Structural fragility of cities to airborne releases

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Cities are particularly vulnerable to air pollution due to the presence of many potential sources and a high population density. Urban air pollution is mainly related to vehicular traffic and the heating of buildings. However, urban areas are also exposed to accidental releases such as those related to gas leaks, industrial plants or the transport of hazardous material. Evidently, this has also a link to city security (Coaffee et al. 2008), since toxic substances could be maliciously dispersed in the urban atmosphere for terroristic purposes.

In this framework, public authorities are urged to adopt operational tools to rapidly assess the transport of pollutants within the urban canopy and their impact on citizens health.

To this aim, computational fluid dynamics and simplified models based on empirical parametrizations have been widely adopted in the last decades (Blocken 2015, Tominaga & Stathopoulos, 2016). These models suggested that flow patterns within the urban canopy are strongly driven by the layout of buildings and the way street canyons cross each other. In this sense, the city structure plays an active role in conveying pollutants, especially for the transport dynamics at the pedestrian level. Consequently, the same pollutant source may have a different impact if released in cities with different urban plans or in different places within the same urban district.

In recent years, the link between urban morphology and air pollution has been investigated by focusing on key geometrical properties as the urban shape (Fan et al. 2019), the packing density of buildings (Buccolieri et al. 2015, Peng et al. 2019) and geometric characteristics of the street canyons (Miao 2020). However, the way street connectivity and layout can affect urban ventilation is still an uncharted territory.

In this work, we investigate these aspects with the aim to shed light on one of the most challenging questions in the field of urban safety and planning: what makes a city or an urban area vulnerable to localized airborne releases? How much does topology, in which the history of a city is written, affect ventilation in the streets and thus the vulnerability of the city in case of a toxic point source?

To answer these questions we adopt the approach introduced by Fellini et al. (2019), i.e. a complex network perspective to study dispersion processes in cities. The urban canopy is modelled as a weighted and directed complex network: the streets and the street intersections are the links and the nodes of the network. The geometry of the street canyon and the wind field inside it determine the direction and the weight of each link. Within this approach, dispersion in the urban atmosphere is modelled as a spreading process on a network and local vulnerability is easily computed (in a variety of meteorological conditions) by means of a centrality metric (Fellini et al. 2020) that associates to each node in the network a value based on its spreading potential, and thus on the extent of the contaminated area when a release takes place in the node.
Adopting this innovative model, we compare the vulnerability of four districts in Lyon, Paris (France), Firenze (Italy) and New York (US) (Figure. 1). These urban areas were chosen as emblematic of different topologies, given by different historical urban layering.

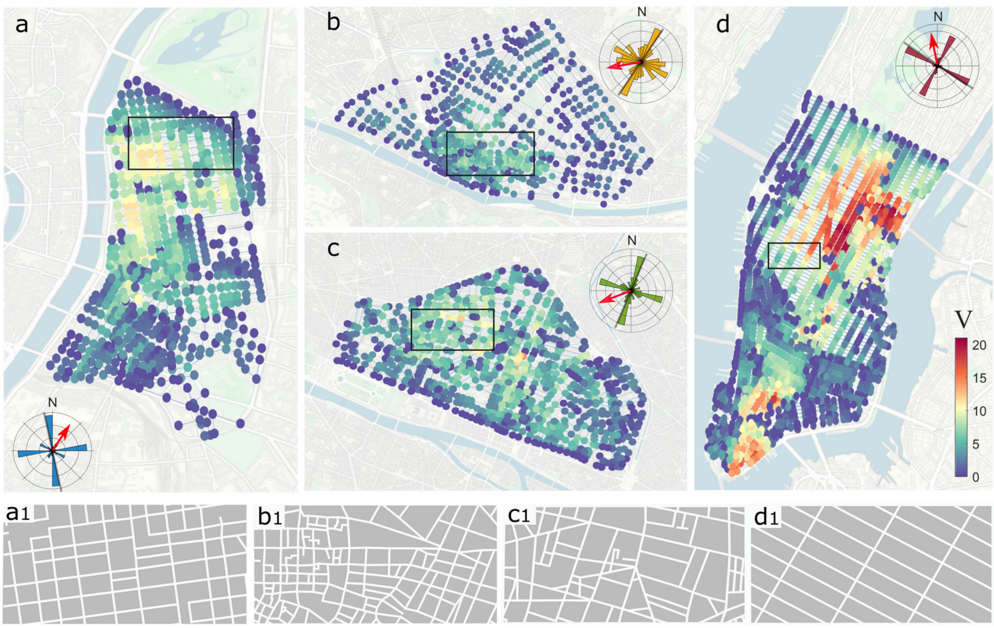

Figure 1: Vulnerability maps for (a) Lyon, (b) Firenze, (c) Paris, and (d) New York for a single wind direction. Panels a1, b1, c1 and d1 show the urban pattern for the different cities.

Simulation results evidence the different resilience of cities to gas propagation. Moreover, vulnerability is highly heterogeneus within a single urban area and sensitive to wind direction.

The reasons for the different fragility of cities (and their patterning) to gas propagation are embedded in the centrality metric adopted to compute urban vulnerability. The key factors for vulnerability can then be analytically recognized in the metric definition.
Here, we decompose the analytical model in its fundamental bricks and we isolate the variables that drive pollutant spreading in the streets. In this way, we are able to link the vulnerability of a city to its tangible, urban characteristics and to capture the dominant role of urban topology.

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