VÉGÉSTATION

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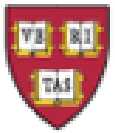

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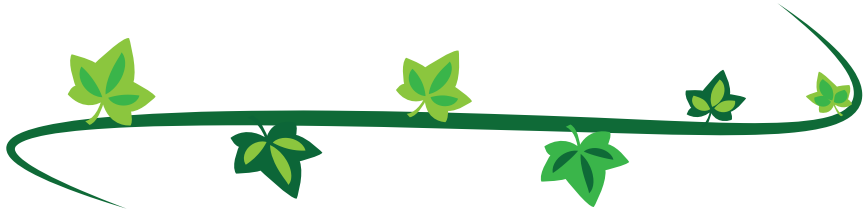
Abstract

VégéStation is a project that tackles both the poor air quality and the low user well-being in the Parisian metro, conditions that affect each of the metro's 4 million daily passengers. The project consists of implementing green walls composed of well-adapted, air-filtering plant species in stations, coupled with an extensive air monitoring system and user well-being surveys.

While VégéStation applies research on phytoremediation and air pollution and builds upon previous efforts to implement vegetation in the metro, it is unique in its emphasis on both public health and well-being and in its integration of technology.

VégéStation transforms the Parisian metro network into the first urban lymphatic network, capable of filtering air pollutants via phytoremediation. Each station, a true underground lymph node, would be equipped with both sensors that measure air quality in real time and green walls tailored to local pollutant types and levels.

Thus, by addressing both the physical and mental health of Parisians, VégéStation provides a sustainable, smart-city approach to the often-overlooked, but serious issue of metro air quality.



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The Issue: the Parisian metro system has poor air quality and low user well-being

Good health and well-being are fundamental human rights

Good health and well-being are a part of the United Nations Sustainable Development Goals.

To breathe clean air is a fundamental human right. The French law on air and the rational use of energy, adopted in 1996, recognizes the right of everyone to breathe an air that does not harm their health.

Under the rule of law, local and national policymakers are responsible to ensure that all Parisians and all persons who are present within the French territory have access to healthy air.

Air pollution is a serious problem in cities

“In the world, one death out of seven is caused by air pollution.”
- Institut de veille sanitaire

Air pollution presents a serious health risk for the population.

Notwithstanding the legal framework, each year in France, more than 48 000 people die prematurely because of PM2.5 air pollution (INVS, 2016).

A recent report of the French Sénat alerts the authorities on the bad health effects of air pollution, which also causes negative socio-economics externalities.

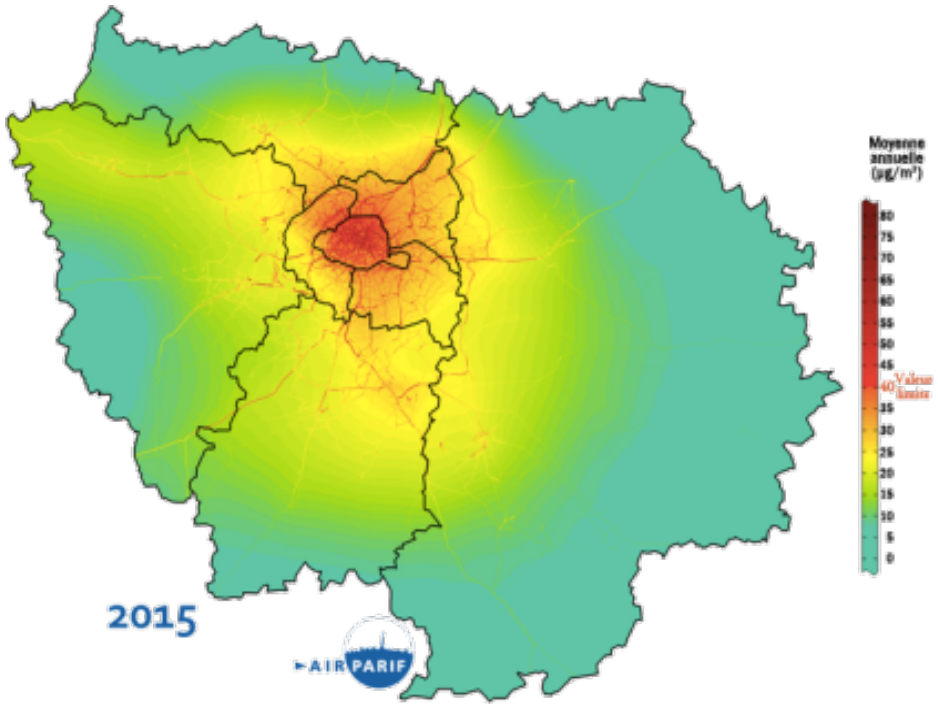
According to the Sénat, the health costs of air pollution are estimated to be between €68 and €97 billion per year in France.

In 2015, in Paris, 1.5 million people were still breathing polluted air

In Paris, regulated pollutants regularly exceed the threshold limits, including nitrogen dioxide, microparticles (PM10 and PM2.5), ozone and benzene (Airparif).

To deal with this problem, the mayor of Paris implemented proactive measures in the city to reduce the air pollution such as alternating traffic during pollution peaks, deployment of the vélib and autolib networks, car-free Sundays in the perimeter of the city, and the pedestrianization of the Seine bank.

Harmful effects of air pollution on health are at 80% caused by daily expositions of polluants below the alert thresholds (Le Monde, 2016).



An NO_2 pollution halo around Paris.

Air pollution is 2.5 times higher in the metro than outdoors

Outdoor pollution is the visible tip of the iceberg.

Yves Pozzo di Borgo, senator of Paris, said about air pollution in the subway station that “the numbers I have confirm that this is a very serious problem” in certains places, he says, air pollution in the subway station is ten times the level of pollution in the ring-road in a big traffic jams, during a pollution peak.

For example, PM10 levels range from 60µg/m3 to 195 µg/m3 in the subway station compared to PM10 levels of 25 µg/m3 outdoors. For some stations, such as Châtelet, the concentration of PM10 is 6 times higher than the outdoor concentration, and during a pollution peak, can rise up to 1000 µg/m3.

The two main sources of air pollution in the subway station are:

2. Outdoor pollution

1. Braking system

Lack of well-being is another issue for metro-users

"*Dans le métro, les gens ont toujours un air triste et malheureux.*"
"*In the metro, people always seem sad and miserable.*"
- Anna Karina in "Bande à part ", Jean-Luc Godard (1964)

More than 1.5 million people suffer from stress caused by public transport in Paris (Technologia survey, 2010). Also, Parisians denounce the psychological stress caused by incivilities, insecurity, and discomfort in the subway (Le Monde, 2010).

Vegetalization can contribute to improve the well-being of users in an artificial urban environnement as the subway station (Stanford Woods Institute for the Environment, 2015).

Visual contrast between the Monceau park and the Jaures metro station in Paris.

Health and well-being as a common good

Health and well-being should not be a luxury but rather a common good for everyone and a priority for public authorities.

Paris is rich in its 2.244 million inhabitants and its 47 millionf tourists.

According to the IFOP 2014 survey, 83% of Parisians perceive a poor air quality in Paris. And 68% people are personally concerned with the problem of air pollution, especially because of its health impact.

Each day in Paris, 4.13 million people use the metro, the 7th most frequented metro system in the world.

Both air pollution and environmental stress decrease the quality of users' experience. This problem is not a local question. In France, 12 million people are affected by air pollution in subway station, and billions more around the world.

Children, pregnant women, seniors, athletes, patients, and smokers are particulary vulnerable to air pollution (Medina, 2015).

Our proposal: VégéStation

To both reduce air pollution and enhance user well-being, we propose installing green walls consisting of phytoremediative plants in metro stations. These plants (namely *Hedera helix*, *Epipremnum aureum*, *Spathiphyllum*, and *Chrysanthemum morifolium*) improve air quality by efficiently removing a variety of air pollutants and boost user well-being by stimulating cognition and creativity and decreasing stress and mental fatigue. Coupled with an expansion of the current air quality monitoring system in the metro and regular metro-user surveys (to monitor and assess air quality and user well-being, respectively), these green walls would transform metro stations in a remediative and restorative manner.

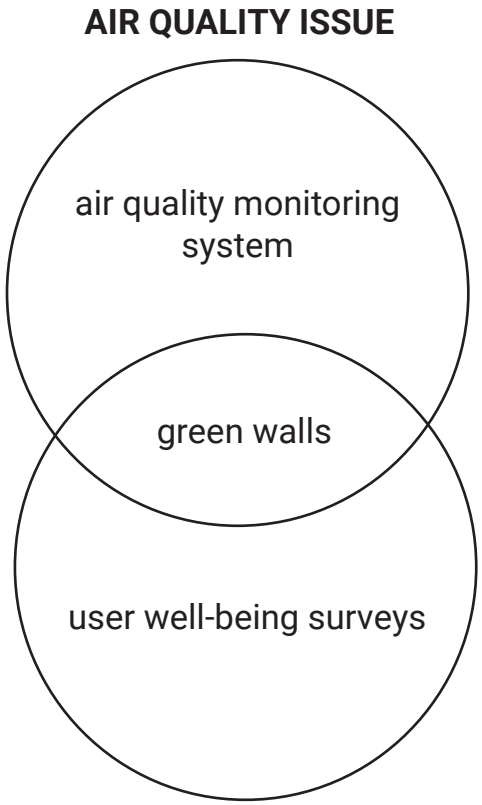
Our proposal consists of four phases:

1. Further **develop** the current air quality monitoring system in the metro and implement user well-being surveys

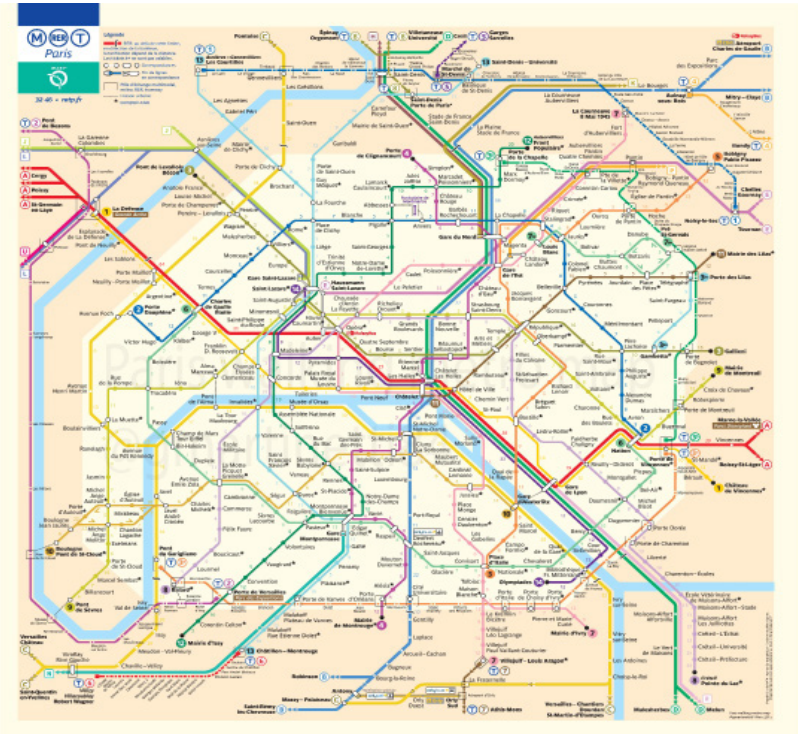
2. **Install** green walls in stations with high air pollution levels, low well-being, and high traffic

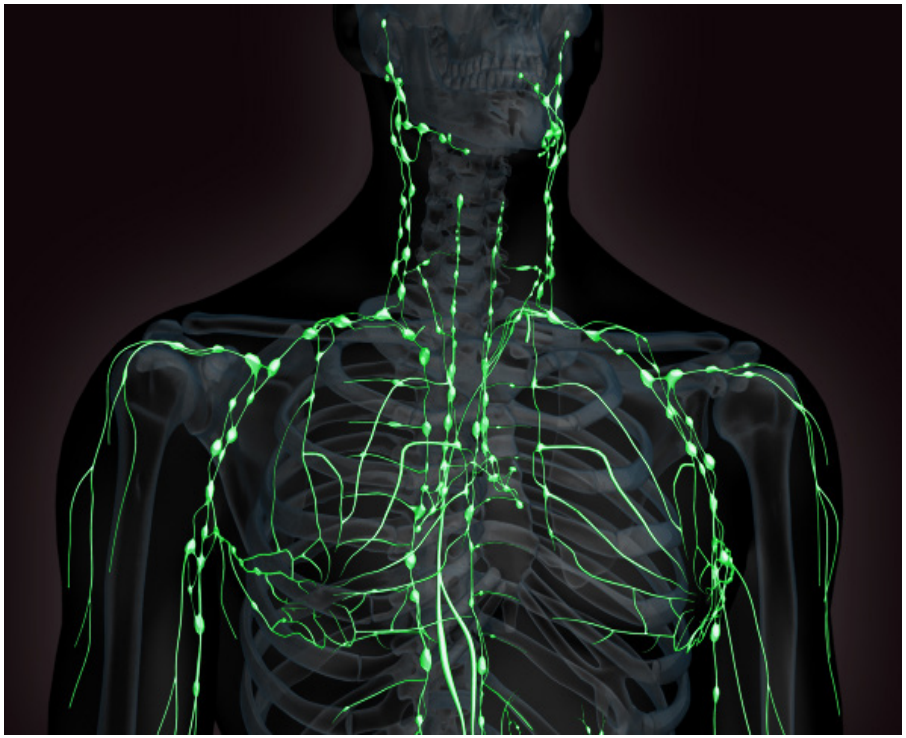
3. **Assess** the success of the green walls using the developed air quality monitoring system and user well-being surveys

4. **Expand** green walls to other stations



The biological principle: the lymphatic system

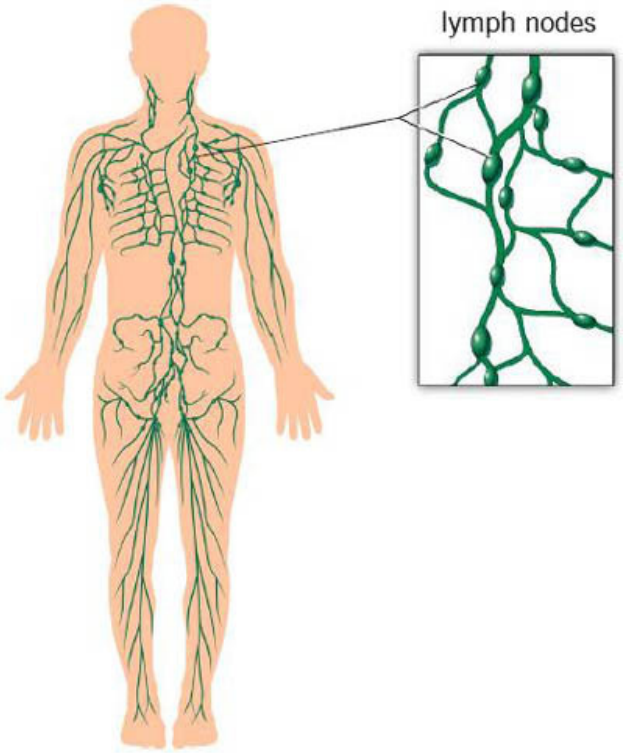




VégéStation would transform the Parisian metro system into the first urban lymphatic system. A vital part of both the circulatory and immune systems, the lymphatic system is a network of lymph nodes, vessels, and organs that circulates lymph, a clear fluid containing white blood cells, throughout the body. White blood cells agglomerate at lymph nodes, destroying pathogens found in lymph as the fluid flows through the nodes. Similarly, as air circulates within the network of metro stations, each of which representing a lymph node, it is cleansed of its pollutants by the plants at each station.

The lymphatic system as an analogy for the metro system

2 Biological Filtering Systems	
Lymphatic system	VégéStation
• Lymph flows through a network of lymph nodes, lymph vessels, and organs • Lymph nodes represent treatment sites; there, lymph is filtered and cleansed of its pathogens by white blood cells • Lymph nodes range in size; larger ones are at the intersection of multiple lymph vessels and experience heavier lymph flow	• Air flows through a network of metro stations and underground tunnels • Individual metro stations represent treatment sites; there, air is cleansed of its pollutants by phytoremediative plants • Metro stations range in size; larger ones are at the intersection of multiple metro lines and experience heavier air circulation



A close-up of the lymph node network. Each lymph node is analogous to an individual metro station.

Background and Precedents

Historical approach to dealing with ventilation in the metro

Ventilation shafts disguised as a building.

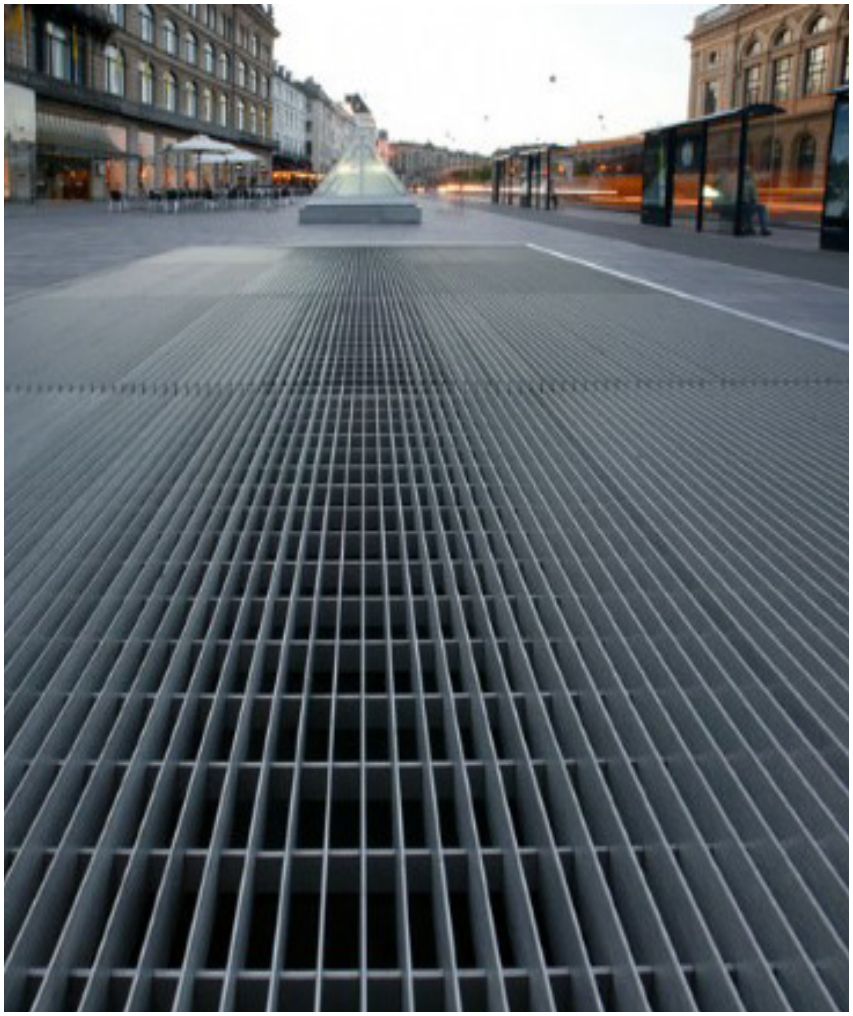
The concern about our planet and human health only started to arise in the last 60 years. As such, during its earliest constructions in the 1910s and 1920s, Paris' underground metro system only featured enough ventilation shafts to allow people inside to breath and to regulate the temperature. We can still see remnants of these huge vents which are sometimes even disguised as buildings.

Construction of a metro station.

Ventilation system

As the underground system grew, so did the need for better ventilation systems in general as the air mass that needed to be displaced increased. On the same principle, technology evolved with the system and the fans inside the shafts became more efficient. Nowadays, this system is enough to regulate the temperature and air flow of the whole system. But what about air pollution?

Large fans increase air flow and circulation underground.



Air vents send underground air to the outdoors.

Metro Pollution

Pollution in such contained environments as the subway are mainly plastic derivatives that come from microparticles from the braking system and paints. In addition, many outdoor air pollutants infiltrate themselves through the air rush. Over time, this results in the slow accumulation of pollutants that are heavier than air inside the metro.

Visual well-being: Art

In terms of increasing user well-being, the Parisian metro has made very uneven efforts. Some stations have benefitted from a complete redesigning, usually done by an artist to give it a tangible personality.

Some stations, such as Arts et Métiers or Franklin Roosevelt have been remodeled and offer a very pleasant experience. But this only applies to very few stations and the rest of the system is usually extremely repetitive with the same corridors, passsages and quais.

In short, the metro stations have tried to increase user well-being mainly through art or technology. They have yet to try implementing plants in an underground space.

Garden at Gare de Lyon

This garden can be found on the right of the quais of the line 14 at the station Gare de Lyon.

It presents a wide variety of exotic plants and even features lighting animation that simulates a rain-forest.

While it was built mainly for the visual aspect, this project still is very interesting because it provides a precedent for our own questions about the light-ing and irrigation system of plants underground.

For this particular garden, the lighting system is disposed well above the plants in the form of full-spectrum light-bulbs. For the irrigation, there is an automatic water distribution system around the parcel that is checked every now and then.

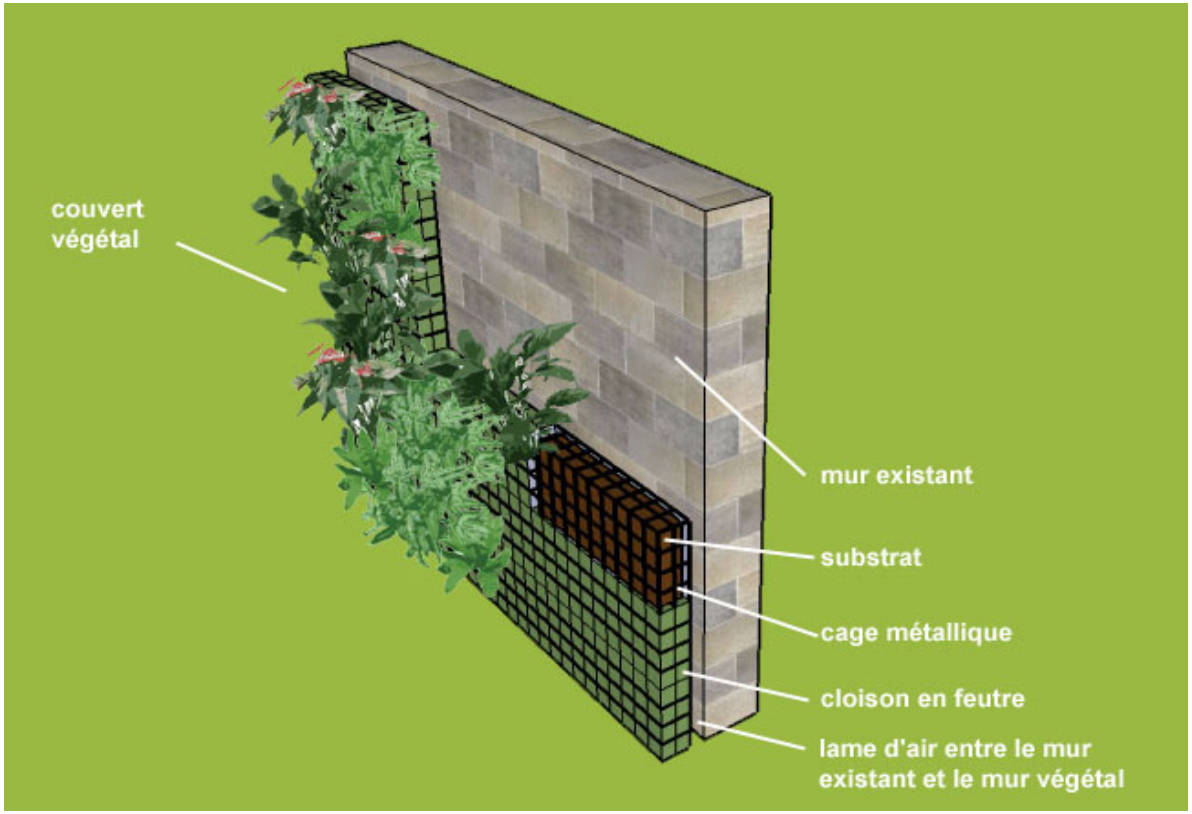
Green Wall at Magenta Station

This is the first green wall implemented in a station. Initiated in 2008 by the SNCF (Société nationale des chemins de fer français), the project created a 70 square meters vegetal wall above ground at the Magenta station. It was finished in 2010 and contains around 3,000 plants of 25 species that have been studied to target train station's pollutants.

Green Wall at Magenta Station : Intake

The wall was designed and installed by a society called Canevaflor. From this project, we got the idea of a micro-irrigation system with recuperation at the bottom to limit water loss.

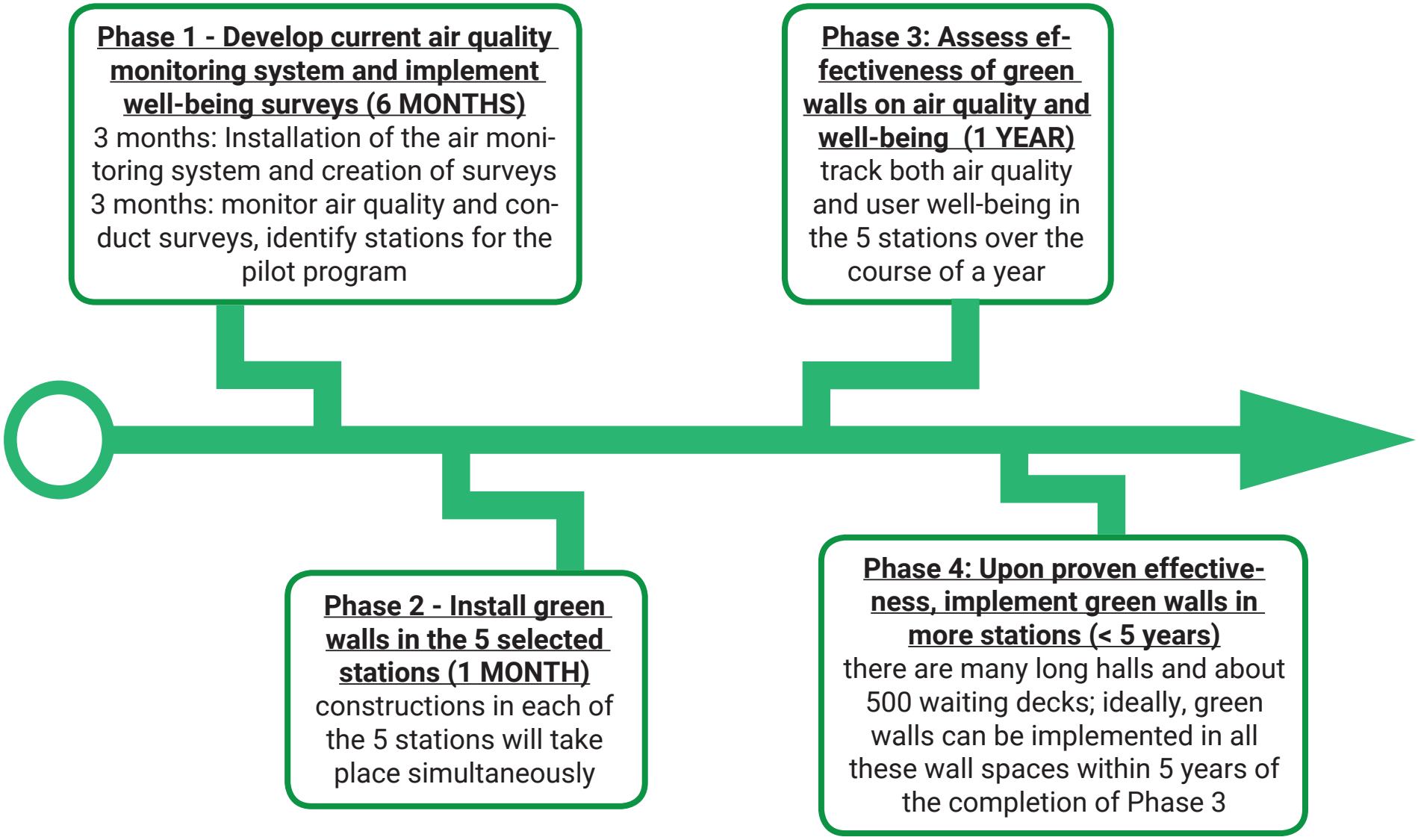
In addition, we also got from this a very efficient method to treat the level of microparticles. Specifically, a ventilation system that pumps the air into the soil of the plants where the microparticles become trapped and then digested by the microorganisms in the soil. These organisms do not need to be implemented as they are already part of the roots ecosystem of our plants.



The structure of the green wall at Magenta station.

The Execution Plan

Projected time frame



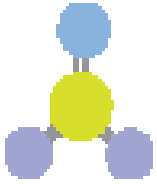
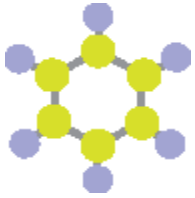
Phase 1: Further develop the current air quality monitoring system

A map of the metro and RER (Réseau Express Régional) network in Paris. The three stations (Châtelet, Franklin D. Roosevelt, and Auber) with air quality measurement systems in place are marked by a leaf.

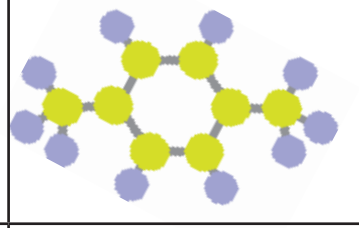
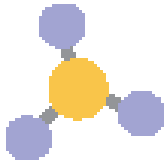
Currently, the RATP (Régie Autonome des Transports Parisiens), the operator of public transport in Paris, has an air quality monitoring system in three stations: Franklin D. Roosevelt (metro line 1), Châtelet (metro line 4), and Auber (RER line A). At these stations, sensors take measurements of NO, NO2, PM10, CO2, temperature, and humidity on a monthly basis. While this is certainly a good start, we propose further developing the current air quality monitoring system, equipping all 314 metro stations in Paris with air pollutant sensors, monitoring more air pollutants, and taking continuous measurements. In addition, these data could be published in real time on the RATP website, enabling the monitoring of various air pollutants and their fluctuations throughout the day, the tracking of air pollutant flow between neighboring stations, and increasing the company's transparency.

Common air pollutants in the metro

In addition to measuring the levels of NO, NO_2, PM10, and CO_2 levels, we propose measuring and monitoring the levels of trichloroethylene, formaldehyde, benzene, xylene, ammonia, nitric oxide, nitrogen dioxide, and microparticles, other common air pollutants that cause adverse health effects. Because the sources of these pollutants can be found in the metro and/or outdoors (outdoor air enters the metro), we suspect that there are rather high levels of these pollutants trapped underground in the metro system.

	Trichloroethylene (C_2HCl_3) 	**Formaldehyde (CH_2O)** 	**Benzene (C_6H_6)** 
Sources	metal degreasing, printing inks, paints, lacquers, varnishes, adhesives	pressed-wood products, paper products, household cleaning products, cigarette smoke, natural gas	gasoline, ink, oils, paints, plastics, rubber, cigarette smoke, vehicle exhaust, detergents
Health effects (short-term exposure)	dizziness, headache, nausea, vomiting	irritation of eyes, nose, and throat, headache, increased risk of asthma	skin irritation, eye irritation, dizziness, headache, nausea, increased risks for respiratory disease
Health effects (long-term exposure)	Increased risk of liver cancer	increased risk of asthma and throat cancer	chromosomal aberrations, leukemia, anemia, and bone marrow disease

Common air pollutants in the metro

	Xylene (C_8H_{10}) 	Ammonia (NH_3) 	Nitric Oxide (NO) 	Nitrogen Dioxide (NO_2) 	Microparticles (PM2.5 & PM10)
Sources	petroleum, paints, ink, vehicle exhaust, cigarette smoke	cleaning products, floor waxes, fertilizers	vehicle exhaust, cigarette smoke	vehicle exhaust, cigarette smoke	motor vehicle exhaust, older metro braking systems (friction within brakes, and between wheel and rails), dust
Health effects (short-term exposure)	irritation to eyes, nose, throat, lungs, dizziness, headache	eye irritation, cough, sore throat	breathing difficulties, irritation of eyes, nose, and throat	respiratory inflammation, worsened asthmatic symptoms	aggravation of asthma, respiratory symptoms
Health effects (long-term exposure)	irritation to eyes, nose, throat, lungs, dizziness, headache				increased risk of respiratory and cardiovascular disease

Implement user well-being surveys

Concurrent with further developing the air monitoring system, we propose implementing user well-being surveys in each station, asking metro passengers to rate their experience in the metro. Also, surveys could ask metro-users how they would feel about vegetation in metro stations.

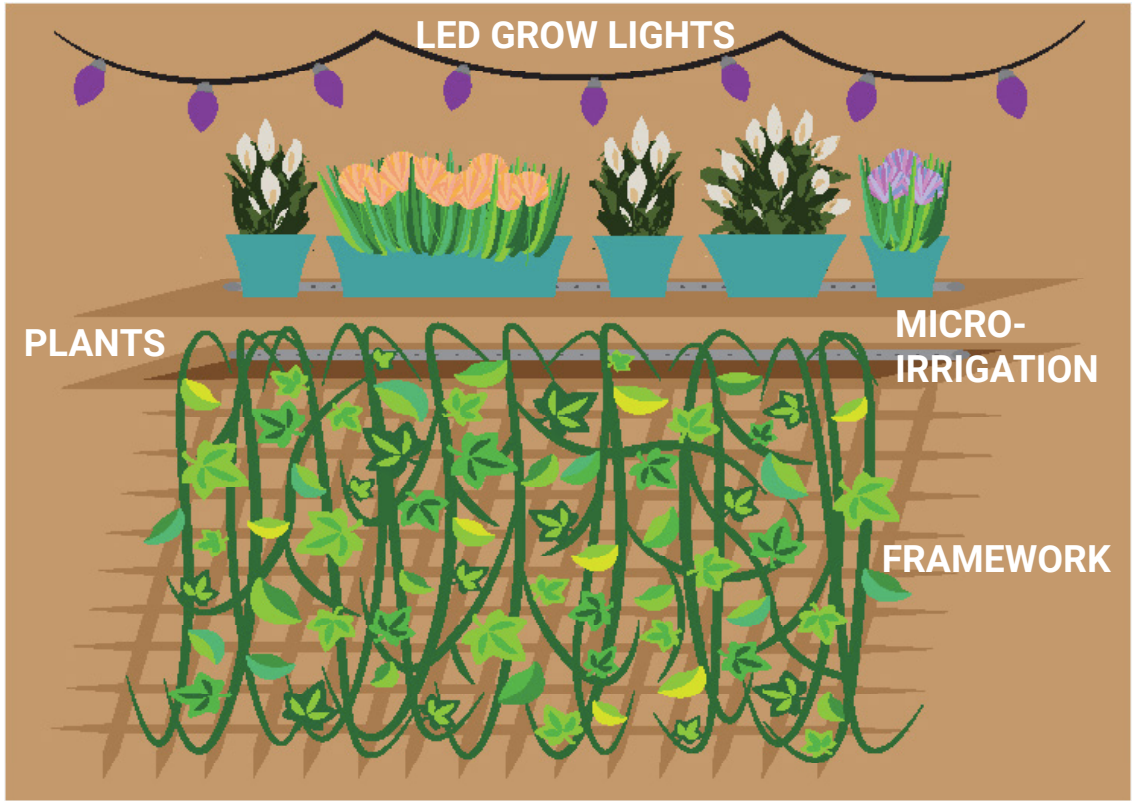
Surveys could take place at waiting decks, while passengers wait for the metro, or in the metro, while passengers wait to arrive to their destination. The best option would be for current RATP workers to conduct the survey. Alternatively, passengers could take the survey at newly-installed kiosks.

Phase 2: Install green walls

Upon assessing air quality and user well-being in each station, green walls will first be installed in the 5 stations with both the highest level of air pollutants, the lowest level of well-being, and the highest traffic.

Each green wall will be inhabited by plants by a combination of *Hedera helix*, *Epipremnum aureum*, *Spathiphyllum*, and *Chrysanthemum morifolium*. Because each plant specializes in removing different air pollutants and because the pollutants may vary from station to station, the particular combination of plants and the quantity of biomass for the green wall at a station will depend on the particular air conditions at that station. However, each green wall will have the following components:

A. Plants (air pollutant removal and well-being enhancer)
B. Micro-irrigation (watering system)
C. LED grow lights (lighting system)
D. Wooden or metal framework (anchoring system for plants and protective system for walls)



An example of a green wall underground in the metro station, with its key components labelled.

Plants

English Ivy *Hedera helix*	**Devil's Ivy** *Epipremnum aureum*	**Peace Lily** *Spathiphyllum*	**Florist's Chrysanthemum** *Chrysanthemum morifolium*
			
removes microparticles, triochloroethylene, formaldehyde, benzene, and xylene	removes formaldehyde, benzene, and xylene	removes triochloroethylene, formaldehyde, benzene, xylene, ammonia	removes triochloroethylene, formaldehyde, benzene, xylene, ammonia

Based on the particular air pollutants that are likely to be in the metro, we propose the plants in the table above for green walls in each station. These plants serve dual-purpose, removing air pollutants and enhancing user well-being. In addition, they are indoor plants, meaning that they are well-adapted to indoor conditions and require relatively low-maintenance, able to survive with minimal water and in rather low light.

Sample estimates of *Hedera helix*'s pollutant removal effficiency

Microparticles (PM2.5)
Assuming PM2.5 levels of 60µg/m³ and that *Hedera helix* (*H. helix*) removes 2.9 x 10^{10} microparticles/m², it would take 0.63m² of *H. helix* to remove all the PM2.5 particles in a station.

Trichloroethylene
Assuming a trichloroethylene level of 25µg/m³ and that *H. helix* removes 7.30 µg trichloroethylene/cm², it would take 2.78m² of *H. helix* to remove all the trichloroethylene in a station.

Benzene
Assuming a benzene level of 50µg/m³ and that *Hedera helix* removes 10.40µg benzene/cm², it would take 3.90m² of *H. helix* to remove all the benzene in a station.

Formaldehyde
Assuming a formaldehyde level of 50µg/m³ and that *H. helix* removes 9.80µg formaldehyde/cm², it would take 4.14m² of *Hedera helix* to remove all the formaldehyde in a station.

Surface area of Hedera helix needed to remove each pollutant *	
Microparticles (PM2.5)	0.63m²
Trichloroethylene	2.78m²
Benzene	3.90m²
Formaldehyde	4.14m²
Total surface area	11.45m²

*this is an overestimate, assuming that *Hedera helix* leaves can only remove one pollutant; in reality, *Hedera helix* leaves can remove multiple pollutants at once

Based on these estimates, a 11.45m² green wall consisting of only *Hedera helix* would be sufficient to remove the above pollutants in a station. However, this is an overestimate, and a sample estimate based on one plant species. The green walls would have other plant species to reduce the Hedera helix surface area, remove more types of air pollutants, and increase pollutant-removal efficiency.

Watering system: micro-irrigation

To water the plants, we propose a system of micro-irrigation (also known as drip irrigation or trickle irrigation) in which the water is delivered slowly and directly to the soil, through a system of rubber or plastic tubes. Micro-irrigation is a very efficient watering method because it targets the water directly to the soil, preventing water waste caused by delivering water to unnecessary plant parts or by evaporation. Watering only when necessary also ensures health plant growth and prevents mold growth. It is an automated system, programmed to water plants at particular times. As a result of its efficiency, micro-irrigation is highly effective, economical, and environmentally-friendly.

To install the micro-irrigation system, we propose either linking it to current water systems in the metro or implementing a rainwater collection system (the latter would further conserve water). Energy to power the irrigation system would come from sustainable sources, such as electricity developed from heat released by the metro system (i.e.(M)Power).

Lighting system: LED grow lights

Since plants in the green wall are underground, they need an artificial lighting system. We propose using LED grow lights, lights specifically designed for growing plants indoors. LED grow lights are an optimal choice for they emit the necessary wavelengths of light (red light, far-red light, blue light, green light) required for plant growth and are highly efficient at converting electricity to light, releasing very little heat.

For the ivies, small LED grow lights could be assembled in a garland and hung among the plants. The localization of light would limit plant growth, keeping plants confined within the area of the green wall. For the potted plants, LED grow light garlands could be fixed to the wall. In addition to providing the necessary light for plants to thrive, these LED grow lights would also enhance the ambiance of the metro station. Ideally, like the irrigation system, the LED grow lights would be powered sustainably.

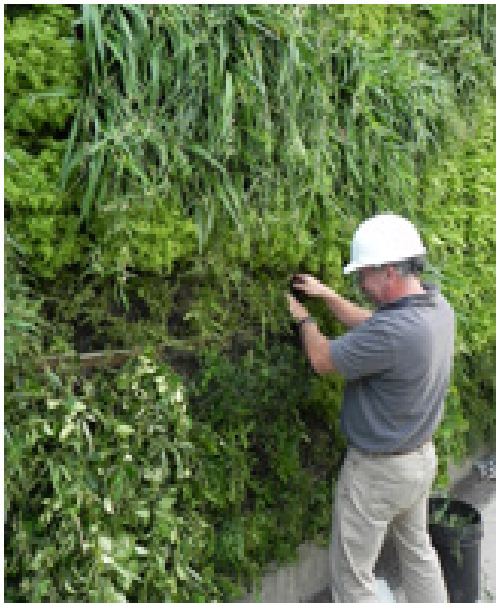
Anchoring and protective system: wooden or metal frameworks

To both anchor the plants and prevent wall damage, we propose installing shelves and a metal or wooden framework on the wall, providing structure for the green wall.

The shelves would either hold potted plants or would contain trays of soil for ivies to grow out from (it is important to use to the appropriate types of soil for each plant to prevent mold growth).

The wooden or metal, grid-like framework provides a structure for the ivies to climb on, preventing ivies from climbing on and damaging the walls of the metro station.

Maintenance



Upon installation of the air quality monitoring system and the green walls, VégéStation is a project that requires maintenance.

Maintenance of the air quality monitoring system: the system requires regular checks and calibrations to ensure accurate data collection.

Maintenance of green walls: Plants on the green wall, particularly the ivies, will need to be trimmed on a regular basis, perhaps once every couple of months (the localization of the lights would likely limit plant size). And while the lighting and watering systems are automatic, they should be inspected regularly to ensure proper function. Plants should also be inspected regularly to ensure healthy growth.

Pest control: Because the green walls are inhabited by living plants, they may attract pests, such as insects, spiders, and mice. If this does occur, a pest control system would need to be implemented.

Further maintenance considerations

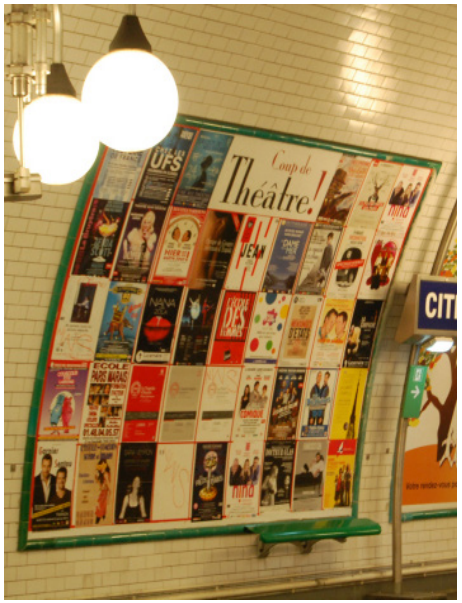
Allergy preventions
Green walls in metro stations may affect people allergic to pollen or mold. Because the green walls consist mainly of ivies (which are pollen-free) and some pots of flowers, they should not elicit severe allergic responses. If pollen allergies do become problematic, plant ratios can be adjusted to minimize pollen-producing plants. As for mold allergies, preventative measures such as using correct soil and watering only when necessary, will be taken. If significant levels of mold grow, then we propose adding a mold removal system to the maintenance of the green walls.

Vandalism
We do not expect any significant vandalism threats to the green wall because RATP takes several measures to prevent vandalism: vandalism fines range from €1,500 to €30,000, RATP agents oversee metro stations during the day both via in-person patrolling and video-surveillance, and metro stations are closed at nights.

An example of plant vandalism.

Caveat: competition for wall space

Because our project aims to improve the quality of the air metro-users breathe and to enhance user well-being, these green walls would be most effective if installed in waiting decks and in hallways, two highly-frequented areas. However, currently, most wall space in these areas are dedicated to large print advertisements. Because advertising represents an important source of revenue for the RATP, installing green walls on these particular wall spaces may result in competition for prime wall space with companies who wish to advertise.



The images above show print advertisements on the walls of along long halls and in waiting decks.

Solutions

The ceiling at Cité station. A typical metro station ceiling, it is white, spaceous, and vacant, and thus suitable for projecting advertisements.

We envision first installing green walls on vacant walls as a test-run. If green walls successfully remove air pollutants and are well-received by metro users, additional green walls will be installed. There may thus be competition for wall space with companies who wish to advertise. To address this issue, we propose the following solutions:

1. Companies who wish to advertise could sponsor green walls. This helps fund the green walls and gives sponsoring companies good publicity.

2. Change the form of advertising: Current paper advertisements consume space on walls and their paints and glues contribute to indoor air pollution. Alternatively, advertisements could be projected onto the spacious, vacant, white ceilings of metro stations, decreasing air pollutants, freeing the vertical walls, removing labor costs tied to print advertisements, and enabling companies to advertise using video (which has more impact than print advertisements).

Cost estimates

For these estimates, we refer to a station as an average-sized station that only services one line. We refer to a panel as a 2m x 4m green wall. For such a station, we imagine implementing 8 panels of green walls for an initial set-up cost of around €50,000 and a yearly maintenance cost of around €20,000 thereafter. The next slide shows a break-down of the cost estimates.

Cost estimates

A break-down of the overall cost estimates:

Component	Cost
Air sensors (per station)	€ 5,000 + € 500 (labor)
Micro-irrigation system (per station)	€ 2,000 + € 1,000 (labor)
LED grow lights (per panel)	€ 200
Green wall shelves and framework, plants (per panel)	€ 4,000 + € 200 (labor)
Electricity (per panel, per year)	€ 600
Maintenance (per panel, per year)	€1,000 (labor)

Funding

The funding for this project would come from the RATP and private companies.

The RATP could fund this project by increasing the metro fare, by slightly reallocating their revenue spending, and by using funds from their Research and Development department. These funds are dedicated to projects, such as VégéStation, that are in line with the RATP's three priorities to improve passenger service, inspire innovation, and to work towards a more sustainable city.

In addition, private companies, including those that currently advertise in the metro, could help sponsor green walls in exchange for good publicity (i.e. the names of the sponsor companies could be listed next to the walls).

Funding: metro fare estimates

Estimates
The following estimates are calculated assuming that costs will be completely covered by an increase in metro fares (since there are other funding sources, these are overestimates). Because Navigo passes are used by wealthier people and often purchased by companies for their employees while tickets are used by the less-wealthy, the unemployed, and by tourists, we plan to obtain 80% of the funding from Navigo card users, and 20% of the funding from ticket users.

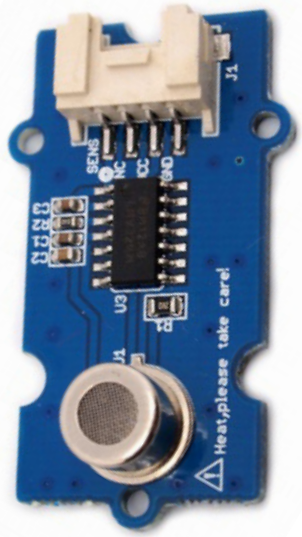
Pilot program - 5 stations
cost: €350,000
Navigo card price: increase by €0.02 (per month)
ticket price: constant

All ~500 platforms - initial installation (first year)
cost: €35 million
Navigo card price: increase by €0.79 (per month)
ticket price: €0.10

All ~500 platforms - yearly maintenance
cost: €10 million
Navigo card price: increase by €0.31 (per month)
ticket price: increase by €0.04

The assessment plan (Phase 3)

Pollutants to measure and monitor	Potential survey questions
microparticles (PM2.5 and PM10), nitric oxide, nitrogen dioxide, formaldehyde, benzene, xylene, ammonia, trichloroethylene	1. Does the addition of the green wall improve the station? 2. Do you notice an improvement in your mood in this station relative to other stations on your commute?

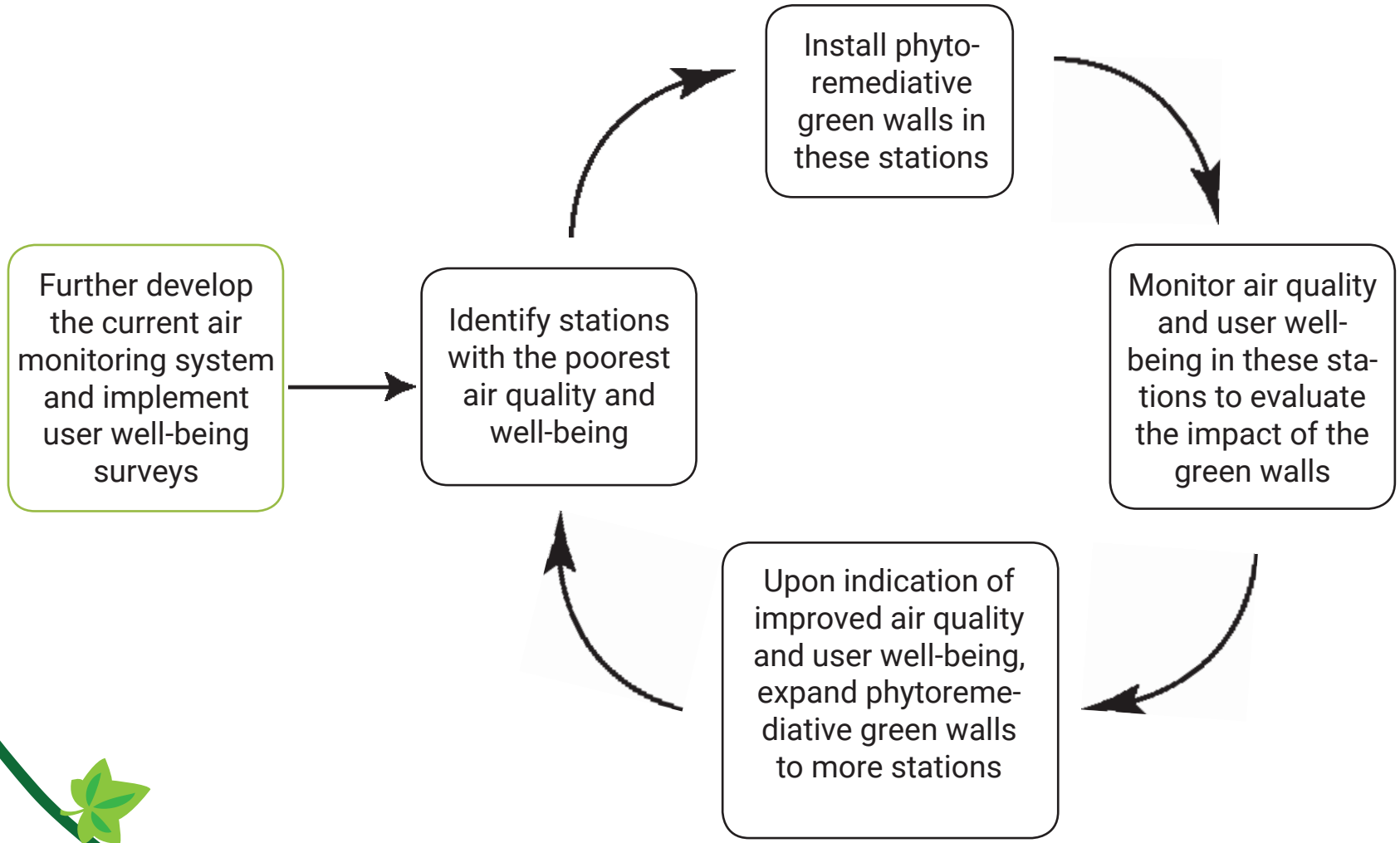


Upon the installation of green walls in various stations, both air quality and user well-being will be carefully monitored. Air quality would be assessed using the air monitoring system. Indication of a sustained decrease in each of the measured pollutants in the station itself and perhaps in neighboring stations as well would reflect the plants' effective air-cleaning.

User well-being would be assessed using surveys at each station and these results would be compared with those taken before the installation of green walls at that station. Increased overall ratings of satisfaction with the station would indicate that the green walls effectively elevated user well-being. The project would be considered a success if it significantly improves both air quality and user well-being.

Phase 4: Expansion

If the initial green walls are deemed successful, the project would expand to the stations with the next poorest air quality and well-being, thus repeating the cycle below.



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