Amsterdam, December 2022

MAQC

Measuring Air Quality from Construction

Low-Cost Air Quality Measuring Guide and Toolbox

Construction Companies

Municipalities

Researchers

Citizen Scientists

	Construction Companies	Researchers	Citizen Scientists	Policy Makers
1. Sensors		●	●	
2. Preparation	●	●	●	●
3. Experiment	●	●	●	
4. Calibration		●		
5. Data & Processing		●		
6. Network	●		●	●
7. Tenders & Policy	●			●

What and for Whom?

Content

Measurements of air pollution from construction sites and activities: that is the main content of this handbook. Enabling easier and improved insight in the air quality of Amsterdam, the handbook offers guidelines and a linked code repository to perform and implement low-cost, construction-related air quality measurement projects. Each chapter offers a set of useful lessons learned and practical tips tackling different elements of the process.

Want to know more about the benefits of measuring? Go to our website.

Target audience

There are four key actors for which this handbook is useful:

Construction companies, researchers interested in measuring air pollution, citizen scientists, and policy makers.

Reading guide

The table above offers a reading guide through the document, to make the handbook relevant and digestible. It works as follows:

1. Identify yourself with one of the four listed actor groups.
2. Read the relevant chapters indicated.

Introduction

Measuring & Construction

Currently, there is a lack of emission measurements of construction activities. Problematically so, since the government is striving to improve the air quality and move towards a sustainable future, while simultaneously facing a housing crisis and booming construction industry. Since many construction projects are scheduled for years to come, if air quality around construction sites remains unmeasured, it becomes difficult to adapt on-site processes in order to improve surrounding air quality.

In cooperation with multiple institutions, we performed a pilot project on the air quality measurement of construction sites in Amsterdam. The insights gained through this process, in combination with +/- 20 expert and practitioners' interviews, the attendance of conferences, and a literature review, are the sources for this manual. The guidelines consist of technical and non-technical considerations, measurement challenges and the translations of research to practice. The attached code repository allows researchers and citizen scientists to replicate similar research projects in the future.

1. Sensors

Types & practicalities

Some specific examples in this report (section 4) were generated using the MIT City Scanner platform. The City Scanner can be built for approximately $450 USD. The most important sensors it includes are:

- Alphasense OPC-N2 (Particulate Matter)
- Alphasense CO-A4 (Carbon Monoxide)
- Alphasense NO2-A4 (Nitrogen Dioxide)

Low-cost, small sensors like the City Scanner can be widely applied and used to collect a large amount of data relatively inexpensively. Low-cost sensors are known to suffer from data quality and stability issues, so some rigorous data processing - calibration - is required (section 4).

Depending on your research objective different pollutants might be of interest. Read about various available low-cost sensors on RIVM's Samen Meten website.

The City Scanner lessons

When using the City Scanner platform (or other US sensor platforms) in the European context, some practicalities need to be addressed.

1. There is a difference in voltage between the American and European power grids which may need to be accounted for to charge your sensor:

    a. A voltage-adjustable charger can be used to combat charging issues.

    b. Swap out the battery for one compatible with the European power grid

2. Reading out measurements over a cellular network requires a location-specific network plan.

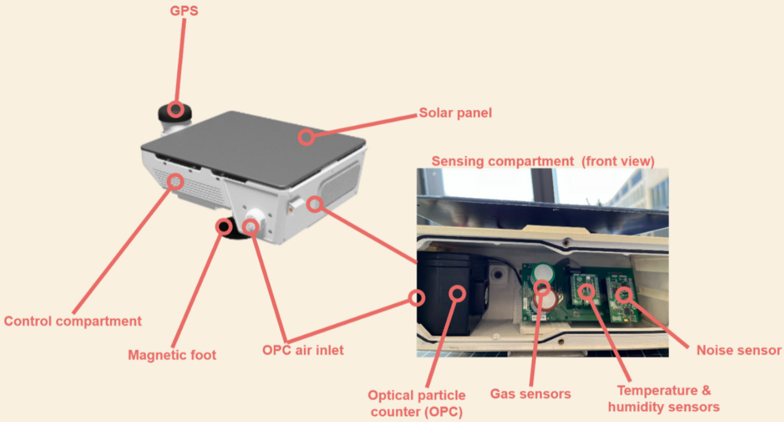
    a. Make sure you have the correct cellular connection.

    b. Use a wifi connection for reading out measurements.

3. The default threading of screws differs between the US and Europe

    a. For the City Scanner sensor, 1/4 inch diameter screws and bolts are used

Image: The City Scanner parts



General lessons

1. *Weather conditions*

Weather conditions can seriously affect the quality and availability of your measurements. Most importantly, low-cost PM sensors are very sensitive to high relative humidity (RH), and can report 2 to 5 times the actual values of pollutants when RH is above 90%. The calibration process (section 4) can improve the discrepancies but measurements under less humid conditions are more reliable.

2. *Power source*

When your sensor runs on battery and relies on a solar panel for external energy, the seasonality will affect the capacity required to run the sensors. Assume sub-optimal conditions to ensure sufficient capacity.

Make sure there is an indicator (e.g. LED) for when a device is (1) powered on or (2) charging to avoid losing data because of insufficient battery. In practice, power plugs can be dirty, damaged or hard to reach. Direct feedback on your experimental setup is essential.

2. Preparation
Pre-sensing Considerations

What to measure?

Larger dust particles e.g. from trucks or drilling ->

Mostly: PM2.5 / PM10 sensors

Diesel or other combustion engines ->

Mostly: Ultra Fine Particles (UFP), Nitrous Oxides (NOx), Black Carbon

For your project, describe the following considerations in the text block below.

I want to measure:

1. Why?
2. What?
3. When?
4. Where?
5. With whom?

Timing

- Season & Humidity: Consider in which season your measurements will take place and how this might affect your results through external factors like humidity and temperature.
- Timespan: Measure for as long as possible, and both when emission sources are present and absent. This shows the impact of the emission sources.
- Study area: if you are measuring on-site, make sure the activities you envision to measure are carried out during that time-period. If you are doing mobile measurements, ensure that the routes you want to measure cover your research objective.

Permissions

- When doing on-site measurements, ensure that all required permissions are granted. For example, from the site contractor or when taking images as part of your research setup (Section 3).
- Arrange a calibration location ahead of time so results can be validated (Section 4).

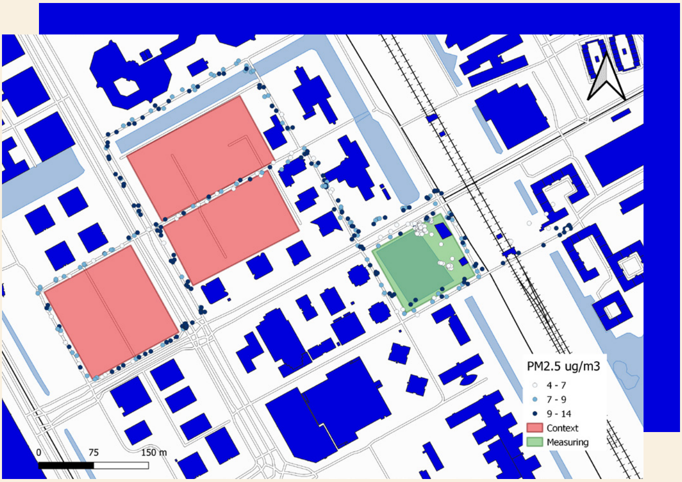


Image: Example Snifferbike experiment measuring PM values next to construction sites

3. The Experiment

Measurements on-site

How to measure?

1. Stationary: A stationary setup with 4 sensors, 1 in each wind direction, around your emission source allows you to allocate the emissions to your source. Make sure you have an anemometer or external wind direction data.

2. Mobile: A Mobile sensing strategy allows for more spatial coverage. Use a mobile sensing platform like the City Scanner or the Snuffelfiets. From experience we recommend passing by the same location at least 4 times if you want to attribute emissions to a source while ignoring coincidental spikes.

3. Insight into measured activities: To link emissions to certain activities, include a camera in your setup. Alternatively, to check what is going on when emissions spike, you could use a detailed schedule or structured field observations.

Construction site or company cooperation, tips and tricks

To ensure smooth cooperation, make partners' lives easy.

1. Use plug- & play devices.
   Make sure your devices have thoroughly been tested before deployment.

2. Transfer data over a mobile data network with a SIM card.
   Besides limiting the number of site visits you require, this also gives you a way to verify that your sensors are functioning remotely.

3. Ensure stable power supply.

Power

Where is your source of power? For your sensor to keep measuring, power is key.

1. Generator: Does it produce power at night?

2. Electricity: Can it reach all your sensors?

3. Battery or Solar: Is there sufficient capacity?

During the calibration process, unvalidated measurements are compared with official monitoring sites to correct any biases or inaccuracies in the measurements. This is done by co-locating the sensors and having them measure air of similar quality. The sensors are then expected to produce the same measurements. Discrepancies between the measurements can often be attributed to the humidity, and taking the measured values, humidity, and several other meteorological factors together, a correction factor can be produced for the unvalidated sensors. The RIVM's Samen Meten website provides an overview of reference station locations.

4. Calibration

Accounting for exernal factors

Why is calibration so important?

As low-cost sensors are especially vulnerable to inaccuracies, the calibration process is very important.

However, the calibration process is perhaps the most tricky step of the whole process: getting permission to use a reference station takes time, and creating the calibration Machine Learning model requires the expertise of a data scientist. Please keep this in mind as you are planning your experiment.

Calibration steps

1. Leave your sensors co-located with the reference station as long as possible, to compare the readings over different weather conditions, but at least two weeks.
2. The weather conditions of the calibration period should reflect those of the experiment.
3. Some reference stations only publish hourly readings, inquire about the availability of higher resolution data to have more data for comparison
4. A Machine Learning model can identify the correction needed from your low-cost sensor to the real-world value, see this code repository for our approach.
5. In general it is best to start with simple models, for example linear regression, and only move to more complex models if needed.

Practical tips:

1. Check for the availability of power on your calibration location.
2. Check whether your sensors are in a secure location.
3. Look at our code to start on the calibration algorithm. However, since it is a complex process, check out the network section (section 6) if you need assistance.

5. Data & Processing

Including code repository

A Git repository has been set up with python code necessary for low-cost air quality measuring projects.

The package includes code to:

1. Import open source context data, such as weather and wind conditions (from the KNMI) or background measurements (GGD).
2. Calibrate the gathered measurements with reference data. Although a baseline model is provided, this model should be tuned to your specific setup.
3. Analyze the measurements, both individually and in comparison to the reference data (point 1). Always note the possible unreliability of low-cost sensors when drawing/publishing conclusions.
4. Visualize the analyses.
5. Analyze camera images of activities during measurements, if using an

City Scanner Data Pipeline

PREPROCESS SENSOR DATA

Raw data from the sensors is preprocessed to remove faulty rows, apply the correct timezone and enforce the correct data types.

ADD EXTERNAL DATA

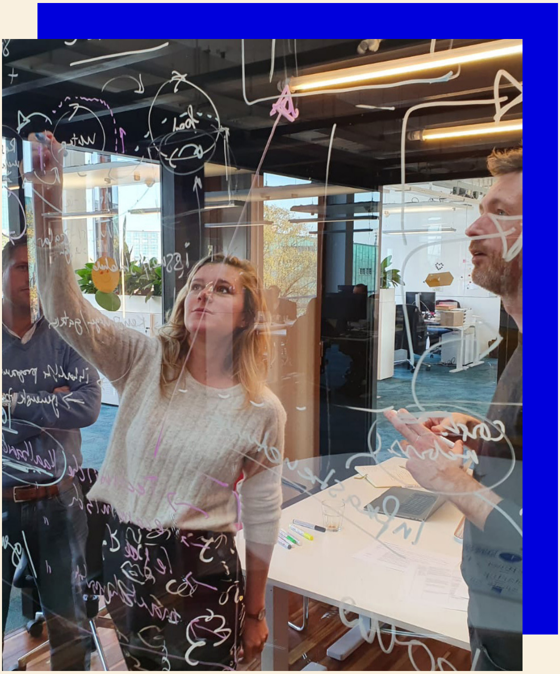
External meteorogical data from the KNMI and background emission data from the GGD is added to enrich the cleaned sensor data.

APPLY CALIBRATION

A calibration model is applied to the enriched dataset to adjust for biases in the data resulting from meteorological factors like humidity.

ANALYZE DATA

Statistics, plots and other figures are generated and analyzed - insight is generated.



6. Network

Of course, we are not the first ones measuring air pollution.

Four helpful departing points to create your (low-cost sensing) network are written below. Even though these are not specifically targeted to the construction industry, they have valuable experience in setting up similar experiments in different settings.

1. Samen Meten
2. MIT Senseable City Lab
3. Waag - Hollandse Luchten project
4. Snuffelfiets

Starting your network

1. Samen Meten. If you want to do air quality measurements mostly with cheap sensors, samen meten from the Dutch RIVM (Rijksinstituut voor Volksgezondheid en Milieu) provides helpful tips on types of sensors, already available data and example projects. If you are a citizen scientist, you can also approach them for questions.

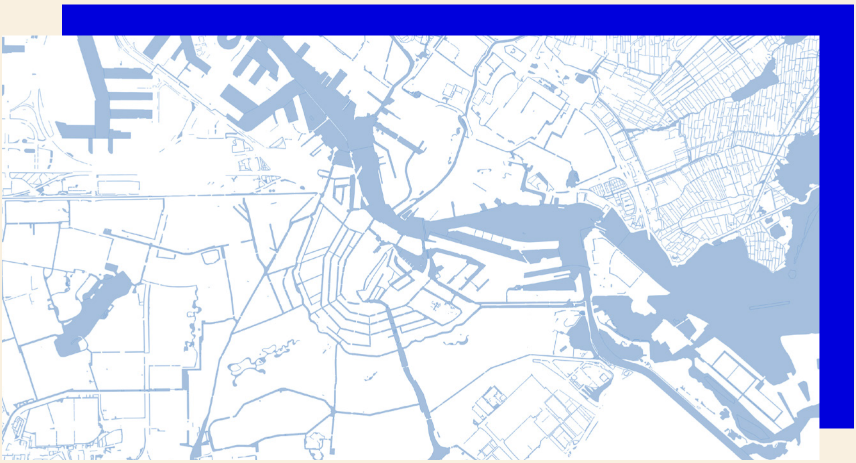
2. MIT Senseable City Lab.

   a. Senseable Amsterdam Lab: The Senseable Amsterdam lab is located at the AMS Institute. Measuring air pollution is one of the urban challenges they tackle. Specifically interested in air quality for construction in the G4 (four biggest Dutch cities). AMS Institute might be able to help you further.

   b. City Scanner Open Source Platform. The City Scanner is the combination of sensors mentioned in section 1. The City Scanner is mainly used to do mobile monitoring in cities across the world, and is now being improved to work stationary as well. The City Scanner will soon be available open source to: 1. make low-cost measuring accessible and 2. share experiences.

3. The Waag / Hollandse Luchten. If you are a citizen scientist in the province of Noord-Holland (The Netherlands), this platform is especially relevant. You can join one of the measuring meetings or contribute in measuring yourself.

4. Snifferbike. The Snifferbike (Snuffelfiets) is an initiative of various Dutch institutes. Their mobile sensors easily attach to the handlebars of a bike and take PM10, PM2.5 and PM1.0 measurements while riding. At the time of writing Snifferbike is also working on making NO2 and O3 sensors available for their platform. Make sure to consider how often you go, when you go (is it rush hour?) and where you are (are you next to a major polluting source?).



Call to Action

As construction is one of the largest sectors in modern day cities, researching its pollution and subsequent adverse health impacts is important. As a result, this handbook has the additional intent of urging municipalities, construction companies and researchers alike to dedicate time, money and - priority - to construction-related air pollution. The problem is too complex to be solved by individual institutes or singly-operating bodies overseeing climatology or health.

7. Tenders & Policy

The tender process

Currently, the municipality of Amsterdam is changing its construction tender process to include the principle of "Het nieuwe Normaal". Incorporating these principles to the construction process is a good start. That said, an alteration of the tender process should also consider the following points:

Verifying indicators

Measure if the indicators adopted in the tender processes are the right ones. Currently, much of the identification of air pollution sources is based on estimates. Measuring can verify assumptions and generate new insights.

Measuring as an evaluation tool

Monitoring air quality repeatedly during the construction process can help map the pollution of different stages of construction. In practice, checking whether construction companies adhere to the building requirements is often done at the beginning of the construction process. However, also because large construction projects often include subcontractors, structurally monitoring the emission changes over time could be valuable. As low-cost measurements become more accessible, continuous air quality measurements could become a feasible evaluation tool.

Policy

Prioritizing policy measures

Many of the proposed policy measures for cleaner construction in Dutch cities are directed towards electrification and building hubs. However, in practice many core construction processes are still too power-intensive for electrification. Prioritizing the most important emission sources and their respective policy measures then, becomes important. Increasing measurements can help identify which activities (e.g. drilling, transportation, demolition) are most polluting and under which circumstances (e.g. time of day, wind direction, humidity, location).

Targeted subsidies

If more knowledge is generated on pollutant sources in the construction industry, more effective targeted subsidies can be set up and rewarding construction companies who act sustainably becomes easier.

Benefits for construction companies

"Meten is weten" (To measure is to know)

Construction companies are increasingly aware of their social responsibility as well as economic incentives to minimize pollutants. However, prioritizing interventions when investment costs are high can be difficult. Implementing low-cost sensors on-site or on your machinery could inform sustainable investment decisions.

Healthy work environment

Creating a healthy work environment for construction workers is important. Measuring on-site, and especially on-person, allows workers to measure their direct exposure to pollutants. This information can be used to improve the working conditions.

Comparative advantage in tenders

There is increasing attention to sustainability measurements in the construction sector from the government and the media. Therefore, if you can demonstrate that you apply sustainable building practices, it will give you a comparative advantage over other contractors in tender processes.

senseable city lab.

AMSTERDAM INSTITUTE FOR ADVANCED METROPOLITAN SOLUTIONS

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Measuring Air Quality

From Construction (MAQC)

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Code Repository Link