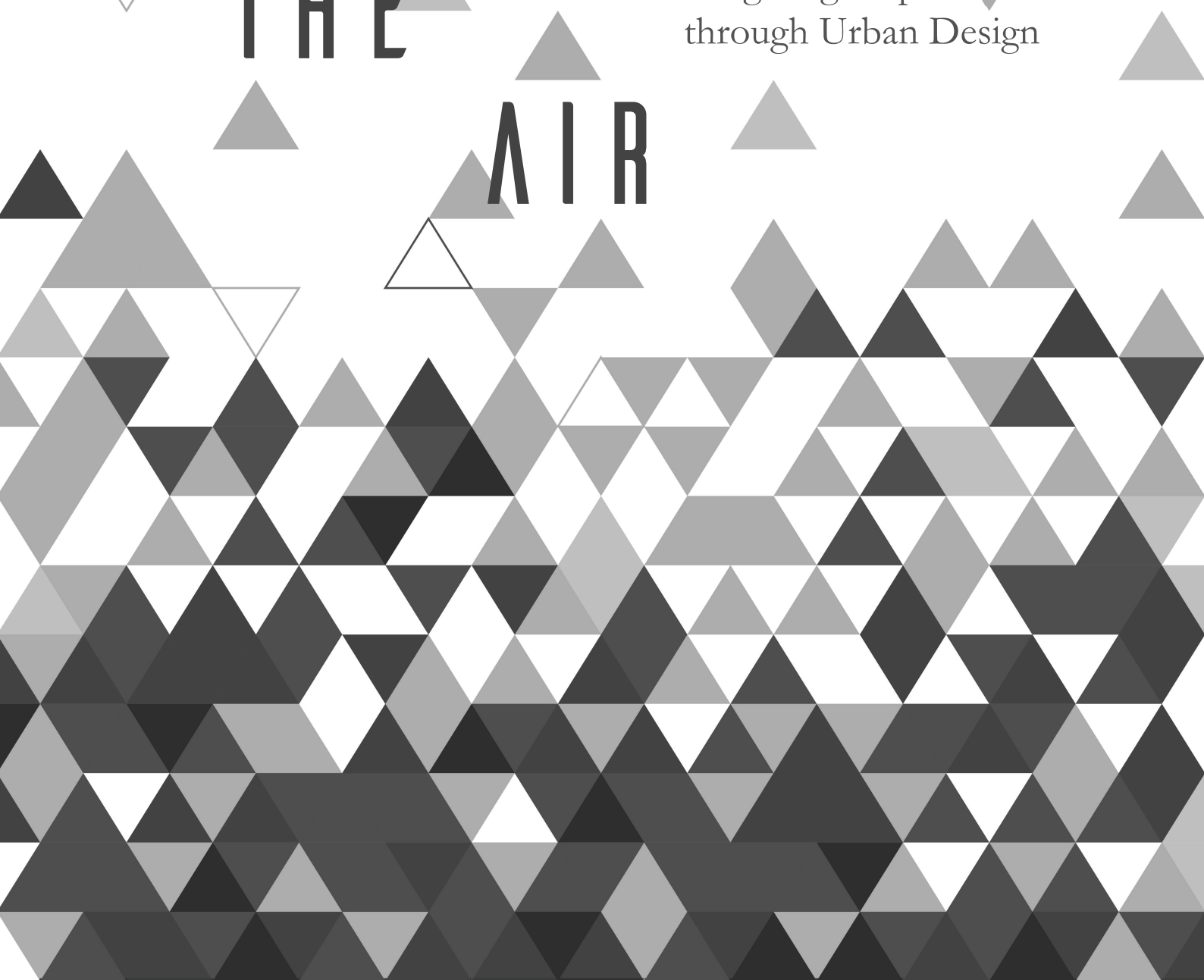
Marcello Felice Vietti

CLEANING THE AIR

Mitigating air pollution through Urban Design



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Cleaning the Air
Mitigating air pollution through Urban Design

Graduation Project
June, 2017

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MSc Thesis
Cleaning the air - Mitigating air pollution through Urban Design

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Abstract

When thinking of air pollution, most of the people refers to Asian countries such as China or India where the air is often unbreathable. However, despite the common believes, air pollution poses the single largest environmental risk in Europe today (EEA, 2015) and, among all the countries, Italy has the highest rate of death related to air pollution. The city of Turin, as one of the four most polluted cities in Italy, has been facing high rates of air pollution concentration for several year. Despite several attempts by the municipality to improve the quality of the air, the situation has slightly changed in the past years and the urgency of the issue calls for alternative and more concrete solutions.

The graduation project, by discovering and analyzing the relationship between air pollution, built environment and urban design, aims to propose a thorough interscalar approach able to mitigate air pollution in the city of Turin. The form and the nature of the built environment are in fact critical to air pollution concentration: street orientation and width, building heights and several other urban features play a key role in air pollution dispersion.

The design proposal focuses on three design interventions which are characterized by different scales of action: from the micro scale of a single public space to an entire neighborhood. Seen together, they form a comprehensive system for mitigating air pollution whose basis rely on the discipline of urban design.

Overall, the graduation project substantiates the relevance of urban design when assessing air pollution in cities. It offers valuable, effective and alternative solutions able to support the already existing urban policies in the city of Turin.

Key words - air pollution, urban design, urban forms, multi-scalar approach, environmental design

CONTENTS

01 INTRODUCTION

Healthy Cities 15

- Health and Planning: from remedy to prevention
- Healthy Cities Project
- Healthy Cities and Air Pollution
- Conclusion

Motivation 25

Problem field 27

Societal Relevance 32

Scientific relevance 33

02 THE ISSUE

Problem statement 37

Problem analysis 39

- Main sources of pollution in Turin and its surroundings
- Factors which influence pollution dispersion
- Receptor site characteristics
- Adopted methods against air pollution

Scope 49

Research Question 53

Methodology 55

Theoretical framework and readings 56

03 THEORY AND ANALYSIS

Introduction 61

Matrix of analysis 62

- Mesoscale and urban canopy: the problem of scale
- Source, dispersion and receptor site
- Units of measurement and aggregation
- Workability
- Impact rate

The analysis 67

- I.3 - Terrain
- I.4 - Land use
- I.5 - Traffic
- I.6 - Vegetation
- I.7 - Roughness
- I.9 - GSI/FSI
- I.10 - Population

Risk assessment: vulnerability and hazard 99

- Analysis and risk hazard approach
- Risk assessment: adopted method
- Results

Sites of interventions 105

- Selection method
- Observations
- Conclusions

04 DESIGN INTERVENTIONS

Design approach 117

Piazza Vittorio Veneto 119

- Introduction
- Analysis
- Design
- Evaluation
- Implementation

Barriera di Milano 147

- Introduction
- Analysis
- Design
- Evaluation
- Implementation

Corso Vittorio

- Introduction 185
- Analysis
- Design
- Evaluation
- Implementation

The systemic effect and the interscalarity of design 195

05 CONCLUSION

Conclusion 201

Reflection 205

- General
- The project and its outcomes

01

INTRODUCTION

Healthy Cities
Health and Planning: from remedy to prevention
Healthy Cities Project
Healthy Cities and Air Pollution
Conclusion

Motivation

Problem field

Societal Relevance

Scientific relevance

Healthy cities

In today's increasingly global and interconnected world, over half of the world's population (54%) lives in urban areas (UN, 2014). Demographers predicted that, by 2030, two-third of population will be living in urbanized contexts (UN, 2014). Unbalanced urban and economic developments, poor infrastructures, spatial and social segregation, lack of services and houses are just some of the several consequences of the on-going fast urbanization that the world is facing. However, there is another, equally relevant, non-visible repercussion which needs to be considered: our health. According to the World Health Organization, almost 12.6 million people died as a result of living or working in unhealthy environments in 2012. Environmental risk factors, such as air, water and soil pollution, chemical exposures, climate change, and ultraviolet radiation, contributed to more than 100 diseases and injuries out of the total (Prüss-Ustün et al, 2016). Therefore, the environmental and health-related conditions of urban living have become a major issue both for individuals and for local and national governments (WHO, 2010). To this extent, urban planning and urban design have recognized a pressing urgency towards ensuring healthy living conditions in urbanized areas, especially for the past 30 years.

The chapter aims to explore the relation between health, planning and design throughout history with a focus on the Healthy Cities Program implemented by the World Health Organization in the mid-80s. It will also delve in detail with the health threat of air pollution as the single largest environmental health risk in Europe today (EEA, 2015) on urban health.

[Fig.1.1] Boulevard Montmartre, Afternoon Sun, 1897, Camille Pissarro

source: http://cultura.biografieonline.it/pissarro-pomeriggio-al-sole/

Specifically, several solutions and responses to this pressing issue are investigated and the lack of valid, compelling and forceful design solutions will be highlighted. Overall, the paper substantiates the importance of assessing air pollution when designing for an healthy environment and the urge of a cooperation between planning, design and other fields of expertise.

Health and planning: from remedy to prevention

Health can represent many things to different people. In the common language, we often refer to it by assessing mainly physical and mental conditions of people; to this extent, the concept of health reflects a medical model where individuals are the main focus and treating diseases is the core goal. However, health can have a much broader and inclusive meaning. The definition of health given by the World Health Organization in 1948 widens its concept:

"Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. The enjoyment of the highest attainable standard of health is one of the fundamental rights of every human being without distinction of race, religion, political belief, economic or social condition."

Firstly, the statement brings to our attention that the absence of disease do not reflect properly the health conditions of population. The concept of health also includes the "social well-being" of people and, by doing it, opens the discussion regarding health quality and values to other fields of expertise than medicine: planners, designers, engineers and other experts are legitimated and can contribute to enhance public health. For instance, Jessie Parfitt, professor of History of Health at Oxford University, (Parfitt, 1988) acknowledged that the greatest contribution to the health of United Kingdom over the past 150 years was made not by doctors or hospitals, but by local governments with the help of other organizations. Secondly, the assertion defines health as "fundamental right" of every human being and tears down any possible distinction among individuals. By including everyone, health is therefore a social problem and needs a multidisciplinary approach.

Study of the role of the built environment in addressing the wider determinants of health has been receiving increased attention in several countries (WHO, 2010) and history has shown that there is a strong tradition of planning and designing cities to tackle unhealthy conditions arising from urban developments. To this extent, governments had often relied on urban planners and designers for developing corrective measures due to natural disasters and human health hazards (WHO, 1999). The case of Paris and the development of the Georges-Eugène Haussmann's Boulevards represents one of the most evident link between health conditions and urbanism. In the middle of the nineteenth century, the city of Paris was facing intolerable health conditions: pestilences, diseases, bad air quality and traffic circulation were strongly affecting population's health. There was, therefore, an urgency of improving living conditions. Among the several undertaken actions, Haussmann planned to build a network of

wide boulevards to increase connectivity but also to improve air circulation, traffic flows and general health conditions.
Another example of planning as remedy to unhealthy conditions is the plan developed by the city of London against the "Great Stink" in 1858. The city had been suffering of unhealthy conditions for years: epidemics, such as cholera and typhoid pulled by water, bad conditions of flow of water and traffic, and dirty streets were the main causes of such a condition. Thus, in 1858, the Parliament approved a massive plan to build the embankment along the Thames, to improve sewer system and street paving and cleansing. Once again, planning was used as tool for improving unhealthy environments, defeating diseases and enhancing good living conditions.

The form and the nature of the built environment is critical to urban population health and the features needed for a city to better support population health are becoming increasingly understood (Rydin et al, 2012). The sanitation of London and the opening of the street network of Paris are clear examples of the evident link between public health, planning and design. However, it must be highlighted that, as far as Paris and London are concerned, planning and design were used as tool or remedy to improve already existing bad living conditions. On the other hand, the WHO constitution looks at health as something that need permanently to be ensured and not as remedy to bad living conditions.

Applying the concept to urban planning and design, our field should rather be thought and used as tool to prevent unhealthy environment than a solution to critical and dangerous conditions. This idea has been one of the main pillars of planning in the past 30 years and was strongly expressed by the "Healthy Cities Project" carried out by the World Health Organization since the 1980s. Planning and urban design need to be used as a tool to prevent and not to cure, as opposed to the past, unhealthy environments and must ensure good living conditions.

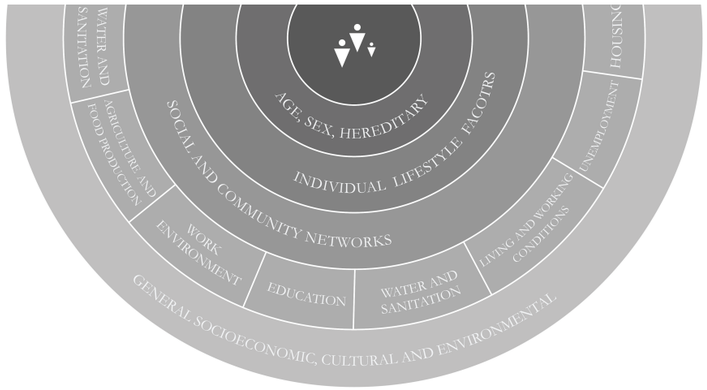
Healthy Cities Project

The healthy cities project emerged in Toronto, Canada, in 1984, during the conference entitled Beyond Health Care. The main goal behind the project was to change the ways in which individuals, communities, private and voluntary organizations, and local governments think, understand and make decisions about health (Webster and Sanderson, 2012). About 40 cities around the world took part of the program; European cities were and are still the majority. The WHO Europe had a determinant role in developing health promotion and environmental health programs. Moreover, it worked as catalyst in the process of bringing together a partnership of publics, private and voluntary agencies together (Petersen, 1996). To this extent, the concept of promotion represents one of the main roots of the project and governments at different scales, from the national to the municipality one, had played a key role in the process. However, after ten years of experience in planning and community actions, the WHO Healthy City Project realized that ensuring health should not be exclusive to one

political party or a singular profession (WHO, 1998) and recognized the need of cooperation among different field of expertise: Urban Planning and Urban Design were among them. There has been a growing consensus that while personal factors are critical in determining health, the urban environment exacerbate or mitigates health and well-being outcomes (Barton, 2009). Globally the impact of the built environment on health is now well evidenced and widely accepted for a large number of health outcomes (Galea and Vlahos, 2005; Rydin et al, 2012).

As part of the Healthy City Project, the WHO launched in 1987 the "European Healthy Cities Network" program which consists of several cities around the WHO European Region committed to health and sustainable development: nearly 100 cities and towns from 30 countries took part of it (WHO, 2016). The program is divided in six phases, each of them, lasting 5 years, has a defined goal. In general, the program tries to tackle several issues such as climate change, public health emergency, exposure to noise and air pollution, healthy urban planning, healthy urban design, housing and regeneration, and safety.

Marcus Grant (Grant, 2015) reviewed the interventions proposed by 46 cities among Europe during the phase V, identifying fields of action, tools, adopted methods and final outcomes. Firstly, he recognizes that healthy urban planning policies may guide physical change over 10-25 years, the period of a city plan. Secondly, he underpins that urban planning has been often used as main tool for change, whilst urban design has not often played a relevant role. To this extent, it might be argued that, when it comes to public health, there is a strong tendency on working primarily with policies and strategic planning that with urban forms. Despite the form and nature of the built environment has been recognized as critical to urban population health and certain physical features for a city to better support population are becoming increasingly understood (Rydin et al, 2012), urban design remains often overlooked.
The reason may be found in the different and sometimes opposing nature of design and planning: on one hand, especially when coping with climate change and air pollution, strategic city-wide policies are main trigger for change; on the other hand, connecting the role of design with visible and countable effects on issues as climate change is very difficult and evaluating its effects is often difficult. Measuring and verifying effects of policies and strategic planning is much easier; for instance, the effect of the improvement of public transportation can be easily seen through increase of users, pollutants reduction etc. On the other hand, proving that urban form may affect behavior and way of living of people is very tricky. Despite that, there is some literature which proves the link between health, urban form and climate. For instance, walkability index is affected by the street network, urban forms and together with land use and functionality (Frank at al, 2007). Street orientation and building height are a more evident example of effect of urban design on climate and, indirectly, to health: their proportion affect the amount of solar radiation within the city (Shishegar, 2013), the temperature, the humidity and several other aspects. Another relevant factor is also that design is often defined by site-specificity and grounded in locational specifics and, therefore, cannot be transferable. The



[Fig.1.2] Health contributors according to Dahlgren & Whitehead (1992)

source: re-elaboration made by the author

effectiveness of a design might change from site to site and it is, therefore, often overlooked. But that is not always the case, the design applied by the municipality of Belfast for the EHCN was found valuable for linking discussion between regeneration and health (Grant, 2012) and this enabled the move from a pilot demonstration project to mainstreaming of the approach. Finally, as far as policies and guidelines are concerned, it must be considered that they are not always successful: external economic or political factors might jeopardize their efficacy. For instance, in 2016 Volkswagen has admitted that 11 million of its vehicles were equipped with software that was used to cheat on emissions tests (NYT, 2016) leading to higher dispersal of pollutants. Another example is the case of the municipality of London, who was judged guilty over its failure to tackle illegal air pollution. In an echo of the Volkswagen vehicle emissions scandal, the judge said ministers knew an overly optimistic model of pollution was being used (Independent, 2016). Basically, reducing air pollution might be or not in governments' agenda and they can be committed to the issue, but if private companies and investors do not respect laws and regulations, municipalities and nations' effort might result useless.

Overall, it can be argued that the Healthy Cities project has been changing during the last 30 years, the openness to multiple fields is certainly a proof of it. Urban planning and urban design are both part of the project: the first one is currently one of the main tools to link the concept of city to health but can be endangered by external factors; on the other hand, urban design seems to remains in the shadow and its potentialities and possible deliverables not enough explored and revealed.

Healthy Cities and Air Pollution

The health of people living in towns and cities is strongly determined by their living and working conditions, the quality of the physical and socio-economic environment and the quality and accessibility of health care services (Webster and Sanderson, 2012). Therefore, describing, measuring and analyzing the "health" of a city is a complex task. There are different factors which may influence it and they can be grouped into four main categories: health promotion, health services, social care, and environmental improvement (Webster and Sanderson, 2012). The latter, with the industrial and technological revolution, has gained more and more relevance in the last fifty years. Among the environmental indicators, air quality is one of the most important.

The World Health Organization recently (2016) announced that almost 92 % of the world's population lives in places where air quality levels exceed the limit values. When thinking of air pollution, people often relate the phenomenon more to Asian countries such as China and India which are often mentioned in newspapers for their bad air quality conditions. Despite our common believes, air pollution poses the single largest environmental health risk in Europe today (EEA, 2015). Furthermore, WHO reports that in 2012 around 7 million people died - one in eight of total global deaths – as a result of air pollution exposure. Among the 7 million, around 500.000 deaths happened in Europe (EEA, 2015). These findings confirm that air pollution is now the world's largest single environmental health risk.

Within the European Healthy Cities Network, air quality has gained certain relevance and different cities tried to cope with the issue. Grant (Grant, 2012) describes that especially during the fifth phase of the program, 10 out of 31 European cities pursued action at strategic city-wide policy level or through local action against air pollution. Transportation policies, network improvements and social promotion has been often the main type of intervention for tackling the problem; most of the time were effective but within long-term results.
When reviewing the literature concerning air pollution, planning and urban design, the connection between the first two is quite extensive (Barton and Grant, 2012; Grant and Braubach, 2010; Rao et al, 2007; Barton, 2009). Depending on how it is applied, urban planning can improve air quality in the long run by strategic location of polluting sources and exposed population, and encouraging a city structure that would minimize pollution emissions and build-up (World Bank, 2002).
On the other hand, the link between urban design and air pollution seems to be still not enough explored. Several attempts and guidelines (Spirn, 1986; Krautheim et al, 2014; Erell, et al, 2010) have been carried out. For instance, the shape of blocks and distribution pattern of land use affect air quality and its health impact. The urban shape determines locations of emission sources and where people spend their time, as well as emission levels by influencing the amount of polluting activities. However, the field of urban design is still lacking of a proper literature which connects urban forms and air pollution and which gives valid solutions for both already existing and developing urban environments.

[Fig.1.3] Pollution in Paris

source: http://www.eltis.org/discover/news/smog-forces-paris-make-public-transport-free-france

Conclusion

In the first section of the paper the relation between health, cities and urbanism has been established. Historic human hazard and catastrophes have often pushed the human kind to find solutions for ensuring population health. Furthermore, the concept of health has been broadened by considering different field of expertise than the medicine one. To this extent, planners and designed gained a relevant role in fostering good living conditions. Another relevant key concept is that of considering health as something to take care of rather in advance than afterwards. The Healthy city project fulfills both this concepts. The program calls for participation from different fields and urban planning and urban design are some of the key protagonists in the process. Our field, especially in the last decades, has developed a strong interest and concern regarding environmental risk factors and human health so that they have been recognized as main priorities in its agenda. These topics were some of the most tackled during the WHO program. In general, there is a tendency on working mainly with planning and to overlook urban design. Planning has often shown effective results while design has still difficulties on proving and demonstrating its relevance to the topic. However, policies and strategic planning often depend on political and economic external factors which may slow down or even stop the processes: changes in municipality governance and consequently in their agenda may affect them.
The environmental risk factor of air quality case showed clearly this duality. Different policies and guidelines have been applied and replicated in different cities leading to successful results. However, there have been cases where policies did not have the expected result. Thus, urban planning cannot stand by itself and needs the help of urban design.

Overall, while analyzing and exploring the relation between health, cities, urban design and planning and finally the specific case of air pollution, it might be argued that there is a gap in the literature relating urban design and health. Examples of design interventions which relate urban forms to health are just a few and do not fill the gap entirely. Thus, the theme deserves to be further explored in order work together with planning for effective and worthy results.

[Fig.1.4] Air pollution in Turin

source: http://www.ansa.it/piemonte/notizie/2017/02/19/smog-superato-limite-per-2017-a-torino_e66c8519-e043-4cf3-8183-c2753200e849.html

Motivation

In 2016, the World Health Organization announced that almost 92 % of the world's population lives in places where air quality levels exceed the limit values defined by the organization itself (Fig1.5). Ambient and indoor air pollution play a key role on population's health. By reducing air pollution levels, countries can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma (WHO, 2016). Due to the relevance of the topic, the graduation project will focus on air pollution and its relation to built environments.

However, that is not the only reason for me to choose air pollution as graduation topic. I am from Turin (a city in North Italy), which has been suffering from a high level of air pollution for several years. Despite several attempts from the municipality to improve air quality, the situation has slightly changed during the past ten years. The urgency of the issue requires, therefore, alternative solutions instead of the conventional answers, and this research is an attempt in that direction.

Finally, it has to be highlighted that air pollution is just one of the health risk factors that Turin but also the world's population is living with. In general, I strongly believe that there is a pressing necessity for understanding and addressing the health consequences of our cities and to try to find efficient solutions and design proposals able to foster both human and environmental health.

Pollutants	EU reference value	Exposure estimate	WHO AQG	Exposure estimate
PM2.5	Year (25)	9-14	Year (10)	87-93
PM10	Day (50)	17-30	Day (20)	61-83
O3	8-hour (120)	14-15	8-hour (100)	97-98
NO2	Year (40)	8-2	Year (40)	8-12
BaP	Year (1 ng/ m3)	25-28	Year (0.12 ng/m3)	85-91
So2	Day (125)	<1	Day (125)	36-37

[Fig.1.5] Percentage of the urban population in the EU-28 exposed to air pollutant concentrations above certain EU and WHO reference concentrations (2011-2013) pollution in Turin

source: EEA Report 2015

- > 75 %
- 50 - 75 %
- 5 - 50 %
- < 5 %

[Fig.1.6] Polluted kiss

source: http://wsource: http://darkroom.baltimoresun.com/2015/12/heavy-smog-hits-beijing-china/#1 - Photo by Kevin Frayer

Problem field

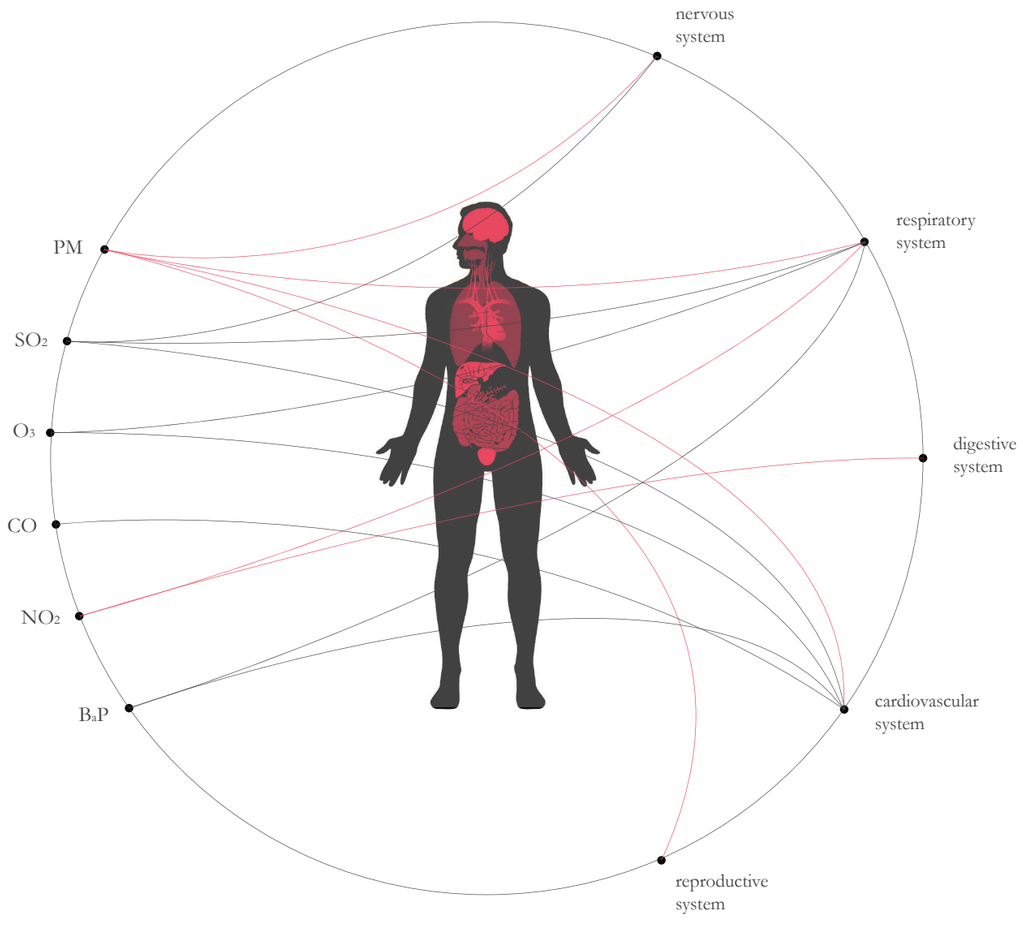
Air is constantly moving, crossing vast areas of land and oceans it mixes itself and its original composition has been dramatically changing throughout time. Anthropological processes such as urbanization, car introduction and industrialization and natural sources as well, are the main contributors to air quality.

The World Health Organization recently (2016) announced that almost 92% of the world's population lives in places where air quality levels exceed the limit values (Fig. 1.5). When thinking about air pollution, people often relate the phenomenon more to Asian countries such as China and India which are often mentioned in newspapers for their bad air quality conditions. Despite our common believes, air pollution poses the single largest environmental health risk in Europe today (EEA, 2015). That means that the risk exists and it is real. During the past 10 years, European countries committed themselves to emissions reductions and, according to the Air Quality Report (2015), air quality policies have delivered many improvements. However, a large proportion of European populations is still exposed to air pollution in exceed of European standards (EEA, 2015) and the situation is even worse if we compared the values to the WHO Air Quality Guidelines. In 4 out of the 6 main pollutants, the percentage of urban population exposed to air pollutants concentration above the WHO levels, exceed 60 % (Fig. 1.5). Furthermore, WHO reports that in 2012 around 7 million people died - one in eight of total global deaths – as a result of air pollution exposure. This finding confirms that air pollution is now the world's largest single environmental health risk. Among the 7 million, around 500.000 deaths happened in Europe.

In order to understand the gravity and the threat we are living with, it is critical first to understand what air pollution is, where it comes from and what the consequences on human health are. Air pollutants are substances which, when present in the atmosphere under certain conditions, may become injurious to human, animal, plant [...] or which may interfere with the use and enjoyment of life (Oke, 1987). Oke defines two factors which are responsible for the amount of pollution at a specific site: the first is the nature of the emissions (sources) and the second one is the state of atmosphere defined by the type of dispersion, meteorological conditions and the physical characteristics of the site itself.

When looking at sources, knowing the type and the form of the emission is essential in order to understand properly the phenomenon. For instance, cities can often be seen as covered by a box of air where sources are everywhere and the pollution is dispersed homogeneously in the built environment. On the other hand, isolated industrial areas can be associated to a punctual source, whose emission's provenience can be easily recognized.

As far as the dispersion is concerned, it is strictly connected to the location of the polluted



[Fig.1.7] Effects of air pollution on human health

source: author

areas, its surrounding topography and of course its meteorology. Atmospheric motion serves both to diffuse (dilute) and to transport air pollutants (Oke, 1987). In general atmosphere has an incredible capacity of dispersal; when this capacity, under certain conditions, is curtained, air pollution can imply severe problems.

When trying to understand air pollution, identifying the main pollutants and their sources becomes very difficult: they are everywhere and come from everywhere. For each environment, proportions of sources can vary. However, in order to understand the relation between air pollutants and environmental and human risks, a brief generic summary (Fig. 1.7) of the main air pollutants, their primary sources and effects is necessary.

Particular Matter (PM)

Particulate Matter affects more people than any other pollutant. It is currently considered to be the best indicator for health effects of ambient air pollution (WHO, 2014a, 2014b). It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. Two main categories of PM, according to their diameter, can be identified: PM10 with a diameter less than 10 µm and PM2.5 with a diameter less than 2.5 µm.

Transportation, industries, domestic fuel burning and natural sources (sea spray aerosol, wind land fires, vulcanos) are the main sources of this pollutant. When living in environments with high concentration, population can face respiratory infections, change in blood coagulation, angina, myocardial infraction, atherosclerosis (CIMT), cardiac arrhythmia, cardiac arrest.

Nitrogen Dioxide (NO2)

The nitrogen dioxide is a brownish gas with a strong odor, and is the compound responsible for the brownish haze of the urban skyline. It is a secondary pollutant, meaning that it is not produced directly by a given source, but is derived from another reactive compound released into the atmosphere, in this case nitric oxide, which is emitted by automobiles (Spirn, 1986). The principle sources are vehicles, coal and natural gas burning, fertilizer and explosives factories. As far as health effects are concerned, exposure to high concentration can cause nose and throat irritation, bronchi-constriction, respiratory infections and heart diseases.

Carbon Monoxide (CO)

Carbon monoxide is a colorless, odorless gas whose principal source is the incomplete combustion of organic fuels such as occurs in automobiles driven in stop-and-go traffic (Spirn, 1986). Main sources are traffic, metal processing factories, refineries, paper factories. Change in blood coagulation, angina and myocardial infraction are just some of the effects on human health.

[Fig.1.8] Brownish haze of cities skyline due to NO_2

source:
https://www.thoughtco.com/what-is-nitrogen-oxide-pollution-1204135

Ozone (O3)

Ozone at ground level – not to be confused with the ozone layer in the upper atmosphere – is one of the major constituents of photochemical smog. It is formed by the reaction with sunlight (photochemical reaction) of pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs). Thus, the highest levels of ozone pollution occur during periods of sunny weather (WHO, 2016). Excessive ozone in the air can have severe effects on human health. It can cause breathing problems, trigger asthma, reduce lung function and cause lung diseases. In Europe, together with particulate matter, it is currently one of the air pollutants of most concern (WHO, 2016). Several European studies have reported that the daily mortality rises by 0.3% and that for heart diseases by 0.4%, per 10 µg/m3 increase in ozone exposure. (WHO, 2016)

Benzo[a]pyrene (BaP)

Benzo[a]pyrene is a gas and it is the result of incomplete combustion of both natural and anthropological processes. For instance, forest fires and vulcanic eruption but also transportation combustion are some of the main sources. Benzopyrenes are dangerous because they form carcinogenic and mutagenic metabolites which can interfere with the DNA transcription. The main health effects are asthma, emphysema, memory disturbances, sleep disorders, anger, fatigue, blurred vision, slurred speech and finally lung cancer.

Sulfur Dioxide (SO2)

Sulfur dioxide is a colourless gas with a sharp odour. It is produced from the burning of fossil fuels (coal and oil) and the smelting of mineral ores that contain sulfur. The main anthropogenic source of SO2 is the burning of sulfur-containing fossil fuels for domestic heating, power generation and motor vehicles (WHO, 2016). SO2 can affect the respiratory system and the functions of the lungs, and causes irritation of the eyes. With the inflammation of the respiratory track, coughing, mucus secretion, aggravation of asthma and chronic bronchitis may appear and makes people more prone to infections of the respiratory tract itself. When SO2 combines with water, sulfuric acid is formed; that causes acid rain which may lead to deforestation.

Finally, European Union (2015) reminds us that air pollutants play a threat role not only for our health but they also have sever implications on climate change, ecosystems, built environments and economics. Overall, air pollution poses a big threat on our societies, it is both an environmental and social problem and need to be faced in every field of expertise.

Societal relevance

As the European Environmental Agency stated, air pollution is both an environmental and social problem, as it leads to a multitude of adverse effects on human health, ecosystem, the built environment and the climate.
In Europe, about 432.000 premature deaths can be linked to long-term exposure to air pollutants (EEA, 2015) and Italy has the highest rate. Italian cities have been in the spotlight for the harming levels of air pollution during the past few years and, despite several measures, the situation has not changed. Both Italian and international news papers reported the severe situation which the city of Turin had to deal with during December 2015. *La Repubblica* (Italian news paper) highlighted that "even if a slight improvement in terms of air quality can be appreciated, the values remain higher than the limit ones provided by both EU and WHO". The New York Times reported an interview with Nicola Pirrone, director of the Institute of Atmospheric Pollution Research at Italy's National Research Council, who reminded that "blocking traffic for one or two days is merely a palliative; so is stopping cars based on license plate numbers".

[Fig.1.9] Newspaper headlines about air pollution

source:
1. http://www.nytimes.com/2015/12/25/world/europe/italy-air-pollution.html?_r=0
2. https://www.theguardian.com/cities/2015/dec/11/turin-free-public-transport-rides-combat-pollution
3. https://www.washingtonpost.com/news/energy-environment/wp/2016/09/27/the-more-we-learn-about-air-pollution-the-worse-it-gets/?utm_term=.919167186cff
4. http://torino.repubblica.it/cronaca/2015/01/30/news/smog_e_polveri_sottili_torino_la_citt_pi_inquinata_d_italia-106139290/

However, air pollution does not concern just Italy or Europe: in 2012, around 7 million people died - one in eight of total global deaths – as a result of air pollution exposure (WHO, 2016). Furthermore, this data confirms hat air pollution is now the world's largest single environmental health risk (WHO, 2016). In addition to health problem, air pollution has also a considerable impact on economic aspects such as increasing medical costs and reducing productivity in terms of working days. According to both EU and WHO, the overall annual economic cost of health impacts and mortality from air pollution in Europe, including estimates for morbidity costs, stood at 1.433 trillion Euro in 2015 (Roy at al, 2015).
Overall, economic and health aspects contribute both on the well-being of societies. Air pollution, as just described, plays a critical role and deserves our attention and concern.

Scientific relevance

general

The relation between built environment, its livability and environmental health has often been discussed. Within the studies of air pollution mitigation measures, different concepts, guidelines and policies can be found but they often rely on variable forces such as collaboration from governments and inhabitants. Public mobility improvements, emissions policies and alternative ways of transportation depend on economic, political and cultural factors that can cooperate or not with the application of those. In this sense, working with and within the built environment can be a valid response and help to policies' instability. Evidences show that local concentrations of air pollutants are often greatly affected by the form of the city, but there has been relatively little attempt to enhance street-level air quality through the manipulation of urban form (Spirn, 1986). To this extent, the graduation project can contribute to the field of urbanism by providing more physical and permanent solutions towards air pollution mitigation. A direct link between urban design and air pollution mitigation will be provided and new openings to research highlighted.
Overall, urban design could play an important role in enhancing air pollution mitigation and in limiting human exposure in areas where pollutants are highly concentrated.

to the urban metabolism research group

The research group describes Urban Metabolism as a "framework for modeling complex urban systems' flows – water, energy, food, people, et cetera – as if the city were an ecosystem". To this extent, air pollution can be considered as the final outputs of different flows: transportation, energy consumption, industrial production, waste management are just some of the causes. The thesis has therefore a direct link to the research group. By investigating the complex flow of air pollution within both the urban and provincial context of the city of Turin, the thesis aims to investigate the relation between different flows, scales and the built environment.

02

THE ISSUE

Problem statement

Problem analysis

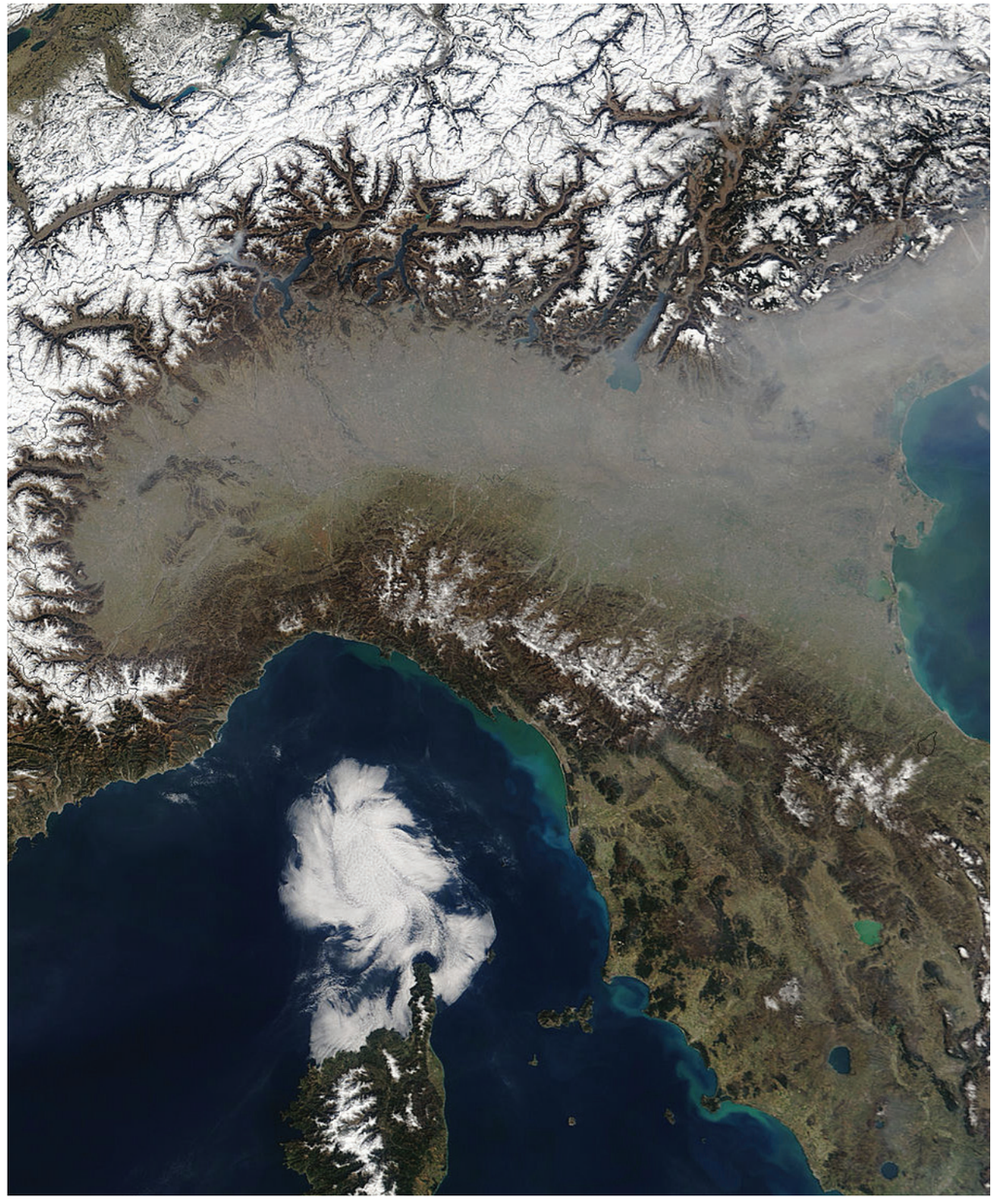
Main sources of pollution in Turin and its surroundings
Factors which influence pollution dispersion
Receptor site characteristics
Adopted methods against air pollution

Scope

Research Question

Methodology

Theoretical framework and readings

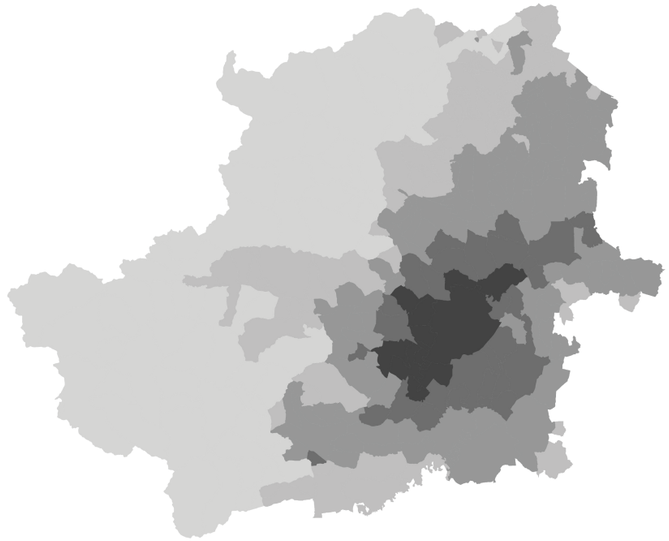


[Fig. 2.1] Air pollution on the Po valley

source: http://legambientept.altervista.org/2013/06/02/autostrada-valdastico-nord/

Problem statement

According to the European Environment Agency's new report, Italy had the highest rate of premature deaths attributable to air pollution in 2015: 84.000 out of 491.000. Among the 90 monitored Italian cities, more than half (53%) have exceeded the limit values defined by both EU and WHO in 2015 (Mal'Aria di Città, 2016). The Po Valley, in the northern part of Italy (Fig. 2.1), is the area with the more dramatic and pressing issues and Turin, the city where I come from, is one of the four most polluted Italian cities (Mal'Aria di Città, 2016). Because of its position, surrounded by the Alps and hills, polluted air cannot be dispersed properly and remains steady. In January 2016, the air became so unbreathable that car circulation was stopped for a few days in order to decrease the rate. Therefore, air pollution in Turin is a real emergency which needs to be tackled as soon as possible.



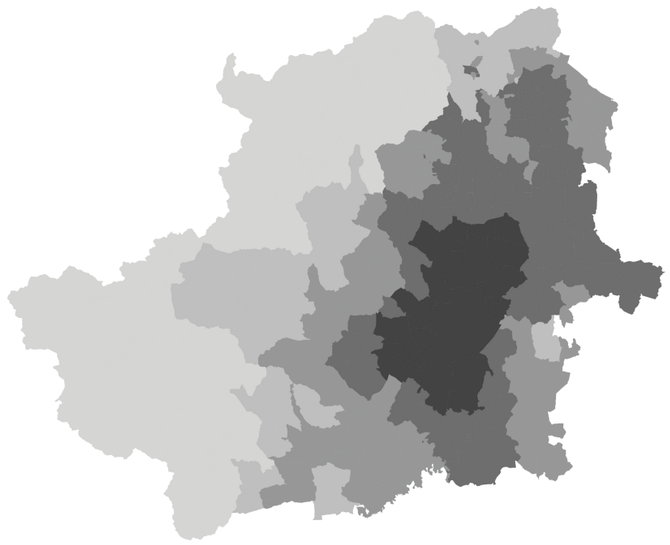
[Fig. 2.2] Province of Turin - Nitrogen Dioxide concentration

source: re-elaboration based on data furnished by Arpa Piemonte – Valutazione modellistica annuale dello stato di Qualità dell'Aria 2015

ng/m³

- 32 - 47
- 23 - 32
- 18 - 23
- 12 -18
- 6- 12

0 15 30KM



[Fig. 2.3] Province of Turin - PM 10 concentration

source: re-elaboration based on data furnished by Arpa Piemonte – Valutazione modellistica annuale dello stato di Qualità dell'Aria 2015

ng/m³

- 30 - 39
- 24 - 30
- 20 - 24
- 14 - 20
- 8 - 14

0 15 30KM

Problem analysis

As previously mentioned, Oke describes pollution within three steps: sources, dispersion and receptor site. Unfortunately, the author begins the analysis without defining the terms. In order to properly understand their features, specifying their meaning is indispensable.

A source can be described as a point of origin or procurement - a generative force (Merriam Webster Dictionary)

The dispersion is the act or process of dispersing - a system consisting of a dispersed substance and the medium in which it is dispersed - a mixture of one substance dispersed in another medium (Oxford Dictionaries). The dispersed substance, in this case, is the pollutant and the medium is the air.

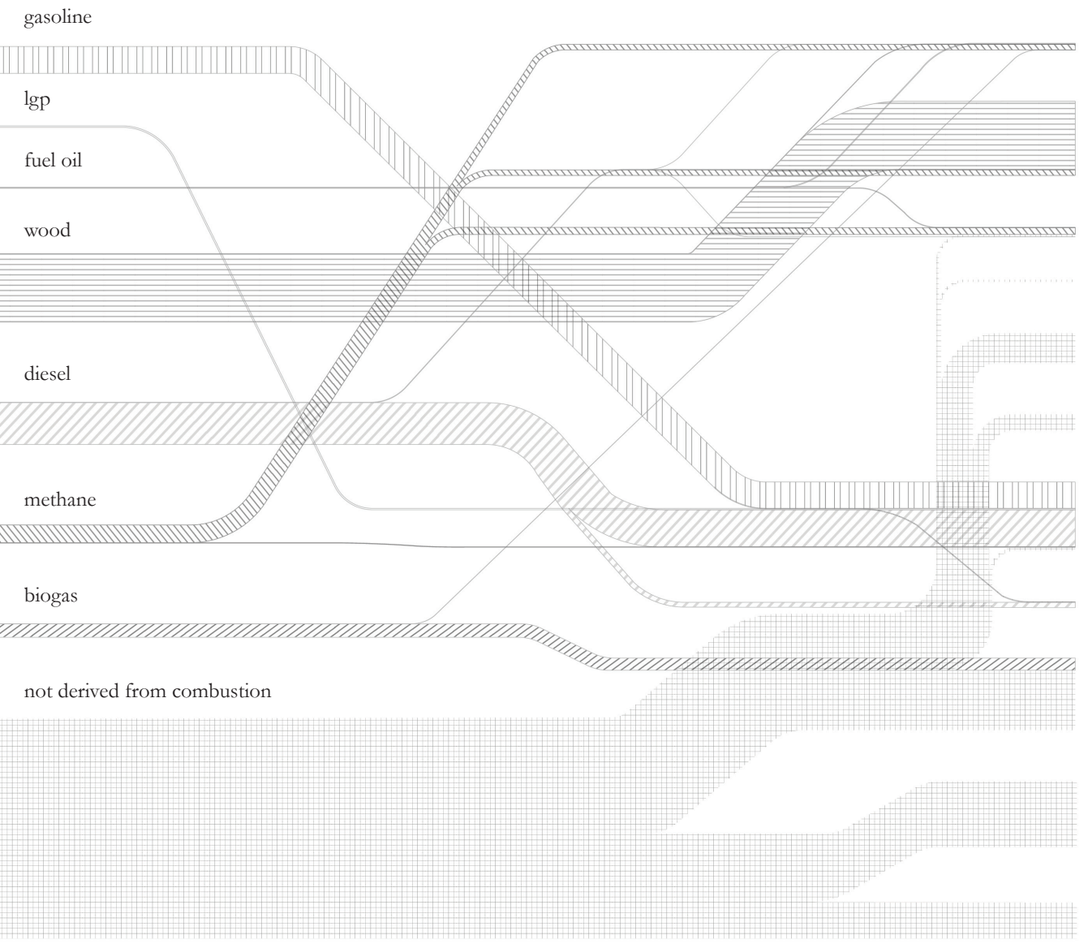
The word "receptor" comes from the field of biology and it is defined as an organ or cell able to respond to light, heat, or other external stimulus and transmit a signal to a sensory nerve (Oxford Dictionaries) - a cell or group of cells that receives stimuli (Merriam Webster Dictionary). The city and its inhabitants can be seen as the organ and cells able (or not) to respond to the external stimuli, the pollutants.

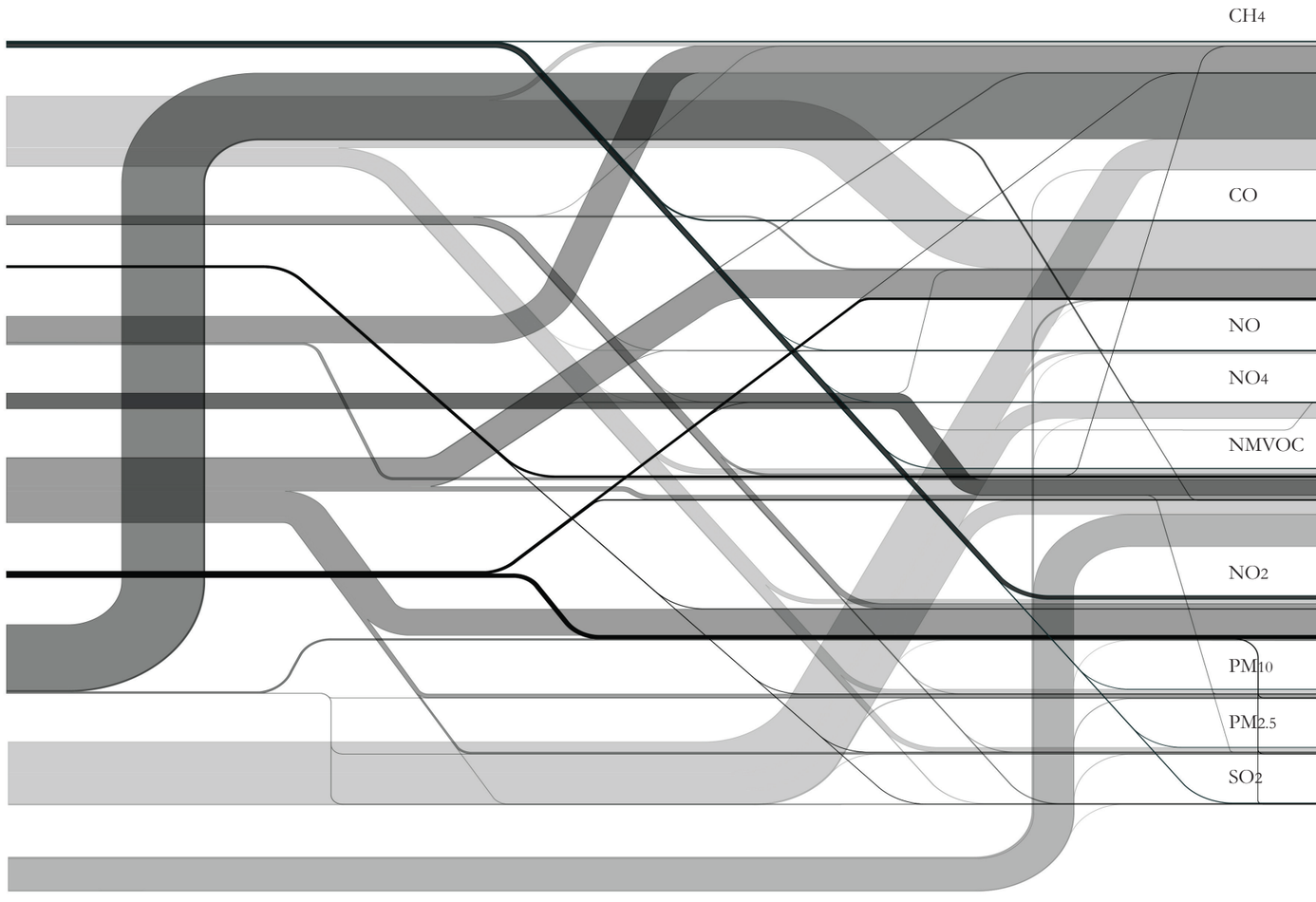
Main sources of pollution in Turin and its surroundings

As being an urban context, Turin air pollution is everywhere and comes from everywhere. However, thanks to the emissions catalog (Arpa, 2010), identifying sources, process and polluting outcomes is possible. Among the main pollutants, 97% is due to CO2. It is known that carbon dioxide is the main responsible for global warming, but not for harming directly our health. Therefore, for the purpose of the research, it will not be taken into account; the attention will be focused on the remaining 3% of the pollutants.

Because the air of Turin is not canned into a box, analyzing data related just to the municipality of the city itself would be reductive and a more complete analysis, including its surroundings, is needed. The pollution flowchart (Fig. 2.4) represents the processes that lead to air pollution, with its inputs (sources), processors, and output (pollution itself) related to the province of Turin. According to Mal d'Aria Report 2015, PM 10, PM 2.5 and NO2 are the main pollutants in Turin. By analyzing the flowchart, it can be noticed that the three pollutants are some of the less produced compared to the others, but nevertheless, as mentioned before, one of the most harmful. As far as the nitrogen dioxide is concerned, the main sources are industrial sector and transportation and for particulate matter, both 10 and 2.5, commercial and households heating and transportation play a dominant role. However, by taking into account only the municipality of Turin (Fig. 2.5), it can be seen that the main source for all pollutants is transportation and its proportions, are almost one quarter of the total.

Overall, that means that there are different type of sources which can affect different scales

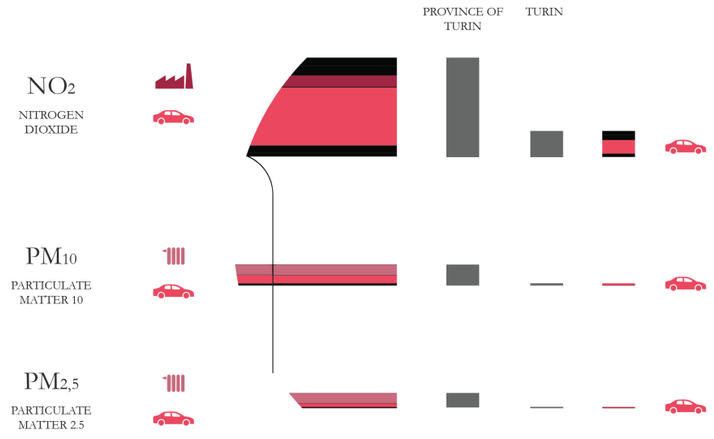




[Fig. 2.4] Qualitative flowchart of air pollution in the province of Turin

source: derived from IREA - Inventatio Regionale delle Emissioni in Atmfosfera | http://www.sistemapiemonte.it/cms/privati/ambiente-e-energia/servizi/474-irea-inventario-regionale-delle-emissioni-in-atmosfera

- energy production
- heating
- industries
- logistics
- fuels extraction
- solvents usage
- road transports
- other transports
- waste management
- agriculture
- others



[Fig. 2.5] Sources comparison: Province and Municipality of Turin

source: derived from IREA - Inventatio Regionale delle Emissioni in Atmfosfera

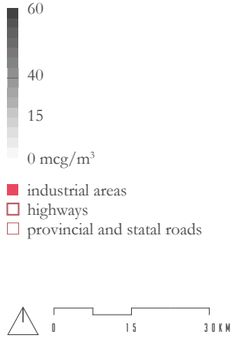
(regional and urban ones), and both are equally relevant for the air quality in Turin. When looking at the typology of source, transportation can be seen as a "dispersed" source while industries are a point sources with a defined spatial location (Fig. 2.6). Finally, the height of the point of emission plays a big role in air pollution as well: for instance, car pollution happens at ground level, on the other hand industries pollutants are released on a higher level.

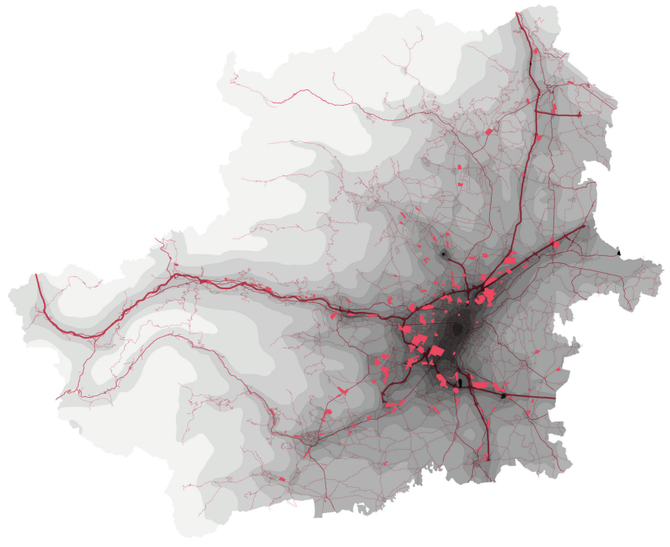
Factors which influence pollution dispersion

Atmospheric motion serves both to diffuse and to transport air pollutants. If the size of eddies is smaller than the pollutant cloud or plume they will diffuse it; if they are larger they will transport it (Oke, 1987). The frequency and speed of wind are, however, a double-edged sword: on one side, it can blow pollution away but, on the other hand can blow it towards the receptors (both anthropological and natural environments). As far as wind speed is concerned, Turin's year average is about 2 m/s and, coming mostly from north-east, is almost non-existing (Fig. 2.9.). Therefore, either dispersion or transportation of pollutants are not consisting and pollutants stay in the air for long periods. Rains would be an alternative way of cleaning the air but, unfortunately it is not likely to happen (Fig. 2.8). It is interesting to notice that according to ARPA the highest probability of increasing rates of PM10 happened from September to April last year (Fig. 2.8); that is the period with lowest temperatures and less rain. Another crucial factor, which contributes to obstruct dispersion, is the geographical context of Turin. The city lies on a basin, surrounded by Alps from North and hills from east; the deep difference in height slows dramatically down winds speed and create perfect condition for air to stagnate (Fig. 2.10). Overall, regional climate, with its meteorological and geographical conditions, plays a relevant role in the "non-dispersion" of pollutants.

[Fig. 2.6] NO2 Concentration and main sources of pollution

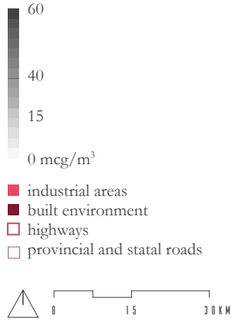
source: NO2 map: Carlino, L. Pallavidino, R. Prandi "Micro-scale modelling of urban air quality to forecast NO2 critical levels in traffic hot-spots", 10th International Conference on Air Quality, 14-18 March 2016, Milan, Italy

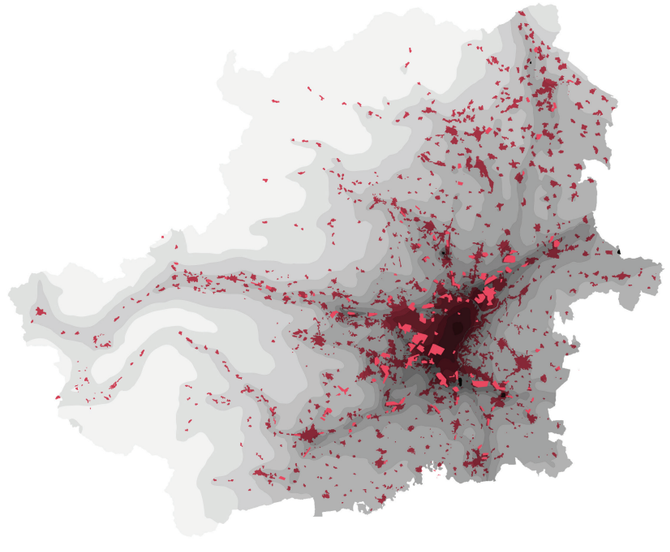




[Fig. 2.7] Relation between main sources of pollution and urban frabrics

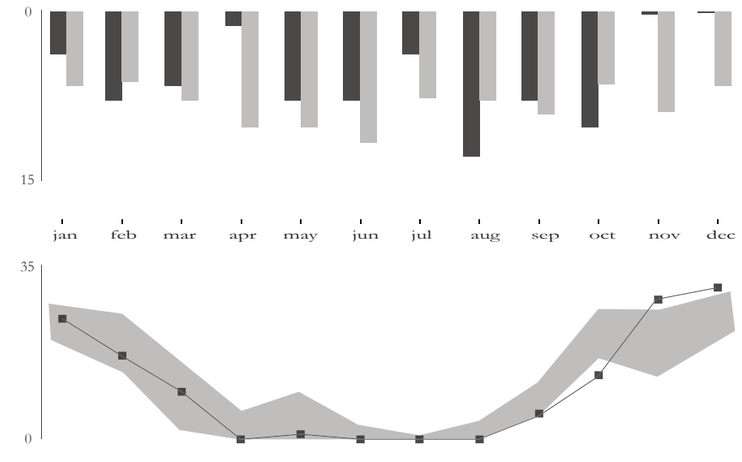
source: NO2 map: Carlino, L. Pallavidino, R. Prandi "Micro-scale modelling of urban air quality to forecast NO2 critical levels in traffic hot-spots", 10th International Conference on Air Quality, 14-18 March 2016, Milan, Italy





[Fig. 2.8] Comparison between monthly number of rainy days (top) and number of days of PM10 accumulation (bottom)

source: Uno sguardo all'aria 2015, Città metropolitana di Torino, Arpa



[Fig. 2.9] Avarage wind speed and direction (2009-2016)

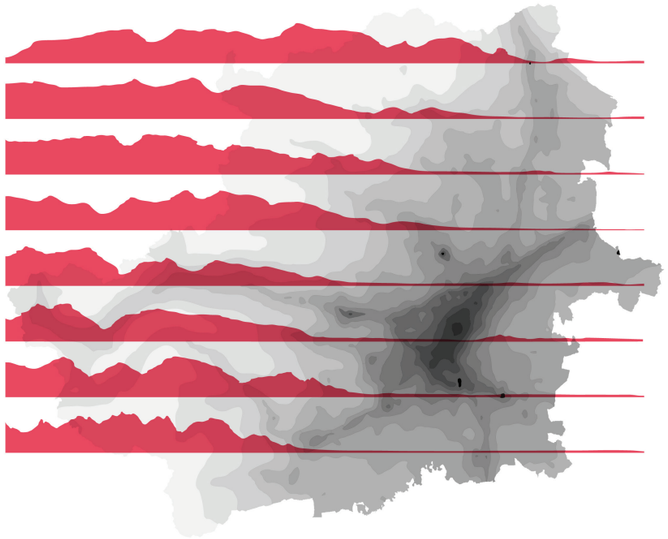
source wind: https://it.windfinder.com/windstatistics/tornino_aeroporto

Receptor site characteristics

The specific receptor site is the municipality of Turin. Urban environments are composed by several elements and they way they articulate themselves provides certain performances in terms of livability, comfort and in this case, air pollution mitigation. Receptors, however, can vary: the built environment is a constant but natural ecosystems are receptors as well and, as mentioned in the previous paragraph, can influence wind formation and speed. At the regional scale, details of analysis are not specif enough for drawing conclusions. In general, forests are mainly on mountains and built areas are predominant in the basin of the valley (Fig. 2.11). Further analysis will be carried out in the *Analysis and Theory* section.

Adopted methods against air pollution

The municipality of Turin has been promoting several policies and guidelines in the past ten years and, trying to collaborate, strategic and spatial planning played a key role. The integration of bike and car sharing, zone 30 (area with 30 km/h as maximum speed allowed), ZTL (area where car can not drive during rush hours) and several other initiatives helped to mitigate air pollution but the results were not the ones expected: the amount of days with high rate of pollution remained steady in the past years (Mal d'Aria, 2016). Furthermore, planning is often affected by social and economic factors. For instance, Italian car dependency seems difficult to fight and policies do not have the desired effect. They can push for a change in social behavior, but if people are not willing to change, different ways of acting need to be found.



60

40

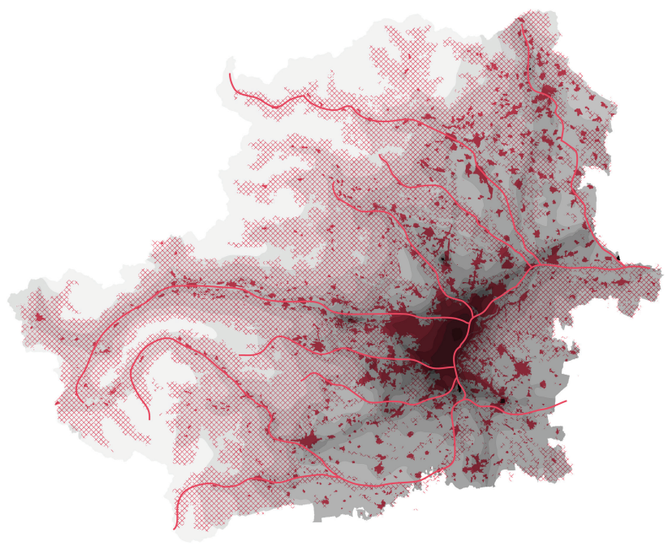
15

0 mcg/m³

0 15 30 KM

[Fig. 2.10] Terrain sections (1:2) and NO2 concentration

source: NO2 map: Carlino, L. Pallavidino, R. Prandi "Micro-scale modelling of urban air quality to forecast NO2 critical levels in traffic hot-spots", 10th International Conference on Air Quality, 14-18 March 2016, Milan, Italy



60

40

15

0 mcg/m³

built environments

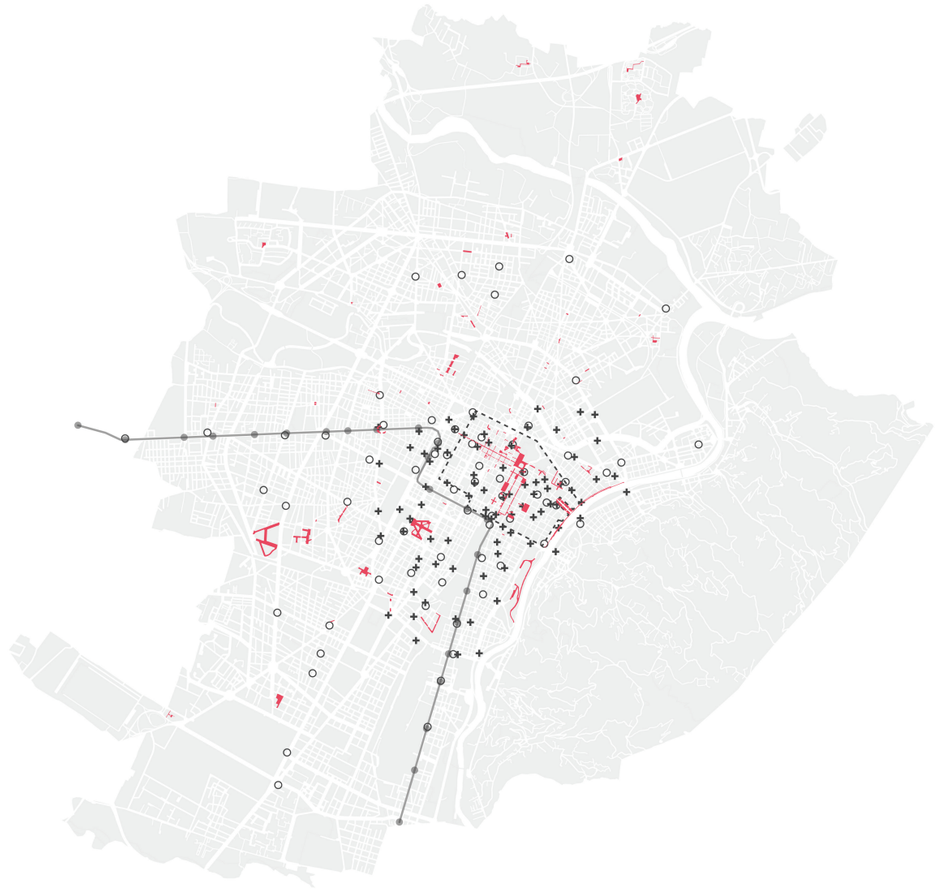
forests

rivers

0 15 30 KM

[Fig. 2.11] Natural and built environment and NO2 concentration

source: NO2 map: Carlino, L. Pallavidino, R. Prandi "Micro-scale modelling of urban air quality to forecast NO2 critical levels in traffic hot-spots", 10th International Conference on Air Quality, 14-18 March 2016, Milan, Italy



0 1 2 KM

Metro

ZTL (Time-based restricted area)

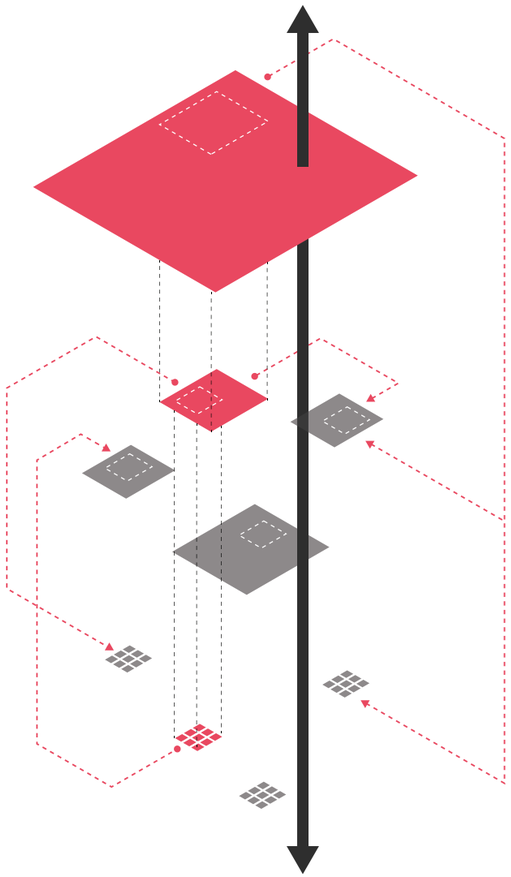
Bike-sharing stations

Car-sharing stations

Pedestrian areas

[Fig. 2.12] Adopted policies against air pollution

source: re-elaboration of GIS data provided by the Municipality of Turin and Province of Turin



[Fig. 2.12] Interscalar approach scheme

source: author

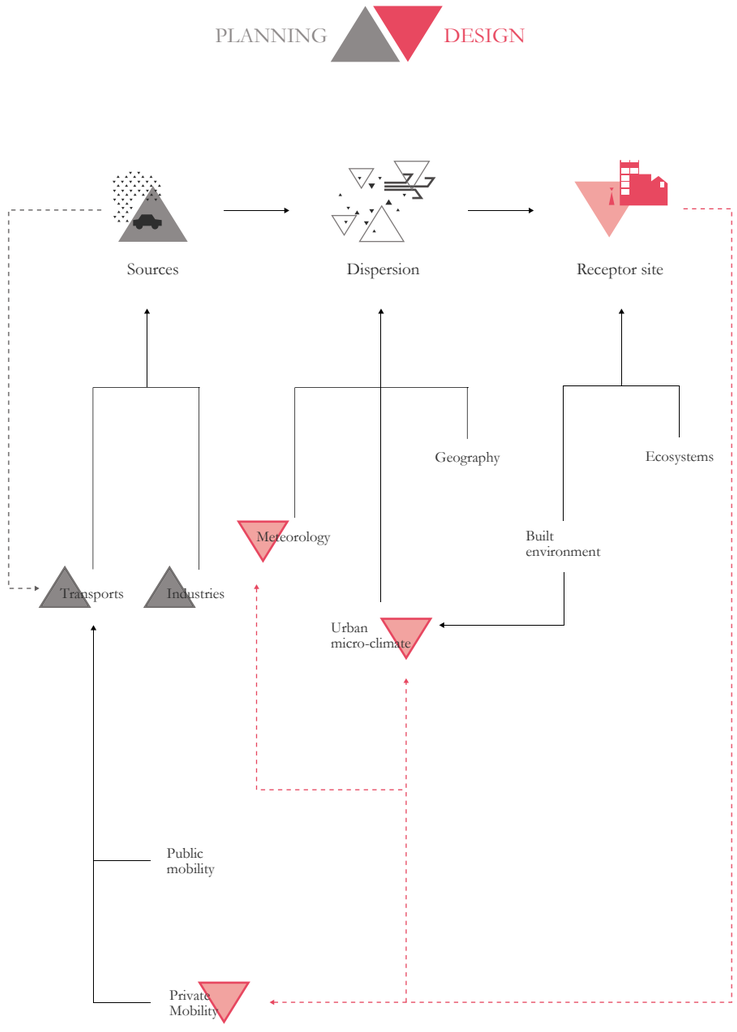
Scope

From the problem analysis, several elements, which need to be considered and whose relationship need to be studied, stood out. Sources, dispersion and receptor site are all interconnected; they can have same or different scales of action but, nevertheless, they influence each other.

Policies are instable and people behavior seems hard to affect. The obtained results for air pollution mitigation in Turin are not working as desired. Therefore, there is a need of more stable and permanent actions which can contribute, along with policies, to air pollution mitigation. By dealing with physical forms of the built environment, Urban Design can provide long-term solutions able to improve urban performances related to air pollution.

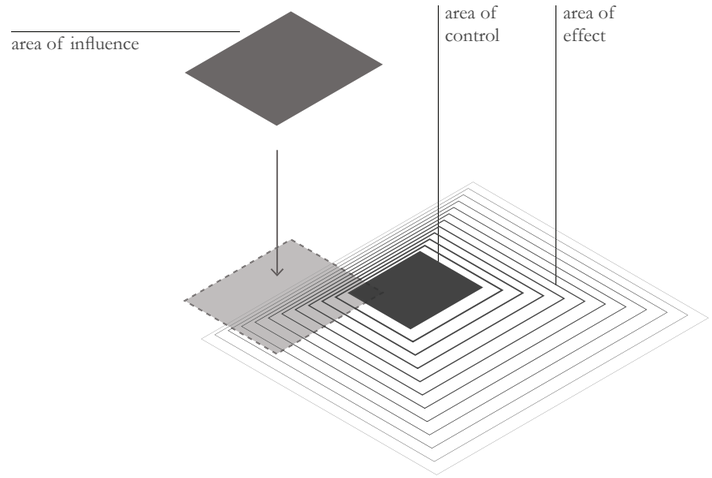
As previously mentioned, air pollution affects regional, urban and neighborhood scale at the same time, but Urban Design does it as well. In this sense, the idea of site conceived by Carol Burns and Andrea Kahn helps to define the aim of the project. They believe that the site, conceived over time, has three distinct areas (Fig. 2.14).

The first, most obvious one, is the area of control, easy to trace in the property lines designating legal metes and bounds. The second, encompassing forces that act upon a plot without being confined to it, can be called the area of influence. Third is the area of effect—the domains impacted following design action. These three territories overlap despite their different geographies and temporalities. The area of control—most commonly referred to in design discourse by the term site— describes the most limited field spatially and temporally. Forces within it predate design action. Lying outside direct design control, the areas of influence and effect situate design actions in relation to wider processes including the often-unpredictable change propelled by design intervention. All three areas exist squarely within the domain of design concerns. (Burn and Kahn, 2005)



[Fig. 2.13] Aim of the project

source: author



[Fig. 2.14] Area of control, effect and influence

source: derived from Lisa Diedrich scheme - http://www.slideshare.net/RETEAsociacion/lisa-diedrich

Design works through geographies, temporalities and scales. The aim of the project is to understand the relation between stages of air pollution, scales and urban design; by applying the concept of area of influence, area of control and area of effect, defining at what scale and at what stage can urban design mitigate air pollution will be the primary goal. The scale definition will be deepened in the analysis section (chapter 3).

More specifically, urban design will work through scales and stages of air pollution (sources, dispersion and receptor site). The area of control and effect defined by Burns and Kahn will shift among scales and stages of pollution.

Furthermore, air pollution can be tackled by several fields; urbanism offers two main tools: spatial planning and urban design. As far as spatial planning in Turin is concerned, it has mainly been focused on tackling emissions of air pollution. Improvements of public transportation, bike and car sharing are solutions whose area of control and area of effect remain in the same stage of pollution. On the other hand, by working with receptor sites, urban design may have the power (to be proved) to mitigate air pollution at different scales and stages (Fig. 2.13). In other words, the area of effect can shift spaces and scales. The project will focus more on urban design, but without denying the importance of planning and the cooperation between them.

[Fig. 2.15] Pollution in Turin

source: art work produced by the author of the project derived http://www.ansa.it/canale_ambiente/notizie/inquinamento/2017/02/03/smog-aumenta-allerta-a-torino-stop-diesel-euro-4_f88e4fe0-eefe-4daa-a05d-3040a76ff90f.html

Research questions

The problem statement and analysis lead to the research question formulation, which can reveal the goal and method of the graduation project. In order to be able to answer the main research question, sub questions are required. These allow to simplify the question and give a structure to the thesis.

main research question

How can urban design mitigate air pollution in the city of Turin?

sub research questions

1 - What is the relationship between air pollution and the built environment ?

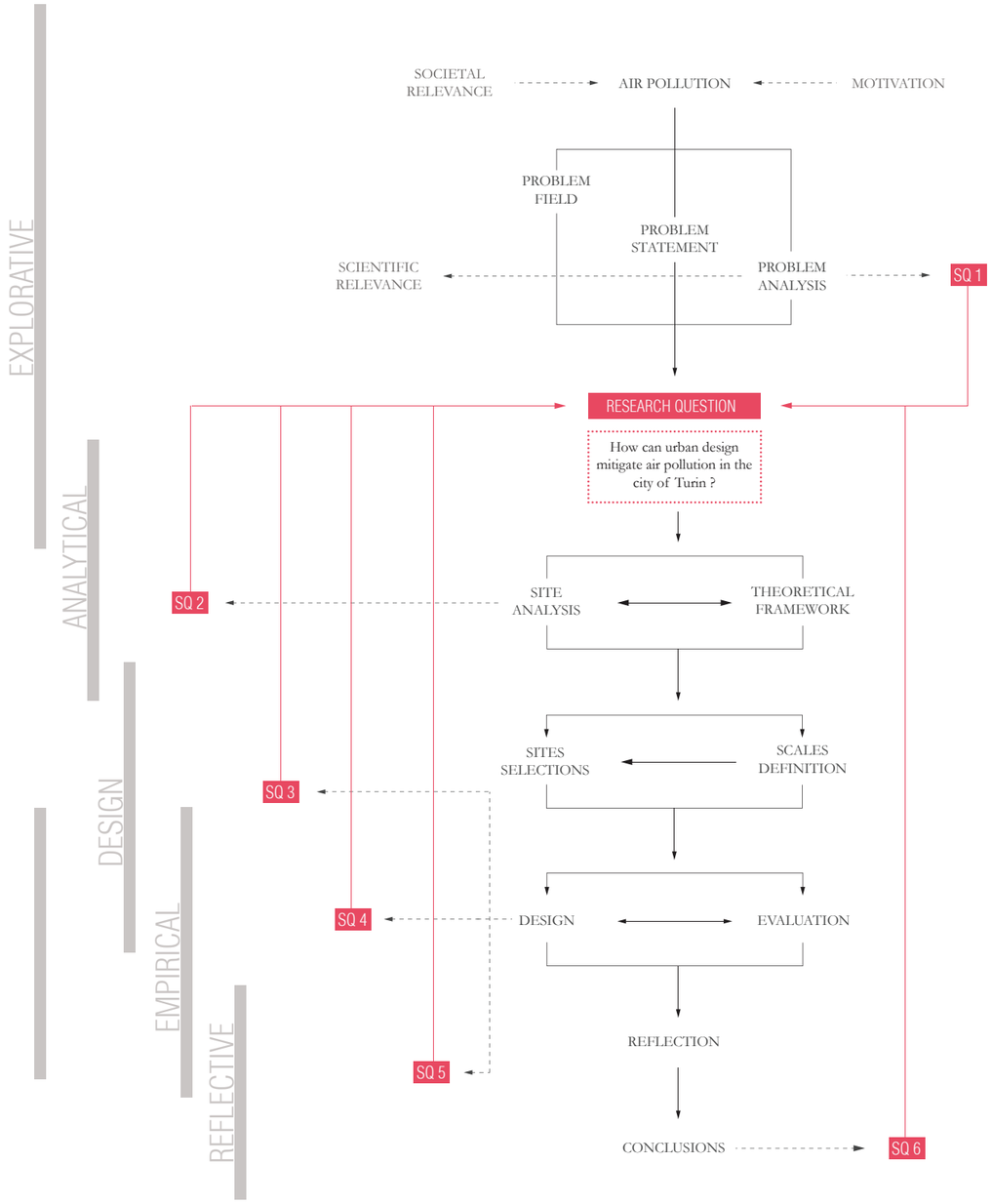
2 - What are the main polluted areas in Turin and what are their physical characteristics?

3 - What are the scales of urban design that address air pollution and what are the existing design proposals?

4 - Do the proposed design proposals have a systemic effect ? How and where could they be applied?

5 - What spatial qualities and values can the design interventions bring to the urban tissue of Turin?

6 - Can the discovered design principles be applied to other cities?



Methodology

In order to answer the research sub questions, a proper methodology is required. It must help to investigate fully the topic and to lead towards a design proposal able to show the discovered relation between urban design and air pollution mitigation.

The methodology reflects the thesis structure and can be divided in five phases: explorative, analytical, design, empirical and reflective phase. During the first phase, the explorative one, the topic of air pollution is investigated: problem field, problem analysis and problem statement are the core of this stage. The combination of the three of them leads to the research questions formulation and the beginning of the second phase, the analytical one. The goal of this phase is that of analyzing the city of Turin in relation to air pollution in order to define possible site interventions. Afterwards, the design phase takes place and design proposals for the spotted sites are defined and evaluated within the empirical phase. The last stage is the reflective one and draws the conclusions of the thesis and tries to reflect on the possible application of the discoveries. In general, to each stage and method, several tools and techniques will be applied.

It must be highlighted that each sub question will be answered at different stages of the methodology with different methods and tools but they all contribute to answer the main research question. Furthermore, some of the methods may repeat themselves in different phases but used for answering different questions. In the next paragraphs the main methods are described and their relation to the sub questions highlighted.

theoretical framework

Sub questions 1 can be answered by a literature research which leads to the theoretical framework formation. By building up a set of specific knowledge, basis for conducting the research and later for developing the design proposal are provided.
The literature review will be divided in two macro themes. The first one, used during the explorative phase, will focus on the phenomenon of air pollution and its relation to the built environment. Urbanism academic background cannot help the research in this instance, therefore a deep understanding of air pollution, winds formation and a bit of fluid-dynamic is required. The second theme, mostly used during the design phase and for answering sub question 3, focuses on the relation between air pollution and urban design. Once the required knowledge is obtained, the scientific basis for dealing with design intervention and for applying it to specific sites will be set.
data collection

Before starting to tackle the problem, data collection is required. Being aware of what are

the main causes of pollution in Turin, what are the current policies and measures is needed. Hence, question 2 is answered partially through a meticulous data collection which lays the foundations for the analysis.

analysing air pollution in Turin

Once a proper theoretical framework has been built and data collected, conducting the analysis by applying the obtained knowledge to the analyzing process will be feasible. Doing so, sub question 2 can be finally answered and the most vulnerable areas in Turin (in term of air pollution mitigation) will be revealed. Different techniques will be used: mapping through GIS, performances simulation through the ENVImet program (multidisciplinary simulation consultancy towards building physics and microclimate adaption and human comfort and health).

evaluating urban performances

Sub question 3 and 4 can be answered partially through an evaluation of urban performances. Because of lack of literature, establishing to what extent different urban scales can address air pollution is very difficult. Where literature will not be able to help, using ENVImet will be essential. The method will enable new discoveries which will be applied and tested in the design intervention.

reflections and conclusions

Question 5 and 6 tries to draw the conclusions of the thesis and to reflect on the possible application of the discoveries. The answer to the main research question will be underpinned but criticisms and lacking contents will be also mentioned. Those will rise new questions and highlight possible follow-up for future researches.

Theoretical framework and readings

The theoretical framework consists of concepts and, together with their definitions and reference to relevant scholarly literature, existing theory and provides the basis for conducting the research and further on for analyzing and developing design interventions. In general, it can help on addressing questions, describing phenomena and developing design ideas. While defining a structure on leading the research, the literature review helps on finding gaps in dealing and coping with the phenomenon of air pollution.
As already mentioned in the previous paragraphs, the chosen literature tackles two main themes: the first one mostly related to air pollution and micro-climate and the second one

regarding design solutions for air pollution mitigation. The themes are strictly connected to each other; the existing literature clarifies different aspects of both of them but it does not cope with them simultaneously. That means that there is a gap or missing connection between them.
The chosen "pillar" literature will be now mentioned, while being aware that it will need to be expanded, especially the one related to design solutions for air pollution mitigation. It must be also underpinned that newspaper articles and academic papers which treat urban issues related to air pollution also received a special attention but they will not be mentioned.

air pollution and micro climate

+ Oke, T.R. (1987). Boundary layer climates. New York, Rutledge.
key concepts: boundary layer, climates of non-uniform terrain, pollution (sources, dispersion, receptor site), urban and regional pollution

+ Pijpers-van Esch, M. (2015). Designing the Urban Microclimate
A framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process. PhD, Delft Univeristy of Technology
keywords: urban environment, micro climates, urban design

+ World Health Organization / European Environmental Agency
keywords: health, air pollution, urbanization

air pollution and urban forms

+ Erell, E., Pearlmutter, D. &Williamson, T. (2011). Urban Microclimate: Designing the Spaces between Buildings, Earthscan, London.
keywords: urban design, air pollution, built environment

+ Krautheim, M., Pasel, R., Pfeiffer, S and Schultz-Granberg, J. (2014). City and Wind. Climate as ans Architectural Instrument. Dom Publisher, Berlin.
keywords: design, wind, comfort

+ Oswald, F., Baccini, P., Michaeli, M. (2003). Designing the urban. Springer Science & Business Media, Berlin.
keywords: design, built environment, scientific approach design

03

THEORY AND ANALYSIS

Introduction

Matrix of analysis

Mesoscale and urban canopy: the problem of scale
Source, dispersion and receptor site
Units of measurement and aggregation
Workability
Impact rate

The analysis

L3 - Terrain
L4 - Land use
L5 - Traffic
L6 - Vegetation
L8 - Roughness
L9 - GSI/FSI
L10 - Population

Risk assessment: vulnerability and hazard

Analysis and risk hazard approach
Risk assessment: adopted method
Results

Sites of interventions

Selection method
Observations
Conclusions

Introduction

In the previous chapters, the phenomenon of air pollution in Turin has been generally described: a first understanding of its features, causes and consequences have been given. However, the problem analysis has not properly described the relation between air pollution and receptor site, the built environment and its inhabitants. This chapter of the report has the goal of investigating this relation through an analytical and a theoretical framework in order to identify areas or streets which are most likely facing major issues of air pollution.

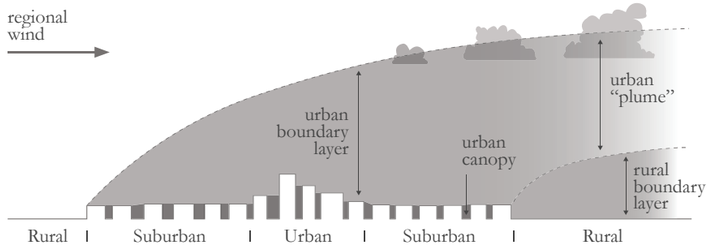
The section is structured according to a mutual parallelism between theoretical framework and analysis. The data provided by the municipality of Turin are not detailed enough for identifying the areas with issues related to air pollution. Therefore, the combination of theory and analysis will allow to identify how the city of Turin responds to air pollution and, more important, what are the scales of urban design that addresses air pollution. In other words, identifying area or streets which air pollution is more likely to affect livability will be possible.

Matrix of analysis

As previously-mentioned, because of lack of information, the analysis leans on principles derived from the literature review. Thanks to it, building up a matrix of analysis able to detect areas with high problems related to air pollution is feasible. The matrix is composed by several variables and tries to define the most important layers which can be responsible for high concentration of pollutants in the city of Turin. It is important to highlight that the proposed analysis is not comprehensive of all the possible variables affecting air pollution. A selection, based on the features of Turin defined within the problem analysis, was made, but it is not the only and right way of looking at air pollution. The matrix is described and the main components are explained in the following paragraphs.

Mesoscale and urban canopy: the problem of scale

The problem analysis defined air pollution as a multi-scalar phenomenon: punctual and dispersed sources, neighborhood and urban receptor sites are some of the elements which emphasize this feature. Furthermore, different authors (Oke, 1987; van Esch, 2015) highlight the relevance of both built and natural environment on formation and mitigation of air pollution. However, defining scales of action of air pollution is not that simple. As part of the urban microclimate, the phenomenon can be described through two main scales: the mesoscale and the urban canopy scale. The first one represents the larger climatic conditions of the boundary layer (the layer of air in the immediate vicinity of a bounding surface) of the atmosphere. The urban canopy, on the other hand, represents the microscale phenomena happening at streets level and it is different from road to road. The layers of the matrix are therefore grouped according to these two extremes.
Though, architects and urbanists work with more than two extreme scales; there are different levels of scales which urban designers use or affect while designing. Therefore, one of the main goal of the analysis, combined with the theoretical framework, is to bridge the gap by discovering scales of air pollution which are approachable by design interventions.



[Fig. 3.1] Scales of air pollution

source: Oke, T.R. (1987). Boundary layer climates. New York, Rutledge

Sources, dispersion, receptor site

As mentioned in previous chapters, the phenomenon of air pollution can be described within three steps: sources, dispersion and receptor site (Oke, 1987). The analysis proposes this distinction again and tries to understand the features of each layer. For instance, the layer of population can be seen as part both of the sources and the receptor site, people are at the same time producers and receivers of pollution. This difference might help when developing design interventions able to cope with the duality of the layer. Furthermore, the same layer, but at different stages of pollution, might require diverse answers.
It must be reminded that the choice of the layers has been made by leaning on academic background; on the other hand the positioning under a certain stage of pollution (sources, dispersion or receptor site) is not "taken" from existing literature but it is a decision made by the author of the project.

Units of measurement and aggregation

The unit of measurement is a definite magnitude of a quantity, defined and adopted by convention or by law, that is used as a standard for measurement of the same quantity (JCGM, 2008). The unit of aggregation expresses the criteria whereby certain data has been aggregated or gathered.
The matrix shows both units for each layer which might have them or not. Clarifying and making these units explicit will be essential when starting to overlay and compare different layers. The comparison would be much more beneficial if the units of aggregation were the same, unfortunately the obtained data have often different units. That is not a real issue, but it must be taken under consideration and notified before starting the analysis.

Workability

Each layer has certain physical, social and economic features which define its nature. Their spatial configuration and their possibility to be modified and changed define what is called "workability". The rate of workability defines therefore which layer urban designer can more easily work with and change. The rate has five levels: very low, low, medium, high and very high. The chosen rate is defined mostly by the nature of the layer and by its physical characteristics and it is not derived by literature.

Impact rate

When reading and exploring the existing literature concerning air pollution and the built environment, it is clear that there are different factors which might influence emission and dispersion of air pollution. However, what remains unclear and unexplored is the impact of each aspect compared to the others. For instance, it has been studied that the street orientation

Mesoscale

Urban Canopy

Source	Dispersion	Receptor Site	Measurament Unit	Aggregation Unit	Workability	Impact Rate	Theoretical Framework
L1 Pollutants			various (different for each pollutant)	municipality	▼▲▼▲▽	to be discovered	derived from problem statement
L2		L2 Land Use + Built environment + Forests + Agricultural land	[-]	-	▼▲▼△▽	to be discovered	Krautheim, M., Pasel, R., Pfeiffer, S and Schultz-Granberg, J. (2014). City and Wind. Climate as ans Architectural Instrument. Dom Publisher, Berlin. Oke, T.R. (1987). Boundary layer climates. New York, Rutledge.
Terrain L3		L3	[-]	-	▼△▽△▽	to be discovered	Oke, T.R. (1987). Boundary layer climates. New York, Rutledge.
		L4 Land Use + Residential + Touristic + Commercial + Mixed Use + Production Industrial + Green Areas + Services	[-]	-	▼▲▽△▽	to be discovered	Meurs, H., van Wee, B. (2003). Land Use and Mobility: a Synthesis of Findings and Policy Implications. EJTIR, 2, 219-233 De Vos, J. (2015). The influence of land use and mobility policy on travel behavior: A comparative case study of Flanders and the Netherlands. The Journal of transpoirt and land use, 1, 171–190 Meurs, M. (2003). Special issue: Land Use and Sustainable Mobility. EJTIR, 3, no. 2, 109-117 Oke, T.R. (1987). Boundary layer climates. New York, Rutledge. Erell, E., Pearlmutter, D. &Williamson, T. (2011). Urban Microclimate: Designing the Spaces between Buildings, Earthscan, London
L5 Traffic			Intensity (avarage number)	neighborhoods subunit	▼▲▼▲▽	to be discovered	derived from problem analysis
Vegetation L6		L6	[-]	-	▼▲▼▲▽	to be discovered	Vos, P., Maiheu, B., Vankerkom, J., JanssenImproving, S. (2013). Local air quality in cities: To tree or not to tree? Environmental Pollution, 183, 113-122 Erell, E., Pearlmutter, D. &Williamson, T. (2011). Urban Microclimate: Designing the Spaces between Buildings, Earthscan, London.
L7 Wind + Direction + Speed			meters [m] angles [degree]	-	▼△▽△▽	to be discovered	Oke, T.R. (1987). Boundary layer climates. New York, Rutledge. Krautheim, M., Pasel, R., Pfeiffer, S and Schultz-Granberg, J. (2014). City and Wind. Climate as ans Architectural Instrument. Dom Publisher, Berlin.
L8 Roughness			meters [m]	buildings	▼▲▽△▽	to be discovered	Oke, T.R. (1987). Boundary layer climates. New York, Rutledge.
L9 Density + FSI + GSI			qm/qm	building - block	▼▲▽△▽	to be discovered	Pont, P., Haupt, P. (2010). Space Matrix: Space, Density and Urban Form. Met Boyko, C., Cooper, R. (2011). Clarifying and re-conceptualising density. Progress in Planning, 76, 1–61 Hilber, C. (2014) Urban Development and Air Pollution: Evidence from a Global Panel of Cities
L10		L10 Polulation + Density + Age	Inhabitants for squared kilometer [inh/skm]	neighborhood - neighborhood subunit	▼△▽△▽	to be discovered	Alexis, N., Barnes, C., Bernstein, L., Bernstein, J. A., Nel, A., Peden, D., Brock Williams, P. (2004). Health effects of air pollution. J Allergy Clin Immunol, 114

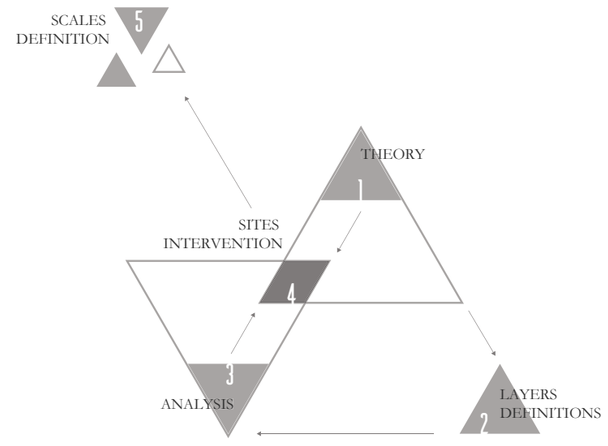
(Oke, 1987) and the existing vegetation (E.J. Vos et al, 2013) are both relevant to pollutants dispersal. But could we define a hierarchy between them? Could we compare all the layers and discover their relative importance? Hence, the matrix of analysis shows a column called "impact rate" which aims to discover this value. Unlike the other values, these will be obtained as result of the analysis or the design and cannot be set without a proper investigation. Therefore, at this stage of the analysis, the rate will be the same for each layer.

Objectives and expected results

Overall, the analysis has three main goals. The first one is that of identifying areas of Turin with the highest chances of suffering because of air pollution: a risk map will show the weakest areas of the city and the site interventions will be decided. Secondly, once the areas are defined, the scales which relate urban forms and air pollution will be revealed. Finally, a hierarchy of the chosen layers will be established.

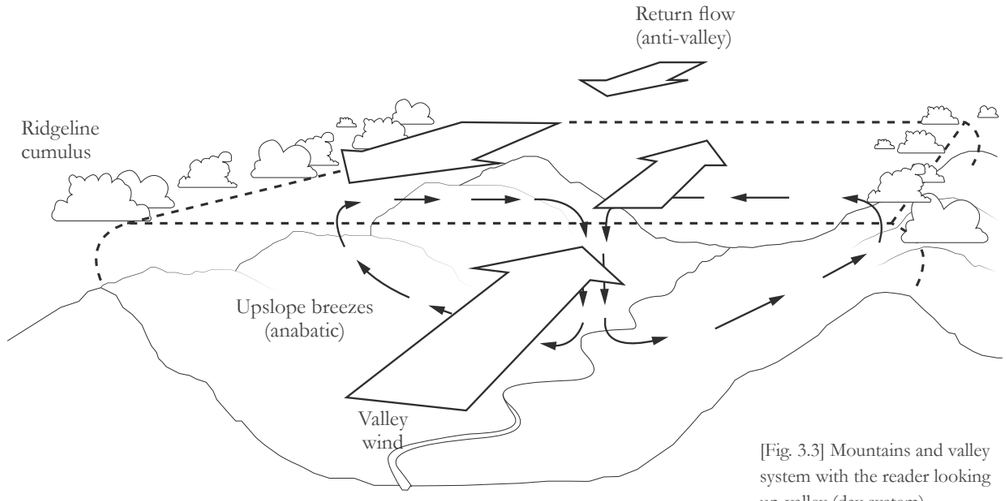
The analysis

The analysis is built according to the following structure. Each layer has been chosen for certain reasons, therefore, before analyzing the city of Turin, a proper explanation of the theoretical backgrounds behind the choice is given. Once the necessary information is acquired, the assimilated knowledge and concepts are applied on the analysis of Turin itself. Doing so, the strict connection between theory and analysis will be evident and recognizable. After the single analysis of each layer, they will be all combined in the risk map. Some of the layers related to the mesoscale will not be taken under consideration because already analyzed within the problem analysis. In particular, layer L1 and L2 have been already deeply discussed and analyzed in the previous chapters. Therefore, the analysis will start from the layer L3 - Terrain.



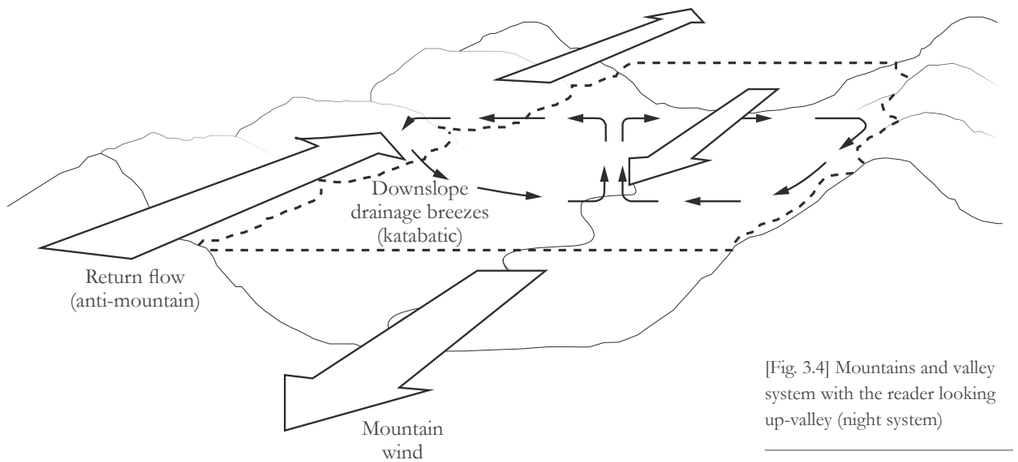
[Fig. 3.2] Analysis process

source: author



[Fig. 3.3] Mountains and valley system with the reader looking up-valley (day system)

source: derived from Oke, T.R. (1987). Boundary layer climates. New York, Rutledge



[Fig. 3.4] Mountains and valley system with the reader looking up-valley (night system)

source: derived from Oke, T.R. (1987). Boundary layer climates. New York, Rutledge

L3 - Terrain

Theory

As previously described, the concentration distribution of pollutants is often related to the occurring wind flow patterns (van Esch, 2015). Our world can be seen as a patchwork quilt of different surface slopes and material (non-uniform terrain); its characteristics are responsible for winds flows patterns.

In general, wind is caused by differences in air pressure. Air pressure is related to air density, which is influenced by temperature: heat causes air to expand and decrease its density. The air temperature depends on the specific features of Earth surfaces: their radiative, thermal, moisture and aerodynamic proprieties regulate their thermodynamic characteristics (Oke, 1987). Physic explains that warm air has lower pressure than cold air and that wind blows from areas with high air pressure to areas with low air pressure. The greater the pressure differences and the closer the areas with pressure differences are located to one another, the faster the wind will blow (van Esch, 2015). Earth's surface can be divided in two main categories: the natural and the anthropological environment.

The city of Turin lays in a basin, between the Alps and hills. Valleys, especially those in mountainous regions, produce their own local wind systems as a result of thermal differences (Oke, 1987). Heights differences and varied topography contribute to the climate response; for instance, solar loading differences would arise because differences of slope (Oke, 1987). Because of the heights difference, by day the air above the slopes and floor of the basin will be heated by underlying surface to a temperature well above that over the centre of the basin. As a result shallow, unstable upslope flow arises and [...] a closed circulation develops (Oke, 1987). By night the valley surfaces cool down and the air slides down-slope under the influence of gravity. These winds usually flow gently downhill at bout 2-3 m/s (Oke, 1987).

The basin of Turin is defined by a north-south axis and by an asymmetric geometry and, according to Oke's theory (Oke, 1987), the flow pattern may be therefore incomplete or uneven. Because of the distance from the Alps to the city, the mountains are not taken under consideration.

Analysis

The map (Fig. 3.5)shows the contour lines of the city of Turin in relation to the forest and the green areas of the city and tries to predict the night winds directions. By identifying the valleys where night winds are canalized, future strategic interventions for facilitating wind circulation and increasing air pollution dispersion might be implemented.

[Fig. 3.5] Non uniform terrain

source: re-elaboration of GIS data provided by the Municipality of Turin and Province of Turin

Workability | ▼△▽△▽

Dealing with natural environments, their slopes and vegetation but also with the built environment is a difficult task. Changing urban forms, streets for facilitating wind flow patterns is very unlikely to happen. Therefore, the workability of the considered layer is very low.

[Fig. 3.6] Landuse

source: re-elaboration of GIS data provided by the Municipality of Turin and Province of Turin

L4 - land use

Theory

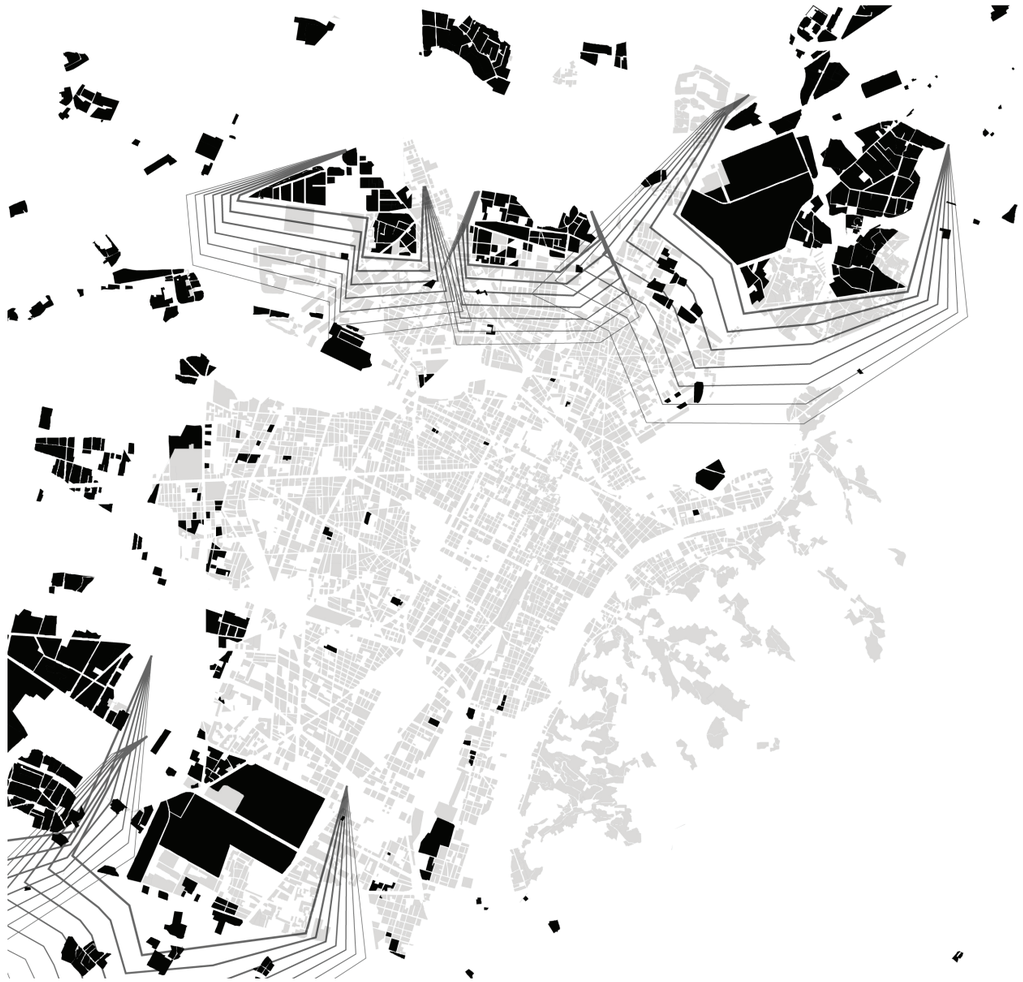
Although recent studies suggest that car use is ceasing to grow in the developed economies ("peak car use") (Metz 2013; Newman and Kenworthy 2011; as cited in De Vos, 2015), most western countries have also faced a rapid increase in car use over the past decades. The close relationship between urban land use and transport is common knowledge among spatial and transport planners (Meurs, 2003). For instance, walking, cycling, and public transportation use in suburban or rural neighborhoods is significantly lower than in urban neighborhoods, while car use is significantly higher (e.g., Cao et al. 2009; Cervero 1996; Cervero and Kockelman 1997; Ewing and Cervero 2010; Mokhtarian and Cao 2008).
Related to air pollution, land use studies can show several features. Firstly, definition of residential, productive, service, and commercial areas will reveal the grade of integration of neighbourhoods, consequently, the need or not of inhabitants to travel. Secondly, Oke (1987) highlights that vicinity of residential area to industrial ones must be considered in air pollution exposure assessment.

Analysis

The land use map shows that industrial areas are mostly in the periphery of the city. The city functions are well mixed and integrated. Most of the neighborhoods are residential with mixed functions at ground floors.
When combining the land use map, highlighting industrial areas, and wind direction, it is possible to identify which areas are more likely to be directly exposed to industrial air pollutants.
A precise estimation of how far and for how long industrial pollutants are dispersed in the air is not possible though. Data related to specific emissions, their capacity of dispersion and other characteristics are not available. Therefore, the map is not reliable and it is just a possible simulation of an hypothetic dispersion. However, while knowing the wind speed, it can be assumed that pollutants will flow towards south and the areas next to the industries will be the most exposed, hence the areas with higher vulnerability concenring this matter can be revealed.

Workability | ▼▲▼△▽

Land use might can constantly change. Relocating and re-distributing function can be made by developing a proper strategic planning. However, in the case of Turin mixed uses are already well integrated. The workability rate is therefore medium.



[Fig. 3.7] Industrial air pollution and vulnerable areas

source: re-elaboration of GIS data provided by the Municipality of Turin and Province of Turin

[Fig. 3.8] Industrial and residential neighbourhood

source: Google Hearth

[Fig. 3.9] Morning traffic flows

source: re-elaboration of data provided by 5T (Tecnologie Telematiche Trasporti Traffico Torino)

highly congested
congested
almost fluid
fluid

0 2 4 KM

[Fig. 3.10] Evening traffic flows

source: re-elaboration of data provided by 5T (Tecnologie Telematiche Trasporti Traffico Torino)

highly congested
congested
almost fluid
fluid

0 2 4 KM

L5 - Traffic

Theory

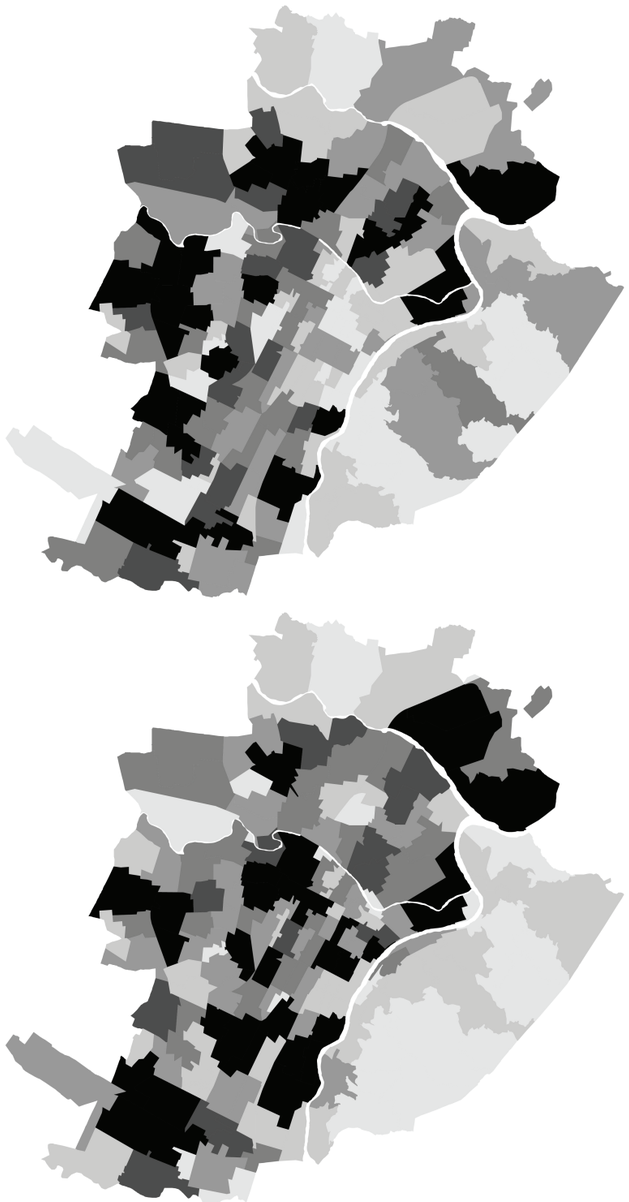
As already stated in the problem analysis, traffic is one of the main sources of pollution in Turin. Traffic intensity, frequency, streets with higher probability of congestion are some of the data that can be taken under consideration. It is known that traffic congestion increases vehicle emissions and those, consequently, affect ambient air quality. Mapping and tracing the roads with high percentage of traffic defines the areas or lines where inhabitants are more directly exposed to air pollution. The relation to the problem is therefore evident, hence it represents one of the more important layer in the analysis.

Analysis

The maps (Fig. 3.9 and Fig. 3..10) show the traffic intensity during the morning and evening rush hours. Traffic on the main streets, which connect the periphery to the rest of the city, is often the most intense. The maps (Fig. 3.11 and Fig. 3.12) show which areas most of the people come from and go to by car, excluding ways back home. Therefore, it might be assumed that these areas are also the areas where there is the highest concentration of cars. Finally, when combining the just described maps and isolating the streets with the most intense traffic and the areas where most of the people come from and go to, a conclusion map (Fig. 3.13) shows what are the most vulnerable, related to traffic, areas and streets of the city. It is surprising that the center of the city is not included in those areas. Furthermore, peripheries are the most vulnerable areas and the streets which connect them to the rest of the city are the most congested.

Workability | ▼▲▼▲▽

Traffic has been already tackled by the municipality of Turin through policies and public transportation improvements. Working with traffic flows and intensity is possible. Planning approaches are easier to apply than urban design interventions.



[Fig. 3.11] Origin car map. Number of people traveling, excluded ways back home.

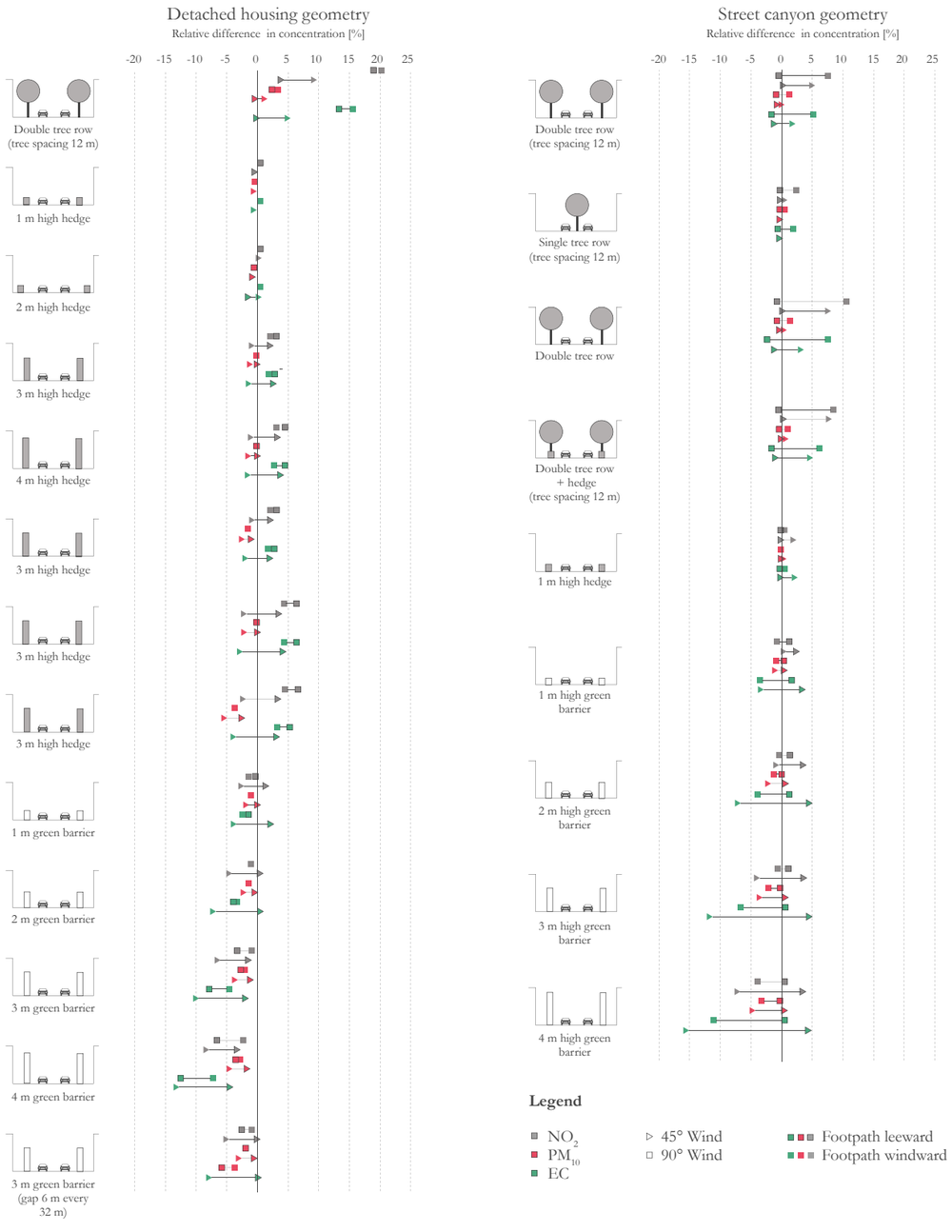
source: re-elaboration of data provided by 5T (Tecnologie Telematiche Trasporti Traffico Torino)

[Fig. 3.12] Destination car map. Number of people traveling, excluded ways back home.

source: re-elaboration of data provided by 5T (Tecnologie Telematiche Trasporti Traffico Torino)

[Fig. 3.13] Conclusion map: traffic

source: derived from previus maps



[Fig. 3.14] Effects of urban vegetation in urban canyons

source: VOS, P., MAIHEU, B., VANKERKOM, J. & JANSSEN, S. (2013). Improving local air quality in cities: To tree or not to tree? Urban Environmental Pollution, 183, 113-122

L6 - vegetation

Theory

Vegetation is often quoted as an effective measure to mitigate urban air quality problems. However, studies have demonstrated that the air quality effect of urban vegetation is more complex than implied and that roadside urban vegetation rather leads to increases pollutants concentration than it improves the air quality, at least locally (E.J. Vos et al, 2013). Trees and other types of vegetation reduce the ventilation in urban canyons and, doing so, obstacle air pollution dispersion.
The study conducted by Peter E.J. Vos and his colleagues in 2013 revealed that the aerodynamics effect is shown to be much stronger than the pollutant removal capacity of vegetation. Hence, the layer of vegetation is also an important factor in determining the most polluted areas in the city of Turin. To this extent, type, height and disposition of trees are very relevant.

Analysis

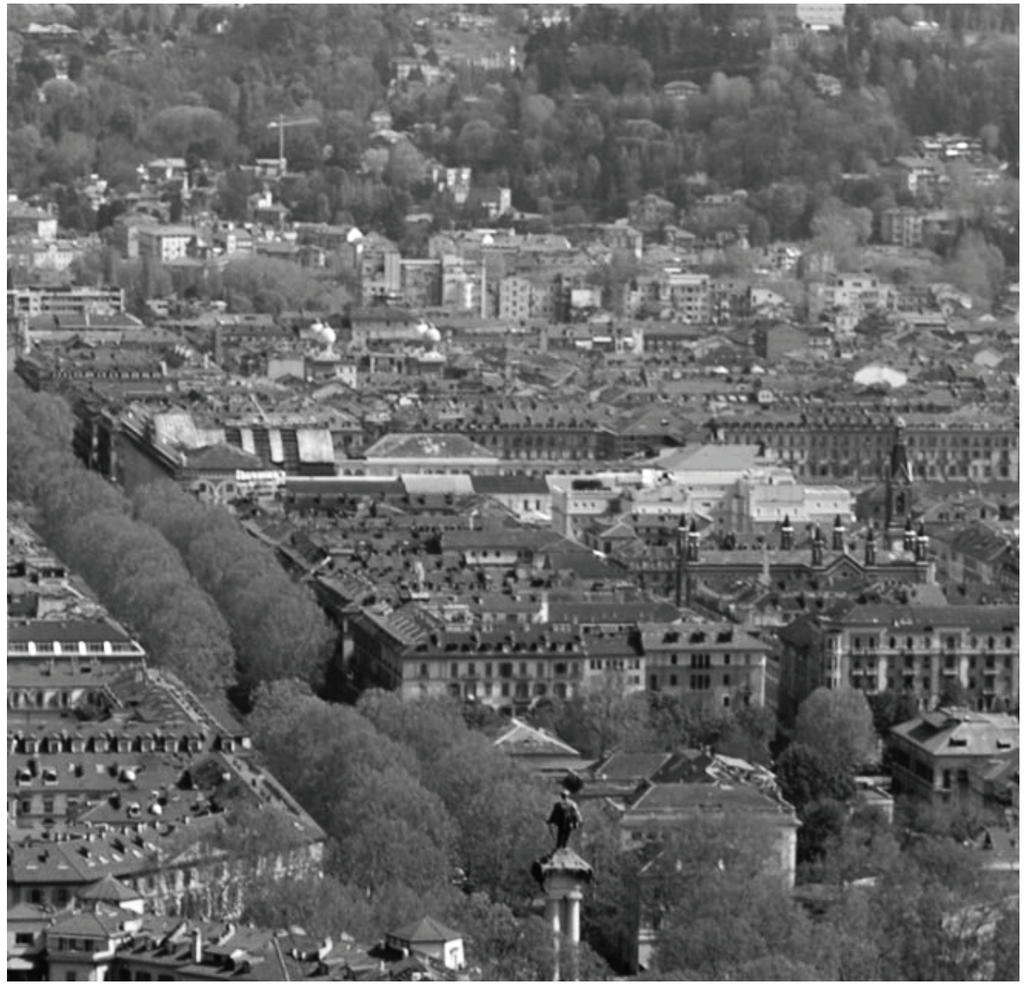
The map (Fig. 3.15) shows the streets network in combination with the urban vegetation. Major roads are often characterized by trees which probably decrease air flows in the urban canyons. Those streets should have consequently higher rate of pollution. There are more than 30 different species of trees and each of them has specific characteristics (height, type of crown and leafs). However, the analysis of the species will be deepened when analyzing specific streets. For the moment, knowing their location is sufficient.

Workability | ▼▲▼▲▽

Designing and working with trees is probably one of the more feasible actions for reducing air pollution. Despite environmental conflicts may be faced, trying to define a new configuration for tree plantation might be one of the main task. Hence, workability is set to high.

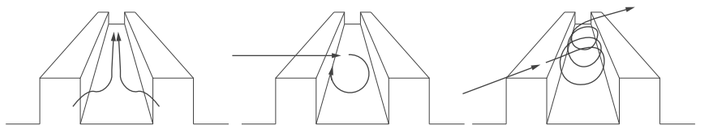
[Fig. 3.15] Urban vegetation

source: re-elaboration of data provided by the Municipality of Turin



[Fig. 3.16] Urban vegetation

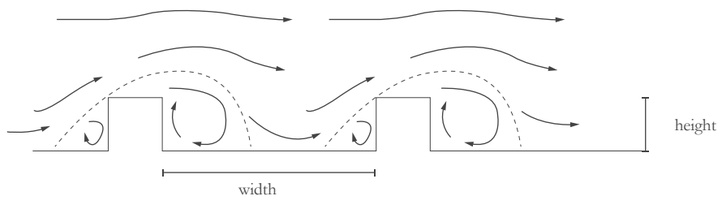
source: http://www.parallelo45.com/p45gallery_display1280.asp?Foto=1697&Cat=5005



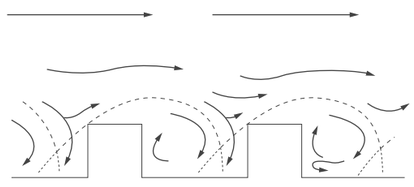
[Fig. 3.17] Flow patterns in the urban canyon, related to the wind direction at roof height; parallel, perpendicular or at an angle to the canyon axis

source: Pijpers-Van Esch, M. (2015). Designing the Urban Microclimate A framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process. PhD, Delft University of Technology

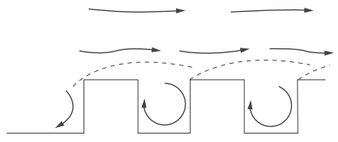
Isolated roughness flow



Wake interference flow



Skimming flow



[Fig. 3.18] Flow regimes associated with different geometries

source: Oke, T.R. (1987). Boundary layer climates. New York, Rutledge.

L7 - Roughness

Theory

The interrelations between turbulent wind flows along buildings and urban environments are highly complex and difficult to calculate (Krautheim et al, 2014). Airflow patterns near obstacles are highly dependent on the geometrical characteristics of the obstacles themselves (van Esch, 2015). In general, the size, form and arrangement of buildings determine the degree of influence on wind flow behavior. Therefore, a brief explanation regarding airflow patterns in urban canyons will follow.

The wind flow pattern in the built environment can be study by considering the relation to one building, urban canyon or urban tissue. The analysis of flow pattern around single building will be not described because not relevant to the analysis of Turin.

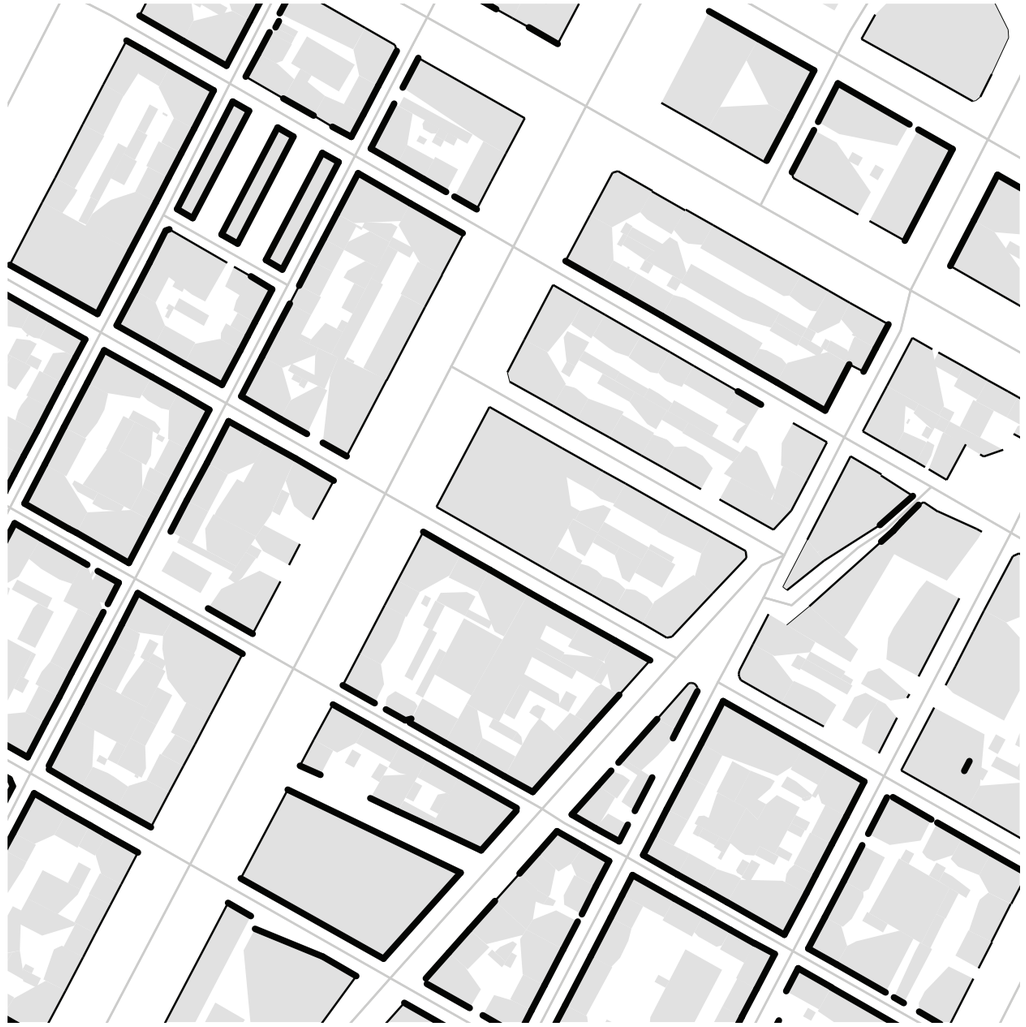
As far as the wind flow patterns in urban canyons are concerned, three flows, correlated to the wind direction at roof height, can be defined: parallel, perpendicular or at an angle to the canyon axis. When the wind direction is parallel to the canyon axis, the wind flows right through the canyon (van Esch, 2015). In this case, pollutants are easily transported and dispersed. If the wind direction is more or less perpendicular to the canyon axis, three sub flow regimes can be distinguished: isolated roughness flow, wake interference flow and skimming flow (Oke, 1987, van Esch, 2015). These flow regimes depend upon the geometry of the array, especially from the height to width ration of the canyon (Fig. 17 and 18).

[H/W < 0.1] - This is the case of isolated roughness flow where there is a very little interaction between the flows of the upwind and downwind area of the canyon (van Esch, 2015). Their flow pattern appears almost the same as if they were isolated.

[0.1 < H/W < 0.7] - At closer spacing, the wake of any building interferes with that of the next downstream leading to a complicated pattern. This is the case of the wake interference flow regime; wind speeds are higher than the ones in the isolated roughness flow.

[H/W > 0.7] - In even narrow canyons, the main flow starts to skim over the building tops and drives a lee vortex in the cavity. The wind speeds in this regime are slower than the ones in the wake interference flow and they might be even slower than wind speeds in the isolated roughness flow – in case of very narrow canyons.

The above-mentioned regimes are found when the wind direction is normal to the urban canyon axis. If the wind has a different angle the vortex takes a cork-screw motion with an elongation along the street (Oke, 1987). Overall, proportions of urban tissue play a relevant role in wind flow patterns and in air pollution dispersion as well. Moreover, the study of these proportions can reveal the role of urban forms in air pollution dispersion.



0 25 50 M

H/W > 0.1
0.1 > H/W > 0.7
H/W > 0.7

Blocks divisions

[Fig. 3.19] Roughness

source: data provided by the Municipality of Turin. GIS calculation and script made by Anna Labetsky

The calculation was carried out by Anna Labetsky, PhD student at the 3DGeomatics Department of the Faculty of Architecture, TU Delft. A brief description of the adopted methodology for the calculation is given.

Methodology (written by Anna Labetzky):

The original roads dataset had some holes where there are traffic islands or green-spaces which needed to be filled in order to get an accurate measure of the road width and this was done utilising ArcGIS. Many of the green-spaces were easily fixed by intersecting the roads shapefile with a parks and greens-pace shapefile and merging the intersecting pieces. Remaining holes were fixed by filling in any hole that did not intersect with the buildings shapefile, indicating that a hole did not have any buildings in it and was therefore a hole in the road dataset and not an actual absence of a road. The initial building dataset contained over 70000 buildings that had multiple facades. ArcGIS was utilised to generalise the original buildings input in order to reduce processing time, manage crenulation (i.e. overly-detailed building components) and to filter down to the sides of a building that actually face the road. This was achieved by creating minimum bounding boxes around each original input building. The resulting simplified polygon edges were then converted into lines that were split at the vertices to have each side of a building stored as a unique element in a new shapefile.

Utilising Python with the Fiona and Shapely packages, the shapefile was parsed and each polygon edge was stored as a line segment. The midpoint of each line segment was calculated and a 100 metre line perpendicular to the original line was cast in both directions from the midpoint. The coordinates of the resulting perpendicular lines were saved to a CSV and within ArcGIS the lines were generated as a shapefile. The lines were clipped with the roads layer to only include the portion that is within the road and the distance for each clipped feature was calculated. The distance from the start of each line to the building edge was calculated and filtered to only include distance less than 1.3 metres to exclude building sides that were far from a road. The final step was calculating, for each remaining side of a building, the height of the building divided by the length of the line segment that measured the width of the road. The resultant calculations were grouped into three categories <0.1, 0.1 – 0.7 and >0.7.

Analysis

Anna Labetsky's calculation allows to define values for each building, however at an urban scale the data is too detailed for drawing conclusions. Therefore, the discovered values were summed and aggregated according blocks subdivision.
The analysis shows that areas with values under 0.1 are extremely rare and they often coincide with open and green spaces such as parks or graveyards. Overall, it can be said that most of the streets of the city have values above 0.7 and that makes the skimming effect, among the three, the most common flow. It must by highlighted that the map (Fig. 3.20) shows the most

[Fig. 3.20] Roughness conclusion map

source: data provided by the Municipality of Turin. GIS calculation and script made by Anna Labetsky

common values for each subdivision and it does not take under consideration their area. Consequently, wide subdivisions belonging to the hills of the city, with low GSI and FSI and values above 0.7, have been assigned to the skimming flow effect, without considering the low density and therefore they do not play a relevant role in air pollution dispersion.

Workability | ▼△▽△▽

Working with the built environment is a difficult task. Developing new assets or proportions of streets requires major changes which are often unlikely to happen. However, intervening on urban blocks is more likely to happen. Their workability is considered low.

Floor Space Index (FSI)

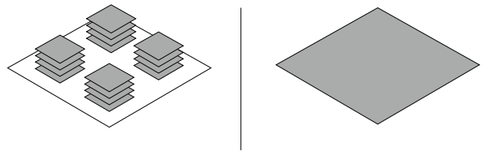
$FSI_x = F_x / A_x$

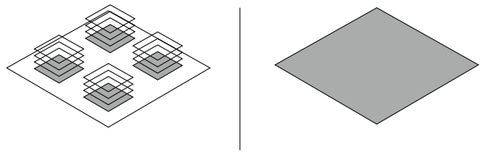
F_x = gross floor area [m²]
A_x = area of aggregation x [m²]
x = aggregation [lot (l), island (i), fabric (f), or district (d)]

Ground Space Index (GSI)

$GSI_x = B_x / A_x$

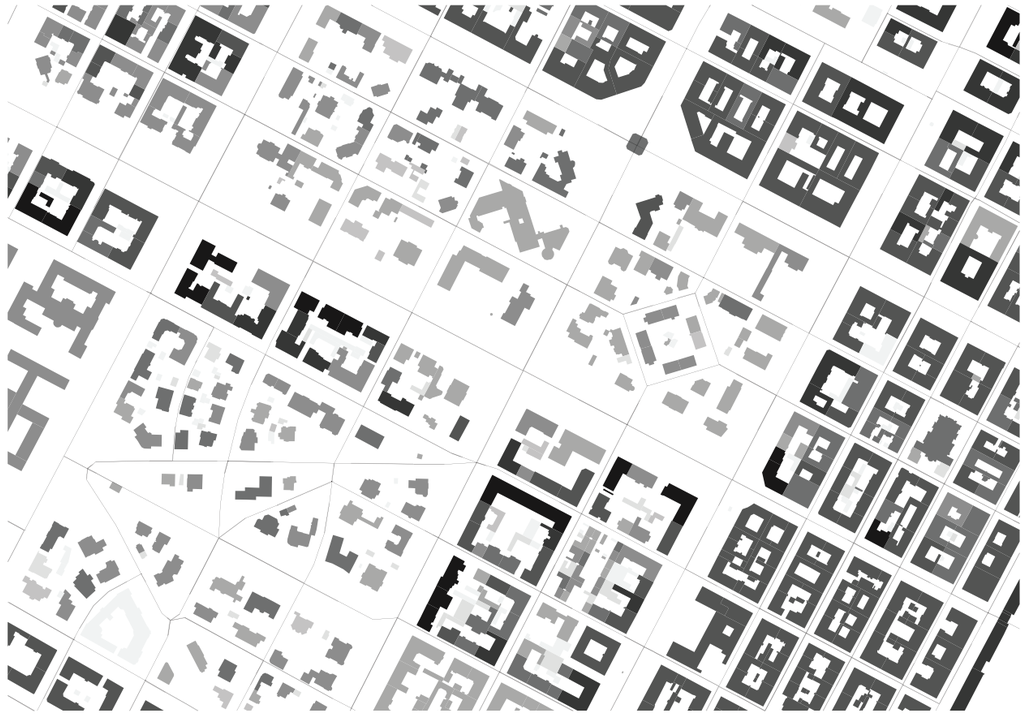
B_x = foot print of [m²]
A_x = area of aggregation x [m²]
x = aggregation [lot (l), island (i), fabric (f), or district (d)]





[Fig. 3.21] GSI and FSI

Source: Pont, B., Haupt, P. (2010). Space Matrix: Space, Density and Urban Form Meta Rotterdam, NL: Nai Publisher.



Height [m]

- 3 - 4
- 5 - 7
- 8 - 10
- 11 - 13
- 14 - 15
- 16 - 20
- 21 - 24
- 25 - 30
- 31 - 42
- 43 - 69

[Fig. 3.22] Buildings heights and blocks divisions

Source: Pont, B., Haupt, P. (2010). Space Matrix: Space, Density and Urban Form Meta Rotterdam, NL: Nai Publisher.

L9 - GSI/FSI

Theory

As previously-mentioned for the layer of roughness, buildings represent obstacles which may interfere with wind flows through the city. Therefore, analyzing the density of the built environment becomes crucial: the higher is the density, the less wind will blow through the urban tissue. Pont and Haupt (Pont and Haupt, 2010) define several variables able to describe density: the floor-space index and the ground-space index are the most important.
The floor-space index (FSI) expresses the built intensity of an area. It shows how many square meters is built within a hectare of land. The higher the number, the more intensely built up the area is. FSI is also commonly referred to as Floor Area Ratio.
The ground-space index (GSI) expresses the compactness of an area. It shows what percentage of a hectare is covered by a building footprint. The higher the number, the more land is built upon within an area, the more compact it is.

Analysis

From both the analysis of the FSI (Fig. 24)and GSI (Fig. 23), it can be said that the city center is the most compact and built area of the city. However, the surrounding areas between the peripheries and the center are compact as well. Generally, the city is highly built and dense. The FSI and GSI of the city can contribute to define the roughness of the urban tissue. The higher the values, the slower are the wind flows. That means that, for instance, the center will need microscale interventions able to filter, instead of moving, the polluted air.

Workability | ▼▲▽△▽

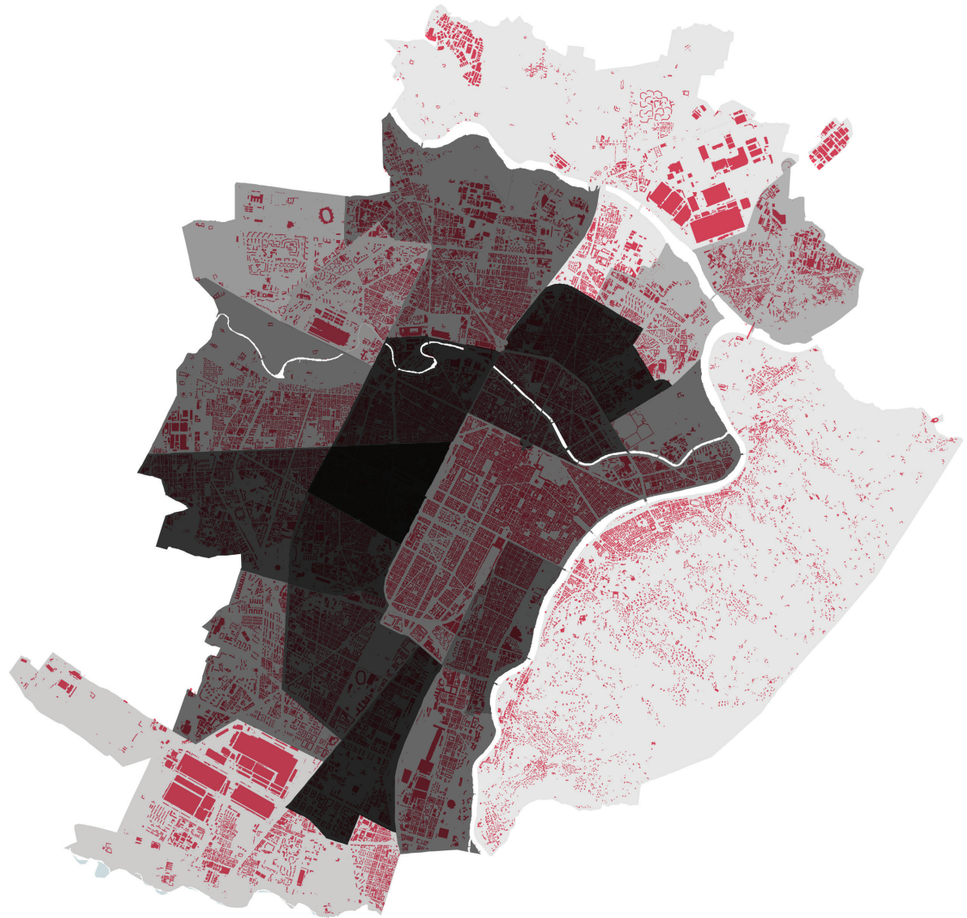
The urban tissue is composed by physical forms and changing them is difficult but possible. . Hence, the workability is low.

[Fig. 3.23] GSI - Ground Floor Index

Source: re-elaboration of data provided by the Municipality of Turin

[Fig. 3.24 FSI - Floor Space Index

Source: re-elaboration of data provided by the Municipality of Turin



[Fig. 3.25 Population density (inh/km^2) and urban frabric

Source: re-elaboration of data provided by the Municipality of Turin

L10 - Population

Theory

The receptor site is made not only by physical features such as buildings and green infrastructure but also by its inhabitants. When assessing the vulnerability of Turin regarding air pollution, population data are critical. Age, rate of births and deaths can be localized and define the areas which should get more attention.

Analysis

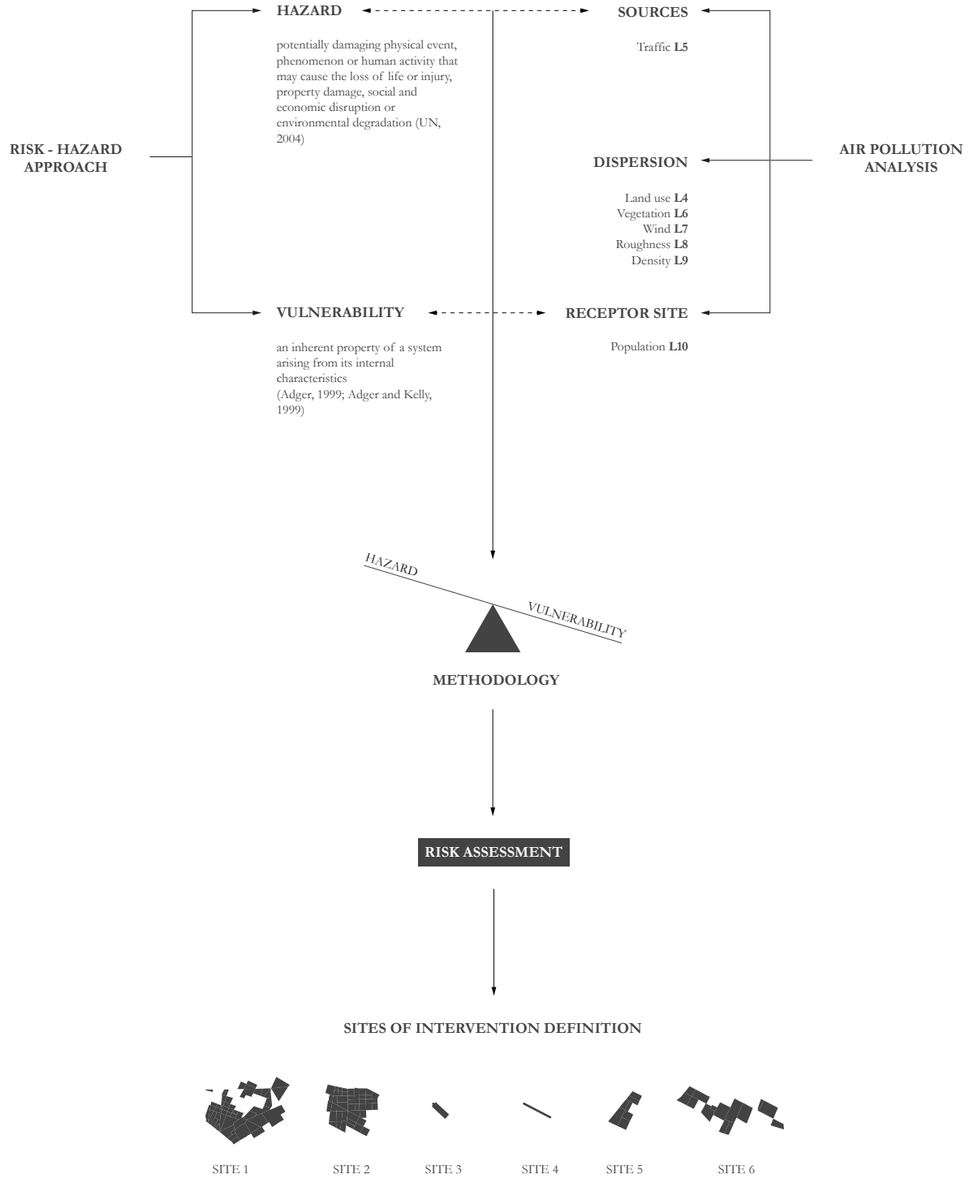
Unfortunately, data availability is reduced and maps only shows population density related to the main neighborhoods of the city and age proportions. In the first map (Fig. 25) it can be noticed that the west parts of the city are the most dense populated, but there is no such a relevant difference with the center or other neighborhoods. The layer can be seen both as source and receptor of pollution, hence its relevance.
As far as the age is concerned, the map (Fig. 26) shows where most of the old (above 60 y.o.) and young (under 14 y.o.) people live. A clear distinction between central and peripheral neighborhoods of the city can be noticed: the city centre shows itself as more homogeneous area with low concentration of the previous mentioned age categories. On the other hand, heterogeneity is what defines the peripheries of the city. In general, most of the youngster and the elderlies live there but areas with low concentration interchange with high ones.

Workability | ▼△▽△▽

Dealing with social issues, population growth, density and age is a difficult task and effective measures require time and a proper strategic plan. Furthermore, the connection between urban design population growth and density it very weak. Hence, the workability rate is set to very low.

[Fig. 3.26] Percentage of people under 14 and above 60 years old.

Source: re-elaboration of data provided by the Municipality of Turin



[Fig. 3.27] Risk assessment methodology

source: author

Risk assessment: vulnerability and hazard

One of the main goals of the analysis is that of identifying what are the most vulnerable areas in the city of Turin. However, before illustrating the obtained discoveries, several clarifications on the concepts of risk, vulnerability and hazard need to be elaborated.
The term vulnerability has been widely explored in the past 20 years in academia with different definitions being proposed. They tend to fall in two main categories, viewing vulnerability either in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2003), or as a state that exists within a system before it encounters a hazard event (Allen, 2003). The latter category therefore perceives vulnerability as something that exists within a system independently of external hazard. Due to limitations with regards to the availability of empirical data to assess impact frequency and probability of air pollution in Turin, the graduation project focuses on vulnerability as "an inherent property of a system arising from its internal characteristics" (Adger, 1999; Adger and Kelly, 1999). Within this definition, vulnerability depends purely on the system's features and does not take under consideration the likelihood that the system will encounter a hazard. Within the vulnerability-research field, several major approaches have been developed: among them, the graduation project proposes the risk-hazard approach. This method is useful for assessing the risk to certain valued elements (exposure units) that arise from their exposure to hazards of a particular type and magnitude (Burton et al, 1978; Kates, 1985). To this extent, the hazard can be described as a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (UN, 2004). Within the risk-hazard approach, vulnerability has been often conceptualized as "exposure to hazard" (Hewitt, 1997), which is again determined by the inherent characteristics of the system.

Overall, within the risk-hazard approach, it can be argued that vulnerable elements are defined primary by the hazard and the biophysical vulnerability of the considered system.

Analysis and the risk-hazard approach

Keeping in mind the goal of the spatial analysis, the link between its features and the risk-hazard approach needs to be established. Within the matrix of analysis, different layers have been grouped according their role in the pollution process: sources, dispersion and receptor site are the three categories. When comparing their definitions with the previous-mentioned of hazard and vulnerability, certain similarities can be found.

The parallelism between hazard and sources seems obvious. Sources can be described as a point of origin or procurement (Merriam Webster Dictionary) and in this case correspond to human activities which, as highlighted in the problem analysis chapter, cause severe damage

[Fig. 3.28] Hazard

source: derived from previous maps

0 2 4 KM

highly congested roads
congested roads
areas with the highest rate of cars
areas with high rate of cars

[Fig. 3.29] Vulnerability

source: derived from previous maps

0 2 4 KM

> 60 %
50 - 30 %
< 30 %
healthcare and education infrastructure

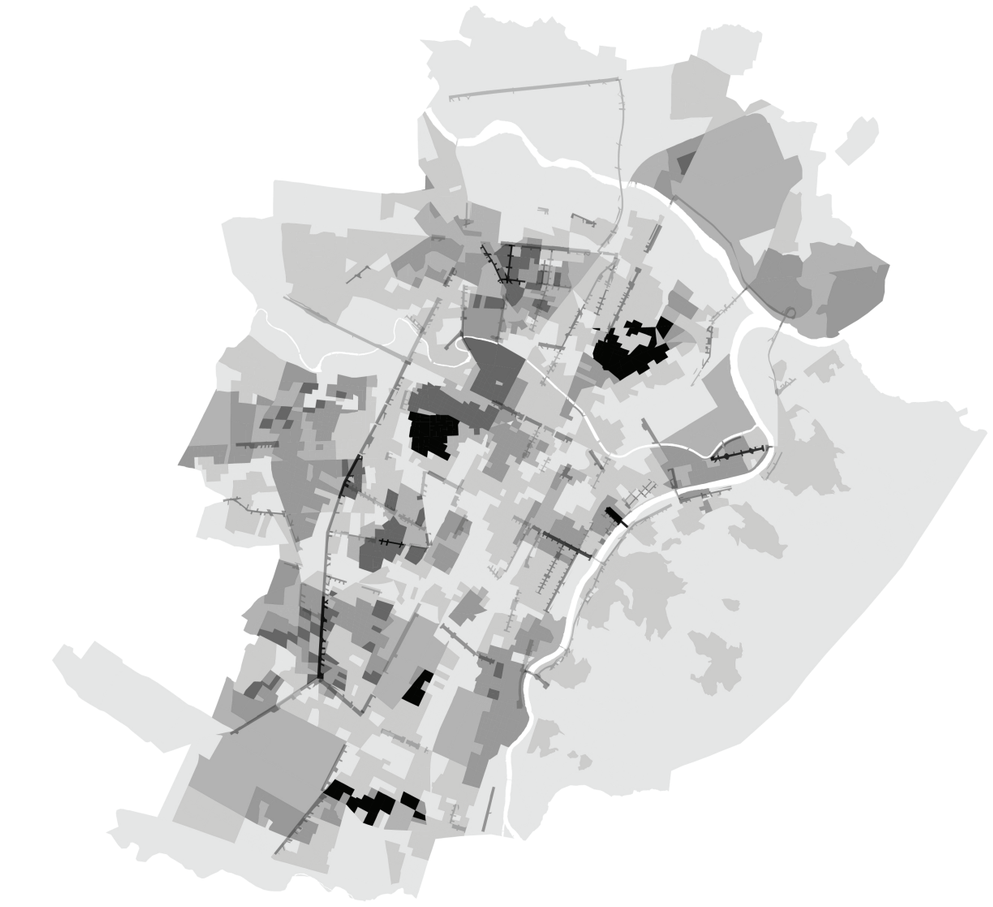
and loss of life. To this extent, sources of pollution represent the hazard and for each layer the most extreme case has been isolated.
In the previous paragraphs, vulnerability has been defined as "an inherent property of a system arising from its internal characteristics". In this case, the layers grouped under the "receptor site" stage express the system's vulnerability. Population density, average age, education and healthcare infrastructure (Fig. 3.29) are in fact features which exist in the system (the city of Turin) before they encounter the hazard (pollution).

Risk assessment: adopted method

Defining an empirical air pollution health risk assessment is not an easy task. The World Health Organization in 2016 published a simplified manual with general requirements, methodology and tools which need to be used for conducting a scientific risk assessment of air pollution. Specific levels of air pollution, exposed population, health outcomes are just some of the required data to make an empirical assessment. Furthermore, a comprehensive risk assessment requires usually the cooperation amongst professionals with diverse expertise and knowledge base: by taking different variables under consideration, they can assess the risk. The proposed risk assessment in the graduation project is limited in this respect and is thus based on a few key assumptions pertaining to the specific nature of the project site and the literature review.

As earlier mentioned, the risk-hazard approach perceives hazard and biophysical vulnerability as main factors in the risk assessment. The analytical layers determined for Turin have already been categorized into these main factors of hazard and social vulnerability. The layers of traffic intensity, origin and destination map contribute to hazards emerging from air pollution in Turin, whereas the layers of population density, age, and education/healthcare infrastructure determine the degree of vulnerability.

What is unclear is the empirical relationship between hazard and social vulnerability that would contribute to a comprehensive risk assessment. In this graduation project, vulnerability is given more weightage as it provides a direct impact and co-relation to the urban built environment of Turin and its data information are more reliable. In doing so, areas and roads within Turin are explored and arranged hierarchically by first for the presence of the layers that contribute to vulnerability. The presence of layers that contribute towards hazards further classify this larger hierarchy of vulnerable areas in Turin. This process determines and identifies areas in Turin which exhibit the highest combination of hazard and vulnerability, and thereby the highest concentration of risk.



[Fig. 3.30] Risk assessment map

source: derived from previous maps

Results

As previously-mentioned, defining an empirical risk assessment concerning air pollution for the city of Turin remains a difficult task. However, within the proposed approach, several considerations can be made.
In general, it can be noticed that the majority of the vulnerable areas lay towards the periphery of the city where population density is higher and most of the youngsters and elderlies live.
Surprisingly, the center of the city fits among the areas with the lowest risk factor; that is due probably to strong presence of commercial activities and offices, but also to the traffic limitations rules that the municipality has been implemented during the past years. However, vibrant public spaces such as squares and touristic spots remains some of the most vulnerable.

Scales

At the beginning of the chapter air pollution, as part of urban microclimate phenomena, was defined by two main scales: the urban canopy scale and the meso-scale. The analysis and the risk map show that there are several intermediate scales within the two extremes. Linear layers such as streets with high traffic concentration can be considered, in combination with adjacent similar streets, as layers which define areas of risk. The shift from linear to plain layer may coincide with the shift of scales. Singular streets represent the micro-scale, but if considered as a whole, can represent the neighborhood or the urban scale.
Notably, the risk map reveals different areas with different scales: each area is defined by specific street networks and hierarchies. Defining and classifying each specific scale seems reductive. The multiscalrity of the phenomenon is much more complex and must remain aleatory and open to change. Furthermore, its interscalarity will be deeply investigated with the specific sites of intervention.

The impact rate

While formulating and building the risk assessment, vulnerability layers (receptor site) were given more weithage than the hazard ones. By doing so, an overall impact rate has been given but it is the result of a thinking process which might not reflect the reality. Therefore, the impact rate cannot be defined at this stage of the project yet and it might be revealed within the design interventions.

[Fig. 3.31] Areas with the highest risk value

source: derived from previous maps

Sites of intervention

The risk assessment revealed the most vulnerable areas in Turin and showed the interscalarity of air pollution. Six are the areas with the highest risk rate and each of them has specific features and peculiarities and deserves our attention. However, due time limitations, focusing on all of them is not feasible and a selection, through a compelling selection method, needs to be undertaken.

Selection method

Within the risk assessment, most of the layers belonging to "source" and "receptor site" categories are considered as main contributors, whilst layers under the "dispersion" class are not contemplated as they are not attributable neither to definitions of hazard nor vulnerability. For instance, it has been proven that building density and proportions of streets play a relevant role in air pollution dispersion but they cannot be esteemed neither as "an inherent property of a system arising from its internal characteristics" nor a "physical event, phenomenon or human activity that may cause the loss of life or injury, property damage". However, as previously-mentioned, dispersion layers do affect air pollution and can be used as compelling criteria for selecting sites of intervention: by comparing and analyzing the six areas according to those layer, sites of intervention can be narrowed down. Furthermore, additional layer of land use contributes to the final choice of site of interventions.

Generally, the analysis is based on both qualitative and quantitative methods. For each area, the most common values or features of the layers have been identified and finally contrasted. The selection of the areas is not however based uniquely on presence or absence of those, specificities and peculiarities of areas and their design challenges might have played a crucial role. More specifically, risk rate of an area might have been downgraded by other factors. such as scale, position, social and economical traits.
Overall, the main goal is to define the most emblematic and characteristic areas in order to enhance applicable design solutions with systematic implications able to mitigate air pollution.

[Fig. 3.32] Selection scheme

source: all the maps are derived from previous ones

GSI

- 0.00 - 0.20
- 0.21 - 0.40
- 0.41 - 0.60
- 0.61 - 0.80
- 0.81 - 1.00

FSI

- 0.00 - 2.21
- 2.21 - 4.42
- 4.42 - 6.63
- 6.63 - 8.84
- 8.84 - 11.00

Roughness

- H/W > 0.1
- 0.1 > H/W > 0.7
- H/W > 0.7

Land use

- S - Services
- R1 - Residential Type 1
- R2 - Residential Type 2
- R3 - Residential Type 3
- M - Mixed

Vegetation

- Green Areas
- Trees

Barriera di Milano

Lingotto

Poveri Vecchi

[Fig. 3.32] Selection scheme

source: all the maps are derived from previous ones

GSI

- 0.00 - 0.20
- 0.21 - 0.40
- 0.41 - 0.60
- 0.61 - 0.80
- 0.81 - 1.00

FSI

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- 4.42 - 6.63
- 6.63 - 8.84
- 8.84 - 11.00

Roughness

- H/W > 0.1
- 0.1 > H/W > 0.7
- H/W > 0.7

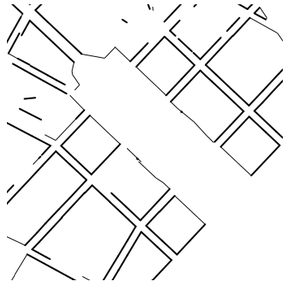
Land use

- S - Services
- R1 - Residential Type 1
- R2 - Residential Type 2
- R3 - Residential Type 3
- M - Mixed

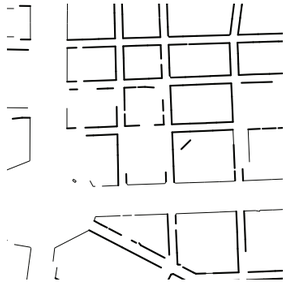
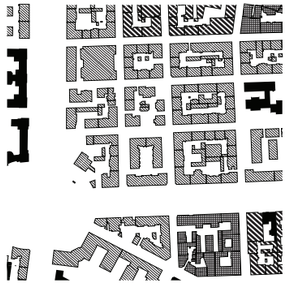
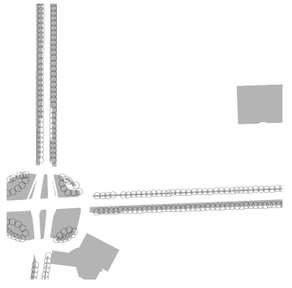
Vegetation

- Green Areas
- Trees

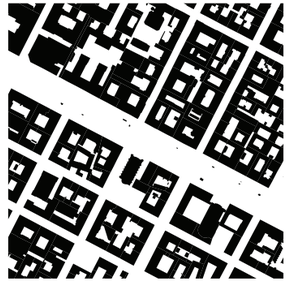
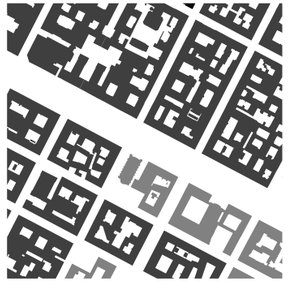
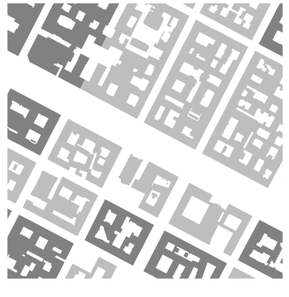
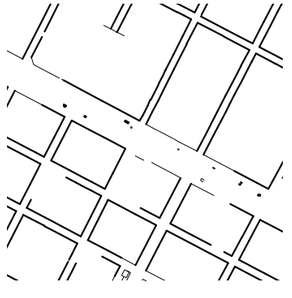
Piazza Vittorio

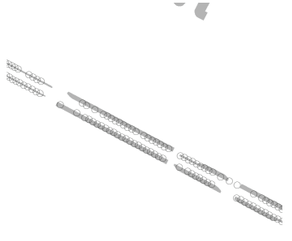


Cit Turin

Corso Vittorio



1

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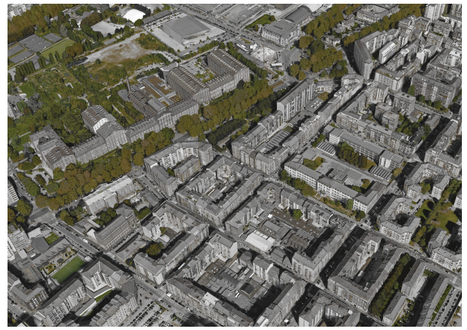


3

4

5

6

[Fig. 3.34] Natural and built environment

1. Cit Turin
2. Lingotto
3. Poveri Vecchi
4. Piazza Vittorio
5. Barriera di Milano
6. Corso Vittorio

source: all the pictures are derived from Google Earth

Observations

The six areas have been compared according the following layers:

L6 - Vegetation, Green Areas
L8 - Roughness (H/W)
L9 - Density (FSI, GSI, Block Typology)
L4 - Land Use

Block typology are usually homogeneous: closed or semi-open blocks with private courtyards define the streets network in all the areas. Consequently, the Ground Space Index values are generally among 0.4 with the exception of *Lingotto* where wide open spaces take over the urban tissue. Furthermore, *Piazza Vittorio* and *Corso Vittorio* are the areas with the highest GSI since they are located in the centre of the city, one of the most dense area.
As far as the FSI is concerned, low values (between 0.00 and 6.63) are quite common; generally, buildings do not exceed 7 or 8 floors; *Cit Turin* is the area with the highest values.
When it comes to roughness (ratio between buildings height and streets width), the areas have similar features: major roads are defined by wake interference flows whilst narrower roads cause the skimming flows. *Lingotto* area is again the exception, its wide green open spaces allow air to flow easily through the built environment.
In relation to land use layers, Turin's functions are well integrated in all the areas: both residential and mixed-use functions are defined by commercial and tertiary ground floors. In general, the difference lays in the allowed actions that the municipality of Turin has thought for each function. Closed residential courtyards (R1) in the centre of Turin are often off-limits because of their historic value. On the other hand, residential R2, R3 and mixed areas M have a higher workability rate; for instance, the municipality promotes the implementation of green courtyards. Finally, concerning urban trees and green areas, both *Piazza Vittorio* and *Barriera di Milano* lack of green spaces, while areas such as *Corso Vittorio* and *Poveri Vecchi* are defined by the strong presence of urban canopy tree which might be responsible for wind flows decrease.

Conclusions

Lingotto, among the six sites, seems to be the area with the lower risk rate: low values of GSI, FSI, roughness but also the presence of green open space should facilitate, when compared to the other sites, wind flows and therefore increase air pollution dispersion. For these reasons the site has been excluded.
Poveri Vecchi, *Cit Turin* and *Barriera di Milano* can be considered quite similar: block typologies, GSI, FSI and roughness fluctuate around the same values. However, there are some difference which contributed to decision to exclude the first two areas and choosing the latter as one of the sites of intervention: Barriera di Milano is an extremely dense area with evident lack of green and public spaces. Because of their similarities, future design solutions will be applicable also to

	Block Typology	GSI	FSI	Roughness	Land Use	Vegetation
Barriera di Milano	II	C - D	B	+/++	R2 - R3	Ø
Lingotto	I - II	B	A	-/+	R3	O - T
Poveri Vecchi	I - II	C	A - B	+/++	R3 - M	O - T
Piazza Vittorio	II	C - D	B - C	+	S - R1	Ø - T
Cit Turin	I - II	C - D	C	+/++	R3	T
Corso Vittorio	II	D	B - C	+	R1 - R2	Ø

[Fig. 3.35] Selection method

source: author

Legend

Block typology
I - Open block
II - Closed block

GSI
A - 0.00 - 0.20
B - 0.21 - 0.40
C - 0.41 - 0.60
D - 0.61 - 0.80
E - 0.81 - 1.00

FSI
A - 0.00 - 2.21
B - 2.21 - 4.42
C - 4.42 - 6.63
D - 6.63 - 8.84
E - 8.84 - 11.00

Roughness
(-) - H/W > 0.1
(+) - 0.1 > H/W > 0.7
(++) - H/W > 0.7

Land use
S - Services
R1 - Residential Type 1
R2 - Residential Type 2
R3 - Residential Type 3
M - Mixed

Vegetation
T - Urban Trees
O - Presence of Green
Ø - Absence of Green

Land Use

Services - All type of services such as schools, police stations, post offices, hospital etc...
Residential type 1 - Areas with buildings defined by commercial activities (restaurants, services, handcrafts, offices) on the ground floors and residential use on the upper floors. The municipality has been encouraging the conversion of the inner courtyards into private green spaces.
Residential type 2 - Areas with buildings defined by commercial activities (restaurants, services, handcrafts, offices) on the ground floors and residential use or hotels on the upper floors. The municipality has been encouraging the conversion of the inner courtyards into private green spaces.
Residential type 3 - Areas located in the centre of the city with buildings defined by commercial activities (restaurants, services, handcrafts, offices) on the ground floors and residential use or hotel on the upper floors.
Mixed - Areas with building defined by mixed use (residential, services, restaurants, research facilities etc.)on every floor.

the precluded areas.
Finally, *Piazza Vittorio* and *Corso Vittorio* are two emblematic cases and, therefore, are gonna be the other two sites of intervention. *Piazza Vittorio* is one of the most important square of Turin and, placed in center of the city, represents an opportunity for dealing with the micro scale of the city and trying to understand the relation between air pollution and public spaces. As far as *Corso Vittorio* is concerned, it represents a perfect case study for dealing with street vegetation in urban canyons since most of the main roads of Turin are characterized by the presence of trees.

Overall, the chosen sites of intervention aim to build a thorough system of design solutions for mitigating air pollution. In the following chapter the three sites will be analyzed more in detail and design solutions will be proposed.

04

DESIGN INTERVENTIONS

Design approach

Piazza Vittorio Veneto

Introduction
Analysis
Design
Evaluation
Implementation

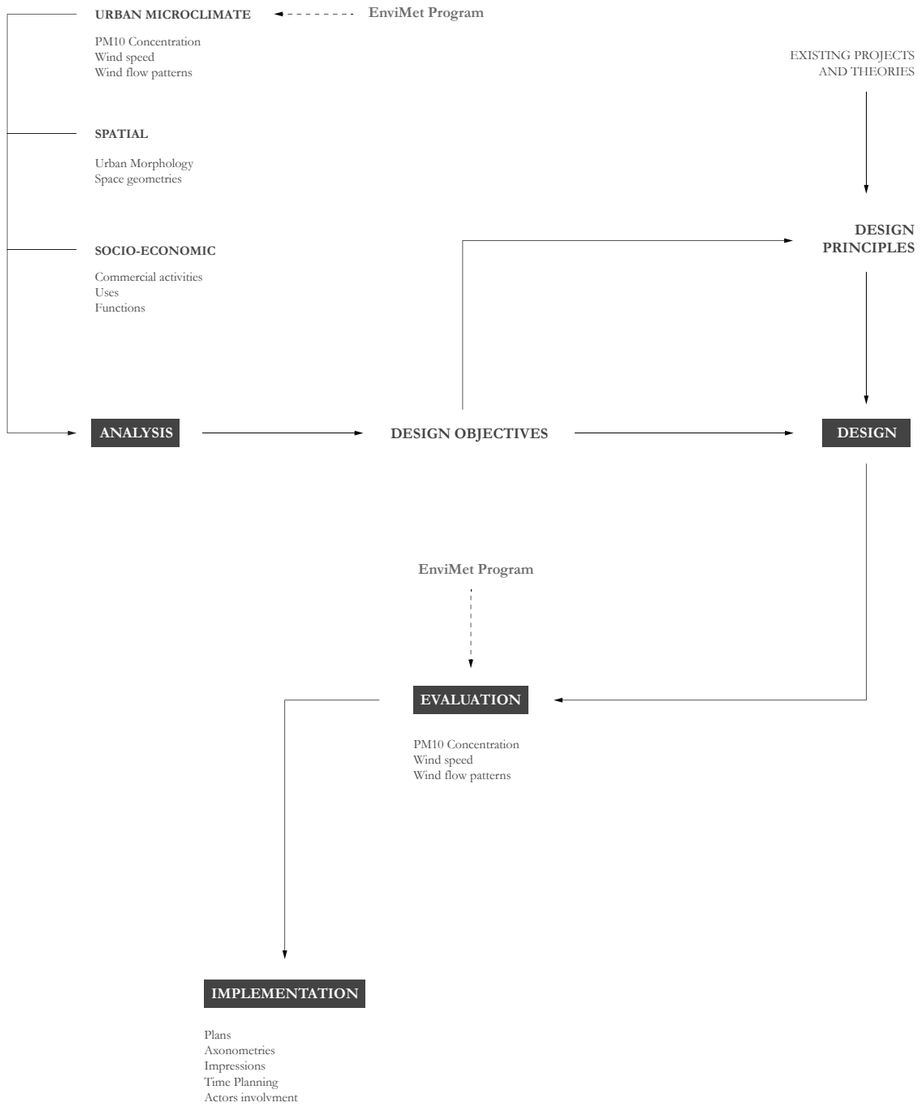
Barriera di Milano

Introduction
Analysis
Design
Evaluation
Implementation

Corso Vittorio

Introduction
Analysis
Design
Evaluation
Implementation

The systemic effect and
the interscalarity of design



[Fig. 4.1] Design Approach

source: author

Design Approach

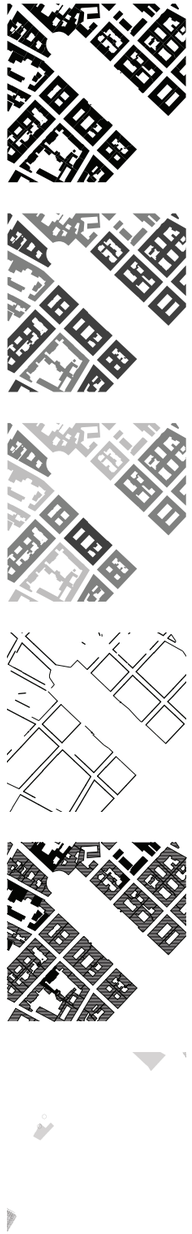
The design phase for each site can be divided in four main stages: analysis, design, evaluation and implementation.

Within the analysis part, in order to understand the relation between air pollution, built environment and wind flow patterns, it is necessary to carry out simulations of their relevant features. Since empirical data concerning actual conditions of air pollution are not currently available, arbitrary standard values of PM10 has been assigned. The choice does not affect the validity of the research, because the goal is that of verifying whether the proposed urban design interventions can effectively mitigate air pollution. To this extent, the comparison between initial and final conditions of the sites will play a relevant role. The simulations are conducted with the software EnviMet. Furthermore, the urban-microclimate analysis will be combined with socio-economic studies leading to a thorough analysis.

Once the sites have been studied, existing design projects or theories will be explored and design principles extrapolated, leading to formation of design proposals. It must be underpinned that the design proposals focus primary on air pollution mitigation without deepening social and economic factors. These aspects will be elaborated during the implementation phase.

Consequently, during the evaluation phase, design interventions will be tested and compared with the initial conditions of the sites in order to verify their effectiveness both for climate and socio-economic conditions.

Finally, since the goal of the design is not only that of mitigating air pollution but also to add new values and qualities to the site of intervention, each design proposal will be implemented and final considerations elaborated.



[Fig. 4.1] Piazza Vittorio

source: art work produced by the author of the project derived from http://www.gazzettatorino.it/sempre-piu-torino-nella-99esima-edizione-del-giro-ditalia/

Piazza Vittorio Veneto

Introduction

From the early years of the 19th Century, an enlargement of the city towards the river and the hills of Turin was proposed and several projects and designs were implemented. Among those, the creation of a square, first thought of as closed and then designed as a large arcaded open space, was planned. (SIAT, 2000). Designed by the architect Giuseppe Frizzi in 1825, Piazza Vittorio, with an area around 39.960 sqm (111x360 m), is one of the biggest square in Europe and one of the most important in the city of Turin.

Its monumental dimensions and the wide empty space give the square a multi-functional use able to adapt and adjust itself to different purposes: the square has changed several times in the past 30 years. Throughout history, Piazza Vittorio has always been a vibrant public space, its arcades host several commercial activities such as pubs, restaurants and shops which give the place a strong attraction force. Moreover, its position, as a big open terrace facing the river Po and the hills of the city, adds a special value.

As previously-mentioned, the dimensions of the square allow it to constantly change. Despite the functions under the arcades have remained a constant during years, the central empty surface was able to accommodate various events and uses: in the past, it had been a green park, a car parking but it also was also used to host public demonstrations, concerts and markets. Nowadays Piazza Vittorio, with its underground car park, is a big empty eclectic space ready to adapt itself to users' necessities and needs.

Despite the levels of a critical environmental threat due to air pollution are less compared to other areas of the city, the decision of choosing Piazza Vittorio as one of the three main sites of intervention is mostly derived by its high vulnerability rate. Its physical, social and economic features make the square an highly attractive public space, where people are constantly exposed

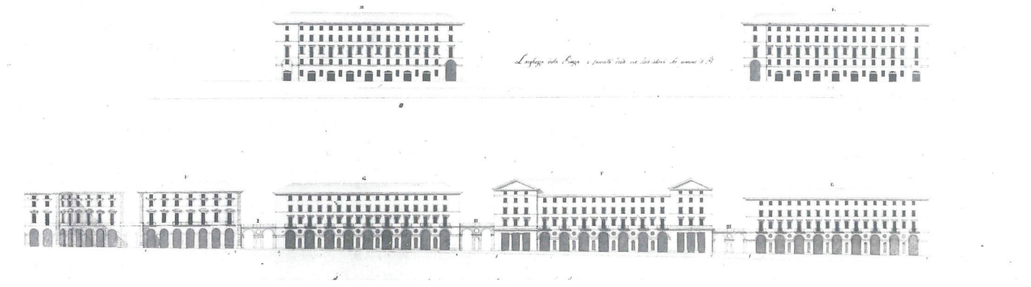
[Fig. 4.2] Public space of Piazza Vittorio

source: author

to fine dusts. Moreover, the chosen spots represents an opportunity for dealing with the micro scale of the city and trying to understand the relation between air pollution and public spaces. Understanding how can urban design mitigate air pollution without decreasing public spaces' quality and implementing design solutions able to improve air quality and at the same time add values to public spaces, are some of the main goals.

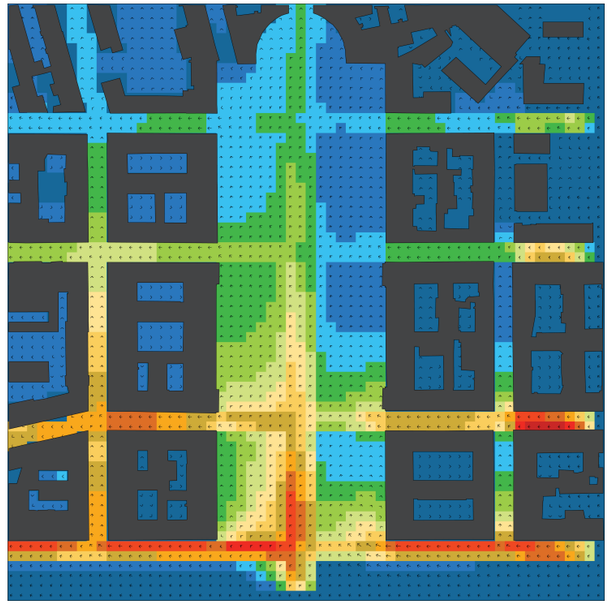
[Fig. 4.3] Facade of the central block of the square

source: Comoli Mandracci, V. (2010). Torino. Editori Laterza



[Fig. 4.4] Giuseppe Frizzi. Sections of the square

source: Torino, Archivio Storico del Comune, Tipi e Disegni, 62-5-33



[Fig. 4.5] PM 10 Concentration

source: author

PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
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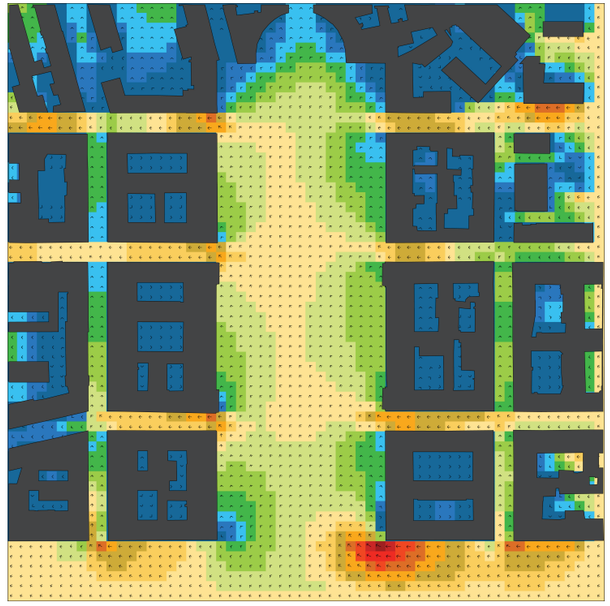
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00



[Fig. 4.6] Wind speed

source: author

Wind Speed [m/s]

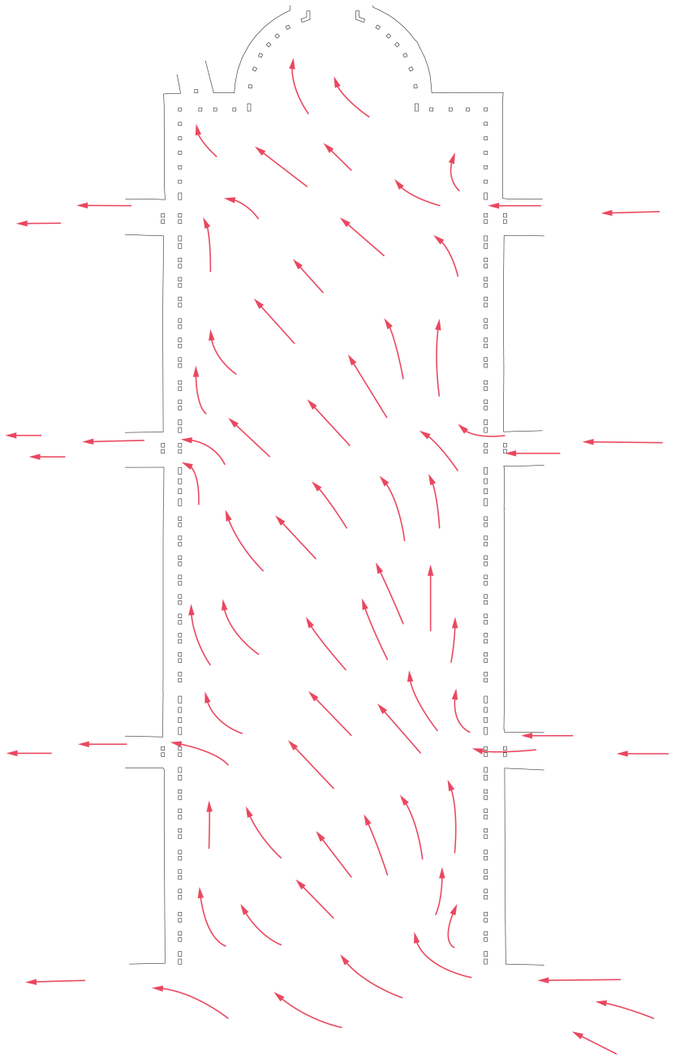
- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

Analysis

When simulating the arbitrary current conditions of Piazza Vittorio, it can be noticed that the left side of the square has higher PM10 concentration than the right one (Fig. 4.5); that is due to the wind direction which flows with an axis perpendicular to the main lengths of the square. Thanks to its width and the height of the buildings, with a ratio between 0.1 and 0.7, winds flow quite easily through the built environment. Moreover, wind speed is slightly higher towards the left site of the square. However, it must be highlighted that, despite higher wind speeds, the left side of the square has higher PM10 values as well. That is due to the transportation capacity of winds: under wind conditions, pollutants do not remain on the origin point, on the contrary, they are conveyed according the wind direction and speed (Fig. 4.7).

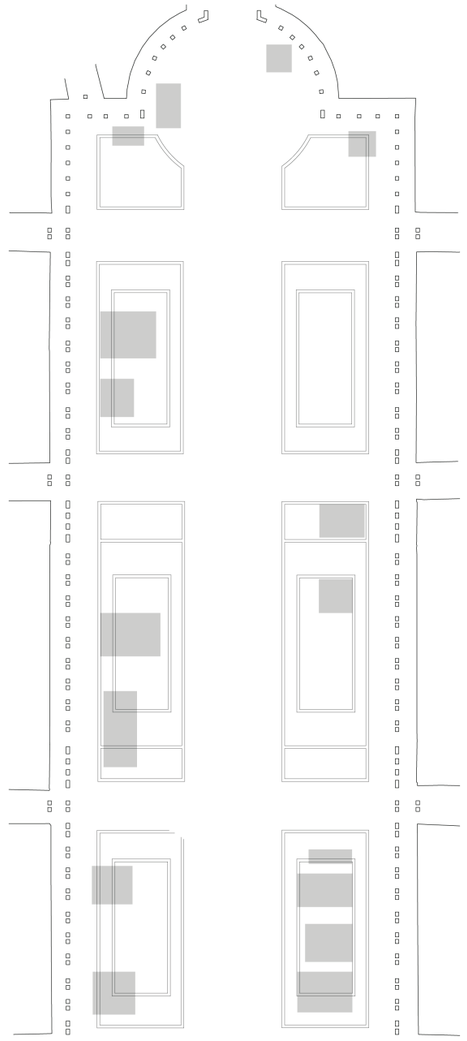
Studying air pollution dispersion and wind flow patterns without considering social and economic factors might result ineffective. Analyzing what are the space that the most of the people use and how they use them can contribute to define the design objectives for the chosen site.
As previously-mentioned, Piazza Vittorio is a vibrant public space where commercial activities, pubs and restaurant offer their user various choices. Moreover, some of them rent parts of the square as out-door space in order to provide their costumers an amazing view towards the hills of the city. Those are the places which the majority of the people use and are the ones that need most of our attention (Fig 4.8).

Overall, design solutions able to protect the people who live those spaces and able to mitigate air pollution without decreasing the spatial quality of the square are required. Moreover, as formerly-highlighted, the square usually hosts concerts and manifestation; that means that assigning a fixed use to it would disrupt its nature. Basically, a more flexible, temporary and adaptive design is recommended.



[Fig. 4.7] Wind flow patterns

source: author



[Fig. 4.8 Most used areas of the square (in grey)

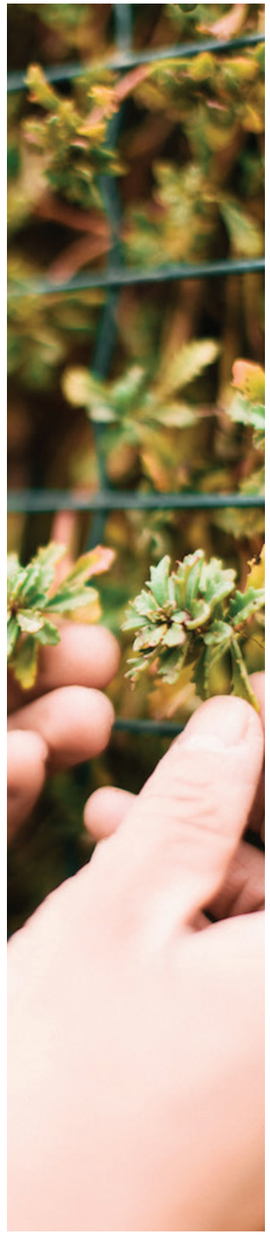
source: author

[Fig. 4.9 CityTree.
Implementation in Berlin

source: https://letitgrow.org/combining-economy-and-ecology-to-battle-urban-air-pollution/

[Fig. 4.10] The moss technology

source: https://letitgrow.org/combining-economy-and-ecology-to-battle-urban-air-pollution/



Design

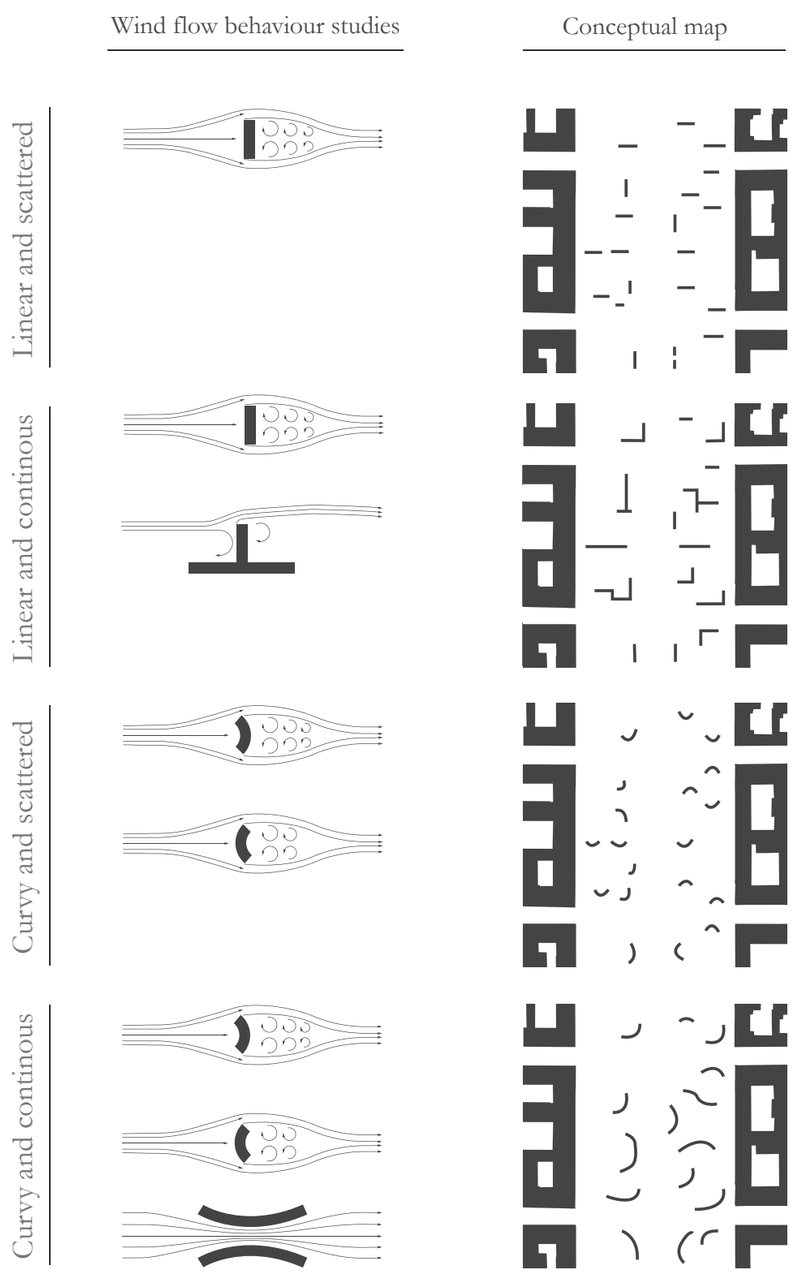
Research

From the analysis, the need of an adaptive and temporary design solution for mitigating air pollution in Piazza Vittorio was discovered.
In 2014, a group of four professionals coming from varied fields of expertise such as architecture, biology, IT and design confounded *Green City Solutions*, a CleanTeach startup, looking to develop sustainable ways to improve the quality of city living. Their interests focus on social and environmental challenges that the world is currently facing, among those, air pollution.
With the goal of counteracting this pressing issues, they design the CityTree, a free-standing, vertical billboard covered in a specific moss culture with vascular plants that absorb and 'eat' toxins like nitrogen dioxide in the air (*Let it Grow*, 2016). Thanks to its technology this green wall have the same effect as 275 trees
but requires 99% less space. Its filtering function reduces NO2 concentration by 15% and PM10 by 25%. Moreover, with the IoT Technology, the walls can measures pollutants concentration levels in their surroundings and generate data concerning air pollution. The walls has been already implemented in several European cities such as Berlin, Oslo and Paris.
However, applying and placing the walls in Piazza Vittorio as they are, without thinking more about their functions and uses, would not contribute to create knowledge and the role of urban designer would be underestimated. Therefore, as designer, my goal is to use the technology of the wall and, at the same time, implement new design objectives, functions and features that can be applicable to the case of Turin.

Design Objectives

The efficacy of the *CityTree* as air pollution mitigator has been proven, but they way they can interface themselves with the surrounding space remains unexplored. In the previous chapters, the interrelation between air pollution, physical elements (buildings, trees, etc.) and wind flow patterns was deeply investigated. One of the main objectives of the design is therefore to understand how can the walls affect this system and, apart from its inherent properties, influence wind flow patterns in order to mitigate air pollution in the square.

Despite their supposed mechanical functions, the walls are not isolated in an empty space, on the contrary, the surroundings are already defined by specific spatial, social and economic conditions. Consequently, the relation among those needs to be investigated. Moreover, since the apparent lack of interest on air pollution from Turin inhabitants, the social function gains a key role in the design process; the walls need, at the same time, to increase social awareness but also to give the space a new meaning able to interface with the already existing functions, both under the arcades and in the open space.



[Fig. 4.11] Design proposals diagram

source: author

Design Proposals

Keeping in mind the design objectives, discovering the most appropriate position and shape of the walls for affecting air pollution becomes crucial. Social, economic and more space-related features of the walls will be ignored for the moment and they will be taken under consideration during the *implementation* phase.
When looking at air flows of Piazza Vittorio, a recurring air patterns can be recognized: wind coming from the streets tend to be canalized towards the upward parallel street (Fig. 4.7). The design proposal are therefore studied and applied to one portion of the square.
Aerodynamic studies can predict how wind might behave when meeting an obstacle with different physical properties (Fig. 4.11); the following design proposals try to understand if there is a difference in terms of position, continuity and length of the walls. In each layout, walls are placed according to two main factors: the existing position of outdoors tables and the pollution particles flows. The four proposals are the following.

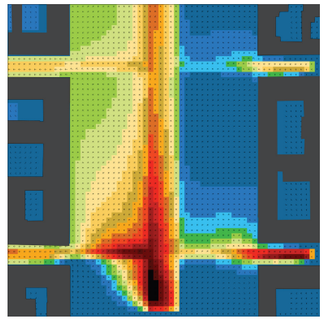
Linear and continuous - Most of the walls have the main axis perpendicular or with a different angle to the main wind direction. The main goal is that of diverting particles flow.
Linear and scattered - Similar to the first proposal, but with shorter walls, the design aims to change local wind directions.
Curvy and continuous - Long curvy walls follow (not always) wind flow patterns and try to channel them in order to increase its speed.
Curvy and scattered - Short curvy walls aim to affect local wind direction by creating new micro-turbulences.

Evaluation

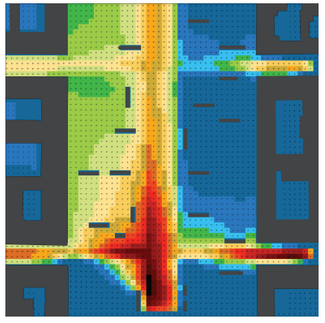
To begin with, regarding PM10 concentration, all the proposals achieve a considerable improvement when comparing it to the current situation. Two aspects can be considered: the empirical maximum value of concentration and qualitative distribution of air pollutants. As far as the maximum values are concerned, the proposals have similar results and they are very close to the value of the Current situation. However, when looking at the qualitative distribution of pollutants (Fig 4.12), it can be noticed that the left part of the square is positively affected by the design interventions.
When considering wind flows (Fig. 4.13), it can be noticed that their speed remains almost the same, while the number of micro-turbulences is increased. Hence, it can be concluded that the "mitigating" capacity of the wall is mostly given by their ability of diverting wind instead of increasing its speed.

N.B. It must be underpinned that the simulation results of the walls do not include the technology provided by the *CityTree*. Hence, the result does not show the full potential of the walls.

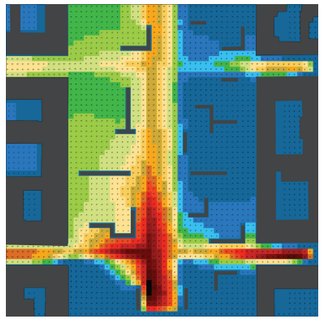
Current min: 0.00 max: 19.00



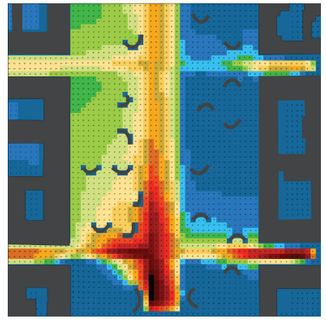
Linear and scattered min: 0.00 max: 18.54



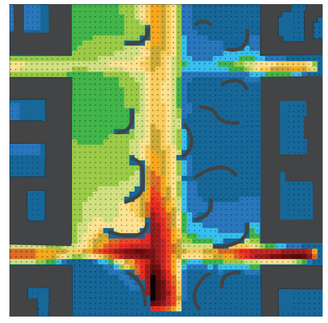
Linear and continuous min: 0.00 max: 19.05



Curvy and scattered min: 0.00 max: 18.88



Curvy and continuous min: 0.00 max: 19.09



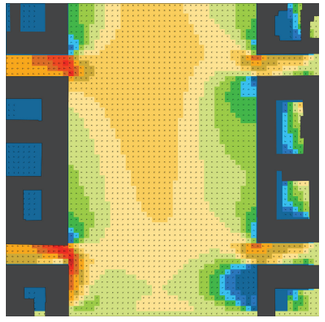
[Fig. 4.12] PM 10 Concentration

source: author

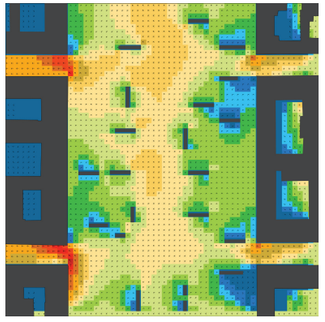
PM10 Concentration [mcg/m^3]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

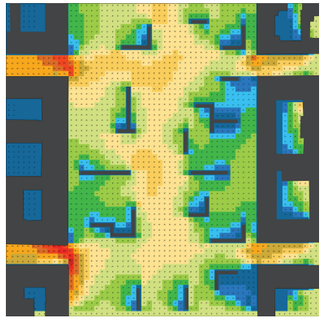
Current min: 0.00 max: 2.65



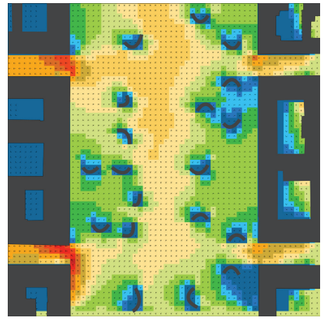
Linear and scattered min: 0.00 max: 2.61



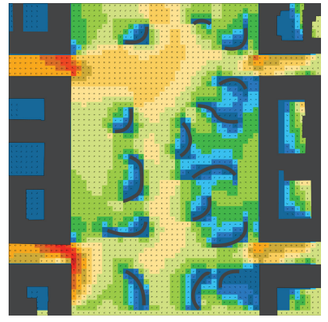
Linear and continuous min: 0.00 max: 2.61



Curvy and scattered min: 0.00 max: 2.65



Curvy and continuous min: 0.00 max: 2.66

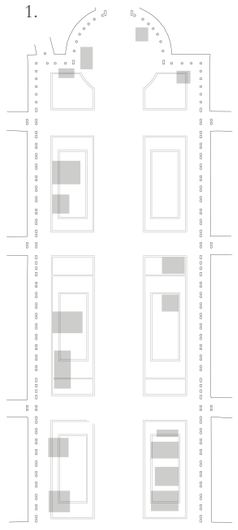


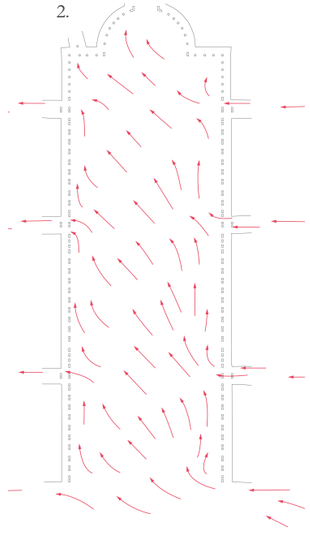
[Fig. 4.13] Wind speed

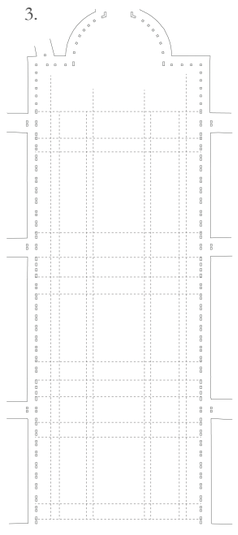
source: author

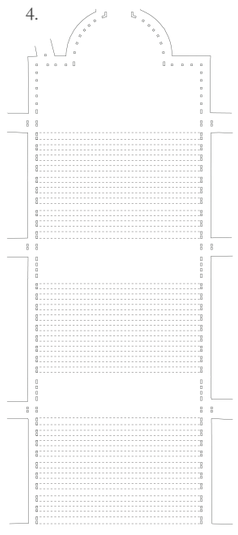
Wind Speed [m/s]

- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80









[Fig. 4.14] Factors with a key role when positioning the walls

source: author

1. Current situation with areas where most of the people stay within the square.
2. Wind flow patterns
3. Grid defined by the pavement
4. Grid defined by the columns of the arcades

Implementation

The spatial and climatic analysis and finally the evaluation phase highlighted some main factors which need to be taken under consideration when implementing the walls in the square. Firstly, concerning air pollution dispersion, wind flow patterns play a crucial role; by studying them, it is possible to predict how and where pollutants come from and flow to. This information is essential and it helps on defining the most critical points and, consequently, where the walls will be more needed (concerning air pollution). Secondly, the current uses of square show what are the areas that are more used by the public of the square and, resultantly, the spaces which deserve our attention mostly.
However these are not the only factors which may influence the position of the walls: spatial qualities play a relevant role as well. The pavement of the square but also the rhythm given by the columns of the colonnade define a specific spatial grid which, combined with the above-mentioned design principles, build a comprehensive spatial framework for positioning the walls. However, before choosing their position, the walls still need to be designed.

Walls detailing

The analysis revealed the need for a more flexible, temporary and adaptive design. To respond to these requirements, the design of the walls is composed by modules of the same dimension (120x200x50cm) but with different functions and, combined to each other, can adapt themselves to several uses. Five are the designed modules and they differ for their objectives and purposes:

Module	Function		
	Pollution-related	**Front**	**Back**
A	Filtering/Diverting	Green wall (CityTree)	Green wall (CityTree)
B	Diverting	Green wall (common technology)	Screen for advertisements, Turin maps, exhibitions panels, cinema, or empty surfaces
C	Diverting	Green wall (common technology	Foldable benches or shelfs both for public space or integrated in outdoors restaurants and cafè
D	Diverting	Foldable benches or shelfs both for public space or integrated in outdoors restaurants and cafè	Foldable benches or shelfs both for public space or integrated in outdoors restaurants and cafè
E	Diverting	Foldable benches or shelfs both for public space or integrated in outdoors restaurants and cafè	Screen for advertisements, Turin maps, exhibitions panels, cinema, or empty surfaces

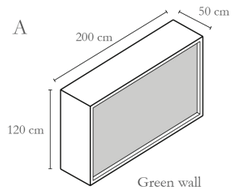
Modules

Front

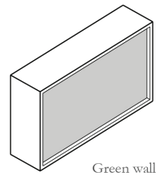
Back

Filtering and diverting effect

A

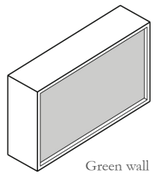


Green wall

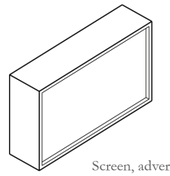


Green wall

B

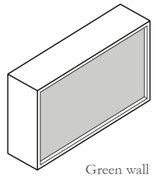


Green wall

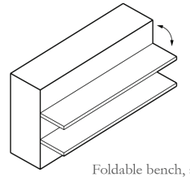


Screen, advertisment, exhibition panel or empty surface

C



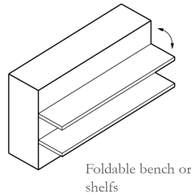
Green wall



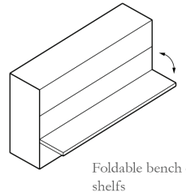
Foldable bench, shelfs

Diverting effect

D

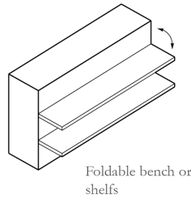


Foldable bench or shelfs

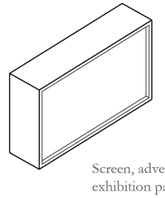


Foldable bench or shelfs

E



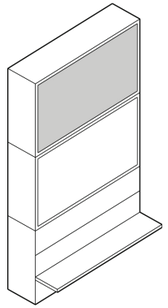
Foldable bench or shelfs



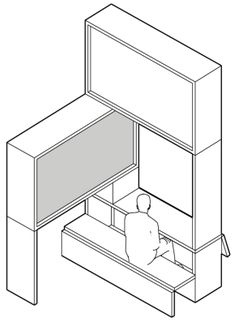
Screen, advertisment, exhibition panel or empty surface

Possible combinations and functions

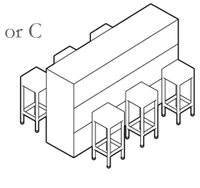
A + B + D



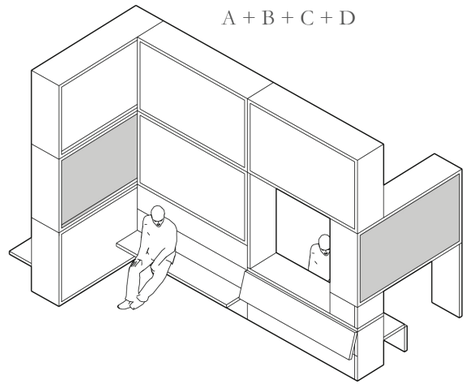
A + E



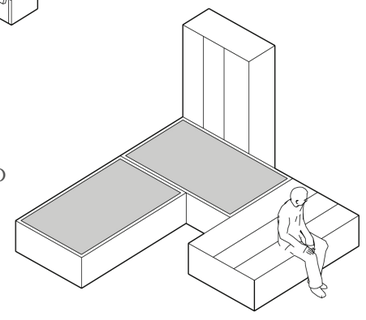
D or E or C



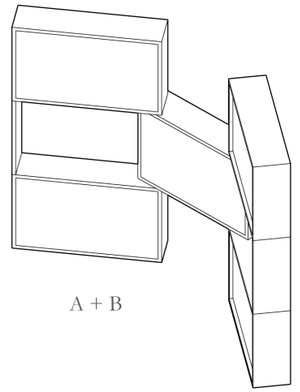
A + B + C + D



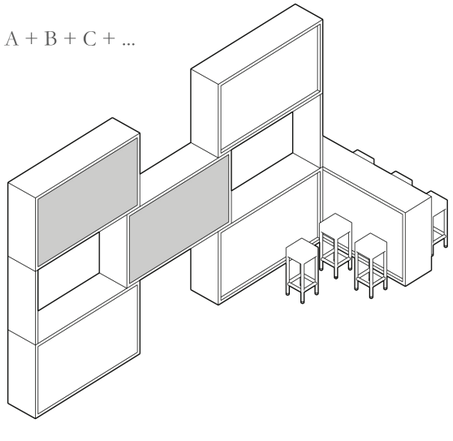
B or C or D



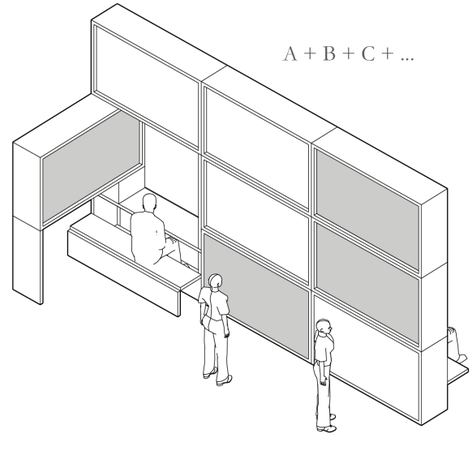
A + B



A + B + C + ...



A + B + C + ...



[Fig. 4.15] RO&AD Architects, Moses Bridge, Netherlands. Application of Accoya wood.

source: http://www.woodworkingnetwork.com/wood-blogs/industrial-woodworker/production-brooks-gentleman/You-Wood-Never-Believe-This-191087171.html

1.

2.

3.

[Fig. 4.16] Walls materials

source: author

1. Moss Tehcnology (GreenCity)
2. Accoya Wood
3. Traditional green walls

All the modules are compatible with each other and they can be assembled and used as users, privates and public institution like. Furthermore, their dimensions allow them to be rotated according to all the axis (x,y,z) giving the module higher adaptivity.

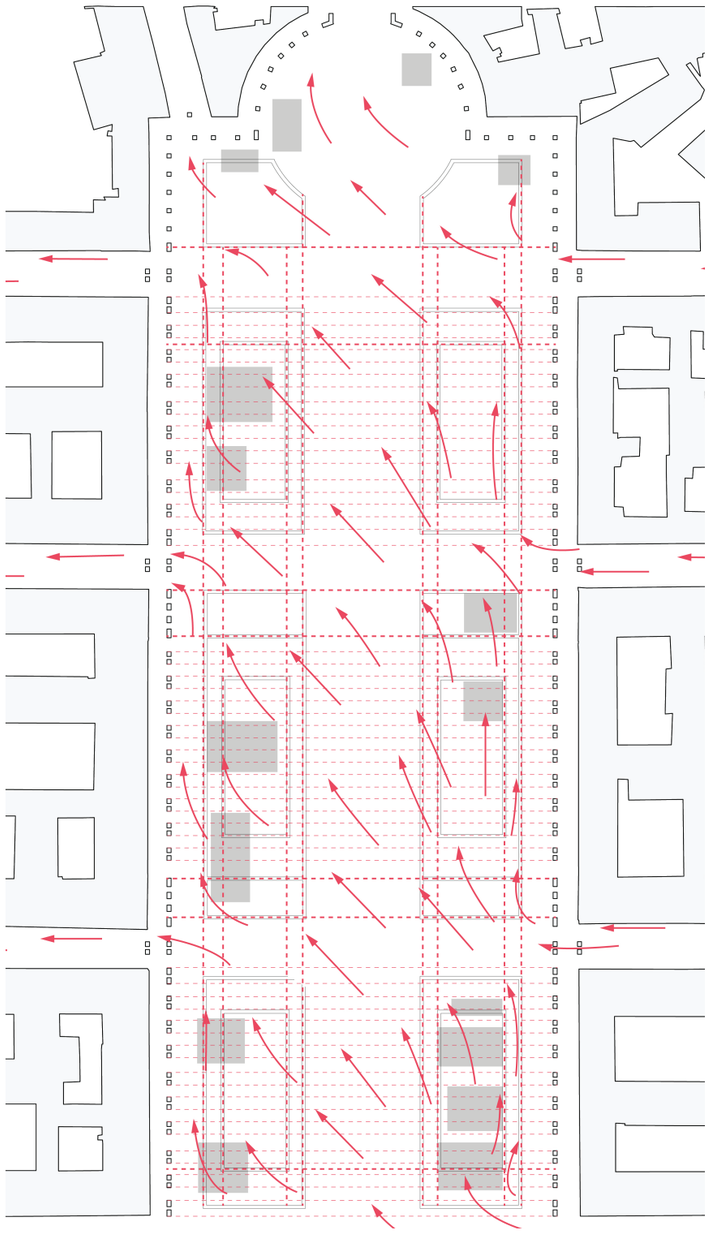
Materials, technologies and additional functions

When thinking of possible materials for the wall, a few aspects need to be considered. To begin with, the walls will be standing outside, hence they will be exposed to rain, variable temperatures and different climatic conditions. Furthermore, since most of them are composed of moss culture and green walls, the chosen material needs to tolerate high level of humidity.
Aesthetic is an other important aspect. The chosen material needs also to smoothly integrate in the already existing environment of the square.
Taking into account the above-mentioned considerations, the structure of the wall is made with Accoya® wood. The technology behind Accoya® is based on wood acetylation, a process which alters the cell structure of wood, improving its technical properties and making it much stronger and more durable (www.accoya.com). During this process, the free hydroxyl groups within wood are changed into acetyl groups which reduces the ability of the wood's cell walls to absorb water by approximately 80%. The wood has been tested and used within several projects (Fig. 4.15) where water infiltration was a constant threat and it resulted extremely successful.
As previously mentioned, green walls are not always characterized by the moss culture, there will be also walls with traditional green walls technologies.

Filtering and diverting air are not the only functions of the walls, their multi-functionality and adaptivity are given also by additional features of the walls. The latter are provided of an Wi-Fi connection and electricity charging points, whose energy is produced by solar panels.

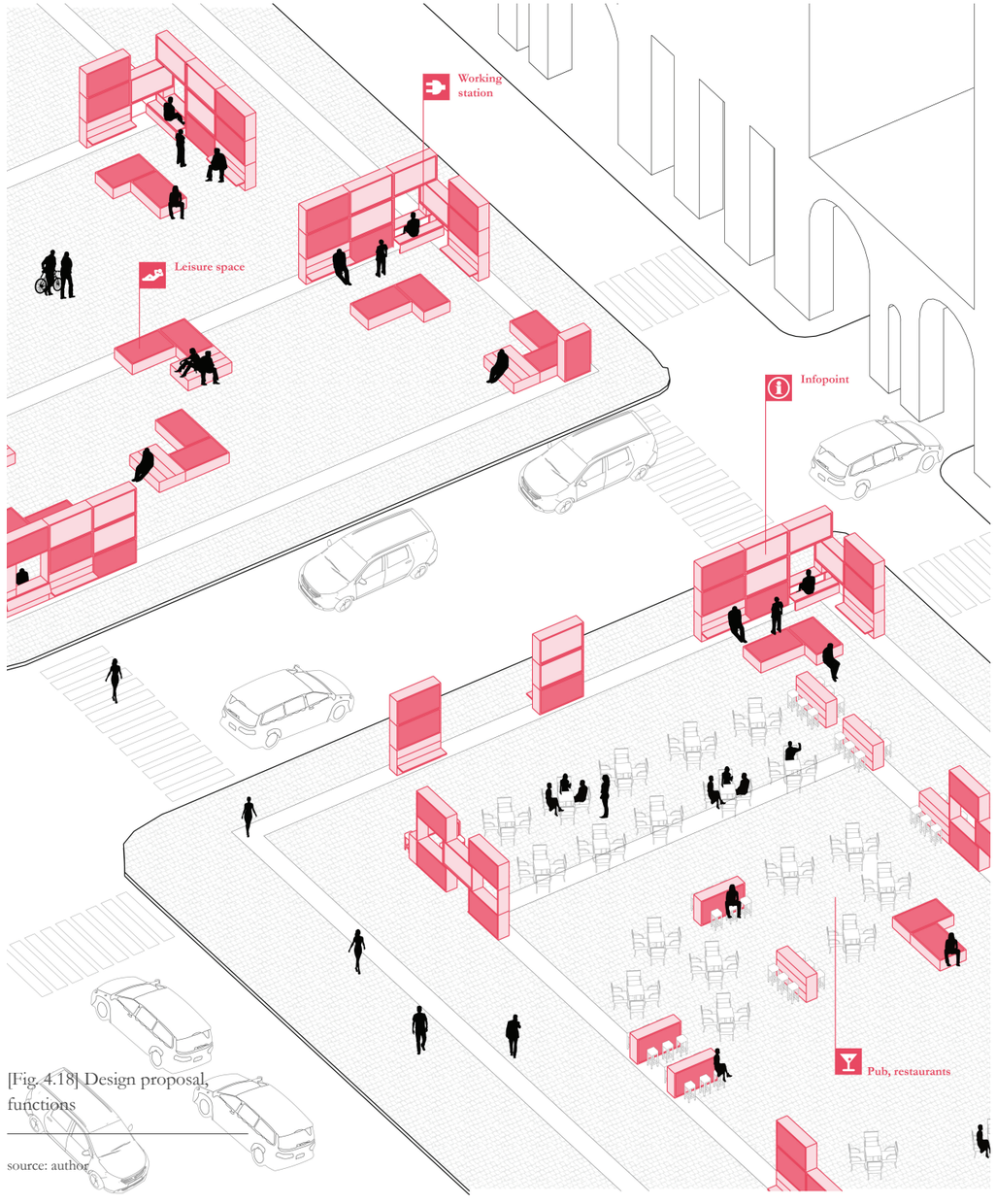
Position of the walls and general spatial rules

Keeping in mind the modularity of the walls, the spatial and social features of the square, several rules are defined:
- given their crucial position and function (both filtering and diverting the air), walls on the right corners of the square and several others will be fixed and composed at least by 50 % of modules A. This walls are called PriorityWalls (red walls in Fig. 4.19 and 4.20). All the others, if necessary, can be shifted according to specific needs.
- modules integrated in commercial activities will follow rigid structure defined by parallel walls which follow the pavement drawing in order to define more clearly the space
- for the rest of the possible activities, the walls will adjust to the desired functions (market, free public space, exhibition etc.)
The above-mentioned rules create a flexible, adaptive and temporary design able to respond to multiple needs and most important applicable to different areas of the city as well (Fig 4.19 and 4.20).



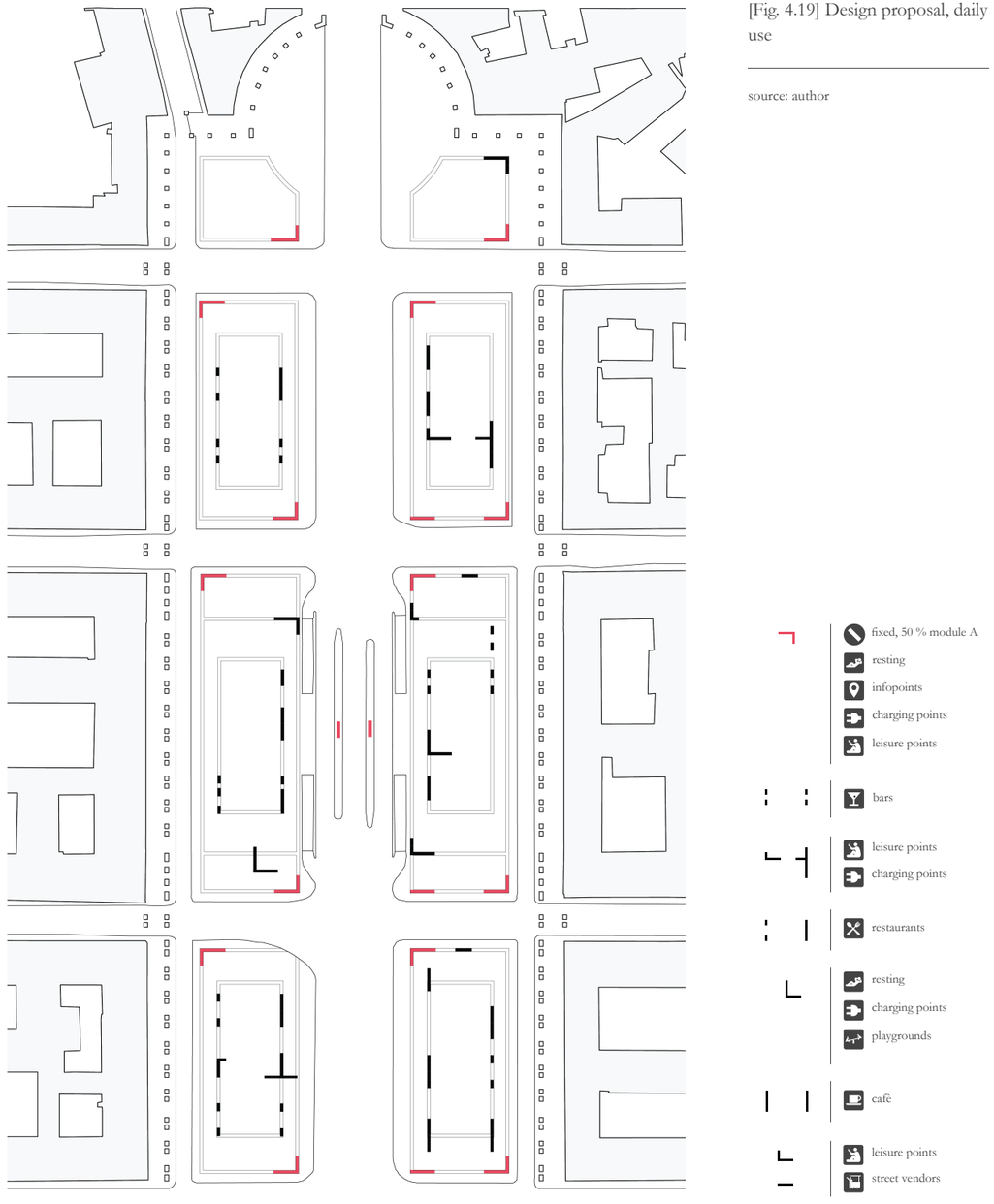
[Fig. 4.17] Combination of the factors with a key role when positioning the walls

source: author



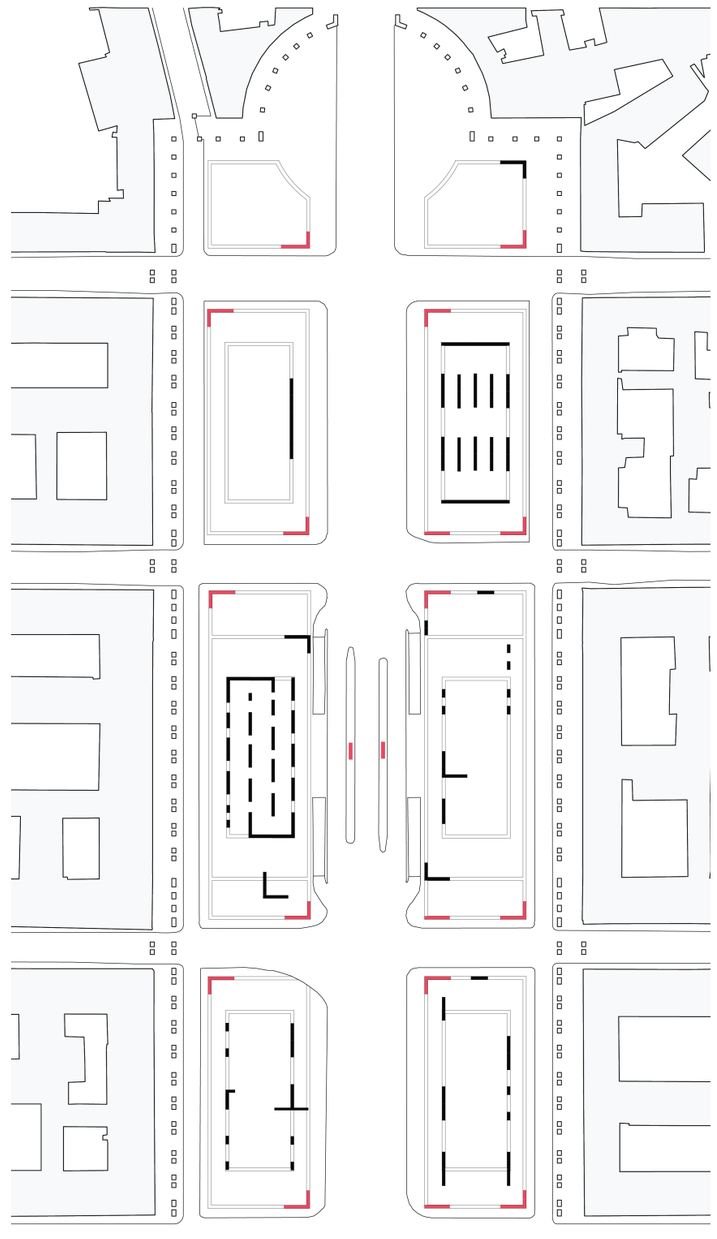
[Fig. 4.18] Design proposal, functions

source: author



[Fig. 4.19] Design proposal, daily use

source: author



[Fig. 4.20] Design proposal, special events

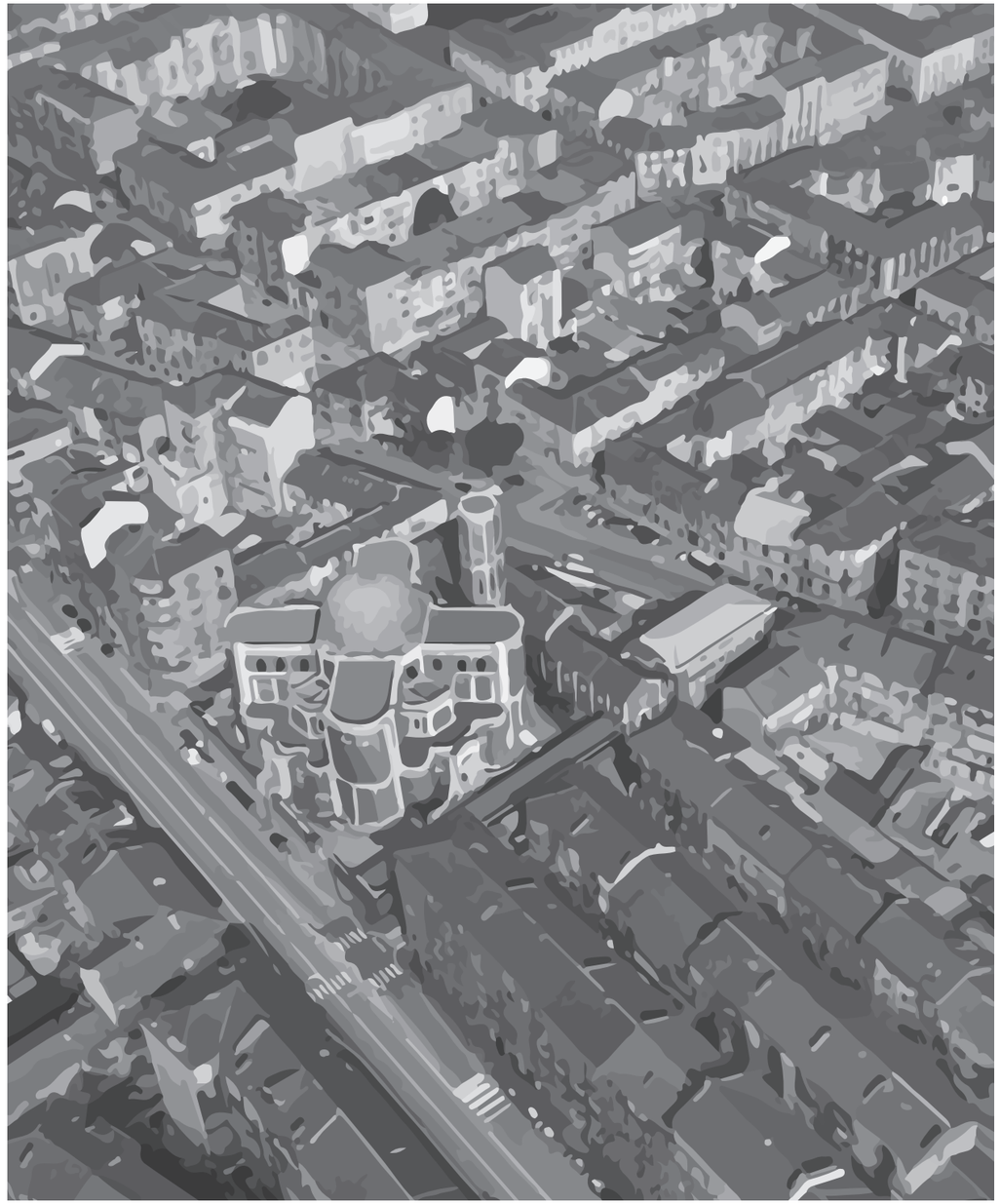
source: author

[Fig. 4.21] The Walls, pulic space

source: author

1. Moss culture (occupies at least 50 % of the total wall surface
2. Advertisements (possible sponsors for the walls)
3. Sitting places (foldable benches)
4.Sitting places
5. Info point
6. Air pollution education
7. Art exhibitions / posters
8. Working station (plugs and Wi-Fi integrated)

2
4
5
area pedonale



[Fig. 4.23] Barriera di Milano

source: art work produced by the author of the project derived from images of Google Earth

Barriera di Milano

Introduction

Barriera di Milano is a neighborhood in a part of the city which has always faced complex and problematic challenges in terms of its social and demographic make-up, the historical absence of green spaces, and the presence of abandoned industrial buildings characteristic of a 'Fordist' city of the 1900s (2016, European Commission). The neighborhood was born in 1853, with the first town customs barrier, which had the goal to control customs access on the in-coming goods. Barriera di Milano takes its name from one of the main entrances of the barrier. From the last years of the 19th century, the neighborhood started to accommodate several industries which led to population's growth and further expansions. With the industries' developments, immigrants seeking for jobs, from different part of Italy, began to move to this areas: the population increased from 1.901 people in the late 19th century to 39.967 in 1931.
Today, as previously mentioned, Barriera di Milano is still facing complex challenges related to social issues, evident lack of green spaces and abandoned industrial facilities. However, in addition to this, air pollution problems jeopardize the inhabitants' health. High FSI and GSI values, streets width, and the resulting skimming flow effect (see previous chapters), combined with high level of pollution, stand for a real threat. When tackling the problem, economic and social conditions will play a key role and, therefore, need to be investigated.
Since Barriera di Milano covers approximately an area of 25 km^2, due lack of time, the design will focus just on a smaller portion of it. The choice derives from the fact that generally, as mentioned in the previous chapter, the neighborhood is defined by homogeneous buildings and blocks typology. Hence, zooming on a specific spot and working with it is considered satisfactory. Moreover, the closed block typology is widely common in the city of Turin; that makes the following design a case study from which design principles applicable in different

◀ [Fig. 4.24] Lack of green

source: author

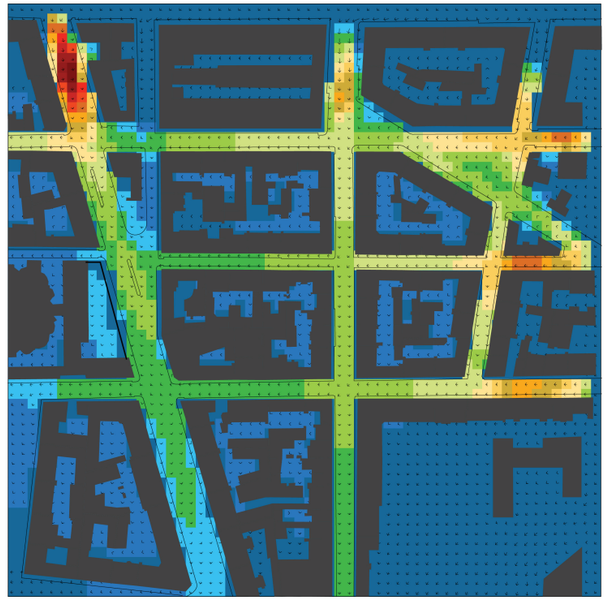
part of the city can be discovered.
Overall, the chosen spot represents an opportunity to work with both private and public spaces in order to integrate green and open spaces, able to increase air pollution dispersion.

▶ [Fig. 4.25] The green hope

source: author

◀ [Fig. 4.26] Commercial activities

source: author



[Fig. 4.27] PM 10 Concentration

source: author

PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
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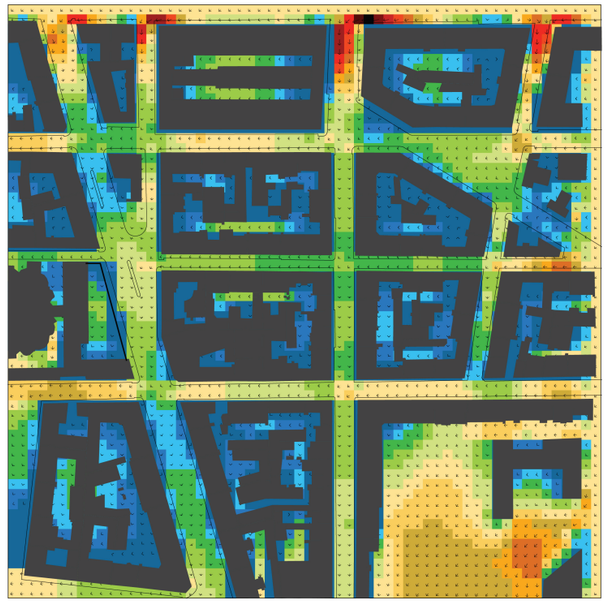
- 18.00 - 19.00
- above 19.00



[Fig. 4.28] Wind speed

source: author

Wind Speed [m/s]

- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

Analysis

When simulating arbitrary current conditions of the chosen area in Barriera di Milano, the simulation results are not as accurate as Piazza Vittorio's ones; that is due to the scale of the simulation. However, several considerations can be made.
To begin with, it can be noticed how the built environment, with the closed blocks, shapes the pollutant dispersion (Fig. 4.27). It is interesting to see that inner courtyards remain completely protected by the direct exposure to air pollution. Furthermore, Corso Palermo, the main and wider street of the area, despite higher level of PM10 emission, is characterized by lower values than the other secondary roads. That is due to its ratio (H/W) which stands between 0.1 and 0.7, allowing winds coming from upper layers of the airs to mix themselves with the ones in the urban canyon. As far as wind flow patterns are concerned (Fig. 4.28), the maximum wind speed is 2.54 m/s; higher values can be founded on corners of buildings and in wide spaces where winds can flow more easily.

As previously-highlighted in the case of Piazza Vittorio, also for Barriera di Milano, studying air pollution and wind flow patterns without considering social and economic factors might result in a ineffective analysis.
When looking on the land use of the area (Fig. 4.30), it can be noticed that different uses are proposed. Most of the blocks are considered as residential areas, there are some slight differences, but the feature that they all have in common is that of having commercial ground floors and allowing to implement green areas into the courtyards. It is interesting to see that "mixed areas" which are supposed to have the most heterogeneous layout, have less shops than the "residential" ones.

Overall, from the analysis two main conclusions can be drawn. Firstly, the urban block, as basic unit of the urban tissue, plays a crucial role in air pollution dispersion, therefore design solutions concerning blocks able to decrease air pollution and, at the same time, increase green and public areas are required. Within the design, social and economic factors need to be also considered. Secondly, design solutions on bigger scale which work mainly with the public space are also required.

[Fig. 4.29] Commercial activities

source: author

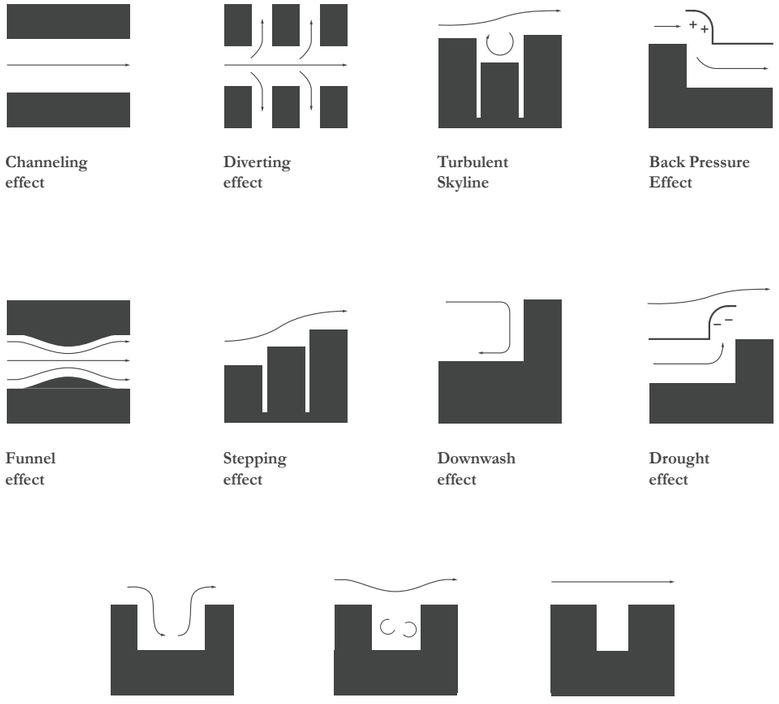
[Fig. 4.30] Commercial activities and land use

source: author

Land use

- S - Services
- R1 - Residential Type 1
- R2 - Residential Type 2
- R3 - Residential Type 3
- M - Mixed
- Grocery stores
- All the others

Services - All type of services such as schools, police stations, post offices, hospital etc...
Residential type 1 - Areas with buildings defined by commercial activities (restaurants, services, handcrafts, offices) on the ground floors and residential use on the upper floors. The municipality has been encouraging the conversion of the inner courtyards into private green spaces.
Residential type 2 - Areas with buildings defined by commercial activities (restaurants, services, handcrafts, offices) on the ground floors and residential use or hotels on the upper floors. The municipality has been encouraging the conversion of the inner courtyards into private green spaces.
Residential type 3 - Areas located in the centre of the city with buildings defined by commercial activities (restaurants, services, handcrafts, offices) on the ground floors and residential use or hotel on the upper floors.
Mixed - Areas with building defined by mixed use (residential, services, restaurants, research facilities etc.)on every floor.



[Fig. 4.31] Aerodynamic flow effects

source: Krautheim, M., Pasel, R., Pfeiffer, S., & Schultz-Granberg, J. (2014). City and Wind. Climate as an Architectural Instrument. Berlin: Dom Publisher.

Design

Research

The relation between air pollution, wind flow patterns and built environment has been already established in the previous chapters, but how can this knowledge be integrated into design processes to create meaningful results which can address air pollution issues has not be investigated. Maraite Krautheim (Krautheim et al, 2014) and her colleagues try to address this question in the book *City and Wind*. Their focus is primary the relation between wind and the built environment and, by building up a catalogue of projects which try to combine wind studies with urban design, provides fruitful design guidelines able to improve climate conditions. Those principle might be applied also in design solutions for mitigating air pollution.

Even if climate conditions always vary from city to city, there are some relevant morphological parameters which represent essential urban qualities (Krautheim et al, 2014): among them, porosity, street orientation and building enclosures are the most relevant. As far as porosity is concerned, defined as ratio of open space and built space, the study shows that strategic placement of buildings can effectively change ventilation in urban areas (Krautheim et al, 2014). In general, highly dense areas reduce air flows, whereas wider solutions might accelerate wind ventilation and, consequently, increase air pollution dispersions.

The capability of street's orientation to increase or decrease wind speed has already discussed in chapter 3; it must be highlighted, however, that as designers this feature need to be taken under consideration while designing.

Finally, the enclosures, as areas surrounded by building volumes, might play a relevant role in enhancing ventilation (air pollution dispersion) or protection against uncomfortable winds (or air pollution).

Overall, the above-mentioned parameters, together with the derived design principles, will be investigated and applied in the chosen area.

Another interesting insight, when looking for existing design solutions able to mitigate air pollution and try to cope with a scale bigger then the single urban block, is the case of the "super-blocks" of the city of Barcelona. The city was facing severe problems related to air and noise pollution due to intense traffic. Therefore, the municipality has planned to create mini neighbourhoods (composed by nine blocks) around which traffic will flow, and in which spaces will be re-purposed towards more healthy and secure environments. The idea is simple and a similar concept might be implemented in Barriera di Milano.

Design Objectives

It is clear that the urban tissue plays a relevant role in mitigating air pollution; one of the main goal of the design is then to discover how different block typologies cope with air pollution and, in the same time, with the existing social and economic conditions. The design aims to give to Barriera di Milano's inhabitants an additional tool to fight air pollution and enhance healthier and

safer environments. Working with both private and public space will be crucial.

Design principles and proposals

Green Crosses - As previously-mentioned, *Barriera di Milano* has always faced complex and problematic challenges due to the historical absence of green spaces and healthy public spaces. Keeping in mind this and the Barcelona's *Super blocks* project, the design proposal aims to provide comfortable and healthy public spaces to the inhabitants of the neighborhood and, at the same time, mitigate air pollution. The design principle, coping with the neighborhood scale, is that of limiting car use in two crossing streets and transforming the latter in linear street pocket parks.
The proposal depends mostly from public institutions such as municipality but also from neighborhood's organizations and the inhabitants of the area. Both inhabitants and owners of commercial activities would benefit from the design.

Green courtyards - The municipality of Turin has been encouraging its inhabitants on implementing green areas in their courtyards. The design proposal, keeping in mind their will and focusing on the block scale, wants to study if this action may have positive effects on air pollution mitigation. The intervention does not affect the already existing volumes since it would deal mostly with their rooftops. Overall, it has been proven that urban vegetation contribute to clean the air at a mesoscale, does it help also at a block scale ?
The success of the proposal depends mostly from the courtyards' inhabitants. The municipality of Turin might give some incentives to people for encouraging the trasformation.

Island - Air flows are strictly related to urban forms, urban blocks are responsible for these aerodynamic effects and consequently for pollutant dispersion. The proposal aims to divert wind flows into multiple direction and, at the same time,
tries to lead winds into aisles. In theory, the desired effects can be verified by opening two corners of the selected block and by reorganizing the inner volumes of the courtyard into a more compact configuration.
The design success relays mostly on the cooperation between inhabitants, owners of commercial activities and the municipality of Turin. The weakness of the proposal is that of removing the corners of the block (somebody's houses) without considering the relocation of those.

Channelling - The proposal combines the diverting and stepping effect of wind flows patterns. The first effect has been already explained in previous proposals. As far as the stepping effect is concerned, continuously rising building heights divert wind flows over the top and it might increase wind speed.
Once again, the corners of the block would be removed and the inner volumes reorganized in order to create a small canyon within the courtyard.
Once again the success of the design depends on the block inhabitants, owners of commercial activities and municipality. As it was for the previous proposal, the weakness of the proposal is that of removing the corners of the block (somebody's houses) without considering the relocation of those.

Porosity - The last proposal, probably the more radical, takes to extremes the diverting effect. The block is divided in small different parcels and that means that buildings are independent from each other. Hence, within the design, some of the residential ground floors are "removed" and "given back" on the top of the buildings and, moreover, the inner volumes of the block are reorganized in more compact solutions.
When considering the social and economic aspects, both the involvement of the municipality and inhabitants is required. Economic activities would not suffer since the ground floors with economic activities would not be involved in the transformation of the block. The strenght of the proposal is that whatever volume is "taken" from the ground floors is always "given back".

Research

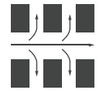
Green crosses

Super blocks
Car, scooter, lorry and bus traffic is restricted to just the roads in the superblock perimeters, and they will only be allowed in the streets in between if they are residents or providing local businesses, and at a greatly reduced speed of 10km/h

Green courtyards

Greening effect
Greening built area gives different benefits such as water retantions, aesthetic valus and affects climate factors such as temperature

Island

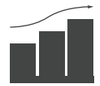


Diverting effect
When channeled by street canyons, wind will be divertited into side streets

Channeling effect
Wind is led into aisles bt the allignment of buildings

Channeling

Channeling effect
Wind is led into aisles bt the allignment of buildings



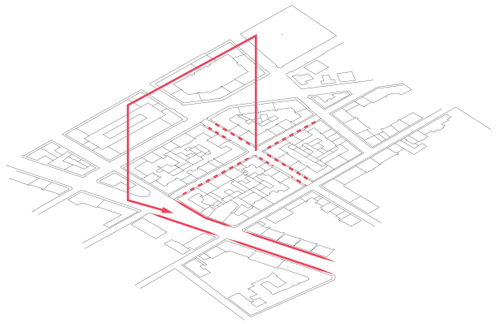
Stepping effect
Continuously rising building heights divert wind over the top

Porosity

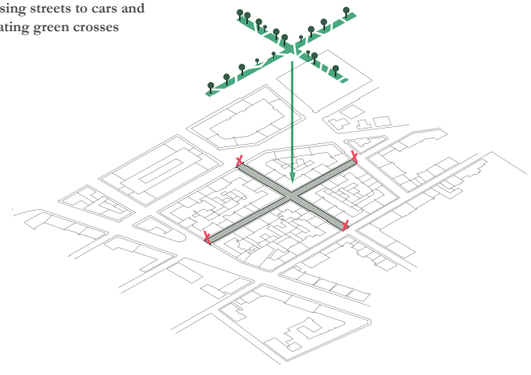
Diverting effect
When channeled by street canyons, wind will be divertited into side streets

Design principle

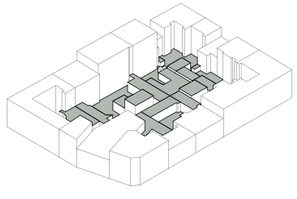
Re-locating and re-organizing parkings spaces



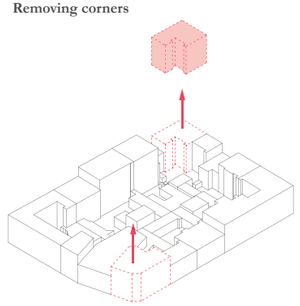
Closing streets to cars and creating green crosses



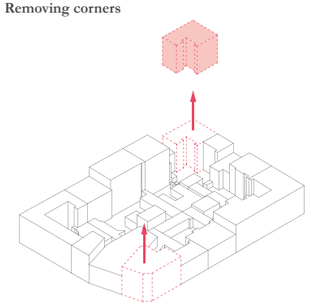
Implementing green spaces in courtyards



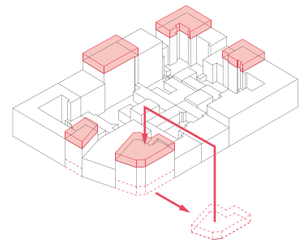
Removing corners



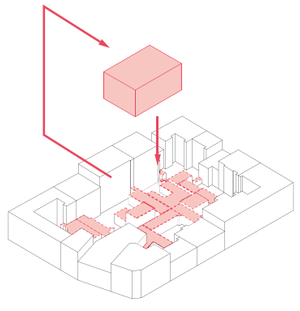
Removing corners



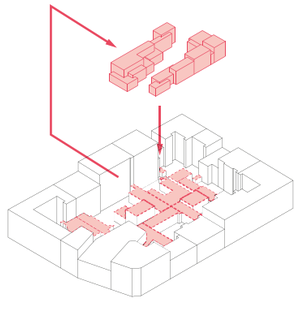
Removal of residential groundfloors and relocation on top



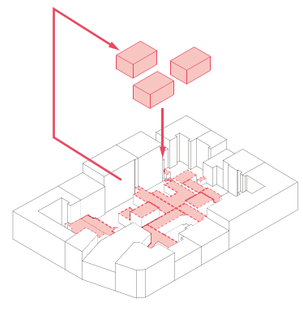
Re-organizing inner volumes of the courtyard into one



Re-organizing inner volumes of the courtyard into two



Re-organizing inner volumes of the courtyard into multiple volumes



Reference projects

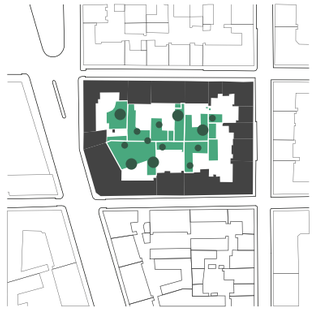
Conceptual plan

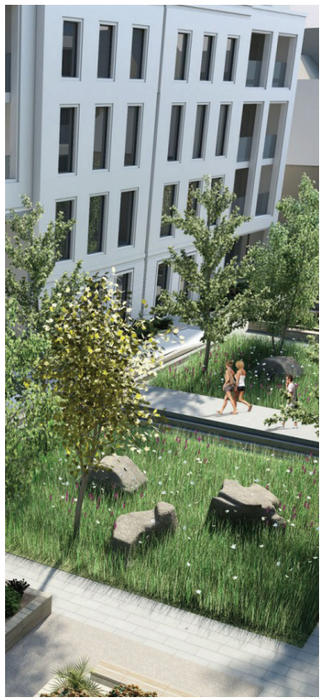
Green crosses

Zanderroth Architekten - BIGyard - Berlin

source: https://www.architectural-review.com/today/chip-off-the-old-block-reinventing-courtyard-housing-in-berlin/8620152.article

Green courtyards

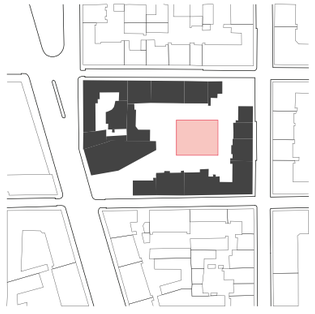




Weddington Architects

source: http://www.waddington.je/housing-in-berlin/8620152.article

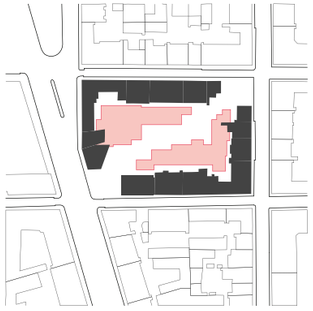
Island



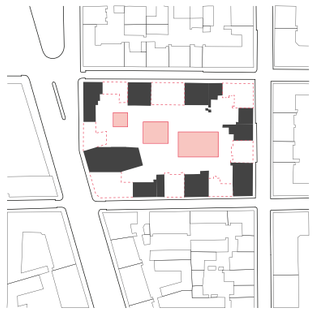
Nunc Architectes - Paris

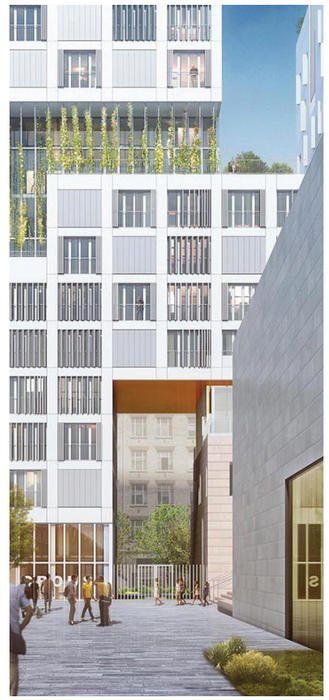
source: http://www.archdaily.mx/mx/766437/107-departamentos-de-uso-mixto-nunc-architectes

Channeling



Porosity

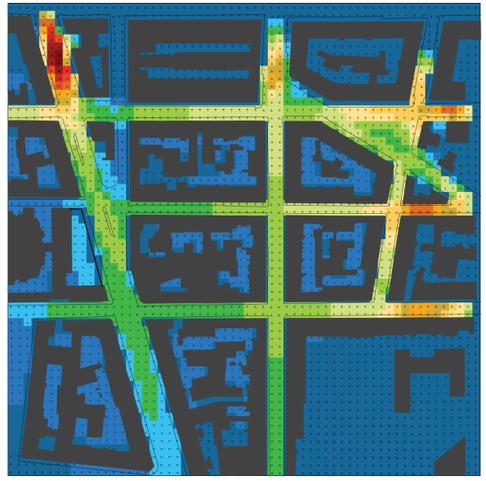




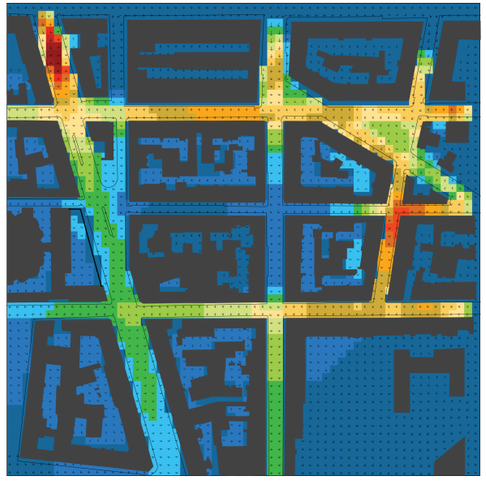
PHILEAS - Rive Gauche - Paris

source: http://parisfutur.com/projets/zac-paris-rive-gauche/

Current



Green crosses



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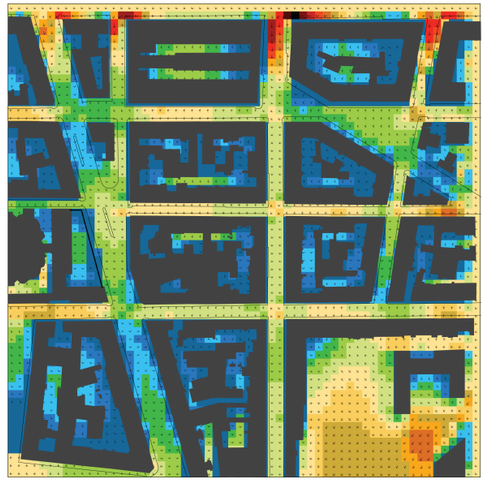
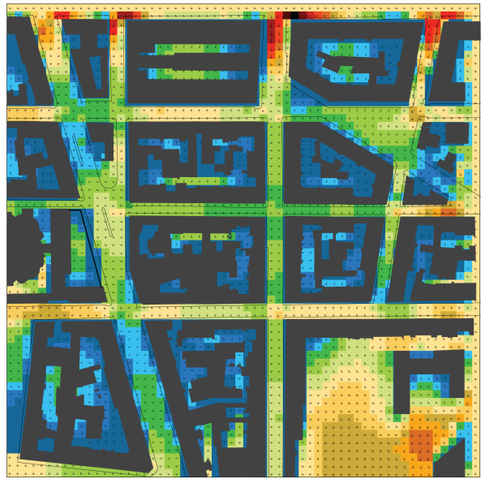


Green crosses



[Fig. 4.31] PM 10 Concentration

source: author

PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

[Fig. 4.32] Wind speed

source: author

Wind Speed [m/s]

- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

Evaluation

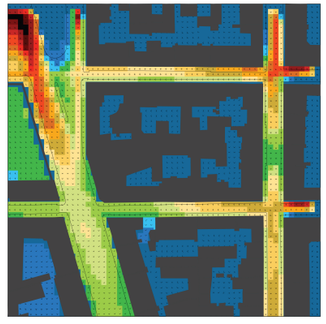
Green crosses

When looking on the simulation of the design proposal, it appears that the streets that were decided to be closed to traffic have lower concentration of PM10. However, because of this, the traffic intensity in the surrounding streets increased and so did the pollution concentration. Therefore, the proposal have both positive and negative effects.
As far as the wind flows are concerned, wind speed decreases where the green cross is places. That is due to the implemented vegetation which actually decreases wind flows.

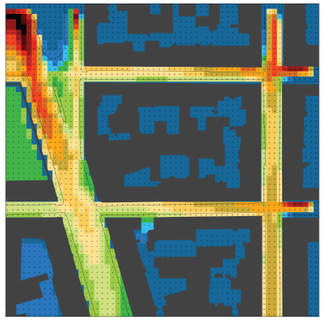
Green courtyards - Island - Channeling - Porosity

Concerning PM10 values, *Porosity* is the proposal with the most effective results. The maximum value is 16.62 whilst the Current's one is 21.62. Furthermore, when looking at the visual results, Porosity proposal affects all the surrounding streets and has a major impact on the main road with higher traffic. Green Courtyard is quite surprising: it actually increases the maximum values of pollutants. That is due probably to the presence of trees which might decrease wind flows on an upper layer of the air and consequently affect air pollutant dispersion. Channeling and Island have results similar to Green Courtyards do not improve the situation.
As far as wind flow patterns are concerned, maximum values remain almost the same as the current situation in all the proposal. Regarding Green Courtyard, the maximum values is higher than the current one, however, it can be noticed that wind flows are slower in the inner part of the volumes because of the vegetation. Once again, what plays the key role is not the wind speed but its diverting flows.

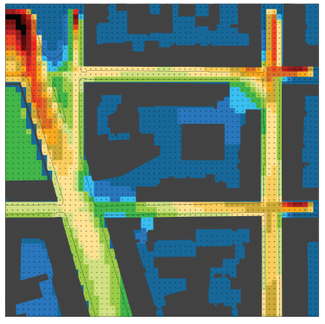
Current min: 0.00 max: 21.46



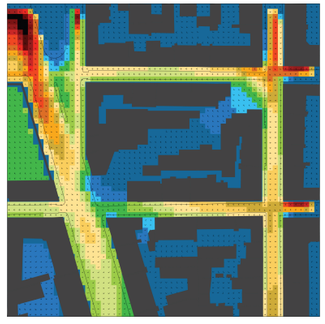
Green Courtyards min: 0.00 max: 21.47



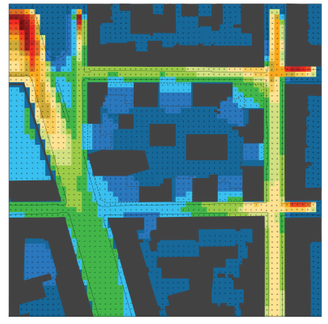
Island min: 0.00 max: 21.50



Channeling min: 0.00 max: 21.54



Porosity min: 0.00 max: 16.62



[Fig. 4.33] PM 10 Concentration

source: author

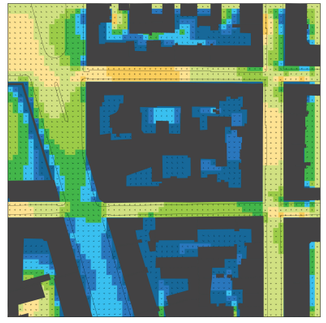
PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

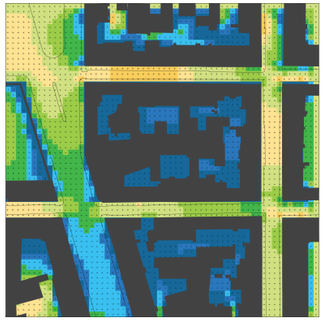
Comparison

- Current - maximum value
- Proposals - maximum value

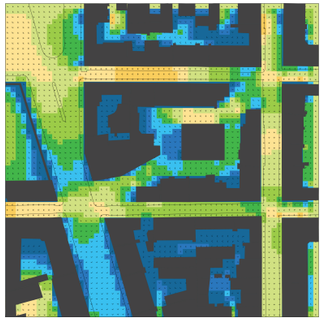
Current min: 0.00 max: 1.53



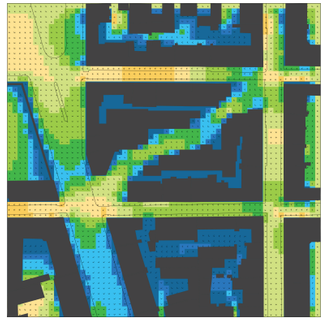
Green Courtyards min: 0.00 max: 1.57



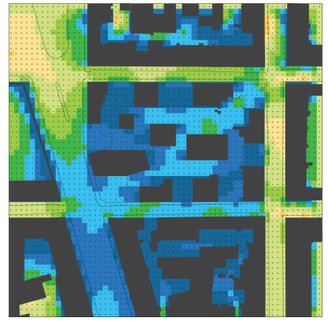
Island min: 0.00 max: 1.54



Channeling min: 0.00 max: 1.54



Porosity min: 0.00 max: 1.52



[Fig. 4.34] Wind speed

source: author

Wind Speed [m/s]

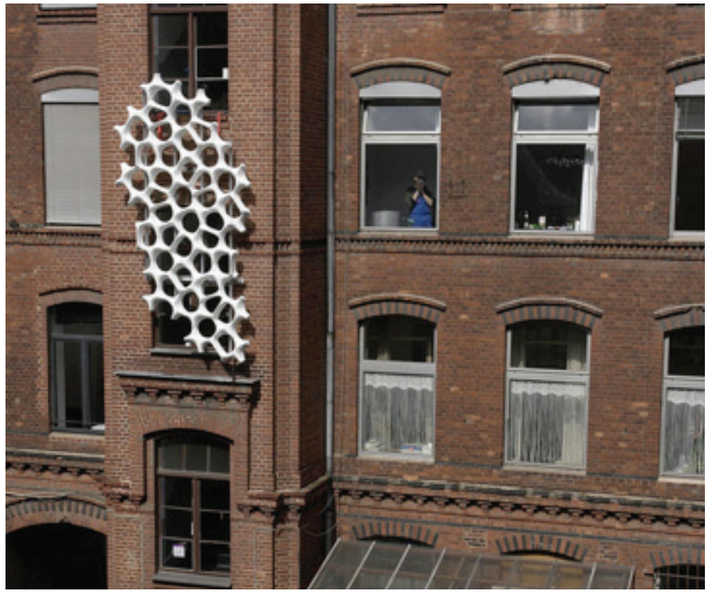
- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

Comparison

- Current - maximum value
- Proposals - maximum value

[Fig. 4.35] Gardening the street

source: http://www.ecoreport.tv/video-guerrilla-gardening-la-lotta-dei-giardinieri-sovversivi/



[Fig. 4.36] Application of prosolve370e

source: https://jayfactory.wordpress.com/2010/01/21/prosolve370e/

Implementation

Green Crosses

The proposal aims to provide and promote the transformation of two crossing streets into a "safe" place from pollution for the inhabitants of the neighborhood. The project development can be divided in three main phases during which involvement and participation of different actors will be crucial.

I phase - Closing the streets

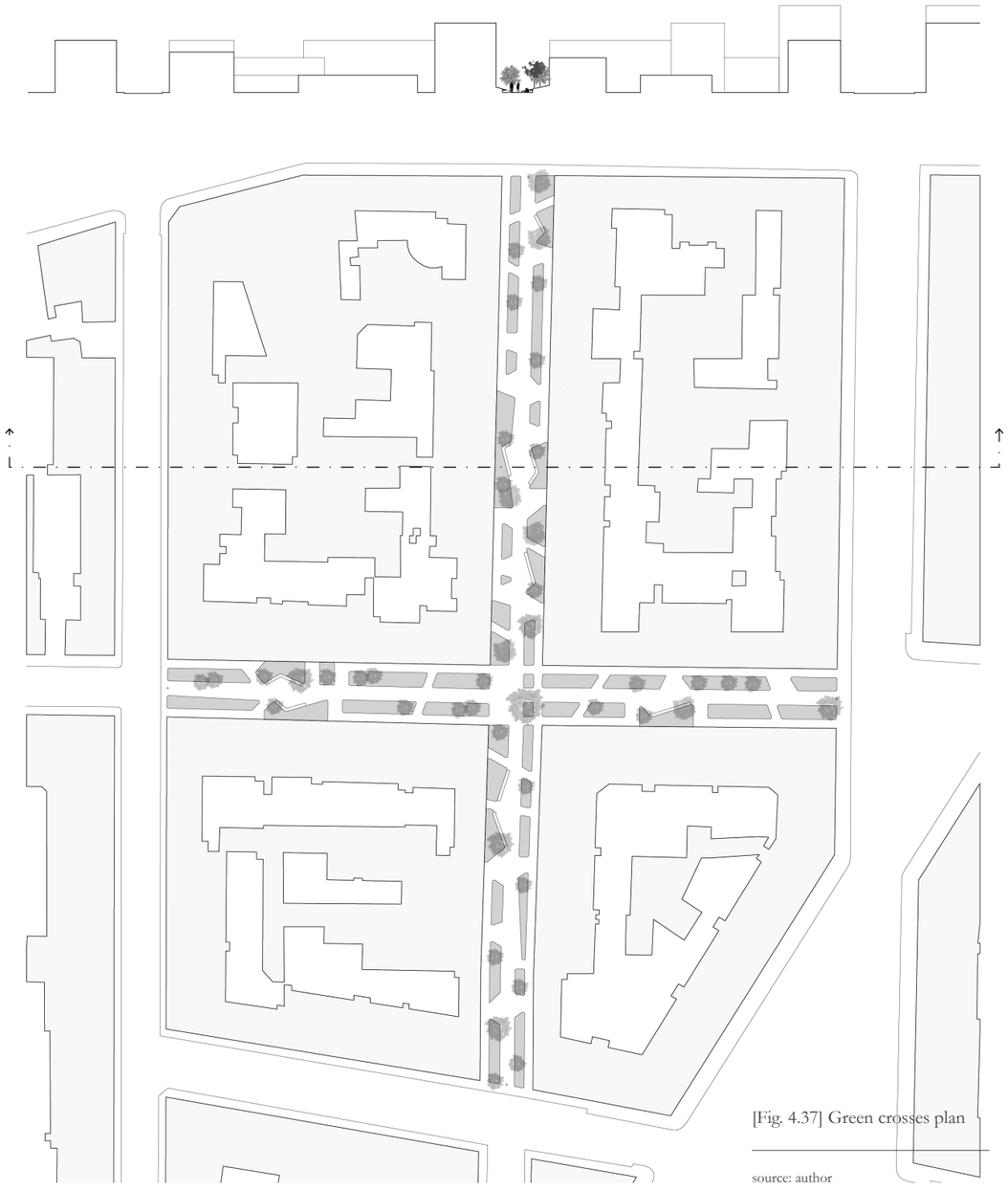
Because of the economic crisis, city developments projects usually require a lot of time to be implemented and budgets are often limited. For this reason, the first phase of the project requires the cooperation between the municipality of Turin and the inhabitants of the areas and it is primarily defined by a bottom-up approach. The municipality will close the selected streets to the traffic and will be in charge of relocating the parking places. That can be done by changing the existing parking layout of the adjacent street from the existing parkings from parallel to a 60°-angle parking space. As previously mentioned during the evaluation phase, when closing the streets to the traffic, the bordering might face an increase of traffic. To deal with this issue, even if out of my domains, there are several architectural solutions which might help. Among this, *prosolve370e* is a valid answer: it is a decorative architectural module that can effectively reduce air pollution in cities. The modules are coated with a superfine titanium dioxide (TiO_2), a pollution-fighting technology that is activated by ambient daylight. Employing a unique configuration of this technology, the tiles neutralize air pollutants when sited near traffic or densely polluted conditions (http://www.elegantembellishments.net).
The module are extremely adaptive since they are attached to existing facades with an external structure.

II phase - Street gardening

Once the streets have been freed, urban workshops regarding street gardening will be organized in order to encourage inhabitants of the involved streets to start greening the streets. For instance, the municipality will provide the main instruments and tools. Entrepreneurs, owners of commercial activities can use this as opportunity to attract more clients. Overall, this phase of the project is mostly community-based and its success depends on the citizens involvement.

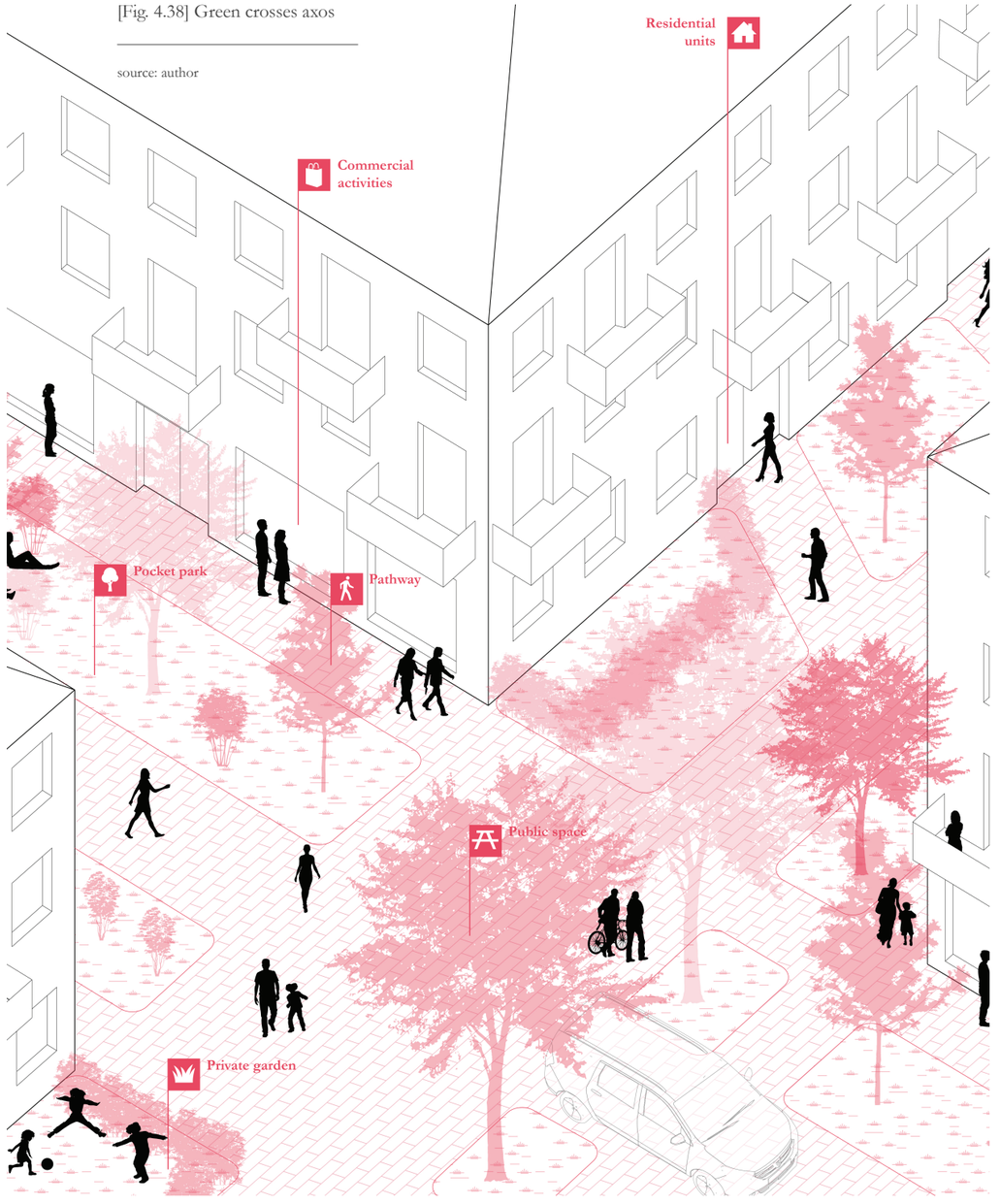
III phase - Transformation

The last phase of the project, depends on the economic availability of the municipality and it would bring to an end the complete transformation of the street to crossed-linear pocket garden. When designing and developing the park, existing interventions designed by the citizens will be mantained.



[Fig. 4.37] Green crosses plan

source: author



[Fig. 4.38] Green crosses axos

source: author

[Fig. 4.39] The Green Crosses, impression

source: author

1. Street gardening developed by inhabitants
2. Sitting places
3. Bike-friendly path
4. Walking path
6. Free sidewalk which allows commercial activities

[Fig. 4.40] Porosity plan/section

source: author

Porosity

Out of the four proposals, Porosity is the one which shows the most effective results in terms of air pollution mitigation. Therefore, the design intervention will be further developed. Despite its proven efficacy in terms of climate conditions, the proposal lacks of a definition of spaces, uses and qualities which may add new values the block. The project can be analyzed according two main phases.

Phase I - Removing ground floors

As previously mentioned, the selected block (as many in Turin) is composed by smaller bordering plots. Each of them works independently from the others. The inner courtyards are occupied mostly by private warehouses or garages.
The first phase of the design focusing on removing some of the residential ground floors and to "give them back" on the top of the chosen volumes. The action might be pursued by the owners of the apartments but it needs to be encouraged socially and financially by public institutions as well. To this extent, public subsidies and incentives would play a key role.

Phase II - Reorganizing the courtyard

As far as the inner part of the courtyard is concerned, by removing some of the ground floors, new passages between the private and the public realm are created. One of the first ideas was that of densifying the scattered warehouses, opening the block and finally creating an extended permeable public space. This idea was then jeopardized by two main factors: firstly, the inner courtyard is property of the inhabitants of the block and secondly, given the danger of the neighborhood and the presence of drug-dealers, providing hidden free spaces behind corners would facilitate those practices. Hence, the design tries to cope with these two impediments by creating a semi-private courtyard (Fig. 4.45). The latter is divided in two main sectors: a private space for the inhabitants of the block and public areas which will opened only during the day hours.
As far as the private areas are concerned, the design provides new functions and values to the space which might encourage different ways of living. For instance, urban farming is something which is still far from Turin inhabitants way of living; it can be easily integrated in this new block configuration.
Focusing on the public realm, the space can offer different uses. Taking into account the previously-mentioned problems of safety, a public facility is inserted in the design of the block since it can attract more people in the courtyards and increase its livability. Furthermore, pocket parks, playgrounds and gathering points could contribute positively to the quality of the space.

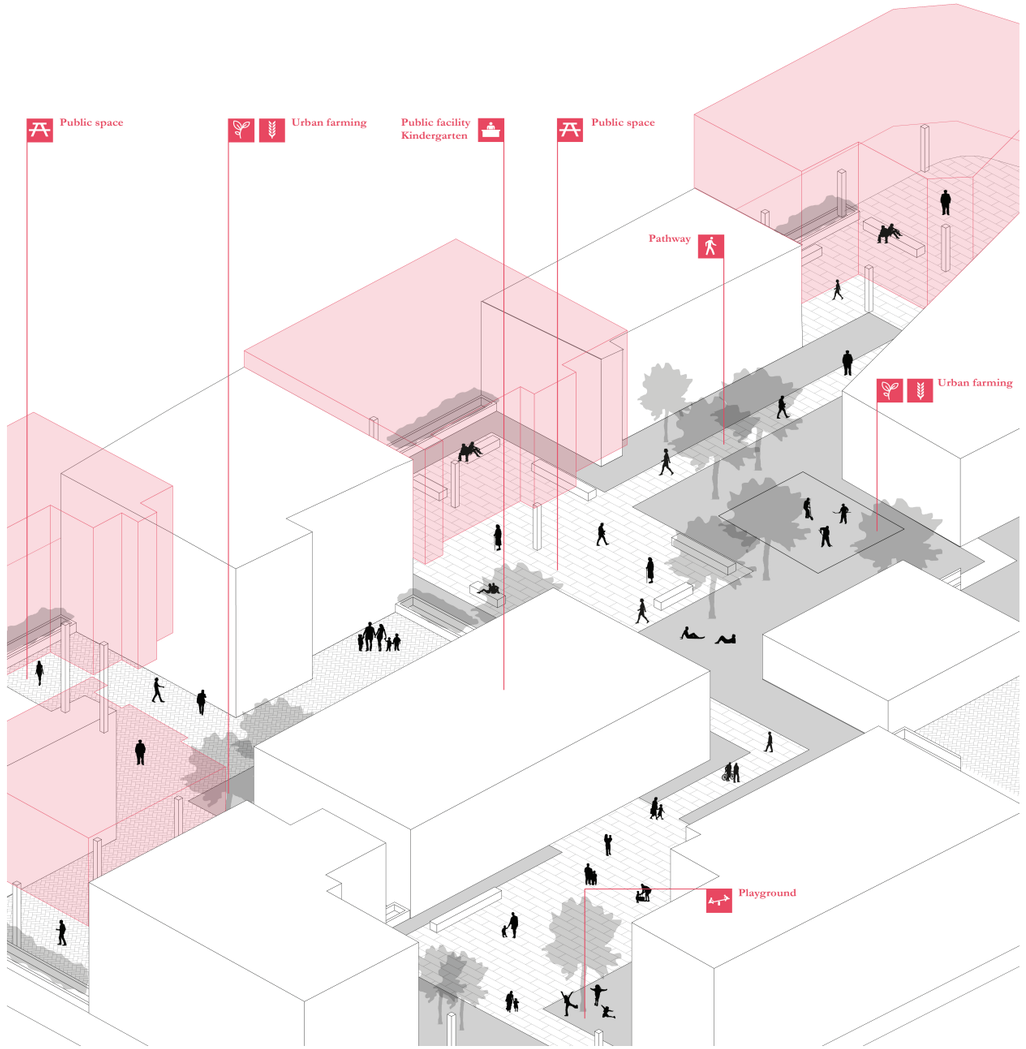
Overall, the success of the design lays on its capability of mitigating air pollution but also of giving new spatial qualities and values to the closed courtyards (Fig. 4.42). For instance, the

entrances of the open block can be used as more than a passage towards the inner space of the courtyard: during rainy days they can be transformed and adapted to a covered public space for both youngster and older people (Fig 4.43). The new added volumes are another important aspect. With the latter, new housing typologies can be implemented and mixed: both high and low income housing could be integrated which might work independently from the existing fabrics.

Overall, the design might be applied also to blocks in other parts of the city and the design principle concerning air pollution can be used as guidelines for future developments. For instance, most of the peripheral areas of the city are characterized by vacant plots and ex-industrial facilities which needs to be re-qualified. When designing from scratch, the principles of the Porosity project can be one used as one of many design principles.

[Fig. 4.41] Porosity design principles

source: author



[Fig. 4.42] Porosity, bird-eye view

source: author

1. Entrance to courtyard
2. Courtyard's opening - access not possible
3. New elevation
4. Urban farming
5. Private courtyard
6. Public facility
7. Public square
8. Green areas

[Fig. 4.43] Porosity, entrance to the courtyard

source: author

1. New elevation with different housing typologies (luxury apartments, low-income housing, new housing typologies)
2. Entrance to the courtyard which can be used also as covered and protected public space during rainy days
3. Sitting places
4. Inner green areas

[Fig. 4.44] Porosity, public square
source: author

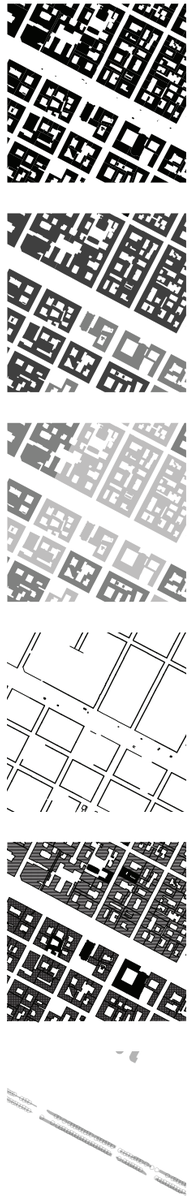
source: author

1. Public facility (kindergarten)
2. Public square
3. Private buildings

[Fig. 4.45] Porosity, semi-public space

source: author

1. Urban farming
2. Public walking path
3. Access to private buildings
4. Private garden
5. Public facility (kindergarten)



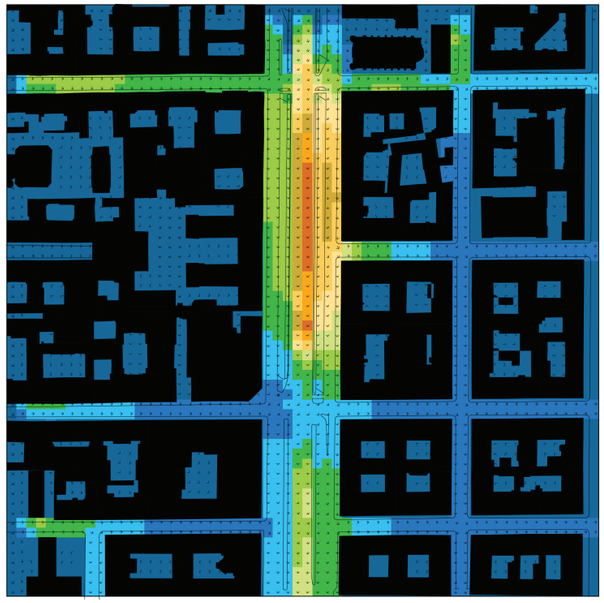
[Fig. 4.46] Corso Vittorio, urban trees

source: art work produced by the author of the project derived from http://24ilmagazine.ilsole24ore.com/2016/10/50-motivi-cui-torino-cool/?refresh_ce= | Ph: Maurizio Camagna

Corso Vittorio

Introduction

Corso Vittorio Emanuele II, also called just Corso Vittorio, is one of the main roads of the city of Turin. It crosses the urban tissue from north-west to south-east and defines one of the borders of the centre of the city.
The road was developed by the architect Carlo Promis during the 19th century within the industrial expansion of the city. The first part of the road (from the river Po to the main rail station Porta Nuova) was however already developed in 1814. Promis transformed it into one of the main arteries of the city. The road, around 55 meters wide, is defined by a double line of trees which divide the primary lanes of the street from the secondary ones. Moreover, Corso Vittorio is also characterized by one of the most intense traffic flow of the city and, in addition, the most important public transport lines run along it.
The urban layout of Corso Vittorio, wide road with tree-lines, is not an isolated case, on the contrary, most of the major traffic axises of the city have similar compositions. As previously-mentioned in the Analysis chapter, studies have demonstrated that the air quality effect of urban vegetation is more complex than implied and that roadside urban vegetation rather leads to increases pollutants concentration than it improves the air quality, at least locally (E.J. Vos et al, 2013). Hence, the choice of corso Vittorio as one of the main site of intervention. The design will focuses just on one part of the street since it has an homogeneous configuration along its entire lenght.

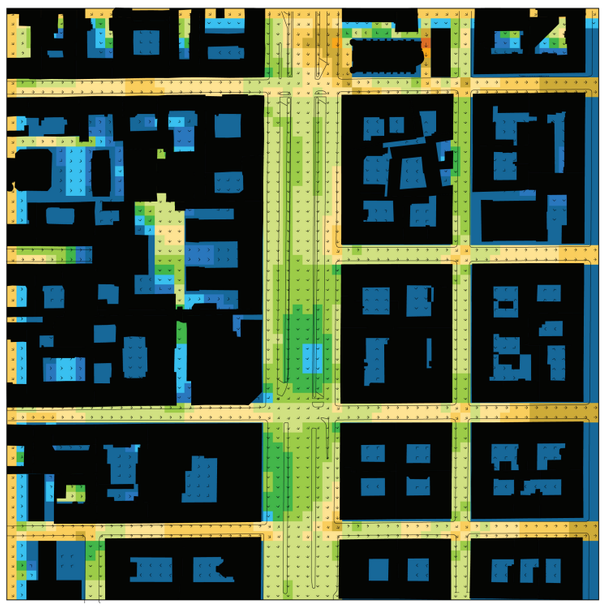


[Fig. 4.47] PM 10 Concentration

source: author

PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00



[Fig. 4.48] Wind speed

source: author

Wind Speed [m/s]

- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

Analysis

When simulating arbitrary current conditions of the chosen strip of Corso Vittorio, several considerations can be made.
To begin with, it can be noticed that parts of the road where trees are missing or are positioned with increased distance from each other air pollution has lower values. As far as wind speed is concerned, streets parallel to the wind speed direction have higher values than the ones with a different angle. Moreover, in the case of Corso Vittorio, wind speed is further decreased by the presence of the tree-lines. Finally, once again, it is interesting to see that inner courtyards remain completely protected by the direct exposure to air pollution.
Overall, these considerations actually show what already existing researches have been highlighted: trees and other types of vegetation reduce the ventilation in urban canyons and, doing so, obstacle air pollution dispersion, and the case of Corso Vittorio explicits those discoveries.

Design

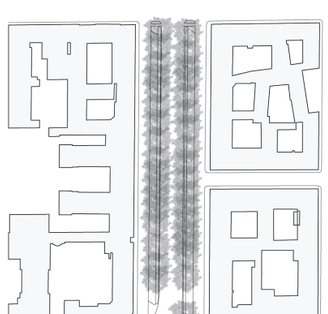
Research

It has been demonstrated and showed that urban trees contribute, in a negative way, to air pollution in urban canyons. When looking for design proposals and guidelines regarding this topic the academic literature does not play a relevant role. There are papers and researches which study the role of vegetation within the air pollution issue, but they do not give any design solutions able to cope with the problem. Hence, for the current design, the "research by design" approach will be followed.

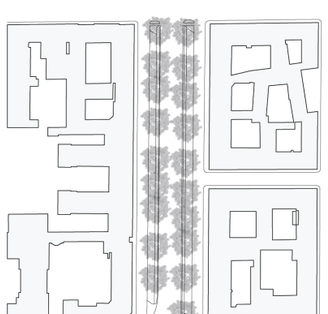
Design objectives

The design goal differs with the ones of previous designs. Within the analysis part, the negative effect that trees have on air pollution mitigation has been highlighted but this is just one of the several property of trees. For instance, trees, as CO2 absorbers, contribute to combat climate change, they help regulating outdoor and indoor temperatures of urban environments, the participate in water retention, on a broader scale, the contribute to improve air quality and counteract the greenhouse effects; finally they also have an aesthetic value which define the visual comfort of urban spaces. Therefore, despite their negative effect on air pollution on street level, trees have so many other qualities and removing them is not the solution. Hence, the design aims to understand what is the role of trees in Corso Vittorio, how they affect air pollution and what could be a possible design solution. The design proposals are not developed to be applied but they can rather build up guidelines for developments of future roads.

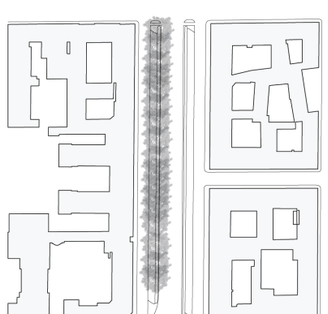
Current



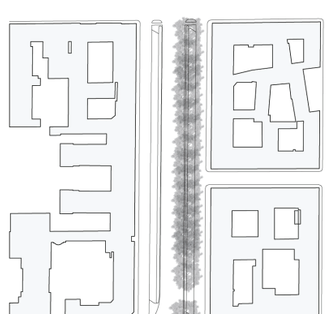
Separation



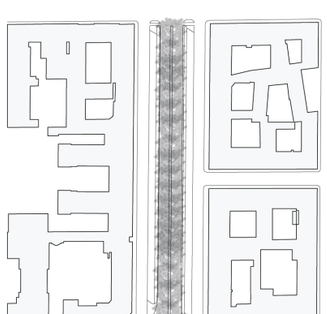
One line (upwind)



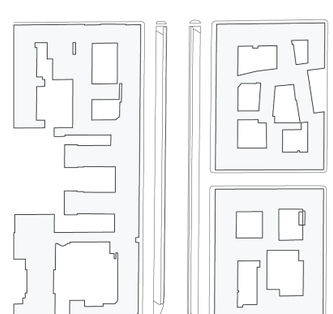
One line (downwind)



One line (in the center)



No trees



Design proposal - What if ?

The current layout of Corso Vittorio has been already described: a double tree-line defines the street canyon. The design proposals try to test different layouts which are derived from the existing trees organization. It must be reminded that the proposals do not take under consideration the social and economic feasibility, they are rather a pure scientific research concerning air pollution.

Separation - The goal of this proposal is to increase the distance between the canopies of the existing trees. Since reorganizing from scratch their layout is highly unfeasible, for each row, trees are remove alternately.

One line (upwind) - The line of trees situated toward the direction from which the wind is blowing are kept, while the other is removed.

One line (downwind) - The line of trees situated in the direction toward which the wind is blowing to are kept, while the other is removed.

One line (in the centre) - One row of trees is moved to the centre of the street, while the other is removed.

No trees - Both of the rows are removed from the street.

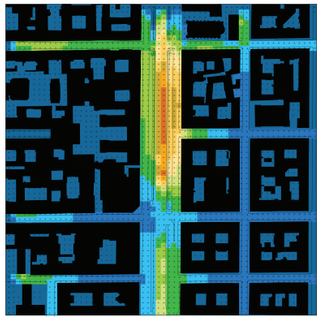
Evaluation

The simulations of the design proposals reveal numerous information.
To begin with, when looking at the maximum values of PM10 in the area, surprisingly, the proposal *Separation* is the one whit the highest value (12.41) while *No trees* is predictably the one with th lowest value (6.80). Moreover, what is totally unforeseeable it that the maximum PM10 value of *Separation* is even higher than the *Current* layout of the street. An appreciated improvement can be noticed also in the case of *One line (upwind)* and *One line (in the middle)*. However, looking just at the maximum PM10 values of each proposal can be highly misleading. For example, when comparing *One line (upwind)* and *One line (downwind),* it might be argued that the latter is worse then the first proposal; that is not true. When comparing the qualitative results (graphic representations) of the two proposals, it can be noticed that, on average, in *One line (downind)* PM10 concentrations are lower than the in the *Upwind* proposal. The fact that one proposal has higher maximum values does not imply the inefficacy of the proposal. As far as the wind speed is concerned, surprisingly, the maximum values of all the proposals are lower than the starting point. Again, this does not mean that there are no improvements. *No tree* is the proposal with the lowest maximum value of wind speed but with the highest average. In general, all the proposals show that with a lower number of trees, wind speed increases. Overall, it can be noticed that the most effective proposal is *No Trees,* followed by One Line (downwind) and One Line (in the middle).

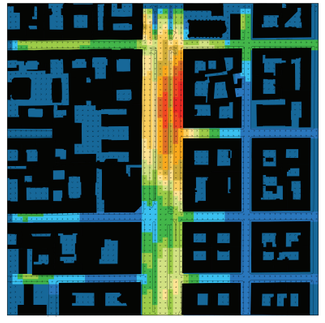
Implementation

Implementing one of the above-mentioned design proposals in Corso Vittorio would be quite challenging. Different aspects need to be considered. First of all, urban vegetation plays a key role in thermal comfort, water retention etc. Removing trees would certainly improve air pollution conditions but it would cause, at the same time, several disadvantages. In addition, the aesthetic value plays another relevant role. Removing trees would change also its proportions, degenerating the visual perception of the street.
Taking into account the aforementioned considerations, the design proposals can mostly be used as guidelines for future developments. However, in extreme cases, One line (downwind) solution might be applied. In general, the municipality of Turin, when planning or designing new infrastructural connections, might contemplate the discoveries made in order to cope with the high level of pollution in the city.

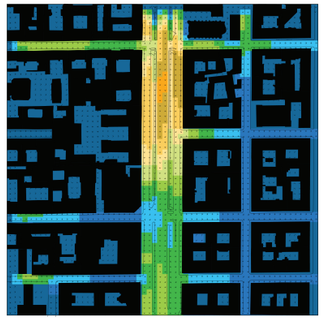
Current min: 0.00 max: 10.41



Separation min: 0.00 max: 12.41



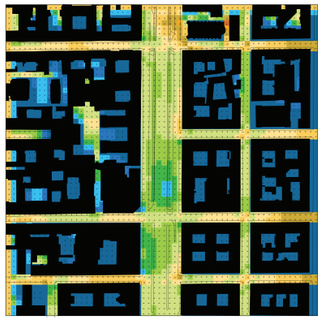
On line (upwind) min: 0.00 max: 9.22



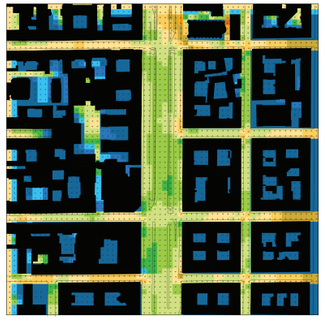
[Fig. 4.49] PM 10 Concentration

source: author

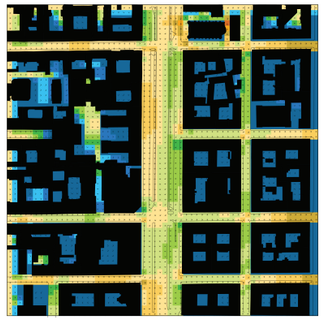
Current min: 0.00 max: 2.14



Separation min: 0.00 max: 2.13



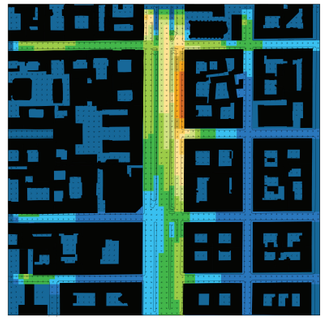
On one side (up) min: 0.00 max: 2.11



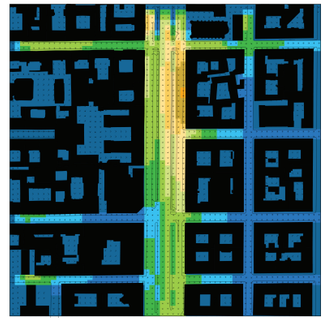
[Fig. 4.50] Wind speed

source: author

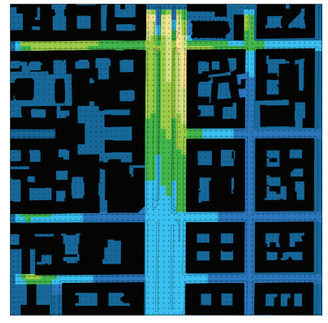
On line (downwind) min: 0.00 max: 10.57



In the middle min: 0.00 max: 9.03



No Trees min: 0.00 max: 6.80



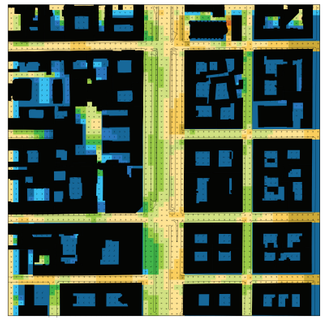
PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

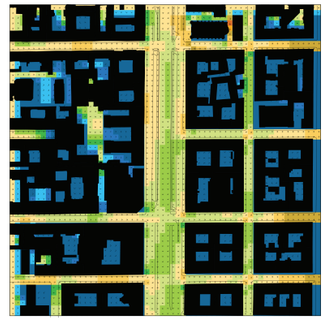
Comparison

- Current - maximum value
- Proposals - maximum value

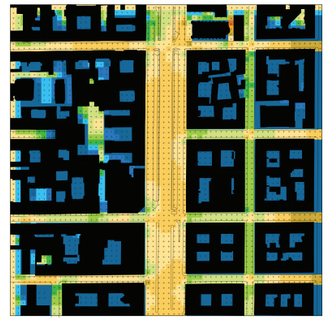
On one side (down) min: 0.00 max: 2.11



In the middle min: 0.00 max: 2.10



No Trees min: 0.00 max: 2.06



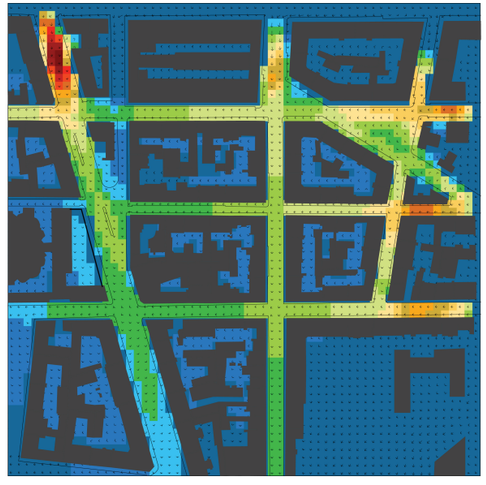
Wind Speed [m/s]

- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

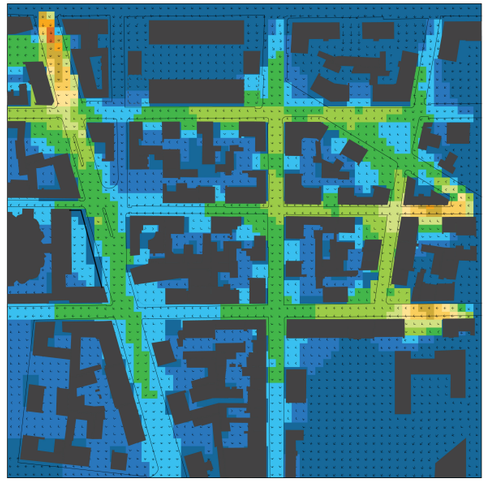
Comparison

- Current - maximum value
- Proposals - maximum value

Current



Porosity



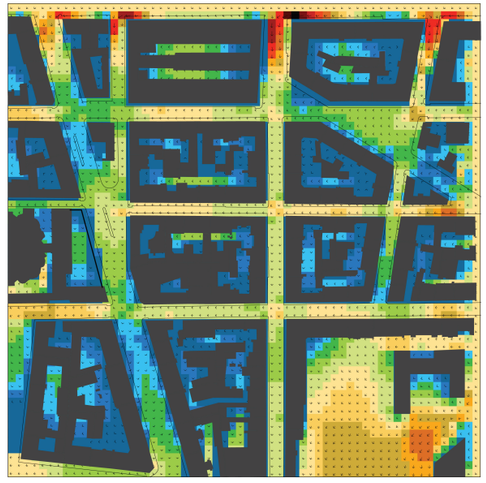
[Fig. 4.51] PM 10 Concentration

source: author

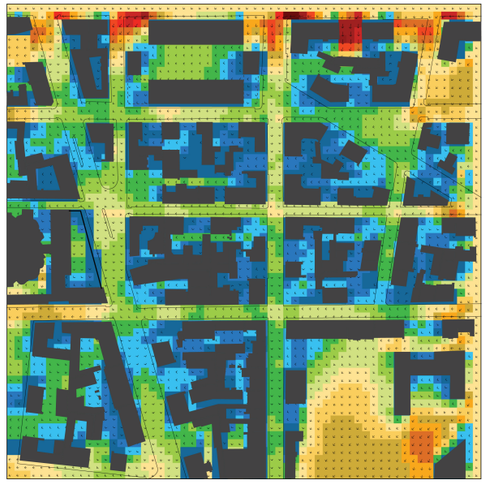
PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

Current



Porosity



[Fig. 4.52] Wind speed

source: author

Wind Speed [m/s]

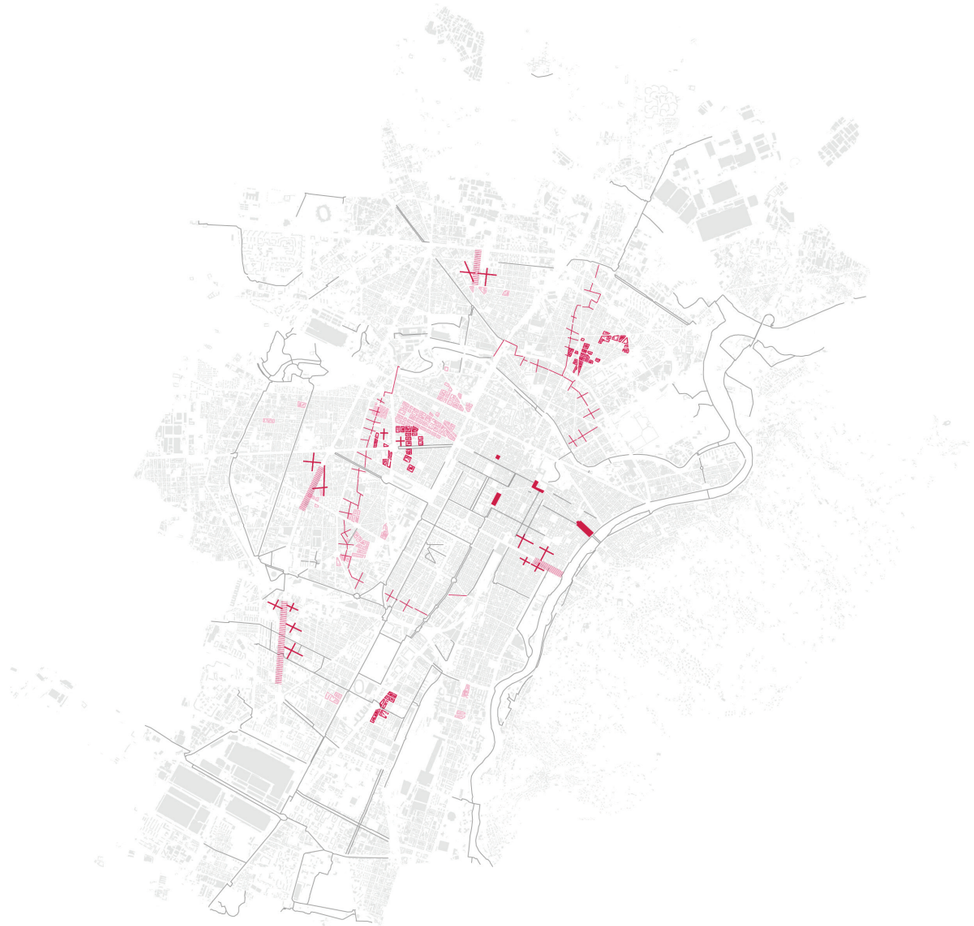
- under 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.40
- 1.40 - 1.60
- 1.60 - 1.80
- 1.80 - 2.00
- 2.00 - 2.20
- 2.20 - 2.40
- 2.40 - 2.60
- 2.60 - 2.80
- 2.80 - 3.00
- 3.00 - 3.20
- 3.20 - 3.40
- 3.40 - 3.60
- 3.60 - 3.80
- above 3.80

The systemic effect and the interscalarity of design

One of the main goal of the graduation project is that of discovering at what scales urban design can affect air pollution and, consequently, if the proposed design interventions may have an "area of effect" (see "Scope" paragraph, chapter 2) which overcomes its physical boundaries. In other words, the following paragraphs aim to establish and verify if a "systemic effect" can be triggered by the design proposals. When choosing the sites of interventions, one of the factors which influenced the choice, a part from the pollution-related ones, was the scale. Piazza Vittorio, Barriera di Milano and Corso Vittorio are defined by three different scales.

As far as Piazza Vittorio is concerned, the design affects just the square itself and, therefore, if applied in other areas of the city, would not be influenced or influence any other scale. As micro-intervention, its area of effect is strictly limited to the surrounding space.

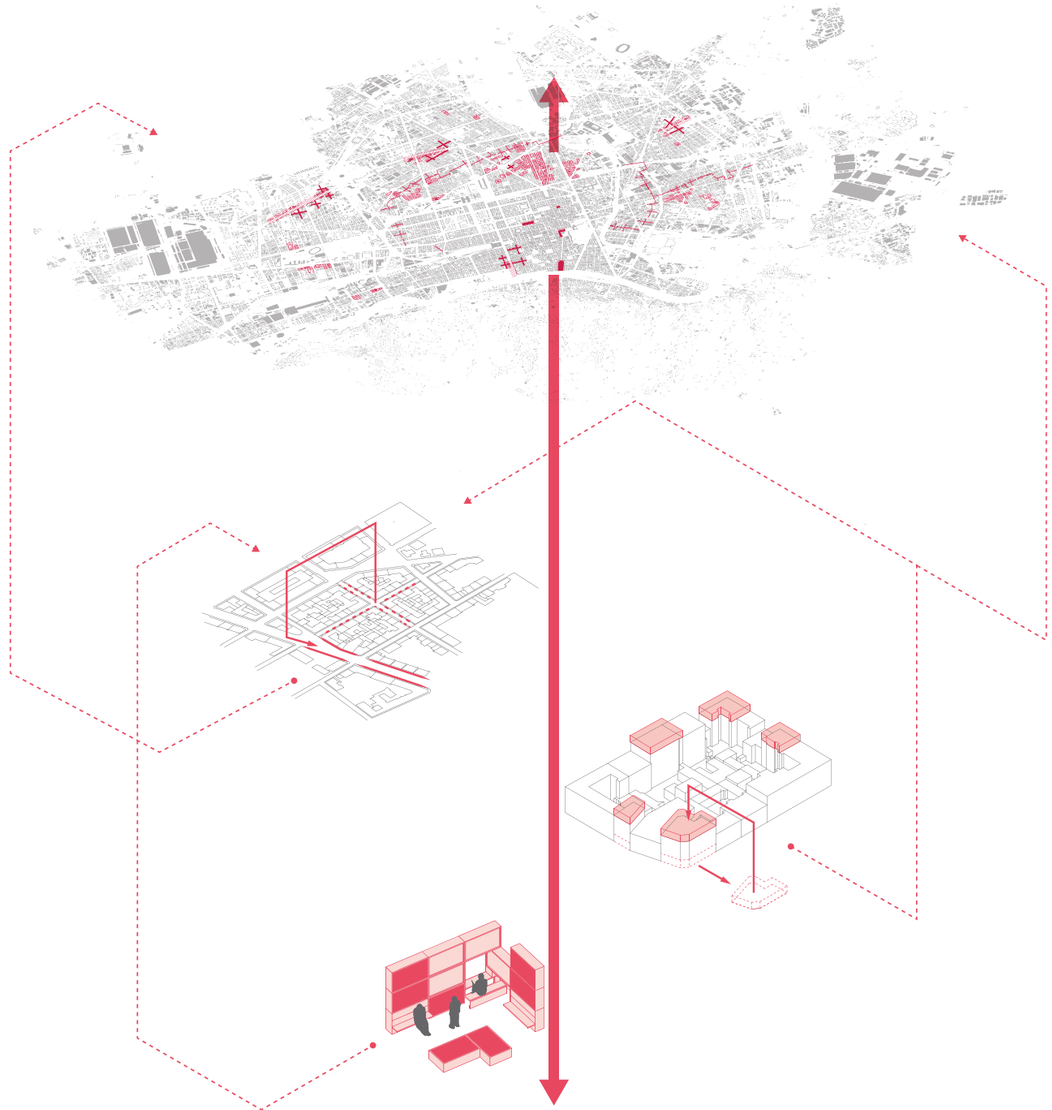
Moving on to Barriera di Milano, the site analysis highlighted the necessity of coping with two different scales: the block scale and the neighbourhood one. As far as the block scale is concerned, the *Porosity* design showed a lot of potentialities; on one side, it enhanced very effective results in terms of pollution dispersion, but it also revealed the capacity of improving the quality of the inner part of the block by adding new values and functions to the space. If applied to the surrounding blocks, the design shows its systemic effect (Fig. 4.51 and 4.52): what is a block-scale design, if up-scaled, has a relevant impact on the neighborhood scale as well. That is showed, once again, by the simulations. Unfortunately, the free version of EnviMet program is not available currently and simulations on a neighborhood or urban scale are not detailed enough or available. However, what remains unclear is that if we compare the maximum values of pollution of the simulation at the block scale (pag. 164-165), values are much higher (almost 3 times) than the one on a large scale. This fact raises the question if the lower values are due to the inaccuracy of the simulation (the free version of the program has limited capacities) or because of broader scale effects that could not be calculated for the block scale.



- Porosity intervention - Urgent need
- Porosity intervention - Possible sites
- Green Crosses - Urgent need
- Green Crosses - Possible sites
- Removal of downwind trees lines
- Existing bikelanes

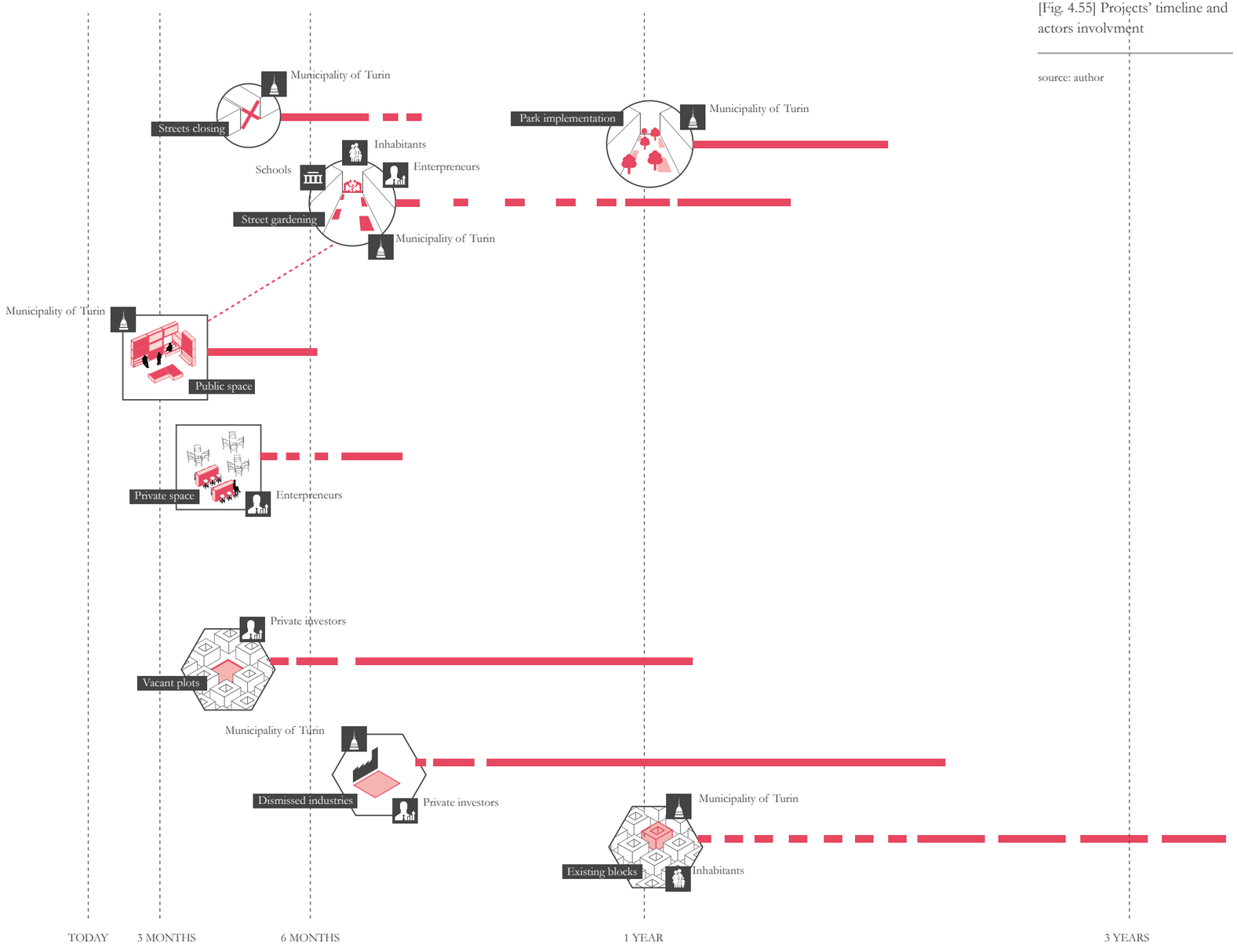
[Fig. 4.53] Vision, systemic effect

source: author



[Fig. 4.54] Project systemic effect

source: author



[Fig. 4.55] Projects' timeline and actors involvment

source: author

The block considered for the Porosity design represents the typical block configuration of Turin. Consequently, its design principle can be applied to most ob the blocks of the city. The map (Fig. 4.53) shows where are the possible areas for future interventions; the selection has been carried out through a combination of the risk map assessment and block typology.
As far as the Green Crosses are concerned, EnviMet program does not allow to take areas broader than the one previously mentioned (Fig. 4.5), therefore verifying their influence on a bigger scale remains unfeasible at this moment. However, a systemic effect might be forcasted. The Green Crosses have the goal of protecting people from air pollution but at the same time to give new values and quality to the space. For doing it, different functions, traffic regulations and green areas have been implemented. One isolated Green Cross works good for an enclosed number of people, but if linked to another one, new positive externalities can happen. For instance, when looking at the bike lane system of Turin, disconnected lanes follow each other without a proper hierarchy and order. Green Crosses, if replicated and adapted to bordering streets, can build a new stronger and more safe bike lane able to connect all the most vulnerable areas of the city (Fig. 4.53). One Green Cross could not serve as bike lane by itself but, if integrated in a bigger system, may affect both pollutants sources and their dispersion.
Overall, the design proposals, despite their different scales of design, they are able to build a strong and thorough system able to affect air pollution on different level and, more important, their areas of effect cross scales.

Projects time-lines and actor involvement

The four interventions, Green Crosses, Porosity, The Walls and Trees removals have different priorities and time of applicability. The most effective, in terms of air pollution mitigation, is Porosity but it requires long planning and implementation time (3-5 years). On the other hand The Walls and The Green Crosses showed faster implementation time (Fig. 4.55), but lower efficacy concerning air pollution mitigation.
As far as the Porosity project is concerned some distinctions must be made. For instance, empty or abandoned blocks may show faster implementation time, since biggest private investors might be interested in housing development. Already existing blocks, on the contrary, require longer time and more complex planning procedures of cooperation between private citizens and public institutions.
Green Crosses can easily start from present days but it might take long time till its completion. Bottom-up initiatives are in fact often very fast and effective since do not depend from the municipality but for finalizing the project public insitutions are reqired.
The Walls is probably the project which should not meet any obstacles in its implementation. Depending mostly from the municipality and entrepreneurs, is the first project which can be implemented.

05

CONCLUSION

Conclusion

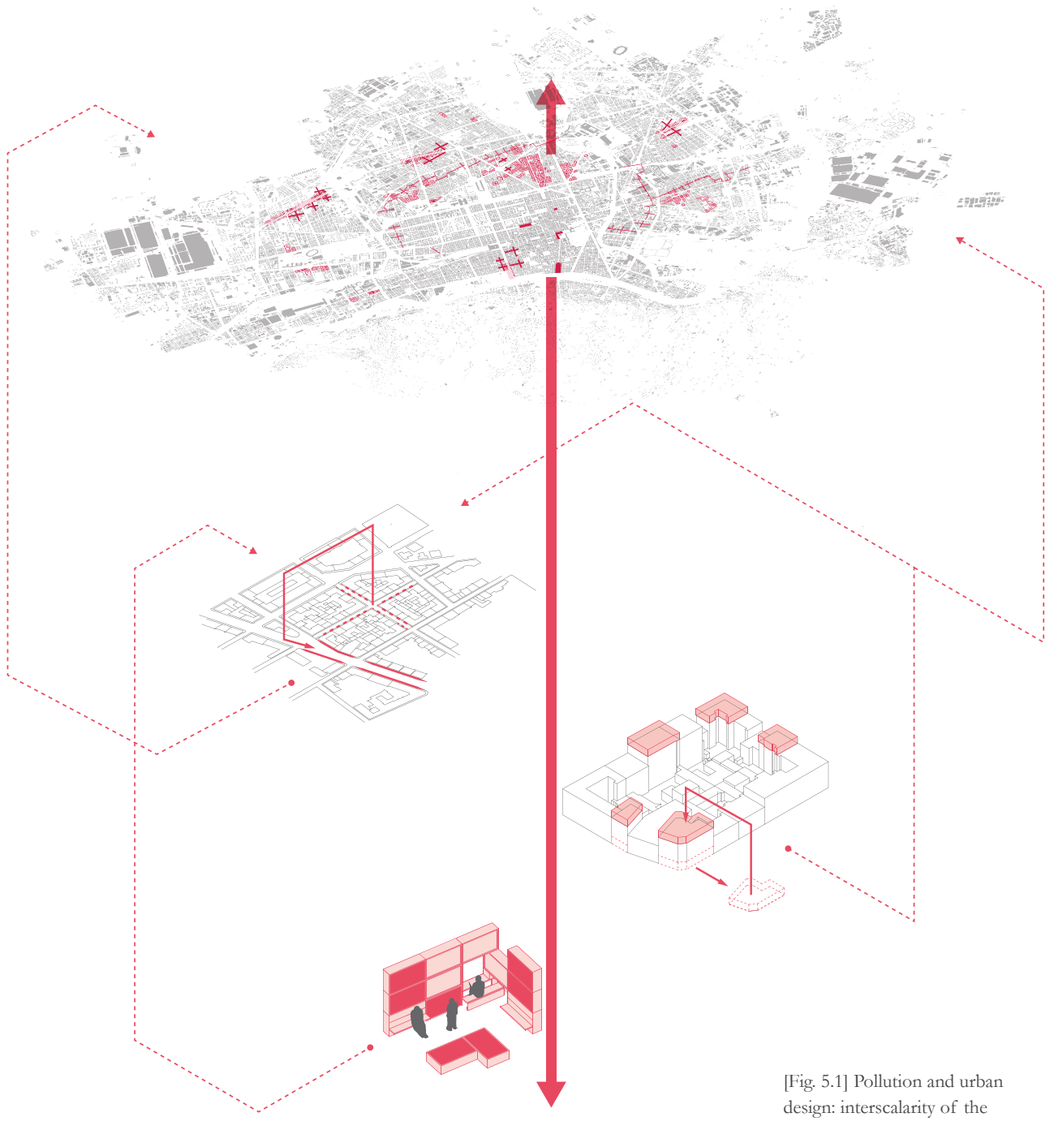
Reflection

Conclusion

In 2016, the World Health Organization announced that almost 92 % of the world's population lives in places where air quality levels exceed the limit values defined by the organization itself (Fig. 1.5, chapter 1). Ambient and indoor air pollution play a key role on population's health. As far as Europe is concerned, air pollution poses the single largest environmental health risk today (EEA, 2015): around 500.000 people died because of exposure to high pollutants concentrations in Europe. Among those, around 20 % of deaths happened to be in Italy.
Turin, the city where I come from, is one of the four most polluted cities in Italy (Mal'Aria, 2016) and it has been suffering of high levels of air pollution for years.
Despite several attempts from the municipality to improve air quality, the situation has slightly changed in the past years and the urgency of the issue calls, therefore, for alternative solutions able to cooperate with the already existing policies and urban strategies. Hence, the research question of the graduation project is:

How can Urban Design mitigate air pollution in the city of Turin?

The research question is at the same time very simple but also very challenging. It tries to discover the relationship between air pollution, the built environment and urban design. To do that, the question was simplified into six sub questions which, by focusing on different topics and issues (but always related) at different times, contributed to building up the structure of the research, the thesis and eventually to the final answer.
To begin with, understanding the relationship between air pollution and the built environment was crucial. Discovering what elements of the urban tissue affect air pollution and how they are related to each other set the basis for the analysis of the city of Turin. The form and the nature of the built environment are critical to air pollution concentration: streets orientation and width, building heights, land cover are just some of the features which play a key role in air pollution mitigation.



[Fig. 5.1] Pollution and urban design: interscalarity of the project

source: author

By looking at different elements of the urban tissues, the analysis firstly revealed that air pollution is an interscalar phenomenon which means that it affects different urban scales at the same time. This characteristic pools together air pollution and urban design: as urban designers, we work through different geographies, temporalities and scales. Air pollution has often been tackled by implementing policies and urban strategies whilst urban design, as possible and valuable answer to this issue, has been often overlooked. The interscalarity of both air pollution and urban design showed a strong alikeness between them. Air pollution can be mitigated by urban design thanks to an interscalar approach.

Once the link between urban design and air pollution was established, the analysis also showed which are the areas with the highest risk concerning air pollution in Turin and consequently defining the scales of urban design that address air pollution was feasible.

The graduation project focuses on three main design interventions. Keeping in mind one of the main subquestions of the project, which is that of understanding the interscalarity of the phenomenon of air pollution and urban design, the interventions try to cope with different scales: micro-scale (public space), block scale and neighborhood scale which, combined to each other, define the urban scale.

The graduation project showed satisfactory results. For instance, it has been discovered that open *porose* blocks have actually the capacity of mitigating air pollution and this principle might be applied, accordingly with specific site conditions, to other cities. Furthermore, the design intervention *Green Crosses* showed how urban design, by working within the street scale, can at the same time affecting air pollution dispersion but also, if implemented at urban scale, influence and offer new movement ways to people and, by doing so, affecting mobility. Moreover, the *Walls*, design at a micro-scale level, by just implementing urban furniture able to filter and divert air flows in the square of Piazza Vittorio, resulted highly effective.

Overall, I strongly believe that urban forms have a great potential in decreasing air pollution concentration and this potential should be further studied and developed. However, as previously-mentioned, urban design cannot stand by itself and, in order to be really effective needs the help of urban policies and strategies. When tackling air pollution, the inclusion of urban design can give new insights to the research. In general, urban designers, when working with climate factors, should include air pollution among the contributing variables to inhabitants well-being.

Trying to draw the conclusions of the graduation project and to answer the research question, urban design and air pollution are both interscalar entities, and this feature allows urban designers to find different solutions at different scales for mitigating air pollution. Micro, block and neighborhood scale interventions, if combined, they can form a coherent and thorough system able to mitigate air pollution. Urban design can therefore contribute efficiently to the already existing policies and urban planning strategies that the city of Turin has been implementing.

Reflection

The graduation project has the aim of understanding the relation between the urban flow of air pollution and the built environment. To this extent, the main objective is that of investigating how urban design solutions can mitigate air pollution in the city of Turin in order to provide alternative solutions to the already existing urban policies. The reflection is divided in two main sections: in the first part, thesis's process, the relation between research and design and the methodology will be reflected upon; in the second part, more detailed considerations regarding the outcomes of the project, its limitations and recommendation for future research will be elaborated.

General

The relationship between research and design

The topic of air pollution is quite insidious since it can be approached with different perspectives and through different disciplines. As mentioned in the first chapter of the report, studying, describing this phenomenon and finally linking it to the field of urbanism is a tricky task. Therefore, the main research splits in two main branches.
The first section focuses on the relationship between air pollution and climate; within this theme, a deep understanding of air pollution, wind formation and fluid dynamic is enhanced. The acquired knowledge allows to define the analytical framework of the project and, consequently, the urban layers which need to be considered when analyzing air pollution in built environments. The discovered layers, which are described according three stages of pollution (sources, dispersion and receptor site) and two extreme scales (mesoscale and street

scale), are used to develop a risk assessment for the city of Turin, which led to the selection of the sites of intervention.
Once the phenomenon of air pollution has been deeply investigated and the most vulnerable areas of the city revealed, the second part of the research contributes to develop design solutions for mitigating air pollution. This section focuses more on discovering and examining existing projects or design principles which cope with air pollution in urban environments. The explored design solutions are studied and the main principles extrapolated and applied within design proposals.
Despite the link between research and design might be more recognizable in the second part of the project, already within the analytical framework, early design thoughts were triggered. Each layer, when analyzed and explored, have underpinned the relevance of a specific feature or area for future design. For instance, when studying wind behavior on a mesoscale, areas with lower wind speed and consequently with less intense air pollution dispersion popped-out and design thoughts on how can wind speed be increased in those areas were triggered.
Overall, research and design are certainly linked both in the analytical and design part of the graduation project and their relationship can be seen as a continuous parallelism, which is recognizable in every stage of the thesis.

The relationship between the theme of the graduation lab (SC & UM) and the graduation project

In this thesis, the overall objective is that of developing design solutions able to mitigate air pollution in urban environments. To this extent, the graduation lab provided by the Smart Cities and Urban Metabolism research group gives the necessary tools, techniques and approaches needed to carry out a thorough project.
The research group describes Urban Metabolism as a "framework for modeling complex urban systems' flows – water, energy, food, people, et cetera – as if the city were an ecosystem". It believes that urban flows can be used to shape urban environments in a more sustainable way. Therefore, within the research group, projects which try to study and link urban flows with urban environment, are strongly encouraged. To this extent, air pollution can be considered as the final output of different flows: transportation, energy consumption, industrial production, waste management are just some of the causes. The thesis has therefore a direct link to the research group. By investigating the complex flow of air pollution within both the urban and provincial context of the city of Turin, the thesis aims to investigate the relation between urban flows, scales and the built environment.

Within the Urban Metabolism, one of the main challenges is that of translating broader data of urban flows into spatial features of the built environment and, eventually, testing their implications on urban forms. To this extent, the graduation lab offered a valid support. Furthermore, the choice of the SM & UM research group played a crucial role in developing a thorough analysis. Air pollution is an abstract phenomenon and understanding its spatial implications is really challenging. The research group helped me in developing compelling methods of analysis.

Methodological approach

The methodology used in the project is guided primary by the research group's (SM & UM) approach of combining a thorough understanding of the considered urban flow (air pollution) with a detailed spatial analysis, leading to a comprehensive investigation of the issue. The analytical model is also reinforced by research methods and tools which reflect the Urban Fabric research group approach; urban morphological analysis and GIS analysis revealed really helpful. The combination of the two methods allow to link the phenomenon of air pollution to the built environment which is, from the beginning, one of the main objectives of the graduation project. What the two methods have in common is the consistent link between research, analysis and design: this relationship is constant during the entire project and both the approaches helped me to deal with the issue.
In general, the chosen methodology follows a linear and well defined structure, which has both positive and negative sides. As far as the pros are concerned, having a "rigid" system helped me to have clear and tackle a complex issue such as air pollution. The theme was decomposed in smaller sections which led to the recognition of its relationship with the built environment. On the other hand, however, this linear, sometimes inflexible, way of thinking slowed down my ability of "cross-referencing". The design approach, in a certain way, rigid as the methodology, was structured according defined stages with the constant parallelism between research. I think that the rigidity of the approach might have limited the design process. Focusing mostly on air pollution-related issues and basing the evaluation only on this factor held me from enhancing a complete holistic design.

The project and its outcome

The matrix of analysis and the risk assessment: a new tool for urban strategies

One of the goals of the matrix of analysis, combined with the risk assessment, was that of identifying the most vulnerable areas in the city of Turin.
As previously mentioned, the analysis is the result of a deep understanding and study of the phenomenon of air pollution and its features. Moreover, the analytical model is built upon a thorough theoretical framework and this feature adds more weightage to it: the choice of each layer is always justified by specific literature.
As far as the risk assessment is concerned, an equally scientific approach could not be ensured and defining an empirical method remains a difficult task. Within the graduation project, the risk assessment is the result of a mix of theories and approaches, but cannot be empirically calculated. General values are given to certain rates of risk but it must be underpinned that the final outcome of the risk assessment is based on a few key assumptions pertaining the specific

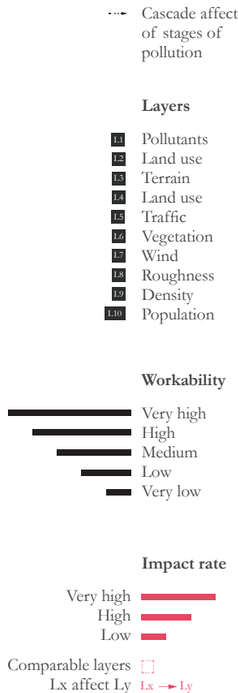
nature of the project site and the literature review. However, despite this, the risk assessment resulted in a successful method for selecting the sites of intervention.
Moreover, the risk assessment can be used for other purposes than just for selecting design sites: for instance, it might be used as tool for planning. The risk map shows where and what are the most vulnerable areas of the city concerning air pollution. This information, in combination with economic and social factors, might build a new environmental layer of analysis useful to the municipality of Turin for future developments. Unfortunately, due to the focus of the graduation project and to time schedule, deepening this aspect could not be possible, but it would have been worthy.

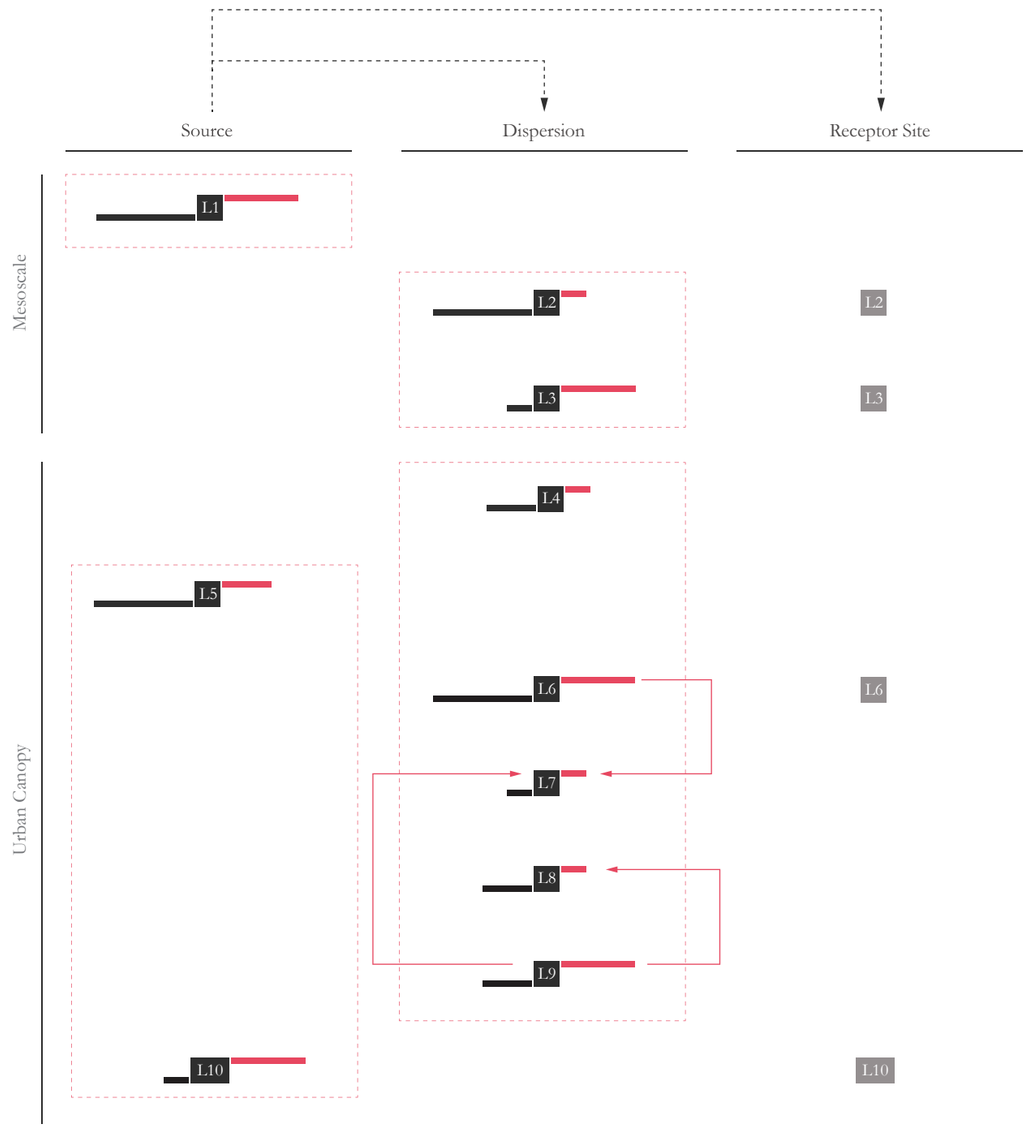
Impact rate and workability

Within the *Theory and Analysis* chapter, the matrix of analysis shows that there are different factors which influence emission and dispersion of air pollution in the city of Turin. However, their impact level, meant as the grade of influence, remains unclear and unexplored. Therefore, as result of the analysis, one of the main goal has been that of comparing and discovering their relative importances and, eventually, building a hierarchy able to identify which layers play the biggest role in air pollution mitigation. The risk assessment, for instance, defines a broad hierarchy between *Sources* and *Receptor Site* layers, assigning to the latter more weightage. However, the method is primary based on the concepts of hazard and vulnerability and, furthermore, it overlooks the layers related to *Dispersion*. Therefore, the method, despite its validity concerning risk assessment, is considered unreliable when it comes to defining the impact rate.
When trying to define the impact rate and drawing conclusions from the analysis, the theories and the design interventions, some distinctions need to be made.
To begin with, the impact rate values need to be assigned independently among the three stages of pollution (sources, dispersion and receptor site); if pollutants (sources) were not there, pollution concentration would be null and, if we had to assign the impact rate considering all the layers together, L1 and L2 would have the highest rate while all the other layers would not count at all (cascade effect). As far as the *receptor site* layers are concerned, since the definition of receptor as "responding unit" has a passive meaning, the impact rate will be the same as the other stages. For example, the layer of Vegetation (L6) falls both in the dispersion and receptor categories; the impact rate will be assigned by looking at the dispersion stage only.
The second required distinction is related to the scale of the layers. The matrix groups the layers according the two extreme scales of air pollution. This divergence can be seen also when trying to assign impact rate values; due to the fact that they work on such extreme scales, the layers are incomparable. For instance, the Density layer (L9) plays a relevant role when it comes to wind flow patterns and pollutants dispersion in urban canyons, but on the mesoscale, the layer is much less relevant while the Terrain layer (L3) is the most influential.
Since a proper scientific assessment cannot be made the impact rate values are divided into three qualitative categories: Low, High and Very High impact.

[Fig. 5.2] Impact rate and workability

source: author





As far as the mesoscale layers are concerned, the layer Terrain (L3) plays the most relevant role when looking at the stage of dispersion. In the case of Turin, hills and the Alps plays a crucial role since they stop most of the winds and by doing so, decrease wind flow pattern at an urban level.
Moving to the urban canopy scale, several considerations can be made. Starting with the *Sources*, between the Traffic layer (L5) and the Population layer (L10), meant as the number of people using cars, the latter has the highest impact since traffic flows are strictly dependent to the users. If the population decided to reduce car usage, pollution concentrations would easily decrease. Concerning the layers related to the stage of *dispersion*, four are the factors which affect pollution and among those the most influent are Vegetation (L6) and Density (L9). The remaining two, Wind (L7) and Roughness (L8) are dependent. That means that by modifying and working with the density and the urban vegetation, the other layer will be affected consequently. For example, by reducing the GSI and increasing FSI, space between buildings would increase, the roughness value and the wind speed as well.

The impact rate assessment showed that some of the layers (Land use L3, Vegetation L6 and Density L9) have an higher impact on air pollution than others. However, when layers fall in the same cluster of scale and stage of pollution, as the case of Vegetation and Density (Fig. 5.2), further considerations can be made.
Within the matrix of analysis (pg. 64), each layer was described, in addition to other features, according to their *workability rate* meant as their possibility to be modified and changed by urban design interventions. These values allow us to narrow down on step further the relevance of the layers. In the case of the layers of Vegetation (L6) and Density (L9), the have both very high impact rate but different workability rates, respectively High and Low. Therefore, when comparing the two layers, having higher workability gives layers more relevance and it suggests which layer the city of Turin should work with as first step towards air pollution mitigation.

Overall, it must be underpinned that the given impact rate values and workability rates are strictly related to the city of Turin, their principles are valid everywhere but their impact might change from site to site.

Air pollution mitigation, social and spatial externalities

Within the graduation project three design interventions at different scales have been proposed and they all showed satisfactory results in terms of air pollution mitigation. However, the proposals do not have only an impact on climate conditions but they also bring social and spatial externalities which deserve to be reflected upon. The design interventions work through the manipulation of urban tissues and, by changing and adapting existing urban forms and spaces, are able to create new functions and to add new values to the space. For instance, in the case of Barriera di Milano, opening the existing block structures (*porosity* design) decreases air pollution concentration but, at the same time, completely changes the

[Fig. 5.2] Porosity, entrance with new residential volumes

source: author

current uses of the outer and inner part of the courtyards and offer citizens new ways of living the space.
As mentioned in the previous chapter, Barriera di Milano has always faced complex and problematic challenges in terms of its social and demographic make-up and the historical absence of green and public spaces. The *Porosity* design intervention not only mitigates air pollution but also provides accessible green and public areas to the citizens. By removing ground floors, access to the inner courtyard is given and new spatial dynamics are enhanced. Starting with the entrances to the courtyards (Fig. 5.2), they are not only transitory spaces which allow air ventilation (air pollution mitigation) and where people walk through; they can also be used as covered public spaces which can easily adapt to different necessities. Children can use it as temporary playground in rainy days, elderlies can find resting places where social interaction can be triggered.
Another important element is the addition (or restitution) of residential volumes on top of the buildings whose ground floors were removed. The design, the related urban programs and the way the volumes are integrated in the existing urban tissue might change the social structure of the neighborhood. For instance, part of the volumes can be utilized as high-end real estate which could attract high-end part of the society to the neighborhood and could generate income for the area.

Overall, the capacity of acting on more than one urban phenomenon (air pollution) shows the value of the design and, in a broader sense, highlights the importance of focusing on more than one aspect when designing. Changing and modifying urban forms often lead to social and spatial implications which need to be always considered in order to achieve a thorough and successful design.

Project outcomes: interscalarity and systemic effect

The graduation project focuses on three main design interventions. Keeping in mind one of the main subquestions of the project, which is that of understanding the interscalarity of the phenomenon of air pollution and urban design, the design tries to cope with different scales. Once again, the strict methodology might have affected the way of thinking resulting in a rigid design approach. The latter is divided in four steps: analysis, design, evaluation and implementation. In this sense, my yearning of proving the efficacy of each design has limited my design thinking.
However, positive outcomes were achieved. Starting with *Barriera di Milano,* the study of urban performances of block typologies led to the discovery that open porose blocks have a huge impact on air pollution mitigation. Moreover, the interscalarity of the design and its systemic effect underpinned the relevance of the design.
As far as *Piazza Vittorio* is concerned, its design has been quite challenging; the dimensions of the space were difficult to deal with. The final outcome of the design is quite effective in terms of air pollution mitigation, but the spatial externalities of the design might have been more strongly defined.
Finally, concerning *Corso Vittorio*, the design can be seen as a scientific research, in fact any design was implemented in the street. However, the outcomes of the design can be used as guidelines for future developments.

Position of the project in the academic and professional debate

Urban designers have showed an increasing interest in urban micro-climate studies; understanding which factors, related to climate conditions, contribute to the physical well-being of inhabitants has gained more priority. Temperature, humidity, radiations, luminance and wind speed are just some of the main focuses of urban micro-climate studies.
Air pollution mitigation, despite its evident connection to urban tissues' climate conditions, is often overlooked by urban designers. In fact, the relationship between air pollution and urban design currently lacks of a comprehensive and extensive literature able to address the issue. As stated in the first chapter of the thesis, this graduation project aims to provide valid and compelling design solutions able to mitigate air pollution and by doing so, also wants to underpin the urgency and necessity of integrating different fields of expertise in the design practice.
As urban designers we deal with more than the physical forms of the urban tissue only: climate-related, social, economical factors influence and are influenced by urban design projects. Since our Master focuses on Urbanism, integrating courses which go beyond urban matters, is quite challenging, but I do believe that the role of universities is that of providing the basic knowledge to future urban designers. It is up to us then (future professionals) to learn and integrate different fields in our practice. I do not believe that urban designers need to become experts in every discipline, but I strongly believe that, nowadays, simple tools are offered to us. It is up to us deciding to use them or not. EnviMet, for instance, is a great example of it. As future urban designer, I am not an expert on air pollution and fluid-dynamic problems, but EnviMet offers me the tools for integrating air pollution mitigation in my design. Of course, I had to study the program but, without being an expert on the topic, I was able to achieve satisfactory results. To this extent, I also believe that one of the strongest qualities of this project is that of connecting and integrating disciplines which are often far from our comfort zone of expertise.

Limitations of the project

Air pollution is a complex issue defined by multiple variables: the type of source, the environment and its physical and climatic features, external economic and social factors are just some of them. It has been highlighted more than once that the issue can be tackled in different ways and by different fields of expertise. As urbanists, we can contribute with two main tools: urban design and urban planning. These are strictly interconnected and cannot stand by themselves, the need and rely on each other: most of the policies and urban strategies

are translated in urban design interventions, and the latter need to back-up by policies for being realized.
Within the graduation project the main focus falls on the role of urban design and on the relationship between urban forms and air pollution. By doing this, the range of possible actions for mitigating air pollution is automatically reduced and narrowed down. That is not a bad outcome but it must be recognized that urban design, even if successful in terms of urban performances in mitigating air pollution, needs the support of more comprehensive and efficient policies. In the graduation project this aspect has been slightly deepened and a major attention was given to the role of urban forms.

Within the Urbanism department of TU Delft, holistic approaches are always encouraged in scientific researches. To this extent, the thesis tries not only to focus on air pollution but also to deal with social and economic factors. During the graduation year, different fields of research such us urban metabolism and urban fabric were combined in order to enhance a holistic approach. However, I realized that, within the studies of climate, air pollution is just one of the factors which need to be studied when designing urban spaces. The goal of the thesis was that of discovering how can urban design mitigate air pollution in the city of Turin and, despite some positive outcomes, other several factors which are equally relevant have been omitted. For instance, when designing open blocks (which resulted extremely effective within the scope of the thesis) noise and temperature were not taken under consideration. This raises the question on how can urban design enhance holistic design solutions able to cope with more than one aspect at time, but also what defines those approaches.

In addition to the above-mentioned limitations, the reliability of the EnviMet program poses an insidious doubt. All the interventions, conclusions and design thoughts of the graduation project rely on the simulation results of the program. Because of lack of founds and subsidies, buying the complete version of the program has not been possible till June 2017 and consequently, the free version was used. The main difference between the two versions lays on the scale of the simulation. The latter are run according to a grid which is composed by a certain amount of simulation units. In the free version the grid is composed by 60x60 units while in the paid version the grid is unlimited (supposedly). In the spatial model it is possible to assign a specific dimension to the unit. This means that if I want to simulate climatic conditions of an area of 600x600meters, within the paid version, any dimensions can be assigned to the grid units (1 meter for example) while, as far as the free version in concerned, in order to make the area fit in the grid, the grid units will have to be set to 10 meters. It is evident then that the accuracy of the simulation might be downgraded: in the first case the simulation is run on multiple cells of 1 m^2 each whilst, with the free version, results are given by clusters of 10 m^2 cells.
Luckily, at the end of the graduation year, the university finally obtained the complete version of the program. Due to lack of time, running all the simulations of the graduation project from scratch was not possible but a comparison between two simulations(one made with the

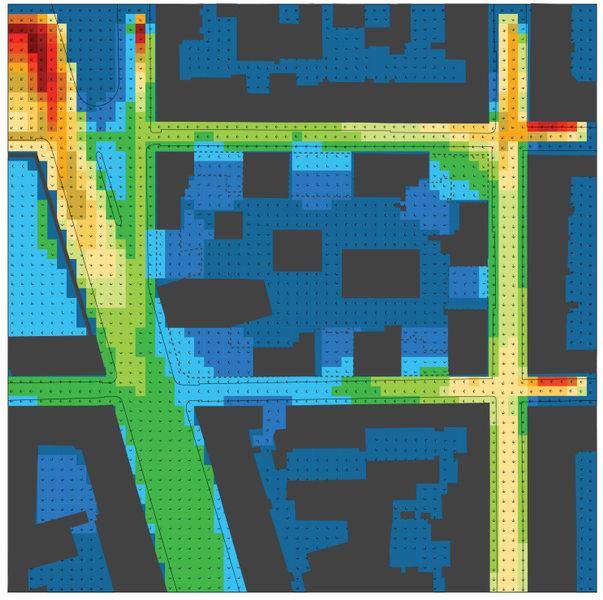
[Fig. 5.3] PM 10 Concentration - Simulation made with the *free version* of EnviMet

source: author

PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

min: 0.00
max: 16.62



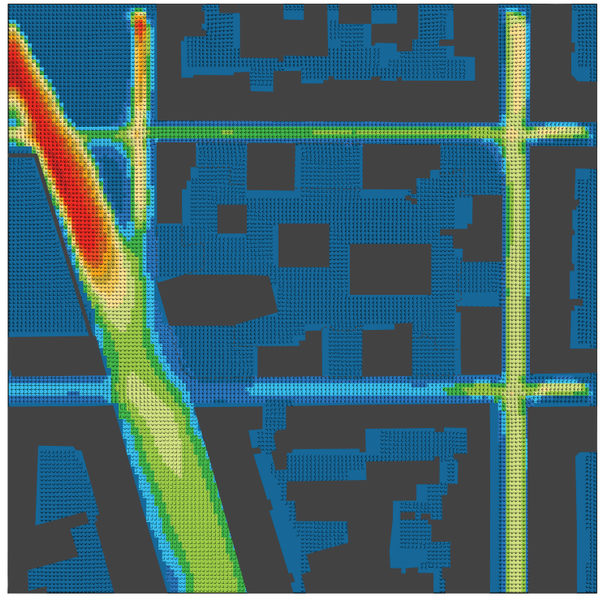
[Fig. 5.4] PM 10 Concentration - Simulation made with the *complete version* of EnviMet

source: author

PM10 Concentration [mcg/m³]

- under 1.00
- 1.00 - 2.00
- 2.00 - 3.00
- 3.00 - 4.00
- 4.00 - 5.00
- 5.00 - 6.00
- 6.00 - 7.00
- 7.00 - 8.00
- 8.00 - 9.00
- 9.00 - 10.00
- 10.00 - 11.00
- 11.00 - 12.00
- 12.00 - 13.00
- 13.00 - 14.00
- 14.00 - 15.00
- 15.00 - 16.00
- 16.00 - 17.00
- 17.00 - 18.00
- 18.00 - 19.00
- above 19.00

min: 0.00
max: 13.74



free version of the program and one with the complete version) helps to understand if the simulations of the graduation project represent a real limitation.

The two simulations (Fig. 5.3 and 5.4) have the same grid dimensions (150 x 150 m) but different simulation units: respectively 5 meters and 1 meter. In general, when comparing the qualitative outcome of the simulations, the results are quite similar. Of course, figure 5.4 is more accurate but, in terms of air pollutant concentration, the main difference can be found when comparing the inner courtyards: the free version shows values between 1 and 3 mcg/m^3 under the open passages of the courtyard while the complete version shows values under 1 mcg/m^3. This discrepancy can be also noticed when comparing the maximum values of PM concentration: 16.62 mcg/m^3 for the free version and 13.74 mcg/m^3 for the complete one.

At the beginning of the paragraph the reliability of the free version of EnviMet was questioned and consequently its effect on the limitations of the project. The comparison between the two versions showed that the results obtained with the free version are quite reliable; their qualitative results (graphic visualizations) might mislead sometimes but in terms of quantitative results (max and min values) they seem to have a value discrepancy between 1 and 2 mcg/m^3.

At last, after trying the complete version of EnviMet, there is one final feature of the program which constitutes a relevant limitation: the grid itself. With the complete version it is possible to build grids with any dimension but the analysis or simulations are possible only on grids with three main dimensions: 100x100, 150x150 and 250x250 meters. That means that, if the simulation units are set to 1 meter, areas broader than 250x250 meters cannot be analyzed. Consequently, simulations at urban scales with the highest accuracy can not be carried out.

Overall, EnviMet can be considered a valid program when assessing climate conditions such as air pollution; it must however be recognized that, as every program, it has its limitations which need to be acknowledged and taken under consideration: it works really well when simulating and analyzing on a block scale but accurate simulations on urban scale seem to be unfeasible, or at least not practical.

References

books and journals

ADGER, W. N. (1999). Social Vulnerability to Climate Change and Extremes in Coastal Vietnam, *World Development*, 27 (2), 249-269.

ADGER, W. N. AND KELLY, P. M. (1999) Social vulnerability to climate change and the architecture of entitlements, *Mitigation and Adaptation Strategies for Global Change*, 4, 253-266.

ALEXIS, N., BARNES, C., BERNSTEIN, L., BERNSTEIN, J. A., NEL, A., PEDEN, D., ... BROCK WILLIAMS, P. (2004). Health effects of air pollution. *J Allergy Clin Immunol*, 114, 1-20.

ALLEN, K. (2003). Vulnerability reduction and the community-based approach, in Pelling (ed.), *Natural Disasters and Development in a Globalising World*, 170-184.

BARTON, H. (2009). Land use planning and health and well-being. *Land Use Policy*, 26, 115-123.

BARTON, H., GRANT, M. (2011). A review on the Progress of the European Healthy Cities Programme. *Journal of Urban Health: Bulletin of the New York Academy of Medicine*.

BROOKS, N., 2003. Vulnerability, risk and adaptation: A conceptual framework. *Tyndall Centre for Climate Change Research Working Paper*, 38, 1-16.

BURNS, J. C., KAHN, A. (2015). *Site Matters. Design Concepts, Histories, and Strategies*. New York: Routledge.

BURTON, I., KATES, R.W., WHITE, G.F. (1978). *The Environment as Hazard*. Oxford University Press, Oxford, UK.

CERVERO, R. (1996). Traditional neighborhoods and commuting in the San Francisco Bay Area. *Transportation*. 23, 373–394.

CERVERO, R., KOCKELMAN, K. (1997). Travel demand and the 3Ds: Density, diversity and design. *Transportation Research ,* Part D , 2, 199–219.

COMOLI MANDRACCI, V. (2010). *Torino*. Editori Laterza

CURTIS, L., REA, W., SMITH-WILLIS, P., FENYVES, E., PAN, Y. (2006). Adverse health effects of outdoor air pollutants. *Environment International*, 32, 815–830.

DE VOS, J. (2015). The influence of land use and mobility policy on travel behavior: A comparative case study of Flanders and the Netherlands. *The Journal of transport and land use*. vol 8., n. 1, 171–190.

DI VITO, S., MINUTOLO, A., ZAMPETTI, G. (2016). *Mal'ARIA di città 2016*. L'inquinamento atmosferico e acustico nelle città italiane. Legambiente.

ERELL, E., PEARLMUTTER, D., & WILLIAMSON, T. (2011). *Urban Microclimate: Designing the Spaces between Buildings*. London: Earthscan.

FRANK, L., LESLIE, E., DU TOIT, L., OWEN. N. (2007). Destinations that matter: Associations with walking for transport. *Health and Place*,13, 713-724.

FÜSSEL, H. M. (2007). Vulnerability: a generally applicable conceptual framework for climate change research. *Global environmental change*, 17(2), 155-167.

GALEA, S., VLAHOV, D. (2005). Urban Health: evidence, challenges, and directions. *Annual Review of Public Health*, 26, 341-365.

GRANT, M. (2015). European Healthy City Network Phase V: patterns emerging for healthy urban planning. *Health Promotion International*, 30, 54-70. GUERREIRO, C & TEAM. (2015). *Air quality in Europe - 2015 report*. (Report no. 5. 2015). Luxemburg: Publication office of the European Union.

HEWITT, K. (1997). *Regions of Risk. A Geographical Introduction to Disasters*. Addison Wesley Longman, Essex, UK.

JOINT COMMITTEE FOR GUIDES IN METROLOGY. (2008). Measurement unit. *International Vocabulary of Metrology – Basic and General Concepts and Associated Terms* , 6–7.

JONES, R. , BOER, R. (2003). Assessing current climate risks Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change, UNDP, in review, see http://www.undp.org/cc/apf-outline.htm).

KAMPA, M., CASTANAS, E. (2008). Human health effects of air pollution. *Environmental Pollution*, 151, 362-367.

KARAGULIAN, F., BELIS, C. A., DORA, C. F., PRÜSS-USTÜN, A., BONJOUR, S., ADAIR, H., AMANN, M. (2015). Contribution to cities' ambient particular matter (PM): a systematic review of local source contribution at global level. *Atmospheric Environment*, 120, 475-483.

KRAUTHEIM, M., PASEL, R., PFEIFFER, S., & SCHULTZ-GRANBERG, J. (2014). *City and Wind. Climate as an Architectural Instrument*. Berlin: Dom Publisher.

KATES, R.W. (1985). The interaction of climate and society. In: Kates, R.W., Ausubel, H., Berberian, M. (Eds.), *Climate Impact Assessment*. Wiley, Chichester, UK (Chapter 1).

METZ, D. (2013). Peak car and beyond: the fourth era of travel. *Transport Reviews* . 33,3, 255–270.

MEURS, H. (2003). Special issue: Land Use and Sustainable Mobility. *EJTIR*, 3, no. 2, 109-117.

MOLINA, P., PAVONE, F., BERTELLO, A., MARIA, D. (2014). *Uno sguardo all'aria 2014*. Torino, Arpa, Città Metropolitana di Torino.

NEWMAN, P., KENWORTHY, J. (2011). Peak car use: Understanding the demise of automobile dependence. *World Transport Policy and Practice* . 17, 2, 31–42.

OKE, T.R. (1987). *Boundary layer climates*. New York, Rutledge.

OSWALD, F., BACCINI, P., & MICHAELI, M. (2003). *Designing the urban*. Berlin: Springer Science & Business Media.

PARFITT, J. (1988). *The Health of a City: Oxford, 1770-1974*. Oxford: Amate Press.

PASSE, U., BATTAGLIA, F. (2015). *Designing spaces for natural ventilation. An architect's guide*. NY, Routledge.

PIJPERS-VAN ESCH, M. (2015). *Designing the Urban Microclimate. A framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process*. PhD, Delft Univeristy of Technology.

PONT, B., HAUPT, P. (2010). *Space Matrix: Space, Density and Urban Form Meta*. Rotterdam, NL: Nai Publisher.

PRÜSS-USTÜN, A., WOLF, J., CORVALÁN, C., BOS, R., & NEIRA, M. (2016). *Preventing diseases through healthy environments: a global assessment of the burden of disease from environmental risks*. Geneva: World Health Organization.

ROY, R., MARTUZZI, M., GEORGE, F. (2015). *Economic cost of the health impact of air pollution in Europe*. Chopenhagen: WHO Regional Office for Europe.

RYDIN, Y., BLEAHU, A., DAVIES, M., DÀVILA, J.D., FRIEL, S., DE GRANDIS, G. (2012). *Shaping cities for health: complexity and the planning of urban environments in the 21st century*. London: Lancet.

SHISHEGAR, N. (2013). Street Design and Urban Microclimate: analyzing the Effects of Street Geometry and Orientation on Airflow and Solar Access in Urban Canyons. *Journal of Clean Energy Technologies*, 1, 53-56.

SIAT. (2003). *26 Itinerari di Architettura a Torino*. Torino, SIAT.

SPIRN, A. (1986). *Air quality at street-level: strategies for urban design*. Boston: Redevelopment Authority

VIANA, M., PEY, J., DE LEEUW, F., QUEROL, X., ALASTUEY, A., DALL'OSTO,M.& MORENO, T. (2012). *Particulate matter from natural sources and related reporting under the EU Air Quality directive in 2008 and 2009*. (Report no. 10. 2012). Luxembourg: Publications Office of the European Union.

UN. (2004). *Living with Risk: A Global Review of Disaster Reduction Initiatives*. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

VOS, P., MAIHEU, B., VANKERKOM, J. & JANSSEN, S. (2013). Improving local air quality in cities: To tree or not to tree? *Urban Environmental Pollution*, 183, 113-122.

WEBSTER, P., SANDERSON, D. (2013). Healthy Cities Indicators - A Suitable Instrument to Measure Health? *Journal Urban Health*, 90, 52–61.

WHO. (2006). *WHO Air quality guidelines for particulate matter,ozone, nitrogen dioxide and sulfur dioxide*.Geneva: World Health Organization.

WHO. (2010). *Urban planning, environment and health. From evidence to policy action*. Copenhagen: World Health Organization.

WHO. (2014). *World Urbanization Prospects. The 2014 Revision*. New York: United Nations.

WHO. (2014a). *Burden Diseases from Ambient Air Pollution for 2012, Description of Methods*. Version 1.3. Geneva, WHO.

WHO. (2014b). *WHO's Ambient Air Pollution Database - Update 2014. Data summary of the AAP Database*. Geneva, WHO.

WORLD BANK. (2002). *Urban air pollution. South Asia Urban Air Quality Management Briefing* . Note n. 6.

news paper articles

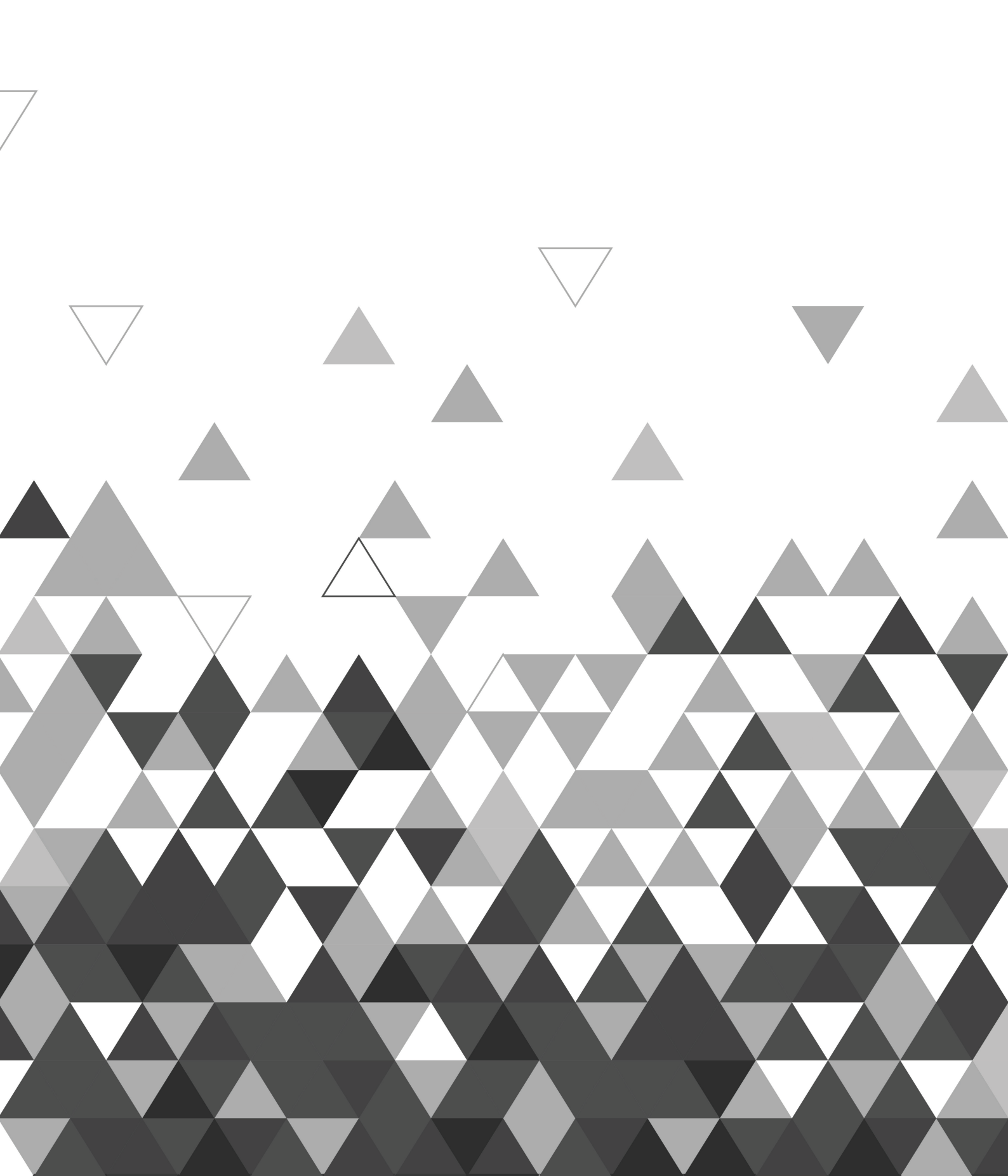
GATES, G., EWING, J., RUSSELL, K., & WATKINS, D. (2016, December 20). How Volkswagen Is Grappling With Its Diesel Scandal. *The New York Times*. Retrieved from http://www.nytimes.com/interactive/2015/business/international/vw-diesel-emissions-scandal-explained.html?_r=0

GIACOSA, M. (2015, January 30). Smog e polveri sottili, è Torino la città più inquinata d'Italia. *La Repubblica*. Retrieved from http://www.repubblica.it/

JOHNSTON, I. (2016, November 2). UK Government has breached air pollution laws and failed to take enough action on emissions, High Court rules. *Independent*. Retrieved from http://www.independent.co.uk/environment/air-pollution-verdict-uk-high-court-government-breach-laws-not-doing-enough-a7392876.html

MONDO, A. (2016, September 1).A Torino e Milano lo smog quadruplica la velocità di usura di cuore e cervello. *La Stampa*. Retrieved from http://www.lastampa.it/

MOONEY, C. (2016, October 27) The more we learn about air pollution, the worse it gets. *The Washington Post*. Retrieved from https://www.washingtonpost.com/

websites

http://www.who.int/mediacentre/factsheets/fs313/en/
http://www.eea.europa.eu/media/newsreleases/air-pollution-still-causing-harm
https://urbanmetabolism.weblog.tudelft.nl/
http://www.envi-met.com/company#profile
http://ec.europa.eu/regional_policy/en/newsroom/news/2016/03/23-03-2016-a-make-over-for-turin-s-urban-spaces
http://www.elegantembellishments.net/home-1/
http://www.accoya.com
http://www.prosolve370e.com/