1er Congreso Internacional
Estudios de Planeación Territorial y Ambiental 2021

UAEM

Territorio-ambiente: problemáticas y tendencias *14 y 15 de octubre*

UNIVERSITÀ DEGLI STUDI DELL'AQUILA

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Resilient urban structure and Disaster Risk Reduction. A proposal for Sulmona's (it) Evacuation Plan

The research described in this presentation is part of the "**Open Territories**" project, University of L'Aquila.

TERRITORI APERTI

https://territoriaperti.univaq.it/

It is an **interdisciplinary center for documentation**, **training and research**, which will act as a promoter of an international network of expertise on **all aspects of the prevention and management of natural disasters**, as well as the processes of reconstruction and development of the affected areas.

Project activities also include **research on urban and regional planning**. This presentation deals with this subject and in particular with **urban planning and management of evacuation following a disaster**.

The issue of **civil protection planning** is closely related to the **development of urban resilience** in the face of disastrous events, such as earthquakes, floods, landslides, storms, etc.

In this context, **two approaches to planning** are central:

- **Pre-disaster planning**, that aims to **reduce** as much as possible the risks and **prepare** the urban structure to respond to the disaster.
- **Post-disaster planning**, that aims to **manage** the emergency and the subsequent physical and social **reconstruction**.

The contents of this presentation deals with **pre-disaster planning** and in particular with a ***methodology to verify the location of emergency areas*** based on research from the University of L'Aquila hat concerns the ***minimization of the total evacuation time***.

The **evacuation modeling** is set in two phases:

- The first one concerns the extraction of **GIS data** describing the **evacuation network** according to different parameters.
- The second one concerns the definition of a **dynamic optimization model** that calculates the **safest paths on the evacuation network** and in relation to the location of emergency areas.

The application of this assessment method **allows to adapt the system of emergency areas** to make it as efficient as possible compared to the simulation, but also to intervene on the **urban structure** to eliminate elements that reduce the **response capacity**, and therefore the resilience, and avoid that the ***Limited Condition for the Emergency (LCE)*** is reached.

An application on a real case will be presented, the **City of Sulmona (Abruzzo Region, Italy)**, a small city, with an important historic center, which has a **high seismic risk** and on which we are studying the application of pre-disaster planning and management practices aimed at Disaster Risk Reduction (DRR).

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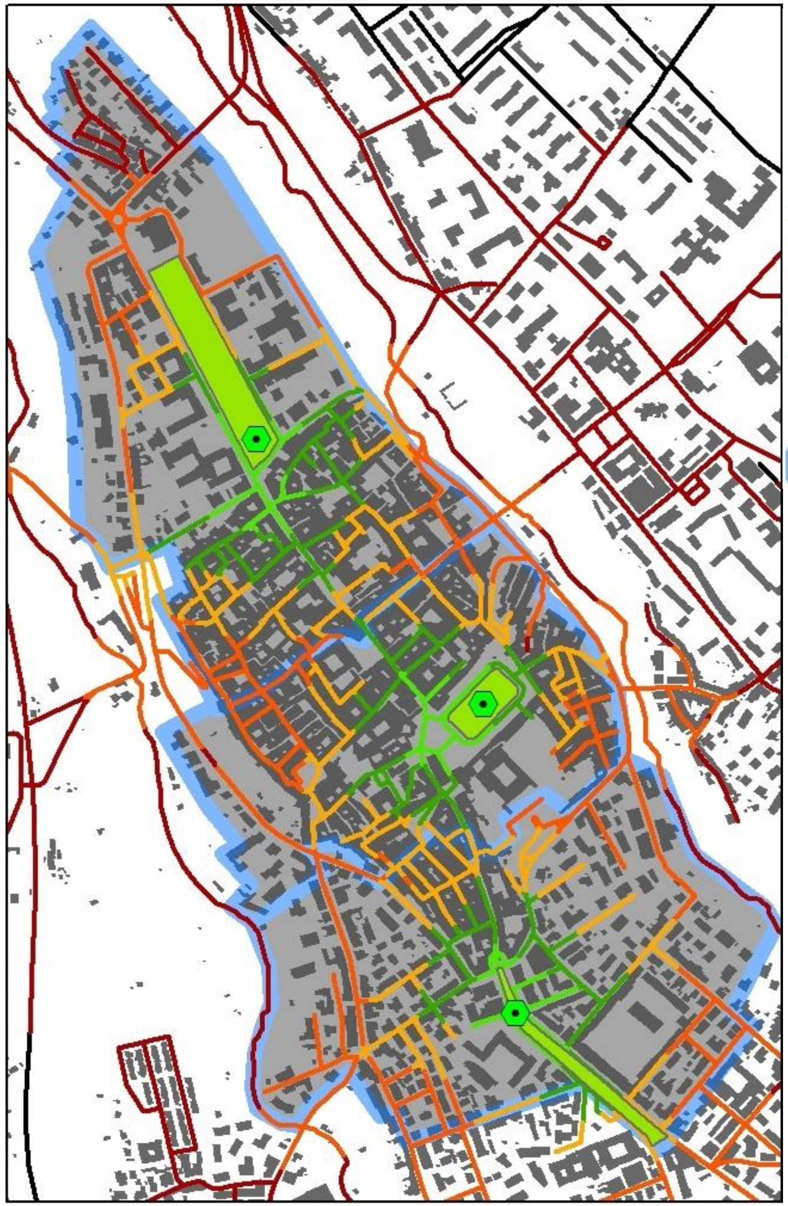

CASE STUDY CITY OF SULMONA (Abruzzo, IT)

A study on the **functionality of Waiting Areas**, assessed through the ***Functionality of Waiting Areas Index*** (Di Ludovico, Di Lodovico, Basi, 2017) that **assesses the size and shape** of the Waiting Area, found that the **Waiting Areas** provided by the Emergency Plan of the City of Sulmona **are insufficient, therefore not suitable**, to accommodate citizens escaping following a natural disaster, particularly following an earthquake.

It is necessary a **study** of a **suitable Waiting Areas** not only in terms of size and shape but also in terms of location with respect to the **behaviour and relative location** of the escaping citizens (study of **escape routes**).

Di Ludovico, D., Di Lodovico, L., and Basi, M. (2017). Rischi e funzionalità urbana per la pianificazione dell'emergenza. il caso studio di Sulmona (Aq). Planum Publisher, 1:1–7.

Anhorn, J. and Khazai, B. (2015). Open space suitability analysis for emergency shelter after an earthquake. Natural Hazards and Earth System Sciences, 15:789-803.

In relation to **human behaviour** during a disaster event, there is some research in the scientific literature that models the **process of evacuating people**, also taking into account the influence of human behaviour through ***panic models***.

To produce this simulation, for example, are used **Agent-based models (ABM)**, computational models used to test the collective effects of the selection of individual actions. In general, **ABM allows us to examine the macro-level effects of micro-level behavior**.

In agent-based modelling, **a system is modelled as a set of autonomous decision-making entities called agents**. Each agent individually assesses its own situation and makes decisions based on a set of rules. An agent can interact with other agents, is flexible and has the ability to learn and adapt its behaviour based on experience. The definition of an **agent** may represent **individuals**, **groups**, **companies** and so on. The patterns of their behaviour and mutual interactions are **formalised by equations**.

ABM can be combined with other simulation methods used in the natural and engineering sciences, including statistical physics, biology and cybernetics.

There are several methods of classifying crowd behavior.

- *Optimization models*
- *Simulation models*
- *Risk assessment models*

Optimization models are created to **optimize the position of all emergency facilities and shelters**. In these models human behavior is not defined and evacuees are considered to be a uniform flow.

Simulation models consider **all aspects of human behavior during an evacuation**, including sensations and actions that are not strictly related to the evacuation process. These models allow designers to simulate, for example, how people use emergency exits, crowd formation and evacuation time during a specific damage scenario.

Risk assessment models seek to **identify the hazards associated with evacuation** resulting from a related hazard or incident and attempt to quantify the risk.

An **optimization model** can be applied to the identification of the Sulmona **Waiting Areas**.

The optimization model applied calculates **the safest route that citizens should follow** to reach predetermined safe areas, such as the Waiting Areas.

By composing **several scenarios**, different from each other based on the number and location of the Waiting Areas, it is possible to define the **best network of safe routes** for the citizens escape.

The first step was to create the **network of routes** (with a GIS application), built in two phases: the first concerns the collection of information about the city, the second concerns the transformation of data into **nodes, edges and attributes of a graph**.

Howard, E., Pasquini, L., Arbib, C., Di Marco, A. and Clementini, E. Definition of an Enriched GIS Network for Evacuation Planning. DOI: 10.5220/0010452302410252. In Proceedings of the 7th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2021), pages 241-252.

Beyond the basic geometric information on buildings, crossroads and streets also need to consider other information necessary for suitable application of the optimization model:

- **Risk of buildings**: indicates the level of risk from the most seismically vulnerable to the most resilient (there exist several scales expressing seismic risks).
- **People in buildings**: number obtained from the city census.
- **Streets length and width**: useful to understand how many people a street can contain at a given moment in time.
- **Risk of streets**: initially estimated as the highest degree of risk of the buildings flanking the street, but the estimate can be refined as a function of width, length, and of more information on the street (such as the presence of dangerous artifacts or peculiarities of any kind).
- **Waiting Areas**: obtained from data provided by the Civil Protection Services, in particular related to geometry and capacity of sheltering people.

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Risk of buildings, ***Streets length and width*** and ***Risk of streets*** define the **capacity of the routes** to contain the escaping crowd.

In particular, the presence of **vulnerable buildings that may collapse on the routes** (***Risk building***) and the presence of **obstacles on the route** (***Risk of streets***) are analysed through the tools of the **Limiting Condition for Emergency (CLE)** of the urban settlement, an analysis provided by the Italian legislation and aimed at *assessing the efficiency of escape routes and the maintenance of accessibility to emergency areas* (such as **Waiting Zones**) and strategic buildings for the emergency.

These elements concern the **urban form**. It must be addressed by a **pre-disaster recovery plan** with the detail of **urban design**, oriented to **reduce these risks**, i.e. **obstacles and interferences**, and **increase the route capacity**.

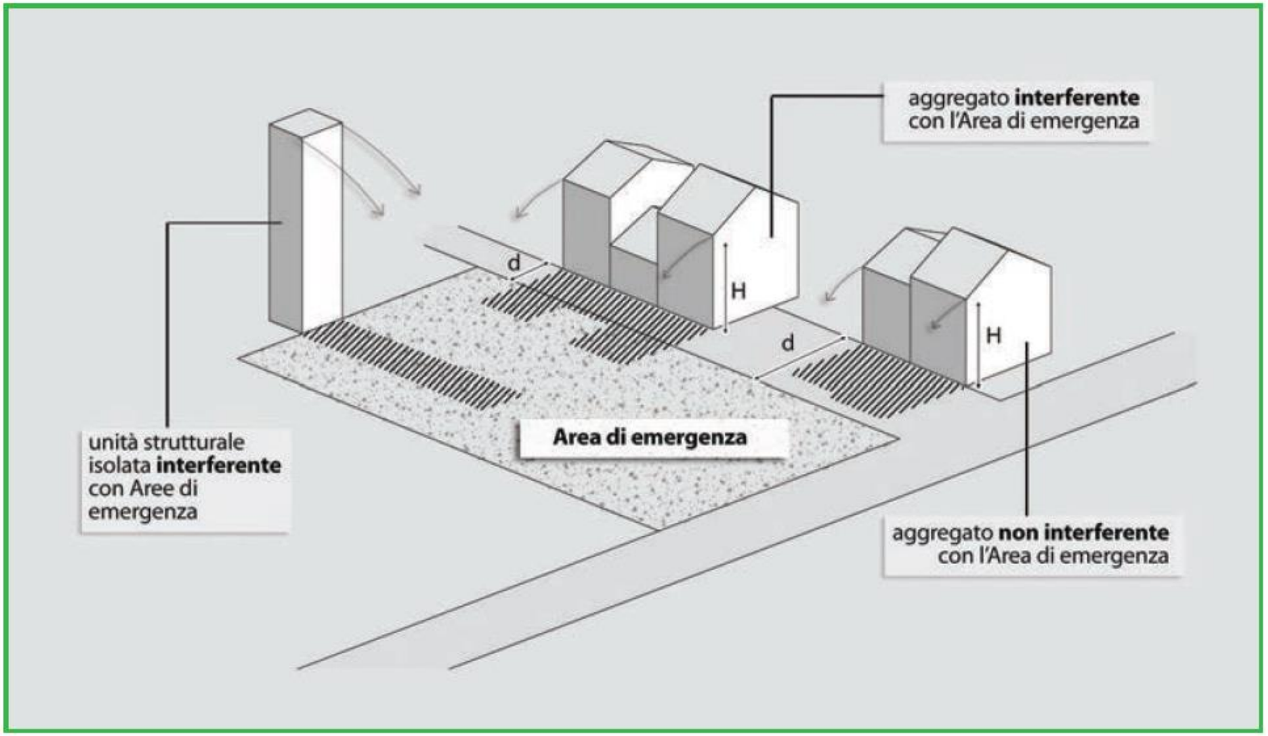


Figura AE 3. Aggregati interferenti con l'Area di emergenza.

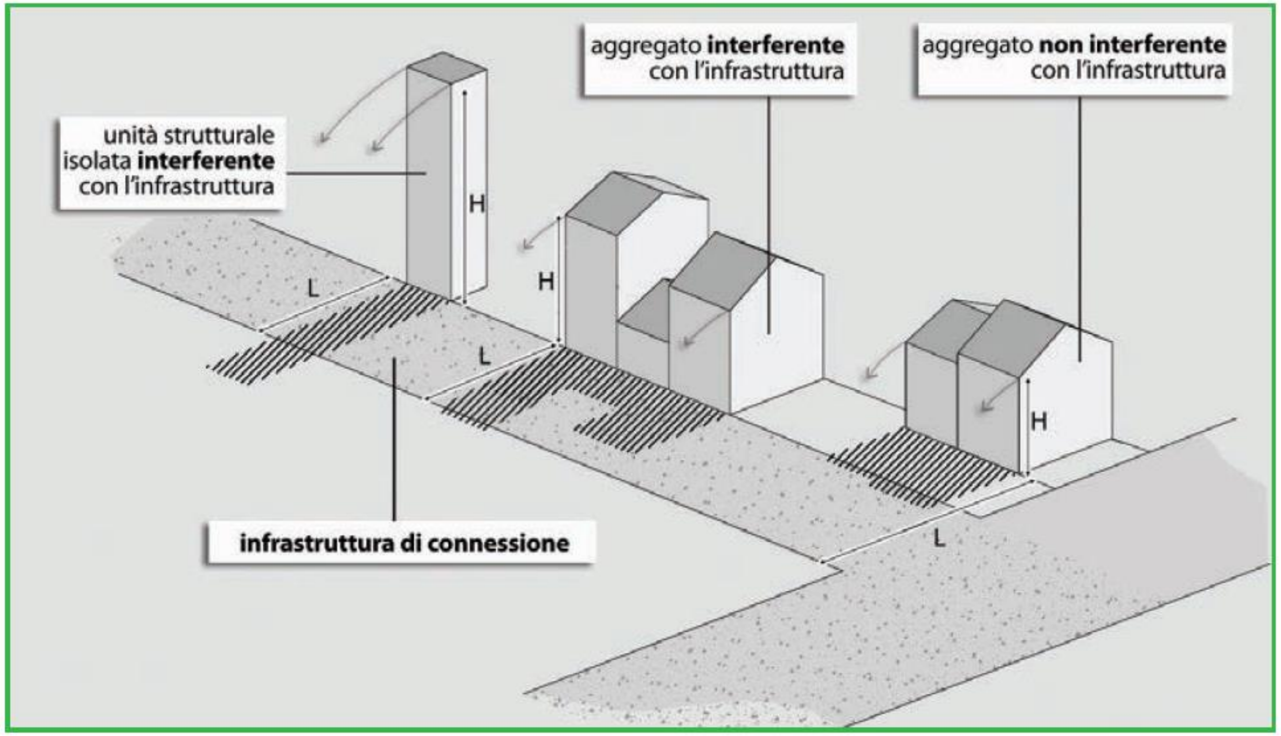


Figura AC7. Aggregati strutturali e unità strutturali interferenti.

http://www.protezionecivile.gov.it/media-comunicazione/pubblicazioni/dettaglio/-/asset_publisher/default/content/manuale-per-l-analisi-della-condizione-limite-per-l-emergenza-cle-dell-insediamento-urbano

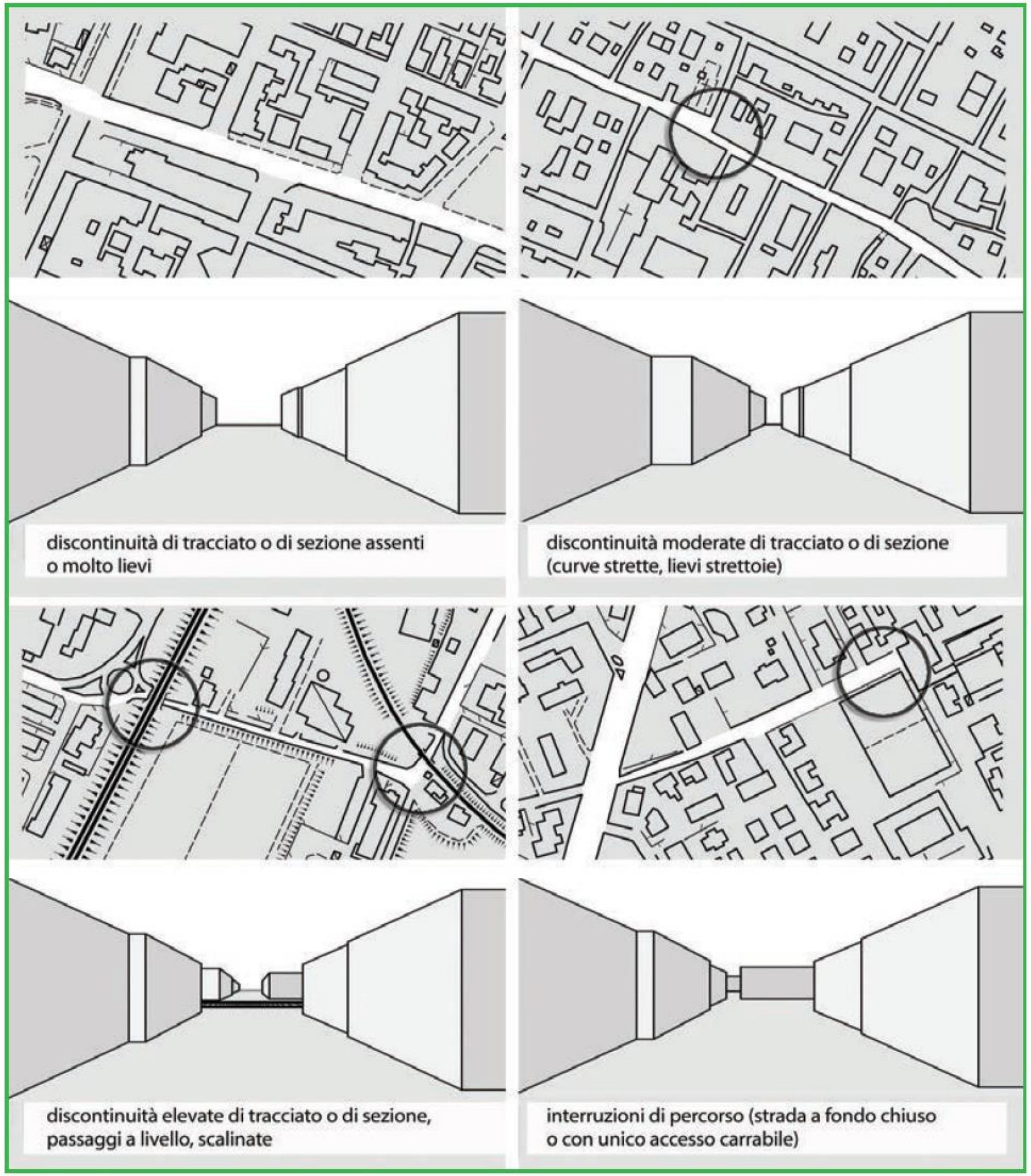


Figura AC 6. Ostacoli e discontinuità.

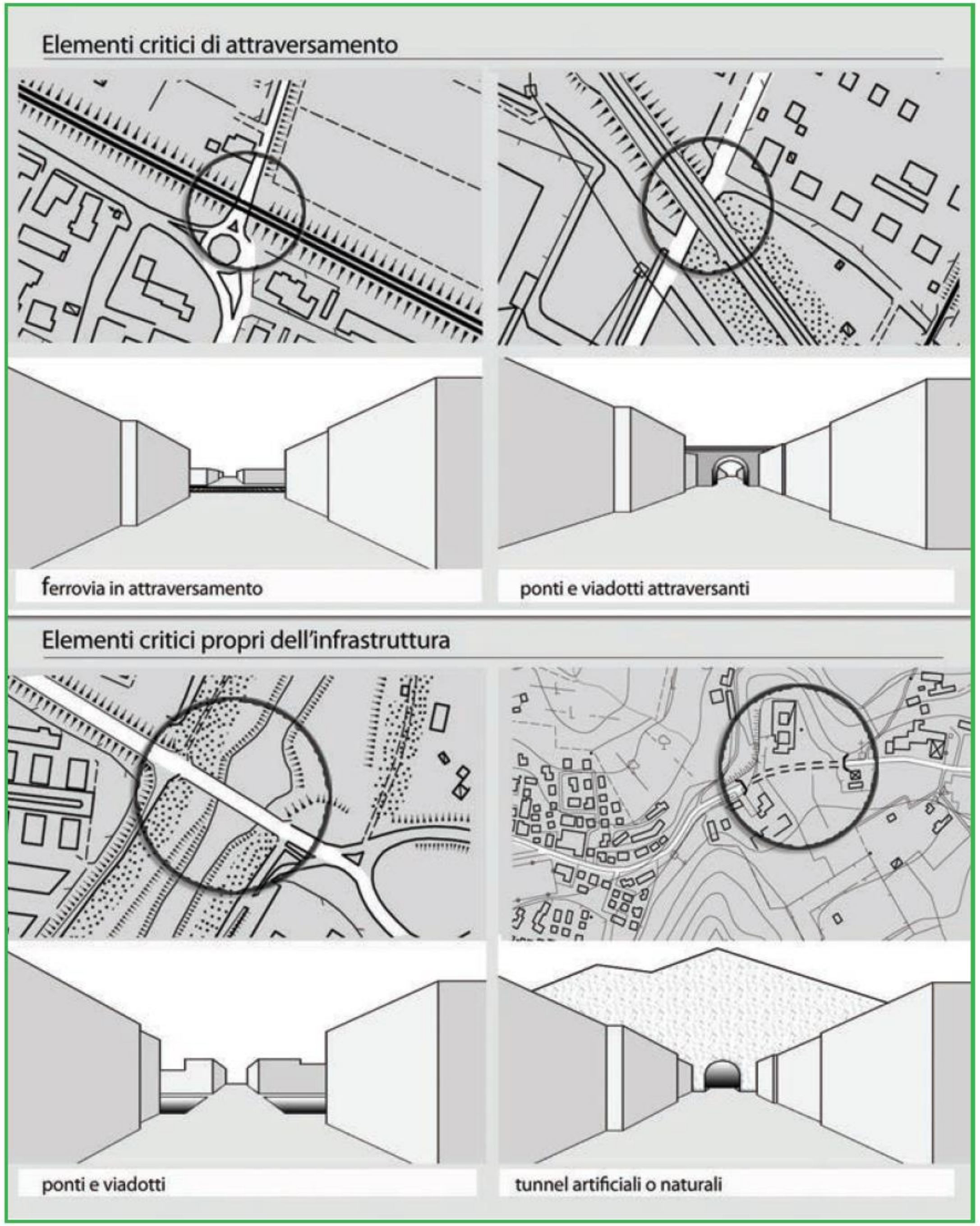
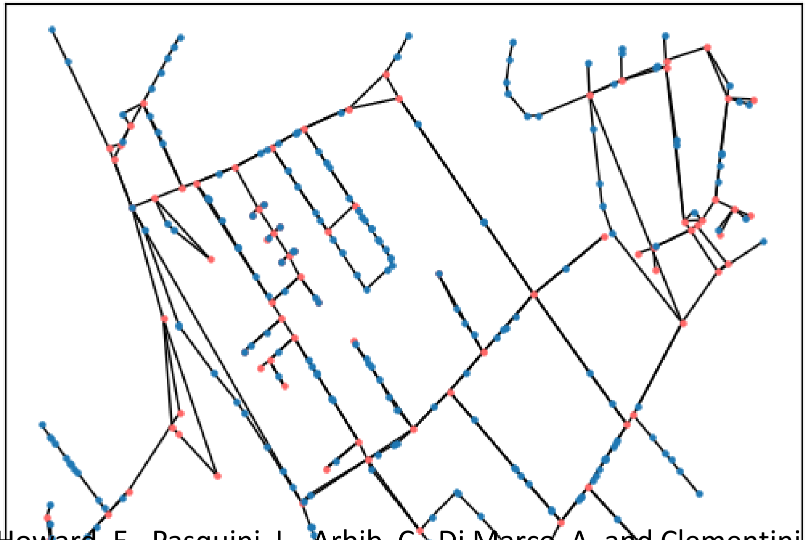


Figura AC9. Elementi critici.

The figure shows the **buildings** (violet areas), the **streets** (yellow lines) and the **crossroads** (red points).
The orange points have been identified to simulate the **location of people** who live in each building and running away on the routes (streets).



The figure shows the **graph** used for the **optimization model application**.
The red nodes are the crossroads, the blue nodes are the buildings and people, and the black line are the edges that connect them to each other.

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To dynamically generate a plan that minimizes the total evacuation time **has been adapted a linear optimization model** originally developed by (Arbib et al., 2019) for building evacuation.

The starting point of the model is a **static oriented network** obtained from the graph in the previous slide by a suitable embedding of the city streets into a **set of elementary cells.** The arcs connect geometrically adjacent cells in both directions. Cells may in general have **different shapes or sizes**, and in this case **every cell can approximately be traversed in a single time unit**.

Depending on size, **the cell has a capacity equal to the maximum number of people it can host** and, at any given time, contains some number of people. Moreover, depending on street size, **a limited amount of people can move in the unit interval from a cell to an adjacent cell**. Finally, depending on **scenarios**, the network may consists of a number of maximal connected components: in each component, **safe places collectively correspond to a single super-sink** (all the safe locations/Waiting Areas, are labeled as Node 0) **with a capacity large enough to host all evacuees**.

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The geometry of the grid can vary and, due to the structure of the streets, **a rectangular grid was used** where **each street is split into an integer number of cells**.

It has been assumed a **free flow walking speed** for a flat surface of **1.00 m/s**. The **maximum capacity of each cell** is calculated by assuming **0.5 sqm per evacuee**.

It has been considered **"virtual doors"** as the width of the streets, assuming a **constant door capacity of 1.8 persons per second per 1-meter door width (p/m/s)** meaning that a maximum number of **12.6 persons can pass through a 1-meter street width per time slot (7 seconds)**. Also, capacities are assumed to be proportional to street width.

The network used for **Sulmona** consists of **920 crossroads (junctions) and 1162 interconnecting streets** with different widths and lengths. **The streets were split into unit cells**, each behaving as a (virtual) quasi-rectangular crossroad that can be traversed in a unit time slot.
After the splitting, we obtained a **graph of 12675 nodes** corresponding to the cells of the crossroads and including the super node 0 as safe place, and **25892 arcs linking adjacent cells** that allow people to traverse cells. All arcs are assumed **bidirectional** except the those towards the safe places/Waiting Areas.

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The simulation regards an **evacuation of 26050 people** who are randomly distributed in the cells.

We run the experiment with **two different scenarios**: **SCENARIO A** that considers **30 safe places** and **SCENARIO B** with 15 safe places (the safe places/Waiting areas, are **open areas**, *of sufficient size to accommodate evacuated citizens and uniformly located*).

In **SCENARIO A**, all the 26050 evacuees were safely evacuated in 180 time slots (i.e., in 1670 secs corresponding to **27 minutes and 50 seconds**). In **SCENARIO B**, considering the same time slot, only 14147 evacuees were moved to safety whereas, everyone was evacuated in 296 time slots (i.e., 2558 seconds, corresponding in **42 minutes 38 seconds**). The total time taken to evacuate all the residents was somehow smaller than what would be expected in real-life. This is due probably because we used a simplified model which **does not account for any possible congestion** that would occur on along the passages between adjacent cells. The congestion of some arcs could result in **bottlenecks** thereby reducing the amount and speed flow along those arcs.

In case of SCENARIO A, it took **700 seconds to evacuate approximately 50% of the population**. Whereas, in SCENARIO B it took **1176 seconds to evacuate the same number of evacuees**.

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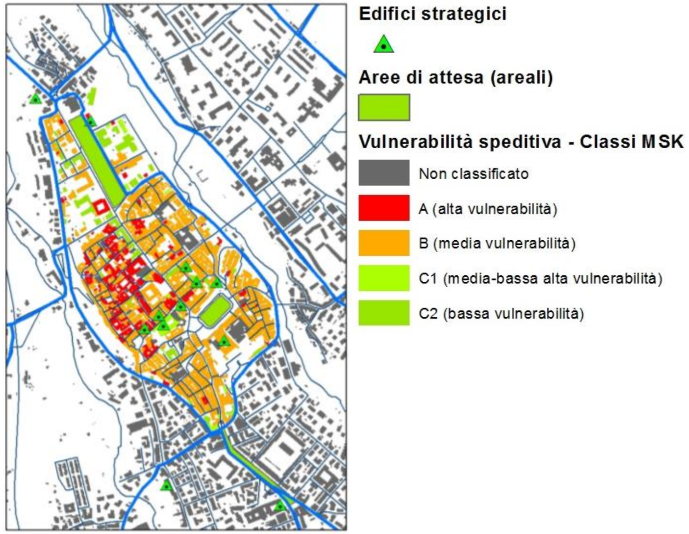
This first application of a simplified optimization model, which **does not take into account many factors such as congestion** in the cells during evacuation **or panic**, tell us that **the number of safe places available in the city affects the total time needed to evacuee the entire population**, in fact the more the safe places/waiting areas uniformly localised, the shorter the population evacuation time.

Therefore, rather than identifying only three Waiting Areas, it would be better an evacuation plan that **identifies a diffuse system of Waiting Area** (**not a crown** of areas around the city but a distributed system, uniform).

The next step of the research will **enrich the optimization model with other parameters** already recalled in the previous slides and that have not been used in our simplified example. These parameters, on the one hand **better characterize the capacity of the escape routes** (for example by establishing where congestion can be created), and on the other hand **become the object of urban design practices**, typical of a **pre-disaster recovery plan**, aimed at improving the capacity of the escape routes.

These parameters mainly concern obstacles and interferences on escape routes:

- Irregular **shape** of streets
- Physical **obstacles** on the streets
- Very **vulnerable** buildings that could collapse onto the streets
- Uneven **pavement** or pavement made of unsuitable materials
- Etc.



The **future experimentation of a pre-disaster recovery plan**, which is a tool of prevention, will aim precisely to **eliminate all these risks and increase the capacity of escape routes**, **reducing the time and number of Waiting Area**.
In addition to a richer optimization model, we are now working on this plan.

Thanks for your attention