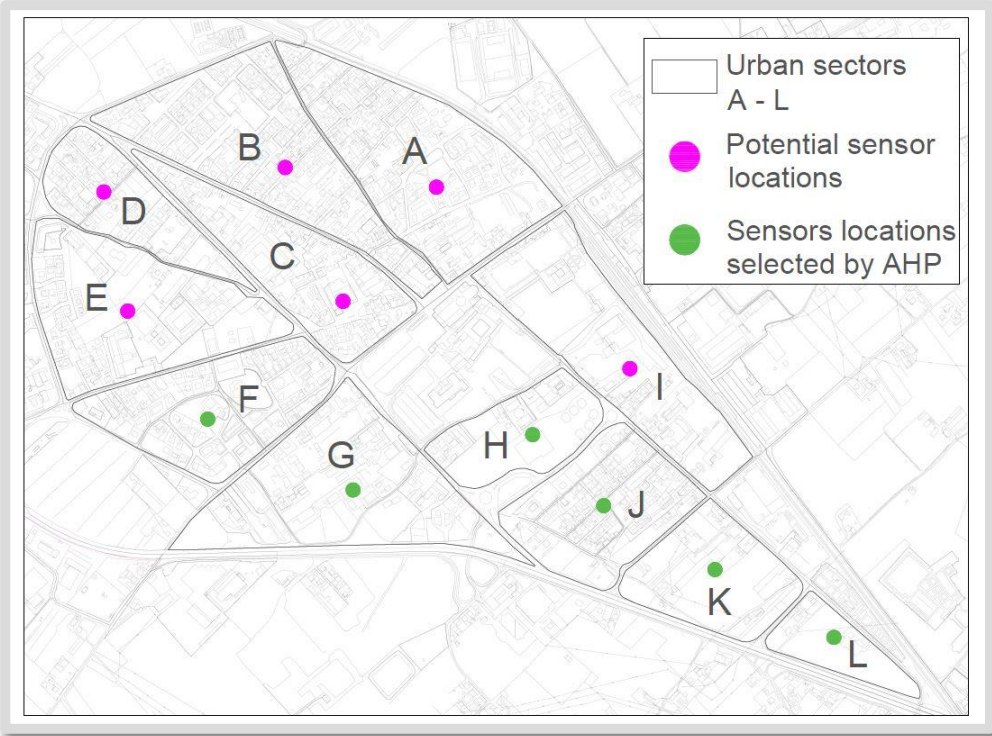
- **Home heating criterion:** on the basis of the **population data** in each sector as recorded in the Municipality database
- **Traffic criterion:** considering how each sector is enclosed by main roads
- **Industrial activities criterion:** considering the average distance of each sector from the foundry and the industrial area to the south-west of the town

# AHP: hierarchical recomposition

| Ranking | Sector | Home heating<br>(0.0544) | Traffic<br>(0.2331) | Industrial activities<br>(0.7125) | Global weights |
|---------|--------|--------------------------|---------------------|-----------------------------------|----------------|
| 1       | G      | 0.1034                   | 0.2832              | 0.2008                            | 0.2147         |
| 2       | J      | 0.0431                   | 0.0689              | 0.2008                            | 0.1614         |
| 3       | H      | 0.0156                   | 0.0271              | 0.1515                            | 0.1151         |
| 4       | K      | 0.0156                   | 0.1685              | 0.1017                            | 0.1126         |
| 5       | F      | 0.08                     | 0.0346              | 0.129                             | 0.1043         |
| 6       | L      | 0.0127                   | 0.2128              | 0.0275                            | 0.0698         |
| 7       | I      | 0.0482                   | 0.0546              | 0.0674                            | 0.0634         |
| 8       | C      | 0.1315                   | 0.0546              | 0.0434                            | 0.0508         |
| 9       | E      | 0.0251                   | 0.0159              | 0.0411                            | 0.0344         |
| 10      | B      | 0.3174                   | 0.0149              | 0.0114                            | 0.0288         |
| 11      | A      | 0.171                    | 0.0214              | 0.0141                            | 0.0244         |
| 12      | D      | 0.0364                   | 0.0434              | 0.0114                            | 0.0202         |

Sensors positions as selected by AHP analysis

# AHP: sensors locations

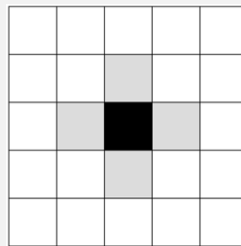




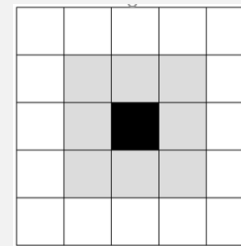
# Cellular automaton (CA)

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- A cellular automaton is a **discrete dynamic system**
- It consists of a set of elements, called **cells**, organized in a **regular spatial grid** and taking on a **finite number of states**
- The state of each cell at a certain moment **evolves** according to a given **transition rule** depending on the present state of the cell itself and the states of the neighborhood
- The neighborhood can be defined in many ways



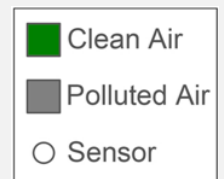
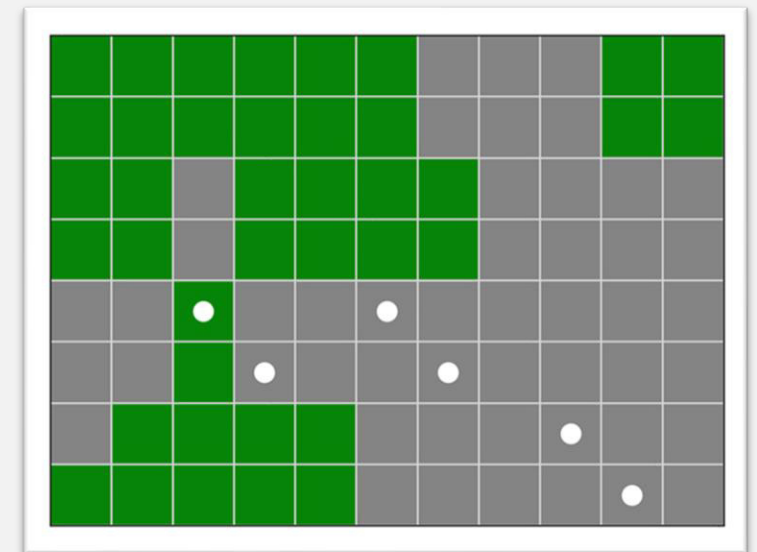
Von Neumann



Moore

# CA for locations optimization

- Goal: **optimizing** the configuration obtained with the AHP method
- **11 × 8 grid** superimposed on the study area
  - Cell dimensions 200 × 200 m
- Two binary variables associated to each cell:
  1. **Absence (0) / presence (1) of a sensor (dynamical)**
  2. **Unpolluted (0) / polluted (1) area, as derived by the survey (fixed)**
- CA initialized with the sensors placed in the position determined by AHP



# CA dynamics

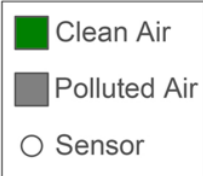
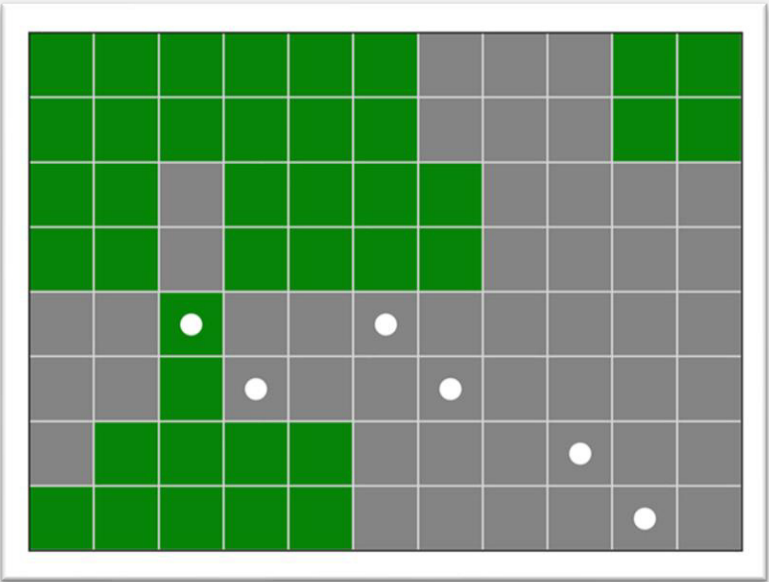
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- At every iteration step each sensor moves in its **Moore's neighbourhood** (or remains in the current position) according to a stochastic dynamics:
  - A probability is assigned to every possible movement of the sensor reflecting the coverage of the polluted areas that the movement will determine
  - The actual movement of the sensor is randomly extracted according to movements probabilities
- The **new configuration is accepted** if it results in an **increase of global coverage**, otherwise it is discarded and the system remains in the previous configuration
- The system evolves till it reaches a **stable configuration...**

# Results

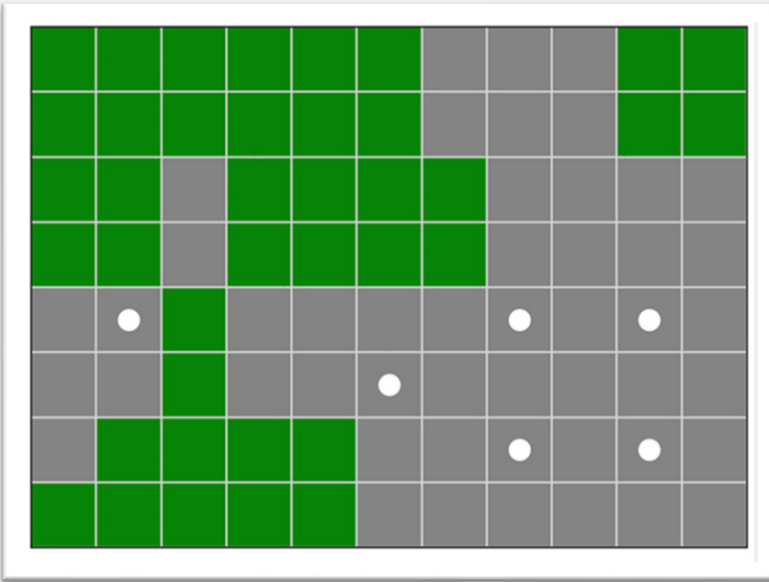
## 1<sup>st</sup> step

Sensors locations resulting from AHP



## Final configuration

Sensors locations resulting from CA



# Outlook

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- A **real** air quality monitoring system is going to be implemented in Santa Maria degli Angeli
- A **more refined optimization** of the sensors positioning, considering levels of pollution determined using not only surveys but also
  - the **measurements** detected by the sensors
  - the **epidemiological data** regarding respiratory and cardiovascular diseases associated with long-term exposure to high levels of pollution
- When the sensors will be installed and when a **significant amount of data** will have been collected the **cellular automaton step will be run again** in order to possibly improve the configuration

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