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Flood risk of Open Spaces: from microscale factors of Built Environment to risk reduction strategies

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Abstract. Urban Built Environment can be defined as a network of Open Spaces (including their infrastructures) and buildings, where users live and interact. In case of an emergency, the risk in the Built Environment highly depends on the characteristics of disastrous event, buildings and Open Spaces physical vulnerability, and on users' behavioral patterns and emergency response. Open Spaces represent a fundamental element during the disaster and the immediate aftermath. Floods denote one of the most challenging disasters for Open Spaces safety. In fact, they influence the floodwater spreading in the urban layout, affecting the building damage and the emergency evacuation process. From a critical review of recent advancement in the field, this work addresses the role of Open Space factors in flood risk - considering the composing elements and their interactions - to pursue a microscale approach.

Keywords: Open spaces, Built Environment, flood risk, risk assessment, human behaviors.

1 Introduction

Built Environments (BEs) in our cities are the result of both planned and unplanned developments [1]. These evolution processes affected the components of the BEs and the interactions between the factors determining the overall BEs structure. Broadly speaking, considering a typological and historical-geographical approach to analyse the urban BEs [2], four main aspects defining the urban form are relevant to characterize further this complex system: spatial relations of physical features; interrelations between BEs users and BEs physical features; users' fruition models of the BE; formation/transformation/ cyclical changes. The response of a BE to disasters is closely related to these four aspects and urban vulnerability and resilience concepts. Between the components of the BE, urban Open Spaces (OSs) is a paramount element [3], especially if considering Sudden-On set Disasters (SUODs) "triggered by a hazardous event that emerges quickly or unexpectedly"[1]. During a SUOD, the network of the urban OSs represents the emergency network for both population's evacuation and rescuers' access to the disaster-affected areas [2, 4, 5]. In this network, areal spaces (e.g., squares, parks, parking areas), which can be used as safe gathering areas for the population, are linked together by linear spaces (i.e., streets), used as evacuation and emergency paths. Both areal and linear spaces can be surrounded by buildings, which can also damage the OSs. Such buildings are characterized by a significant number of exposed people, both indoors and outdoors when the disaster strikes the urban areas [5, 6].

Among the SUODs, flood is one of the most critical for the urban BEs, considering the rising frequency (a consequence of climate-change effects) and severity (due to urbanization growth, which increases the number of exposed people in flood-prone areas) [7, 8]. Therefore, flood risk management requires knowledge of the characteristics of the floods [8, 9]. Floods are often the combination of meteorological and hydrological extreme events. They can be categorized into fluvial floods, pluvial floods, coastal floods, groundwater floods, or floods due to the failure of artificial water systems.

Regardless of the type of flood, the layout, the design and materials, and the supporting infrastructure systems [4, 10] of urban OSs influence floodwater spreading and characterization of the hazard in terms of depth, speed, and solid load. The microscale characteristics of the BE, including physical barriers and surface materials, affect the OSs and the BE in general for damages [11, 12] and to users' safety (i.e., immediate emergency response). This includes the evacuation process and the availability of gathering areas and paths [13, 14]. Increasing the flood resilience of the BE and its community means to promote Disaster Risk Reduction (DRR) actions before the disastrous events, according to criteria of prevention, preparedness, emergency response, and recovery [15]. These 4 criteria correspond to DRR actions aimed at prediction and warning, monitoring, impact assessment, response, and management. These actions refer to a series of structural and non-structural measures against floods [16, 17]. Structural measures are usually engineered measures applied to reduce the flood volume, such as retention ponds, dams, river improvement, urban drainage systems, and levees or dikes. Non-structural measures instead promote strategies based on flood-adapted design and building codes, land-use planning laws and regulations, preparation and evacuation planning, public awareness programs, and flood insurance programs. Both structural and non-structural measures can be reactive (response-oriented) or proactive (risk reduction) [17].

Thereupon, it is essential to describe the interaction systems in the OSs by representing each element at risk. Following a micro-scale risk assessment, adequate safety measures can be implemented to increase the safety and resilience of the BE and its users [5]. Starting from a critical literature review, this paper organizes the microscale building- and OSs-related factors as mitigation strategies related to the hazard, the buildings damages and users' support during the evacuation process.

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[1] https://www.preventionweb.net/terminology/view/475 (last access: 18/03/2020)

2 Overview of microscale factors of Open Spaces affecting flood risk and mitigation

The urban fabric and surface characterization of the BE influence the flood intensity and spreading in an urban area and the overall safety levels for the BE users, in correlation to their risk perception and awareness [4, 5, 18]. Such issues have a great impact on urban management strategies against the hazard sources [19]. Therefore, the overview of microscale factors is organized considering urban OSs (Section 2.2), the delimitating buildings (Section 2.1), and the hosted users before and during the emergency conditions (Section 2.3).

2.1 Open spaces-related factors

The physical characteristics of urban OSs are of primary importance to enhance resilience and mitigate the BE's flood vulnerability. These characteristics are directly related to the interactions among the constituent components of urban form: street network, plot pattern, and built form. In recent years, the unintended interaction among urban form, flooding events, and human behaviour has been systematically investigated through urban morphometrics [20, 21].

Nonetheless, most of the hydrology-based studies on pluvial flooding conceive the urban form just as the spatial distribution of resistance parameters, providing a reliable description of the flood event, leaving out the understanding of the OSs effect. On one side, most of the proposed parameters do not act as urban form indicators [22]. On the other side, OSs factors remain qualitative rather than quantitative [23]. However, it is worth underlining that attention on the characteristics of the urban form components and their effects on the pluvial flood is rising in the hydrology field. Researchers claim the importance of approaching the modelling with a more accurate scale of analysis, essential for describing the complexity of the BE [4, 24]. In this regard, pushing boundaries in urban morphometrics could be helpful because quantitative, comprehensive, and systematic methods and tools to measure the urban form have been developed [25, 26]. This knowledge helps to characterize the urban spaces with the reliable metrics at the appropriate scale of analysis. In association with well-established statistical parameters, the introduction of OSs metrics in flood modelling could represent a groundbreaking approach in the field. Furthermore, the possibility of developing this approach is demonstrated by introducing novel digital tools for urban flood modelling integrating parameters and spatial data describing the characteristics of the urban space [27].

2.2 Building-related factors

According to Section 2.1, the correlation between buildings and the built form generates the OSs configuration, affecting the urban flood in terms of the specific features of the buildings as obstacles to floodwater spreading [4, 28]. Besides the physical vulnerability involving possible damage to the buildings [11], the quality and quantity of openings, and the wall orientation concerning water flow, are fundamental factors, especially considering the characterization at the ground floor. They influence the collection of floodwaters inside buildings and risk and damage for people, furniture, and goods and chattels placed indoors [6, 12, 28].

Building-related factors are connected to the building typology, as adaptive typologies are designed for areas that are characterized by frequent water presence or flood. The building features allow moving towards passive mitigation solutions when the house is built to adapt to flood events. This is the case of amphibious and floating buildings, or houses with elevated floors [29, 30], which can adapt to flood-prone areas due to construction technology and suitable materials.

Sustainable Urban Drainage systems [10] can be integrated or added to the building to reduce vulnerability to extreme rain events. They can be seen as "active" strategies for risk reduction as they provide runoff retention [31], measured as the percentage of water retained. Indeed, these solutions allow rainwater collection, supporting the infrastructure system to control rainwater volume and peak flow in the street. Green solutions can be applied to buildings' vertical and horizontal envelope, as green walls and roofs [32]. They are an effective support for the sewer systems in case of floods. They allow retaining 45-93% of runoff, depending on the substrates composing the green system and their configuration, roof slope, and rainfall event characteristics [34]. Previous work assessed values reductions up to 90% [35], depending on the rainfall intensity concerning the peak flow control. Moreover, green walls and roofs effectively reduce energy consumption and improve thermal comfort in indoor spaces [36]. The main challenge of green roofs and facades is related to the cost of their construction and maintenance [36], leading to long payback periods. Moreover, the characteristics of the building determine the feasibility of the green features, which are not always suitable for existing BEs. Lastly, rainwater can be stored and retained in buildings with rainwater harvesting systems, which gather rainwater, reduce runoff and peak flows [37], and allow water reuse after being filtered, with environmental and economic benefits [31].

2.3 Users-related factors

Exposed users undertake emergency behavioural patterns depending on their features and relation with the surrounding BE, the local flooding conditions, and the emergency management system that can support them [5, 13, 14]. Firstly, from a microscale standpoint, considering each user at risk, the individual features mainly concern: (1) individual risk perception, which varies from community to community and depends on 5 types of indicators, that are age and gender, income and occupation, education, and knowledge, past experiences, house ownership and location [18]; (2) characteristics affecting the motion speeds [38] and human body stability [13], that are age, gender, body mass and height, and motion abilities. Secondly, as shown in Fig 1,.different behavioural patterns appear in the three main evacuation steps from this microscale standpoint [14].

In the pre-evacuation phase, users can spend time evaluating the collection of personal belongings to limit their possible damages and then evacuating, basing on [14, 39]: individuals' risk perception, the value of flood-prone assets, pre-disaster activities (depending on the intended use of OSs and buildings), group decisions. Early Warning Systems (EWS) or rescuers-citizen information channels are the main BE-related attributes of references for a prompt evacuation response [40].

Then, the evacuation movement includes all the actions aimed at reaching a safe area to restore safety conditions [5]. The combination between OSs layout (see Section 2.1) and floodwaters' spreading affects the evacuation target decision since people spontaneously move towards areas with lower water depths and speed. The building configuration could lead people to move towards the higher stories, in case of an adequate number of floors, instead of moving towards gathering areas and shelters provided by emergency plans [5]. Users placed outdoors seem to be more vulnerable than those placed inside the buildings since they cannot directly evacuate. In complex buildings, circumscribed OSs, or small urban areas, people can be effectively guided to a "shelter-in-place" area using adequate wayfinding systems [31]. Floodwaters can slow down the evacuation motion process, mainly in undergrounds, ground floors of buildings and OSs, since they can limit the opening of doors, drag people walking along staircases, prevent people from exiting from cars, or cause the loss of human body stability [5, 13, 28, 38]. Handrails or other immovable obstacles can be used to hang on while moving or standing for the rescuers' arrival, increasing the users' safety regarding the floodwaters [14]. In the OSs, raised areas can additionally host the evacuees in critical floodwater conditions. Elements dragged by floodwaters in the OSs, including debris and street furniture, represent additional threats for individual safety [4, 14].

Finally, once a safe area is reached, the evacuation stops [14]. People reach safe areas in the emergency plan, as shelters, or gather in the OSs/inside buildings.

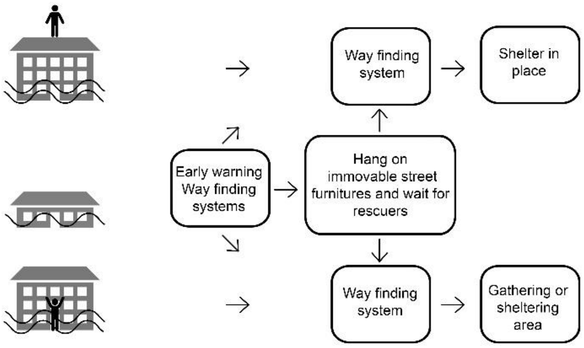

Fig. 1. Users' evacuation options for multi-storey buildings, single-storey buildings, and outdoor areas.

3 Discussion

The microscale factors discussed in Section 2 and the physical elements in the BE can be implemented as structural strategies for DRR applied in the OS, considering their impact on: (i) flood hazard (Table 1), (ii) buildings damages (Table 2), (iii) users' support pillars (Table 3). For each factor, supporting non-structural strategies [16, 17], advantages and limitations, and literature background are traced by distinguishing which of them relate to OSs and their buildings.

These tables provide an overview of BE's factors that can generally increase the decision-makers' risk awareness. Some strategies can boost the individuals and goods safety, such as elevated floors, houses, and harvesting systems. Elevated floor houses are the easiest strategy to shelter-in-place the building occupants but can also be used by outdoor users if the access is ensured to passers-by [5]. However, they have limited reliability in specific contexts, such as historical scenarios. Other structural measures centred on the building preservation could impact on the original features of the OSs, resulting in limited conservation of morphologic and aesthetic elements of the BEs.

Table 1. Microscale factors as structural strategies influencing hazard.

Microscale factor	Non-struct. measures	Advantages / Limitations	Refs
OSs-related			
Floodable areas	Urban planning	Control of peak flow/modifications in existing BEs to the ground profile	[41]
Permeable paving	Urban planning	Control of peak flow	[41]
Raised elements	Urban planning	decreasing the floodwater speed; / obstacles can also hold debris	[4]
Street furniture	Urban planning	obstacles can hold debris; avoiding movable furniture	[4]
Building-related			
Green systems	Building codes, flood insurance	control and reduction of peak flow and volume / not applicable on all existing buildings	[34]
Elevated floors houses	Building codes, land-use planning, flood insurance	possibly restituting soil to permeable paving, thus reducing peak flow / not applicable on all existing buildings	[29]
Harvesting systems	Building codes	reduction of peak flow and volume	[37]
Handrails/fences	Building codes supporting public-private interfaces	obstacles can marginally hold debris	[4]

Table 2. Microscale factors as structural strategies influencing building damage.

Microscale factor	Non-struct. measures	Advantages / Limitations	Refs
OSs-related			
EWS	Preparation and evacuation planning	alert timing to perform protection actions for goods and chattels /	[6, 12, 28]

		precise alert depending on the severity of the event	
Building-related			
Elevated floor houses	Building codes, land-use planning, flood insurance	protecting buildings and indoors from damage	[29]
Floating and amphibious houses	Building codes, flood insurance	protecting buildings and indoors from damage	[30]
Handrails/fences	Building codes supporting public-private interfaces, flood insurance	protecting private areas from debris/avoiding movable elements	[4]

Risk reduction interventions are focused on reshaping public outdoor areas in the OS, and local authorities could easily perform them. They provide support to the evacuees' safety (see Table 3). One of the simplest approaches is implementing unmovable street furniture in the OSs, which could be integrated by risk/wayfinding signage with sensors to support the smart BEs monitoring of EWS, especially in flash flood [14, 31, 40]. They limit the damage caused by floods and debris, and their position in the BE should depend on the hydrodynamics features and the evacuation plan [4, 5, 14].

Table 3. Microscale factors as structural strategies influencing users' support.

Microscale factor	Non-struct. measures	Advantages / Limitations	Refs
OSs-related			
Permeable paving	Urban planning	control of peak flow and floodwater levels causing threats in users' movement / limited effects in some cases, e.g., flash events	[4, 38]
EWS	Preparation and evacuation planning	Direct stimuli to evacuation starting / public awareness and plan dissemination campaign needed	[5, 40]
Raised elements	Urban planning, evacuation planning	Direct support to people placed outdoors / to be considered in the evacuation plan to support people waiting for rescuers	[14]
Street furniture	Urban planning	Benches as raised elements; support to people to hang on them / placed along possible evacuation routes and high hazard areas; avoiding movable furniture	[14]
Wayfinding systems	Preparation and evacuation planning	Visible also in non-emergency conditions, direct support to reach a safe area / public awareness, training (e.g., VR) and plan dissemination campaign needed	[31]
Building-related			
Elevated floors houses	Building codes, urban planning	Direct safety of people initially placed indoor / impacts are limited to residential areas	[29]

Floating and amphibious houses	Building codes, evacuation plan	Direct safety of people initially placed indoor / impacts are limited to residential areas	[30]
Handrails/fences	Building codes supporting public-private interfaces	Direct support to people to hang on them / to be considered along possible evacuation routes and high hazard areas; avoiding movable elements	[14]

Nonetheless, such strategies should be supported by preparedness and risk awareness-increasing non-structural measures to reduce the negative impact of individual's risk attitude and personal experiences in the population's response. Behaviours and personal risk perception can be trained through virtual reality (VR) experiments, where a flood condition is simulated safety [42]. As stated above, users'-OSs interactions significantly affect BEs' safety levels. Thus, risk assessment models and simulation tools should be built on microscale-based interactions to support safety planners in DRR-related activities. Furthermore, they can be integrated into wider-scale analysis on flood sources and spread globally [4–6, 14, 17] according to a Performance-Based Planning [10] standpoint. A plan should perform according to the agreed collective strategy, just like the performance-based design. Simulation-based approaches ensure the effectiveness of the strategies, combining management and structural actions, optimizing the complexity of physical interventions on BEs and OSs and the rescuers' actions [5, 19].

4 Conclusions

Flood risk in urban BEs depends on the microscale features of their OS, surrounding buildings, and hosted users. Therefore, the characterization of the composing elements in terms of influence on the flood hazard, building damage, and users' safety is crucial for defining risk reduction strategies. From this assumption, this work adopted a literature-based review to trace a list of microscale risk factors and countermeasures, evidencing how structural/non-structural strategies can be combined to ensure an adequate safety level in the BEs as well as the reliability of the planned solutions.

Real-world BEs can be analyzed according to the proposed risk reduction perspective to determine if typological and recurring conditions can be identified. This approach will boost the definition of the best practices for risk assessment and reduction depending on the specificities of the OSs. From the results of this work, the outline for detecting the composing elements of the BE, their features, and associated measures to provide support in the public decision-making process can be drawn.

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