La progettazione urbana come strumento per mitigare le concentrazioni locali di inquinanti dell'aria: il caso di Torino

Urban Design as a Tool for Mitigating Local Concentrations of Air Pollution: the Case of Turin

MARCELLO FELICE VIETTI

Marcello Felice Vietti, architetto e urban designer, Master of Science in Architecture, Urbanism and Building Sciences (Urbanism) presso la Delft University of Technology.

marcellofelice.vietti@gmail.com

Abstract

Nell'affrontare l'inquinamento atmosferico urbano, la disciplina della pianificazione urbana ha spesso dimostrato una forte propensione verso soluzioni più sostenibili e rispettose dell'ambiente: trasporti pubblici sostenibili e intelligenti, controllo del traffico e educazione sanitaria sono solo alcune delle azioni intraprese. Tuttavia, a causa della loro natura, le politiche sono temporanee e spesso dipendono da fattori politici, economici e culturali, che possono prevalere sul benessere degli abitanti.
La città di Torino, una delle quattro città più inquinate in Italia, ha dovuto affrontare alti tassi di concentrazione dell'inquinamento atmosferico per diversi anni e l'urgenza del problema richiede soluzioni alternative e concrete. L'articolo riassume un progetto di ricerca di dieci mesi condotto presso la Delft University of Technology, dedicato alla comprensione della relazione tra le forme urbane e le concentrazioni locali di inquinamento atmosferico, prendendo come caso studio la città di Torino. Il documento affronta principalmente i risultati del progetto, rivelando il forte legame tra le forme urbane e l'inquinamento atmosferico: tre proposte di design, caratterizzate da diverse scale di azione, sono esplorate e valutate. Nel complesso, la ricerca conferma la rilevanza del design urbano nel valutare l'inquinamento atmosferico nelle città, ma soprattutto fornisce soluzioni di design valide, efficaci e alternative in grado di supportare le politiche urbane già esistenti.

When tackling urban air pollution, the discipline of urban planning has often shown a strong tradition of developing strategic guidelines and policies towards more sustainable and environmental-friendly solutions: sustainable and smart public transport, traffic control and health education are just some of the undertaken actions. However, because of their nature, policies are temporary and often depend on political, economic and cultural factors, which can prevail on the inhabitants' well-being.
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 years and the urgency of the issue calls for alternative and concrete solutions.
The article is a summary of a ten-month research project carried out at the Delft University of Technology and focuses on understanding and discovering the relation between urban forms and local air pollution concentrations, taking as case study the city of Turin. The paper mostly addresses the outcomes of the project, revealing the strong link between urban forms and air pollution: three design proposals, characterized by different scales of action, are explored and evaluated. Overall, the research substantiates the relevance of urban design when assessing air pollution in cities but most importantly provides valuable, effective and alternative design solutions able to support the already existing urban policies in the city of Turin.

1. Introduction

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[1]. Ambient and indoor air pollution play a key role on population's health and pose multiple challenges in terms of mitigation and management. To this extent, the discipline of urban planning has often shown a strong tradition of developing strategic guidelines and policies towards more sustainable and environmental-friendly solutions (Barton and Grant, 2012; Barton, 2009). On the other hand, the link between urban design and air pollution seems to be very weak. Despite several attempts and guidelines (Spirn, 1986; Krautheim et al, 2014; Erell, et al, 2010) have been carried out in the past two decades, the field of urban design is still lacking a proper literature which connects urban forms and air pollution and gives valid solutions for both already existing and developing urban environments. The paper is a summary of a ten-month research project carried out at the Delft University of Technology and focuses on understanding and discovering the relation between urban forms and local air pollution concentrations, taking as case study the city of Turin, Italy. The paper mostly addresses the outcomes of the project, revealing the strong link between urban forms and air pollution.

2. Turin, the city without wind

According to the European Environment Agency's, 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, is the area with the more dramatic and pressing issues and Turin, is one of the four most polluted Italian cities (Mal'Aria di Città, 2016). Because of its position, surrounded by the Alps and hills (Figure 1), wind speed are dramatically slowed down and, consequently, polluted air cannot be dispersed and remains steady upon the city. As a matter of fact, Turin's year wind speed average is about 2 m/s and either dispersion or transportation of pollutants are not consisting and pollutants stay in the air for long periods, causing high pollutants concentrations.

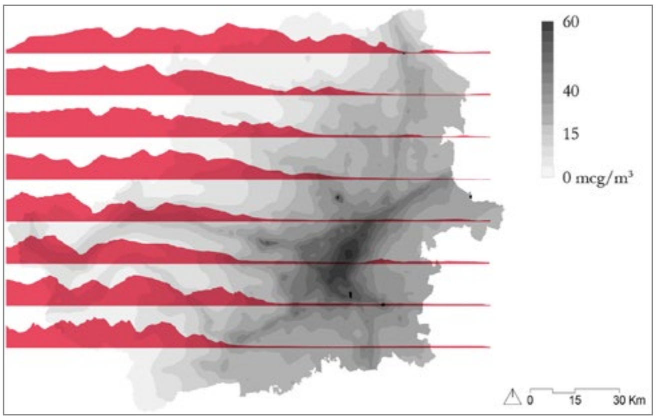

Figure 1. NO_2 concentration and territorial sections in the province of Turin. derived from: NO_2 map: G. Carlino, L. Pallavidino, R. Prandi, Micro-scale modelling of urban air quality to forecast NO_2 critical levels in traffic hot-spots, *10th International Conference on Air Quality, 14-18 March 2016, Milan, Italy.*

3. The project structure

3.1. The social layer as a main basis for the air pollution risk assessment

The research can be broadly divided into two main units: the analysis and the design-by-research. In the first part of the research, after a thorough and meticulous data collection concerning air pollution concentration rates, wind speeds values and urban-micro climate data of the city of Turin, the main challenge is linking the collected data to the physical features of the urban space and -most important- to understand which areas of the city require our attention the most; in other words, the areas with the highest risk of exposure. The most common and straightforward way of thinking would be that of choosing the areas with the highest concentration rate of air pollutants (Particular Matter 10 and Nitrogen [Di]oxide in the case of Turin). The concept of risk has been widely explored (Burton et al, 1978; Kates, 1985; Hewitt, 1997) and it is strictly related to the vulnerability one which can be seen 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 (air pollution). In other words, the fact that certain areas of the city are more polluted than others does not imply the highest risk; what makes the difference is the social layer: population density and age, education and healthcare clusters are the one which make an area most vulnerable. In general, the risk assessment[2] reveals that there are areas in the city of Turin which require more attention than others (Figure 2).

3.2. Simulations as design evaluation method

Moving to the second part of the project, from the risk assessment, three areas are chosen as sites of intervention. Prior to get into the specificity of each site and the outcomes of the design, its approach needs to be specified. To understand the urban-micro climate conditions of each site, air pollution dispersion behaviors are simulated but, since empirical data concerning actual conditions of air pollution and wind speeds are not available at a small scale, arbitrary standard values of Particulate Metter[3] 10 has been assigned. The choice does not affect the validity

Figure 2. Air pollution risk assessment map.

of the research, since 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 play a relevant role in assessing the validity of the design. The simulations are conducted with the software ENVI-met, a three dimensional computational fluid dynamics (CFD) model that is particularly tailored for simulating different urban atmospheric processes such as pollutant dispersion and microclimate effects.

4. Design proposals and evaluation

As previously-mentioned the project focuses on three main design interventions which try to cope with different scales: micro-scale (public space), block scale and street scale which, combined to each other, define the urban scale.

Among the six most vulnerable areas, the selection of the sites is made upon a comparison among layers of the urban tissue which play a relevant role in air pollution dispersion – such as presence of vegetation, FSI and GSI values, roughness (ratio between building heights and street width) and land use. For instance, areas defined by low density imply higher chances for air pollution to disperse and, consequently, express a lower risk. Furthermore, the risk rate of an area might have been downgraded by other factors such as scale, position, social and economic traits. For each site a "what if" scenario is applied, and different design proposals are tested and evaluated. However, due to the scope and interest of the article, the following paragraphs will focus only on the ones which showed the most satisfactory results in terms of air pollution mitigation.

4.1. The public space: Piazza Vittorio Veneto

Piazza Vittorio Veneto is one of the biggest squares 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 to different purposes. 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.

4.1.1. Design proposal: the *green walls*

The main objective of the design is understanding how urban design interventions can affect wind flow patterns and contribute to decrease local air pollution concentration. After simulating the current urban micro climate conditions of the square, a recurring air pattern is recognized: winds coming from the streets tend to be canalized towards the upward parallel street, making the left part of the square more polluted than the right one.

The design modifies the air circulation in the square by inserting self-standing green facades which, while decreasing air pollution concentrations, shape and characterize the surrounding space. Once established the necessity of green facades, the design intervention must be defined in its positions and dimensions. Four layouts are proposed differing for lengths, space continuity and height (Figure 3):

- Proposal A: 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[4].
- Proposal B: Similar to the first proposal, but with shorter walls, the design aims to change local wind directions.
- Proposal C: Long curvy walls follow (not always) wind flow patterns and try to channel them in order to increase its speed.
- Proposal D: Short curvy walls aim to affect local wind direction by creating new micro-turbulences.

4.1.2. Design evaluation

To begin with, regarding PM10 concentration, all the proposals achieve a considerable improvement when comparing it to the current situation (Figure 4). Two aspects can be considered: the empirical maximum value of concentration and the 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 (Figure 4), it can be noticed that the left part of the square is positively affected by the design intervention. When considering wind, their speed remains almost the same, while the number of micro-turbulences is increased. Hence, it

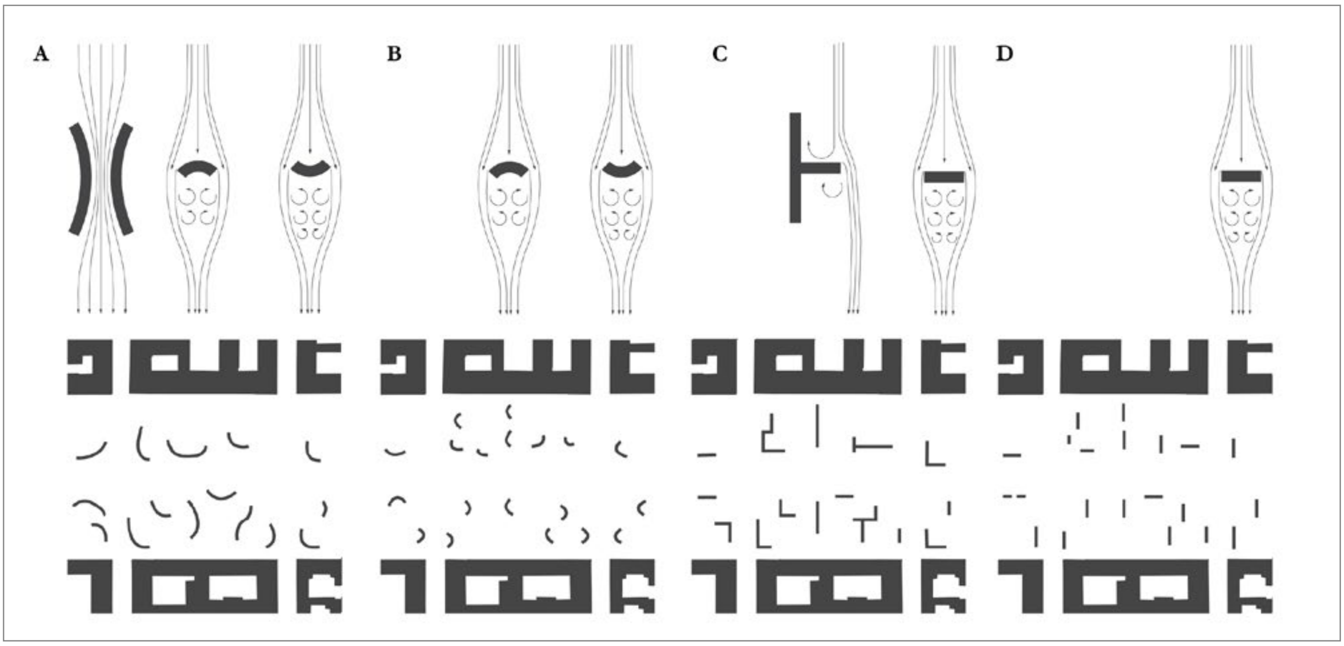

Figure 3. Green Walls design proposal: principles.

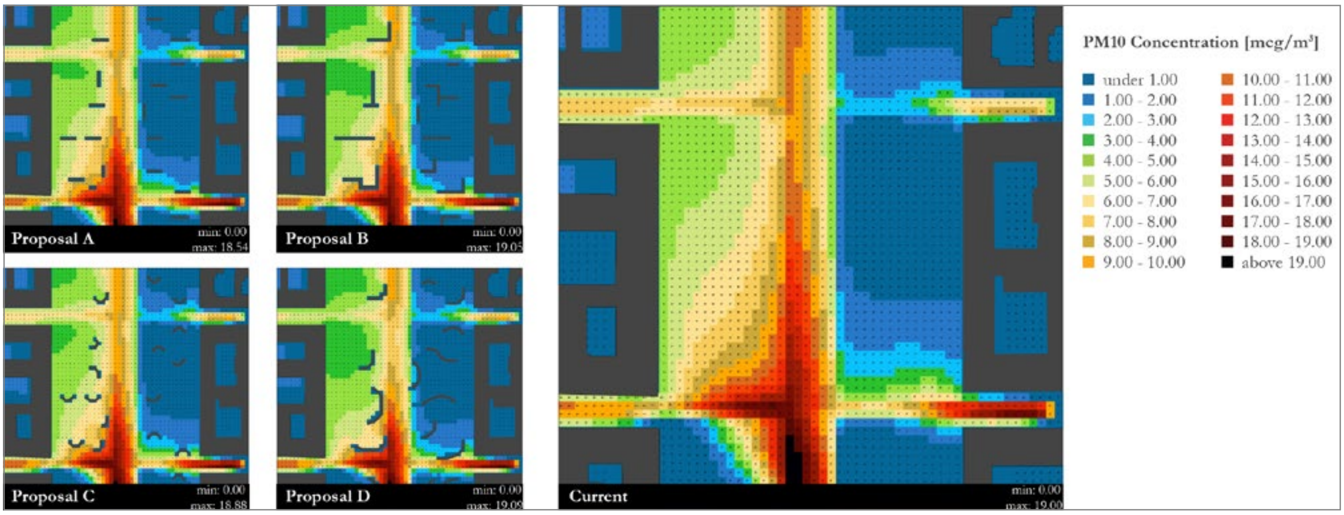

Figure 4. Green Walls design proposal: PM10 concentrations comparison.

can be concluded that the mitigating capacity of the wall is mostly given by their ability of diverting wind instead of increasing its speed.

4.2. Barriera di Milano: the (closed) urban block and the street scale

Barriera di Milano is a neighborhood in the northern part of the city which is 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 GSI values (between 0.61 and 0.81), streets width, and the resulting skimming flow effect[5], combined with high level of pollution, stand for a real threat.

4.2.1. Design proposal: increasing porosity

Different researches (Spirn, 1986; Krautheim et al, 2014) show that urban tissues play a relevant role in mitigating air pollution[6]; the main goal of the design is to discover how different block typologies cope with air pollution and it aims to enhance healthier and safer environments. The urban tissue of Turin is quite homogeneous, the street network defines closed urban blocks. Therefore, the design focuses on one of them which represents a case study from which design principles applicable in different part of the city are revealed by exploring four different way of manipulating the urban block unit (Figure 5):

- Proposal A: The design proposal studies whether implementing green areas in the inner part of the block

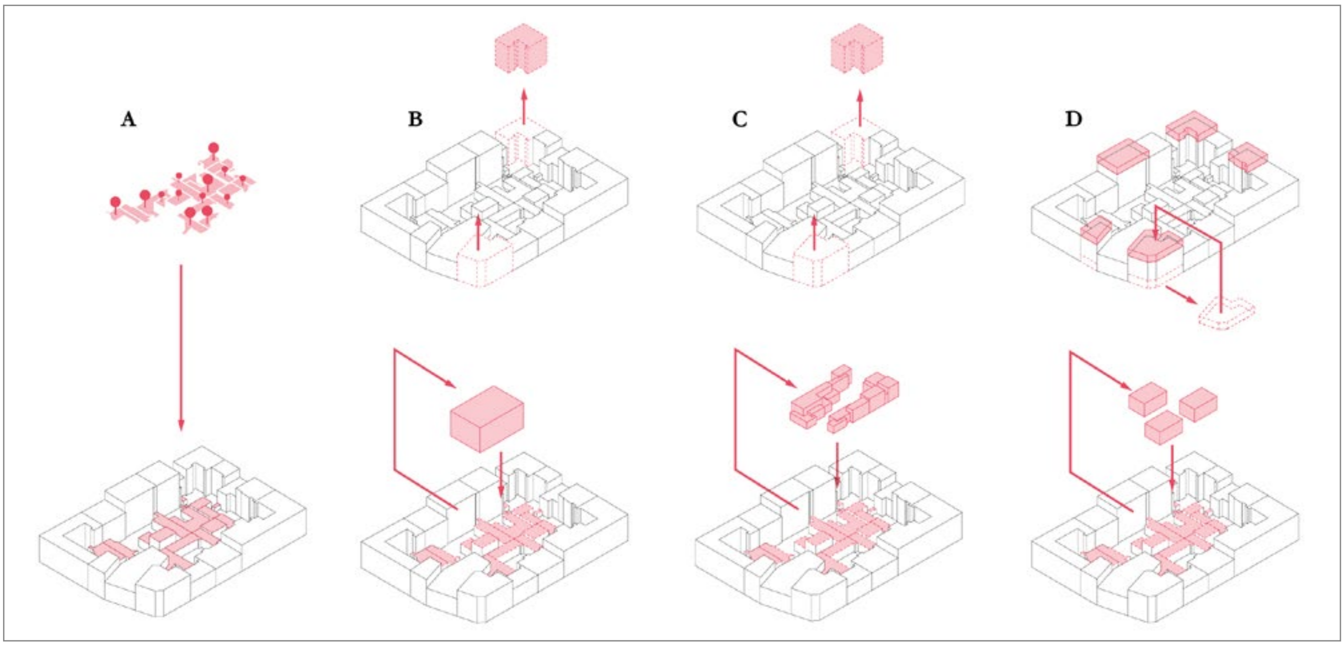

Figure 5. Urban Block design proposal: principles.

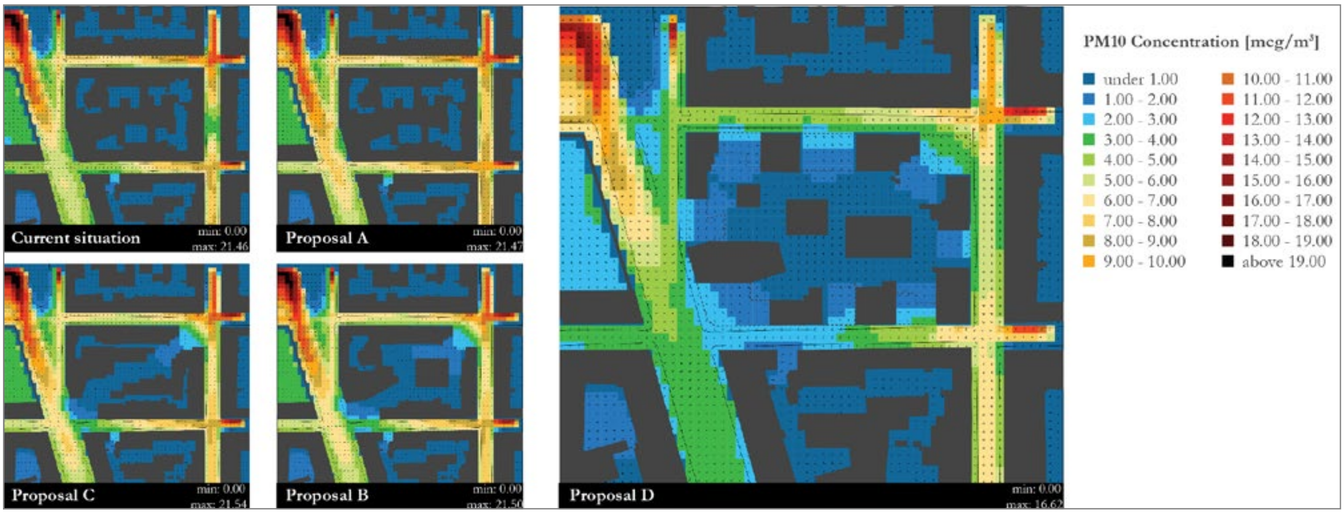

Fig.6. Urban Block Design proposal: PM10 concentrations comparison.

has positive effects on air pollution mitigation. The intervention does not affect the already existing volumes since it deals mostly with their rooftops. Researches have demonstrated that urban vegetation contribute to clean the air at a mesoscale, the design aims to understand whether it helps also at a block scale.

- Proposal B: The proposal aims to divert wind flows into multiple directions and, at the same time, tries to lead winds into aisles. By opening two corners of the selected block and by reorganizing the inner volumes of the courtyard into a more compact configuration (higher FSI) winds are successfully diverted.
- Proposal C: The proposal combines the diverting and stepping effect[7] of wind flows patterns. The design plans to remove the corners of the block and to reorganize the inner part of the block in order to create a small wind canyon within the courtyard.
- Proposal D: The last proposal, probably the most radical, takes to extremes the concept of the diverting effect. The block is opened by removing some of the residential ground floors and giving them back on the top of the buildings. Moreover, the inner volumes of the block are reorganized in more compact solutions, with higher FSI.

4.2.2. Design evaluation

Concerning PM10 values (Figure 6), Proposal D is the design with the most effective results. The maximum value is 16.62 $\mu g/m^3$ whilst the Current's one is 21.62 $\mu g/m^3$. Furthermore, when looking at the visual results, proposal D affects the surrounding streets and has a major impact on the main road with higher traffic. Proposal A is quite surprising: it actually increases the maximum values of pollutants. That is due probably to the presence of the trees which decrease wind flows on an upper layer of the air and consequently affect air pollutant dispersion. Proposals B and C have results similar to Proposal A and do not improve the situation dramatically. As far as wind flow patterns are concerned, maximum values remain almost the same as the current situation in all the proposals. It can be concluded that increasing porosity seems to be the more effective design solution for mitigating local air pollution concentration: the ability of diverting winds increases pollutants dispersion.

4.2.3. Design proposal: 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[8], 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 (Figure 7).

4.2.4. Design evaluation

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 (Fig. 7) 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.

5. Outcomes of the project: towards an interscalar approach against air pollution

One of the main goal of the project is discovering at what scales urban design can affect air pollution and, consequently, if the proposed design interventions can have a systemic effect[9].

As far as Piazza Vittorio Veneto is concerned, the design affects just the square itself and, therefore, if applied in other areas, would not be influenced or influence any other scale. As a micro-scale 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 street one. As far as the block scale is concerned, the proposal D shows a lot of potentialities: it enhances very effective results in terms of pollution mitigations and, if applied to the surrounding blocks, the design shows its systemic effect: what is a block-scale design, if up-scaled, has a relevant impact on the neighborhood scale as well. The block considered for the design intervention represents the typical block configuration of Turin. Consequently, its design principle might be applied to most of the blocks of the city. As far as the Green Crosses are concerned, the free version of the ENVI-met program does not allow to take areas broader than the one previously mentioned, therefore verifying their influence on a bigger scale remains unfeasible. However, a systemic effect might be forecasted. 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 so, different functions, traffic regulations and

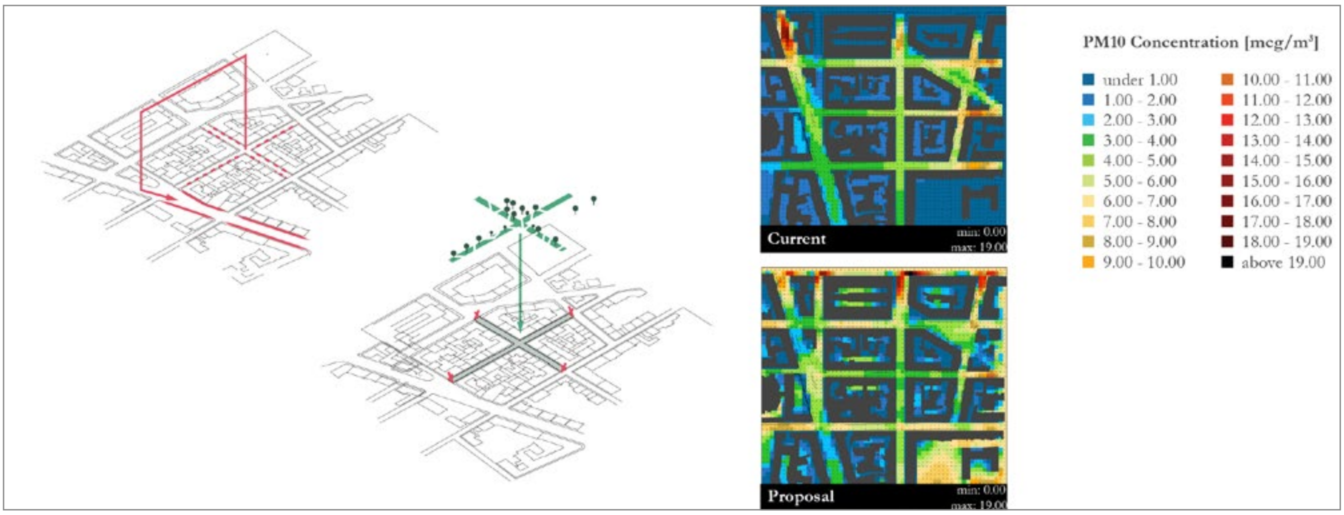

Figure 7. Green Crosses design proposal: principle (on the left), evaluation (on the right).

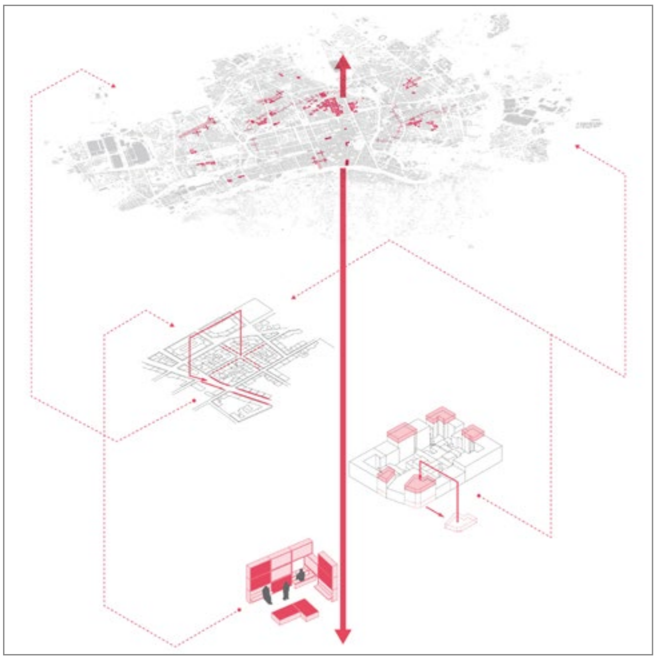

Figure 8. Air pollution mitigation through an interscalar approach.

green areas have been implemented. One isolated Green Cross works properly for an enclosed number of people, but if linked to another one, new positive externalities can happen. For instance, the design, if replicated and adapted to bordering streets, can build a new bike lane network able to connect all the most vulnerable areas of the city. 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, are able to build a strong and thorough system able to affect air pollution on different level and, more importantly, their areas of effect cross scales (Figure 8).

6. Conclusions

The research tries to discover the relationship between air pollution, the built environment and urban design. To do that, understanding the relationship between air pollution and the built environment is crucial: discovering what elements of the urban tissue affect air pollution and how they are related to each other set the basis for a strong and coherent design. 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.
By looking at different elements of the urban tissues, the analysis firstly reveals 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 shows a strong alikeness between them. Air pollution can be mitigated by urban design thanks to an interscalar approach.
The three main design interventions cope with different scales and they showed satisfactory results. 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 people behavior and affect the existing mobility. Moreover, the *Green 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 moderately effective.
Overall, it must be highlighted that urban forms have a great potential in decreasing air pollution concentration and this potential should be further studied and developed. However, 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.

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Notes

[1] The values defined by the European Union are different from the ones set by the World Health Organization; they have, in fact, a higher tolerance allowing higher pollutants concentrations. The compared values can be found at the online page www.eea.europa.eu/publications/air-quality-in-europe-2016.

[2] Defining an empirical air pollution risk assessment is extremely challenging. The World Health Organization in 2016 published a simplified manual with general requirements, methodology and tools which needs 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 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.

[3] Particulate Matter 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.

[4] Air pollution concentrations are strictly related to wind flow patterns. By affecting the latter, particles concentration and flow can be modified.

[5] Skimming flow effect: in narrow canyons, when the ratio between height of buildings and width of the street is bigger than 0.7, winds of the upper layer of the air start to skim over the building tops and drives a lee vortex in the cavity which decrease the possibility of cleaning the polluted air with the one coming from the above.

[6] Maraite Krautheim (Krautheim et al, 2014) and her colleagues try to address this issue 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 principles 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 and shapes of buildings can effectively change ventilation in urban areas (Krautheim et al, 2014).

[7] Continuosly rising buildings heights divert winds over the top creating the so called stepping effect.

[8] The *superblock project* is a project developed by the municipality of Barcelona in 2016. The new plan consists of creating big superilles through a series of gradual interventions that will repurpose existing infrastructure, starting with traffic management through to changing road signs and bus routes. Superblocks will be smaller than neighbourhoods, but bigger than actual blocks. A superblock consist of nine existing blocks of the urban grid of the city. Car, scooter, lorry and bus traffic are restricted to just the roads in the superblock perimeters, and they are only allowed in the streets in between if they are residents or providing local businesses, and at a greatly reduced speed of 10km/h (more information can be found at www.theguardian.com/cities/2016/may/17/superblocks-rescue-barcelona-spain-plan-give-streets-back-residents).

[9] Systemic effect: the word systemic is commonly used in the field of medicine and biology and it defines the capacity of a certain disease to affect the whole body even if directly damaging a specific area or organ. Related to the content of the research, the systemic effect is seen as the capacity of urban design interventions to positively affect the broader urban context.