# BDC

Università degli Studi di Napoli Federico II

24

numero 2 | anno 2024

BDC Università degli Studi di Napoli Federico II

Via Toledo, 402
80 134 Napoli
tel. + 39 081 2538659
fax + 39 081 2538649
e-mail info.bdc@unina.it
www.bdc.unina.it

Direttore Responsabile: Luigi Fusco Girard
BDC - Bollettino del Centro Calza Bini Università degli Studi di Napoli Federico II
Registrazione: Cancelleria del Tribunale di Napoli, n. 5144, 06.09.2000
BDC è pubblicato da FedOAPress (Federico II Open Access Press) e realizzato con Open Journal System

Print ISSN 1121-2918, electronic ISSN 2284-4732

Journal home page www.bdc.unina.it

BDC volume 24, issue 2, year 2024

print ISSN 1121-2918, electronic ISSN 2284-4732

# A crowd simulation-based tool for environmentally hazard-conscious urban design

*Uno strumento basato sulla simulazione della folla per una progettazione urbana attenta ai rischi ambientali*

Federico Eugeni[a,*], Gennaro Zanfardino[b], Donato Di Ludovico[a]

AUTHORS & ARTICLE INFO

[a] Department of Civil, Construction-Architectural and Environmental Engineering, University of L'Aquila, Italy

[b] Department of Information Engineering, Computer Science and Mathematics, University of L'Aquila, Italy

* Corresponding author
email: federico.eugeni@univaq.it



ABSTRACT AND KEYWORDS

**A crowd simulation-based tool**
The paper describes research within the scientific and methodological framework of new urban planning support tools oriented towards the prevention of risks due to natural disasters. In this context, the first results of the application of a prototype of a digital (agent-based) simulation system of crowd behaviour aimed at improving urban resilience are reported. The methodological macro-phases of the research are two: 1. to realise a simulation model of crowd evacuation following a natural or man-made disaster; 2. to define a set of safety-based urban design techniques capable of reducing urban risk and optimising urban shape.
The paper describes the first results of the application of the macro-phase 1, in particular the simulation of Scenario 0 in case of a seismic event related to the case study of the historic centre of the town of Atri (Abruzzo Region, IT). The simulation shows that the current configuration of the waiting areas results in long evacuation times, insufficient capacity to accommodate evacuated persons, and clogged streets. In the next steps of the research, safety-based urban design techniques will be applied to Scenario 0 with the aim of obtaining an optimised design Scenario that improves urban form, reduces risk and increases resilience.

**Keywords:** crowd simulation, agent-based, pre-disaster, risks, evacuation planning

**Uno strumento basato sulla simulazione della folla**
Il paper descrive una ricerca che si inserisce nel quadro scientifico e metodologico relativo ai nuovi strumenti di supporto alla pianificazione urbana orientati alla prevenzione dei rischi dovuti ai disastri naturali. In questo contesto, vengono riportati i primi risultati dell'applicazione di un prototipo di un sistema di simulazione digitale (ad agenti) del comportamento della folla finalizzato a migliorare la resilienza urbana. Le macro-fasi metodologiche della ricerca sono due: 1. realizzare un modello di simulazione di evacuazione della folla a seguito di un disastro naturale o antropico; 2. definire un set di tecniche di progettazione urbana safety-based capaci di ridurre il rischio urbano e ottimizzare le forme urbane.
Il paper descrive i primi risultati dell'applicazione della macro-fase 1, in particolare la simulazione dello Scenario 0 in caso di evento sismico relativo al caso studio del centro storico della città di Atri (Abruzzo Region, IT). La simulazione dimostra che l'attuale configurazione delle aree di attesa determina tempi lunghi di evacuazione, insufficiente capacità ad ospitare le persone evacuate, strade intasate. Nei prossimi passi della ricerca saranno applicate allo Scenario 0 le tecniche di progettazione urbana safety-based con l'obiettivo di ottenere uno Scenario di progetto ottimizzato, che migliora la forma urbana, riduce il rischio e incrementa la resilienza.

**Parole chiave:** simulazione della folla, agent-based, pre-disastro, rischi, pianificazione della evacuazione

## 1. Introduction

The increase in natural disasters is associated with climate change (IPCC-AR6, 2023). It has led the scientific community to focus on the importance of urban planning and design as crucial tools to mitigate risk and improve the effectiveness of civil protection operations. This approach falls under the umbrella of pre-disaster planning and urban risk assessment, to examine how disasters, whether natural or man-made, affect the transformation of cities, and to understand how urban design can contribute to strengthening resilience. This paper describes a study from the University of L'Aquila that focuses on pre-disaster planning, also known as pre-disaster recovery planning (FEMA, 2017). This practice, which is still under development, aims to prevent future damage through preparedness that acts on multiple scales, with risk mitigation and resilience-building interventions to be implemented before the occurrence of disasters. Such planning deals with ensuring the continuity of government functions and essential services, identifying spaces for temporary shelter, determining how and where to rebuild, and restoring basic economic activities. The research focuses on the role of waiting areas in the emergency and evacuation phase in urban areas and consequently on their optimisation in terms of both location and size. The main objective is to minimise risks during evacuation operations through preventive, safety-oriented urban design solutions that shape the urban structure. In addition, the study also examines strategies to improve evacuation planning and the development of practical tools to effectively communicate these plans to citizens and facilitate preparedness exercises (Eugeni et al., 2023). In this regard, the scientific literature analysed covers two main areas of research: studies on the simulation of crowd behaviour during evacuation and studies on urban design techniques aimed at reducing risk during catastrophic events. The method used for the bibliographic survey therefore took into account these two criteria. Specifically, articles were analysed that, albeit in a general or indirect manner, describe research related to disasters of various types (natural and anthropogenic), combining the analysis of crowd behaviour with urban analysis or urban design. Modelling and simulation techniques, as well as applied urban design techniques and approaches to evacuation planning, were extracted from this research.

The first area focuses on models and algorithms for crowd simulation, mainly in disaster scenarios such as earthquakes and fires. These studies frequently use multi-agent models to simulate human collective dynamics (Iskandar et al., 2023; Jobert, Predhumeau & Dugdale, 2023), and also models based on non-human organisms or cellular automata (Shiwakoti & Sarvi, 2013; Wang et al., 2015). These approaches are often applied to specific contexts, such as analysing road connectivity (Kim et al., 2021) or optimising evacuation routes to reduce time and increase safety (Bretschneider & Kimms, 2012). Some studies integrate simulations with GIS tools to visualise results and improve prediction accuracy (Chondrogiannis, Bouros & Emser, 2021). There are also simulation platforms, including some open-source ones, that can be used in fields other than simple evacuation planning (Taillandier et al., 2010; Kleinmeier et al., 2019). Research also extends to crowd simulation in buildings (Liu & Lyu, 2019; Pluchino et al., 2014) and urban environments (Simonov et al., 2018), using gaming and artificial intelligence technologies to improve the accuracy of simulations. Some studies consider crowd panic (Wang et al., 2022; Shiwakoti & Sarvi, 2013) and specific crowd behaviour in particular situations, such as evacuation on stairs (Fujiyama & Tyler, 2009). Furthermore, some researchers use data from mobile devices to more accurately model crowd behaviour (Yin et al., 2020), contributing to open science and open data (Benaben et al., 2021). The second area of research concerns urban design techniques aimed at reducing evacuation risk but is much less developed. Few researchers link risk assessment with evacuation simulation using tools such as agent-based models and GIS (León & March, 2016). Most research still focuses on traditional risk management approaches, such as Disaster Risk Management (DRM) and Pre-Disaster Planning, without fully exploiting the opportunities offered by data science (Fallah, Masoud & Navaie, 2014). Some studies examine the role of public space in disaster, particularly green spaces and shelters, using specific indicators for analysis (Fei, Lu & Li, 2023; Wei et al., 2020). Some research combines disaster prevention with crime prevention (Yang, 2019), while others analyse the effect of urban development on areas exposed to hazards such as tsunamis, showing an increase in vulnerability as cities grow (Vicuña, León & Guzmán, 2022). The literature review highlights two main gaps: the absence of research linking crowd behaviour simulation with urban design to reduce risk, and the lack of attention to the need for transformations in urban shape to improve resilience during evacuations. The issue of risk remains low on the agenda of urban planners. This study aims to fill these gaps by developing a simulation tool applicable to different urban conditions to assess the current state of urban settings and to design future scenarios that reduce risk during evacuation. This research integrates expertise from data science, urban design, and civil protection. The research is based on an integrated approach using two main tools, developed through close interdisciplinary collaboration: an analysis tool and a design tool. The first tool consists of software specifically developed to simulate the behaviour of people fleeing during a natural disaster. This simulation is conducted using an accurate representation of the urban context in which the crowd moves. The second tool uses the results obtained from the analysis to define and implement safety-oriented urban design techniques aimed at reducing risks during evacuation operations. The methodology is therefore divided into two macro-phases, closely interconnected: i) the construction of an integrated simulation model using specific software, which allows the urban space and crowd behaviour to be modelled, also considering the possibility of introducing obstacles and other factors; ii) the development of innovative urban design techniques aimed at optimising the configuration of urban spaces, particularly open spaces, to improve resilience and reduce the risks identified in the analysis. These two phases will be applied to a concrete case study, the historic centre of the city of Atri (Abruzzo Region, Italy), which is of considerable interest for its cultural heritage but also a vulnerable urban centre where approximately 3000 residents present considerable criticalities regarding evacuation following a disaster. Section 2 describes the overall methodology of the research, of which the paper presents the results of one phase. Section 3 describes the characteristics of the simulation software that is being prepared. The case study on which the simulation is applied is described in Section 4, with an in-depth analysis of the municipal emergency plan and the related waiting areas. Section 5 describes the result of the simulation of Scenario 0, that is the current layout of the chosen urban area. In this Section, the critical issues for evacuation are identified and some design solutions will be identified in Section 6 which concerns the techniques of safety-based Urban Design. Finally, Section 7 concerns the conclusions.

## 2. Overall research methodology

The overall research methodology (Figure 1) consists of two main interconnected components, each addressing crucial aspects of urban security and resilience:

a. Advanced modelling and simulation; this is the first phase in which the data required for the research is collected and, through the GAMA platform (Taillandier et al., 2018; Taillandier et al., 2010), an integrated crowd behaviour simulation model is created, capable of providing a detailed representation of the urban environment and crowd dynamics and incorporating random variables to simulate unexpected events (e.g. sudden obstacles).
b. Innovative urban design; this is the second phase in which safety-based urban design strategies are developed to optimise urban morphology, with a focus on open spaces and thus to increase resilience and mitigate the risks identified in the analysis.

The research approach is characterized by the construction of a digital model (the digital twin - DT) of an urban setting to be analysed and, in this DT, the application of a crowd simulation algorithm aimed at understanding urban risks for evacuation. Such modeling, which identifies critical urban issues, enables the identification of innovative urban design techniques for the reduction of said risks. Thus, it is a model-based design approach, which from the analysis of a model and its simulation of operation, implements the control tool in urban design techniques.

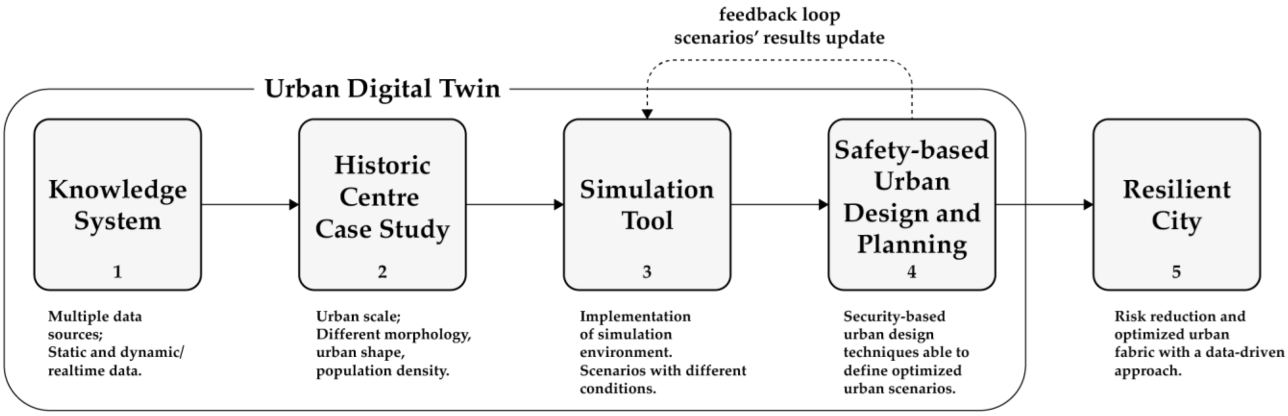
The research process is developed through five distinct methodological stages, integrated into the broader context of an Urban and Regional Digital Twin project (Sacco, Eugeni & Di Ludovico, 2024):

1. Construction of the knowledge system; concerns the collection and analysis of statistical and geographic data; the integration of different sources: regional open data, field surveys, elaborations by the research team; the future incorporation of real-time data from a sensor network (SICURA project, see acknowledgements).
2. Case study selection and analysis; this is the phase of identifying a representative urban area for the application of the model and its validation.
3. Implementation of the simulation model; this concerns the development of GAMA-based software to simulate evacuation scenarios. This tool is initially applied to 'Scenario 0', i.e. the current urban configuration, and is then applied to modified design scenarios obtained through the implementation of phase 4. In this sense, phase 3 and phase 4 are connected by continuous feedback as a control and validation operation of the design scenarios.
4. Application of safety-based urban design techniques; this is the phase in which innovative Safety-Based Urban Design techniques are studied and applied to Scenario 0 to improve the urban shape and make it more resilient, thus determining the Design Scenarios. These techniques in particular focus on the urban shape and role of the evacuation plan waiting areas and thus on the optimisation of evacuation routes and overall resilience.
5. Evaluation and iterative optimisation; in this last phase of the methodology the chosen and most performing and optimised Design Scenario, obtained in phase 4 with the application of innovative Safety-Based Urban Design techniques, is dropped into the existing urban framework and through consistency verification processes its structure is readjusted to increase the overall resilience of the city.

The method has been designed to be replicable and adaptable to different Italian urban contexts and especially to utilise the potential of the Urban and Regional Digital Twin (Sacco, Eugeni & Di Ludovico, 2024) that opens new possibilities for smart urban management through a multidisciplinary approach combining urban planning, information technology and risk management.

This methodology represents a significant step forward in the design of safer and more resilient cities, providing a powerful tool for urban planners, policymakers and emergency managers. It is necessary to emphasize that the methodology is iterative, that is, the simulation algorithm must be applied to the design scenarios iteratively (steps 3 and 4 in Figure 1) until the best optimized urban layout is found. Therefore, the design scenarios should be modified until the best one is obtained.

**Figure 1. Methodology framework**




Source: Authors' elaboration

## 3. The simulation software

Concerning simulation software, the GAMA platform was chosen as the main technology (Taillandier et al., 2018; Taillandier et al., 2010). Due to its Java-based programming syntax, GAMA enables the efficient definition and linking of variables of different types in processes. The variables created form the core of the algorithm and explain the parameters of simulations or experiments, the settings of which allow the results to be visualised in different ways, such as animated maps, 3D models, graphs, etc. Furthermore, GAMA allows the import and visualisation of various types of data, including geographical and geometric data, both two- and three-dimensional, in GIS format. Table 1 presents, in the first column (Section One), the typical structure of a GAMA script. The second column describes the section, about the code developed for our experiments. The initial section of the script, called 'global', defines the general parameters of the modelling, on which the information in the following sections is based. This part includes the initial tasks that the simulation engine performs at start-up, such as importing essential libraries and files - e.g. geographic files - and handling them. The second section of the script, called 'species', focuses on the characteristics of the different species of agents, which represent the protagonists of the simulation. In our preliminary study, we defined four species: people, buildings, endpoints, and road graphs. The 'people' species specify the behaviours or reactions that the agents must have about the other species (for example, in this case, we define the type of movement that individuals must perform following a road graph). Finally, the third section deals with the configuration of the experiment's outputs, which, in the experimental application described in the following sections, will be represented graphically in real-time during the modelling process.

**Table 1. Gama script description**

| Section | Script description |
|---|---|
| Global | In this part of the script, shapefiles related to the simulation environment are imported into the platform. These shapefiles contain data regarding the obstacles, and the number of people for |

| | |
|---|---|
| | each house number. Open areas, pedestrian paths and free spaces are generated by a sub-algorithm that has to be run before the actual simulation starts. It elaborates the street network shapefile (polygon-wise) making a triangulation of it to calculating the shortest path between each house and each waiting area. |
| Species | This part of the script describes the species of agents that will be part of the simulation. The specie "people" here describes the behaviour of people. For example, the speed of people is defined with Gaussian values between a minimum of 3 km/h and a maximum of 4 km/h. The script also instructs people to compute a virtual path towards the nearest waiting area in which there is still available space. |
| Experiment | The experiment block defines what is going to be visualized while the simulation is going. Apart from the three-dimensional simulation that shows the movement of the agents in real-time, it is possible to insert dynamic graphs showing partial results. Here, a pie chart displays the safe individuals and those who are still reaching the safe areas. A line graph, on the other hand, shows the trend over time of the filling percentage of each waiting area. |

Source: Authors' elaboration

## 4. The case study

Phase 2 of the methodology involves the selection of a case study, specifically a representative urban area for the application of the model and its validation. The first application of the first version of the simulation software was applied to the Coppito campus of the University of L'Aquila, to verify and optimise the waiting areas of the evacuation plan for students, staff professors and researchers (Eugeni et al., 2023). In this paper, in which the first results of an updated and more performing version of the software are reported, the simulation was applied to a more complex case, the historic centre of the city of Atri in the Abruzzo Region (IT).

The settlement of Atri was a Roman colonisation centre, but its current structure developed in the medieval period, whose cardo still constitutes the main road axis, to be completed in the historical part in the 18th and 19th centuries and in the peripheral part in the second half of the 20th century. It is therefore an urban centre with a historic centre of considerable cultural interest, featuring a cathedral dating back to the 14th century, the 15th-century Palazzo dei Duchi Acquaviva, a municipal theatre dating back to the end of the 19th century and numerous other palatial buildings of historical-monumental interest. On the edge of the historic centre are archaeological remains of Roman origin, including a theatre from the 3rd-2nd BC, and also remains of medieval walls and gates (Picard, 1991).

From a socio-demographic point of view, it is a city of 10,000 inhabitants (10,012 in 2023) that in recent decades has shown a steady population decline and a significant increase in the old-age index (by 2023 there are approximately 260 elderly people for every 100 young people), an increasingly negative natural balance (by 2023 deaths are three times as many as births) and a fluctuating migratory balance, but one that nevertheless indicates a tendency to migrate to other municipalities (ISTAT, 2024). This is the situation in which many municipalities in Abruzzo find themselves, especially those in inner areas, which are now affected by the National Strategy for Inner Areas (SNAI, 2024).

The area chosen for the simulation was limited to the historic centre (Figure. 2) which, according to the 2021 census, is home to about 3000 residents. In this context, there is not only a considerable cultural heritage that generates tourism but also various public and private facilities, such as the municipal headquarters, a museum, schools and hotels and non-hotel accommodations.

**Figure 2. The historic centre of Atri and its geographical context**


Source: Authors' elaboration

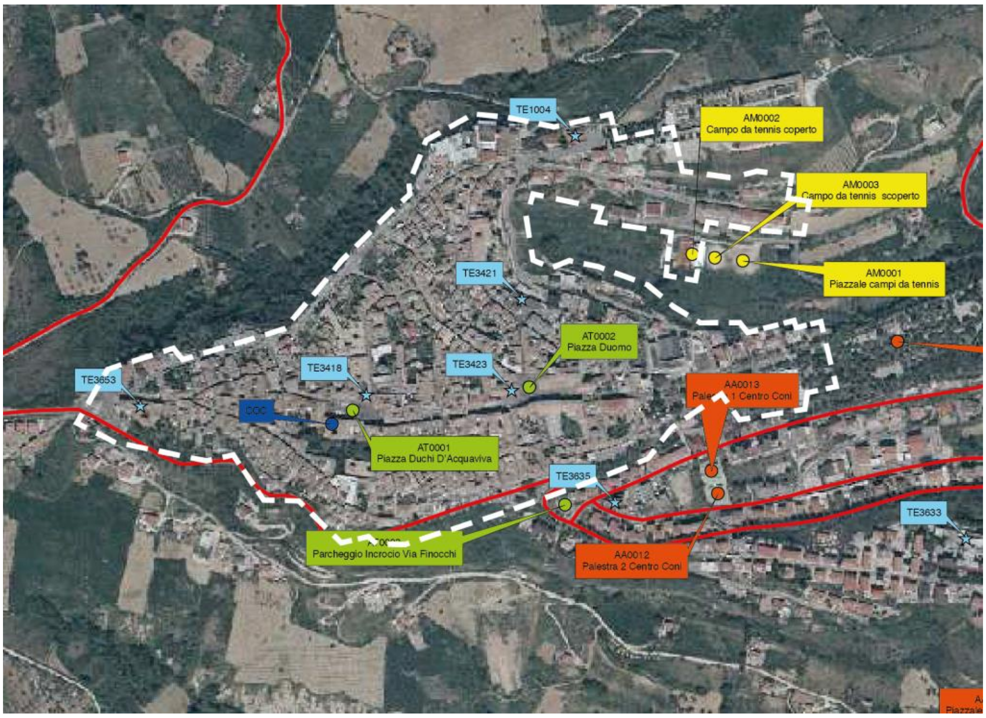
*4.1 Vulnerability of buildings*

In 2012, the Urban Plan for the historic centre of Atri was approved. Among the cognitive elements of the Plan, there is a study of the vulnerability of buildings based on a survey of the qualitative level of the 1st level vulnerability produced by the regional civil protection through the GNDT sheet (National Earthquake Defense Group, https://emidius.mi.ingv.it/GNDT2/Strumenti/Strumenti_home.htm) that take into account the age of construction, typology and use, location of the building, number of floors, structural typology, type of roofing, regularity in plan and elevation and state of decay. The sheets allow to evaluation the buildings of the historic centre in terms of vulnerability and consequently, knowing the resident population, to have a map of the urban risks that can be triggered during a seismic event. These risks do not only concern the probable damage to the buildings but also the possible collapses on the escape routes for evacuation. In this article, this information will not be considered, since it describes the first application of the model in simplified conditions. In future applications, they will also be considered, defining them in terms of obstacles.

*4.2 The Atri city evacuation plan*

The organisation of evacuation in the event of a natural or man-made disaster is contained in the Municipal Emergency Plan (PEC), as required by national legislation. As can be seen in Figure 3, in the area chosen for the simulation, Atri's PEC has identified three waiting areas, shown in green in the figure, which represent the areas where people will concentrate following evacuation and therefore escape. In light blue are identified the strategic buildings for the management of the emergency, in red are the reception areas where the tent camps will be set up, and in yellow are the gathering areas where the rescue vehicles will be concentrated. Our research and simulation work focuses on the urban role of the waiting areas, which at present can only accommodate a limited number of people compared to the actual residents, as shown in the Table 3.

**Figure 3. Atri Municipality's emergency plan**




Source: Authors' elaboration on source material from Civil Protection Department. Case-study area highlited with dashed white line

The maximum number of persons that can be accommodated in the waiting areas as set out in the current PEC (Figure 3) was in the first instance derived from the PEC sheets, as shown in the Table 2.

**Table 2. Capacity of waiting areas in the study area.**

| Area | | Capacity *(no. of people)* |
|---|---|---|
| AT0001 – Piazza Duchi D'Acquaviva | | 1.250 |
| AT0002 – Piazza Duomo | | 875 |
| AT0003 – Parcheggio incrocio via Finocchi | | 300 |
| | **TOTAL** | **2.425** |

Source: Atri Municipality Emergency Plan

In the second instance, the actual surface areas of the waiting areas were measured

(Table 3, column 'Sup.' - Surface) and then these areas were reduced by a % (tab. 3, column 'Red.' - Reduction) that considers any interfering and vulnerable buildings that may give rise to collapses and parked cars (night-time assumption). Having calculated the reduced area of the waiting areas (Table 3, column 'Sup. red.' – Surface Reduced), a coefficient of occupancy of one person (Şenik & Uzun, 2021) of 2.5 square metres was applied to this (Table 3, column 'Req.' - Requirement), a coefficient defined precautionarily by considering that the crowd would stay in the waiting area for a long time. As can easily be seen, the recalculated capacity (Table 3, column 'Cap.' - Capacity) is considerably lower than that of the Plan.

**Table 3. The recalculated capacity of waiting areas in the study area**

| **Area** | **Sup.** *($m^2$)* | **Red.** *(%)* | **Sup. red.** *($m^2$)* | **Req.** *($m^2$/ab)* | **Cap.** *(n° per.)* |
|---|---|---|---|---|---|
| AT0001 – Piazza Duchi D'Acquaviva | 2.480 | 20 | 1.984 | 2,5 | 794 |
| AT0002 – Piazza Duomo | 2.903 | 25 | 2.177 | 2,5 | 871 |
| AT0003 – Parcheggio incrocio via Finocchi | 642 | 30 | 449 | 2,5 | 180 |
| **TOTAL** | **6.025** | | | | **1.845** |

Source: author's elaboration

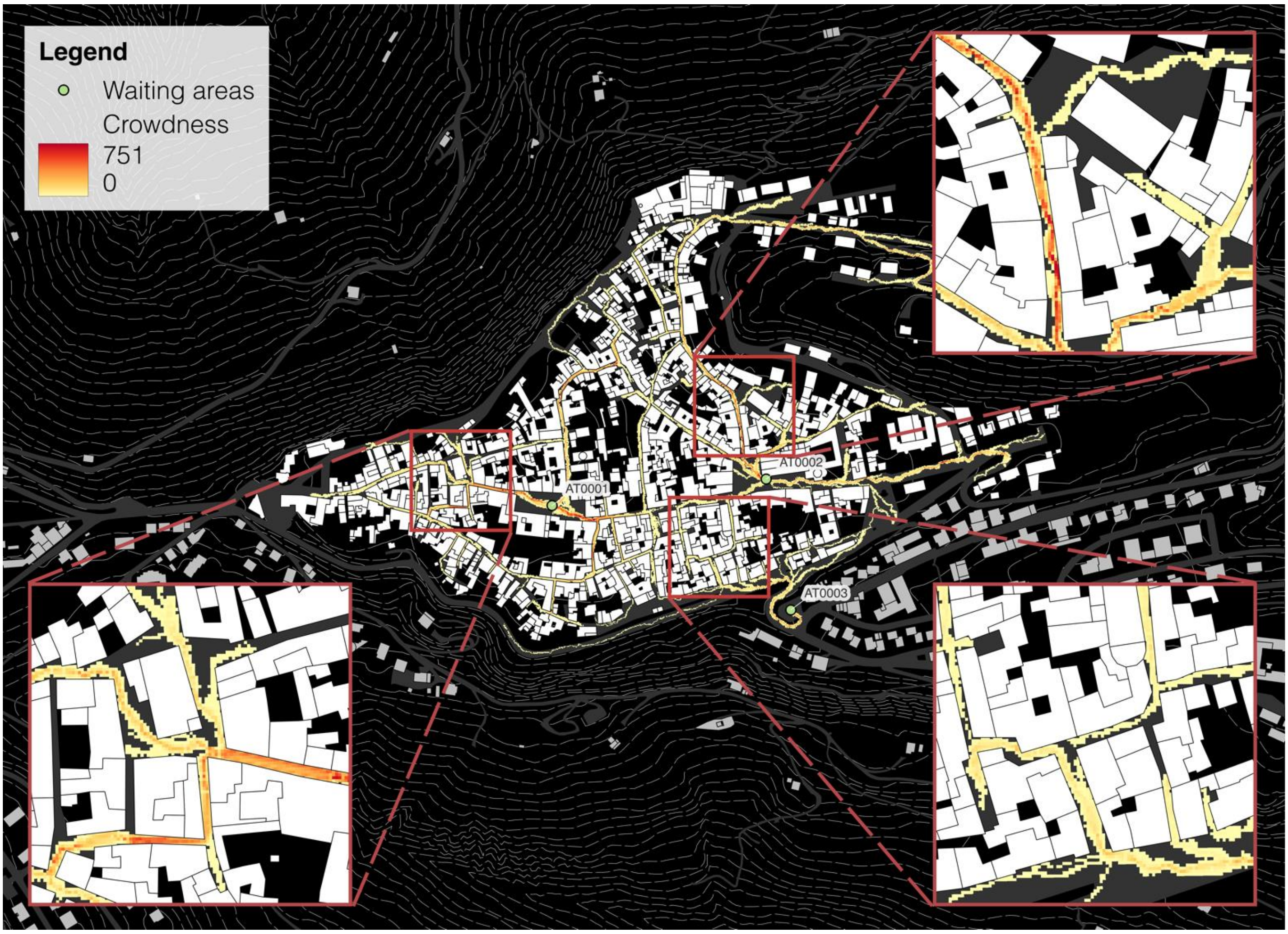
In the simulation of Scenario 0 described in the following Section, the capacities of the waiting areas in the Table 3 apply.

## 5. Scenario 0 simulation results

The general parameters of the simulation are mainly related to the number of people exiting each building, the calculation of the shortest path to the waiting areas, and the capacity of each. The number of inhabitants is associated with points representing house numbers (860 total). Given these conditions, on average, there are three residents at each house number for a total of 2831. As already mentioned, there are three waiting areas to which the simulation agents refer. It is specified that the third one (AT0003) was considered even though it does not fall exactly within the white perimeter in Figure 3 since it is in fact in a position adhering to the perimeter itself. The results of the simulation are graphed in Figure 4.

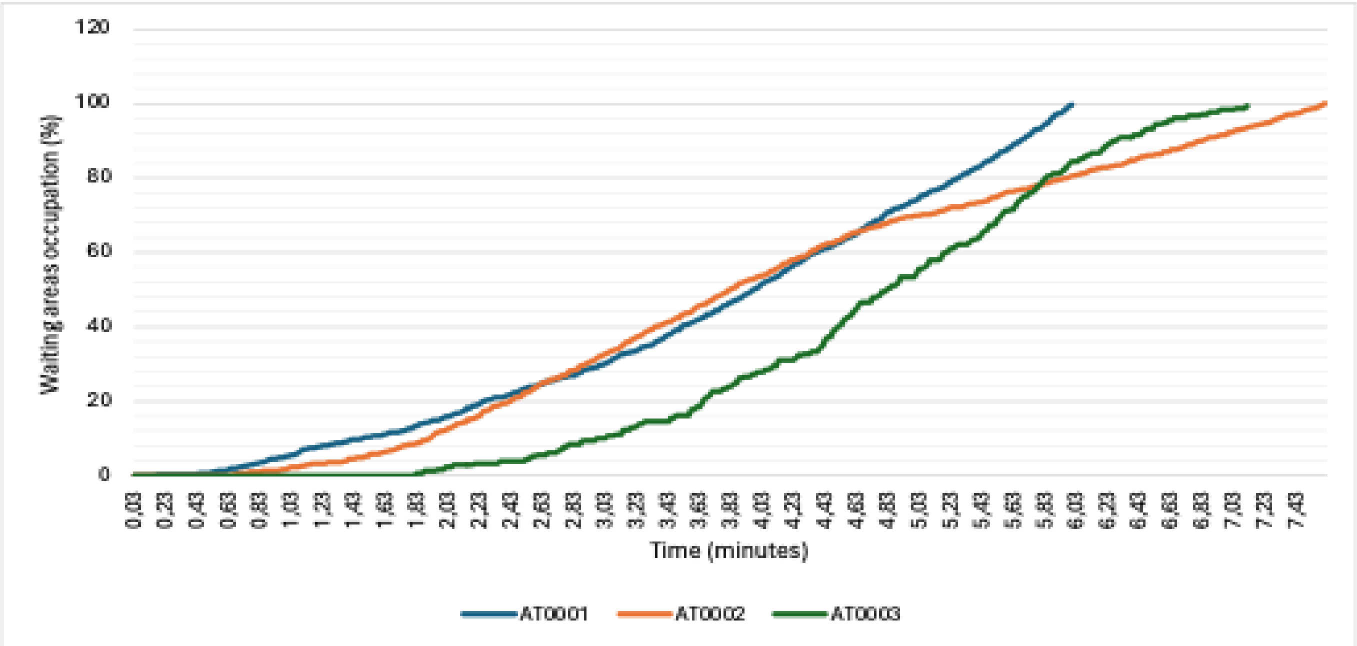
The simulation software was programmed in such a way as to export, at the end of the simulation, a file in georeferenced tiff format (similar in type to a digital terrain model) in which each pixel is associated with the level of crowding detected during the simulation. Obstacles are represented to a first approximation only by buildings (the presence of parked cars and other obstacles commonly found in historic centres is not considered). From Figure 4, it is possible to check how the level of congestion is greater in the portions of the street with smaller cross-sections. This problem is particularly evident in areas where the urban morphology has bottlenecks and dead ends typical of historic centres of medieval or later origin. The figure shows, in the three corners, zooms in on the urban parts with the greatest crowding problems, such that the simulation software highlights their critical issues with the red colour of the heat map. These are three urban parts close to the analyzed waiting areas, whose congestion can be considered problematic for reaching these areas. For these parts, future research studies will consider risk reduction actions through urban and evacuation plan re-design. For instance, one solution will be to identify new micro-waiting areas that relieve the streets of crowding.

**Figure 4. Simulation results overlayed on historic city centre cartography**




Source: Authors' elaboration

**Figure 5. Simulation results graph for the 3 waiting areas**




Source: Authors' elaboration

During the simulation, the data is recorded moment by moment and exported to a spreadsheet at the end of the simulation. This makes it possible to create graphs, such as the one in Figure 5, in which it is possible to see the time order in which maximum capacity is reached. The first to reach maximum capacity is AT0001 (5,83 minutes). AT0003 (7,03 minutes) and AT0002 (7,43 minutes) follow in that order. It should also be noted that not all the simulated persons, or agents, manage to reach the waiting areas before the maximum capacity is reached: 986 agents remain wandering at the end of the simulation. This residue is therefore an indication of the undersize of the waiting areas that should, in theory, be able to accommodate the entire resident population.

## 6. Urban Design safety-based techniques

To optimise Scenario 0 and solve the critical issues highlighted in the previous section, it is necessary to define a set of safety-based Urban Design techniques (UDS-b) and apply them to the Scenario to achieve a new, safer, and thus more resilient urban shape.

**Table 4. Review of risk factors that determine the need for Urban Design Safety-based technique**

| Risk Factors – Urban Design Safety-based techniques (UDS-b) | References (UDS-b techniques) |
|---|---|
| **1. Direct or indirect obstacles**<br>- Stairs, steep areas, damaged pavement;<br>- Areas without sidewalk ramps, bulky street furniture;<br>- Dead ends, collapses, level crossings;<br>- Reduction of the carriageway: protrusions, pillars construction sites;<br>- Vehicles, narrowing of practicable height. | Bramerini & Castenetto, 2016;<br>Alkassabany, Abouelfadl & Alkassabany, 2018;<br>Cai & Wang, 2009;<br>EC-DGJFS, 2007;<br>Murao, 2008;<br>Bernardini et al., 2021;<br>Hosseini et al., 2009;<br>Wang et al., 2022. |
| **2. Shape factor of emergency elements**<br>- Excessive curvatures, redundant grids;<br>- Exceeded capacity of escape routes and emergency areas. | Bramerini & Castenetto, 2016;<br>March & León, 2015;<br>EC-DGJFS, 2007;<br>Hosseini et al., 2009;<br>WHO-ROE, 2022;<br>Fei, Lu & Li, 2023;<br>Santibáñez, 2016. |
| **3. Accessibility/connection to emergency shelters**<br>- Exceeding critical isochrones, poor connectivity \| Urban planning. | Tsai & Chang, 2023 |
| **4. Inefficiency of technological and road networks**<br>- Risky road works (tunnels, bridges, etc.)<br>- Incomplete or unknown technological networks. | WHO-ROE, 2022;<br>Liu, Yanliu & Wang, 2014;<br>Hosseini et al., 2009. |

Source: author's elaboration

To this end, a literature and manual search was conducted, resulting in a table (Table

4) that identifies evacuation risk factors (such as obstacles, shape of urban elements, and accessibility) that determine the need for interventions based on specific literature sources (references column). However, a lack of bibliographic references in many areas and scales emerges, indicating the need for further studies.

Some Urban Design practices aimed at improving pedestrian evacuation for both natural and man-made disasters coincide with those for urban social security, such as Crime Prevention through Environmental Design - CPTED techniques (Cai & Wang, 2009; Newman, 1973). However, specific studies on Urban Design for urban risk reduction are rare.

Concerning obstacles, the literature contains many articles that generically deal with the topic, often focusing on building interiors rather than outdoor spaces. These studies mainly analyse crowd behaviour in the presence of generic obstacles, such as people, animals, or choke points (Wang et al., 2022).

The simulation of scenario 0 (Section 5) demonstrates three critical issues that slow down evacuation and increase risk: 1. Insufficient capacity of waiting areas, which have a small surface area as described in Section 4; 2. Insufficient capacity of some escape routes due to their shape and the presence of obstacles that also reduce accessibility to waiting areas; 3. Lack of performance of the urban shape in terms of safety.

To reduce these critical issues, it is necessary, as far as possible in a historic centre where the principle of conservation is applied first and foremost, to reorganize the urban shape to make it safer by reducing risks and therefore increasing resilience. In this sense, our research is identifying some Urban Design Safety-based techniques (UDS-b), as shown in Table. 4, which, when applied to the analysed urban context, allow for the reduction of urban and evacuation risks. In the specific case and for the three critical areas described and the risk factors in Table 4, at this stage, we are studying the following techniques:

1. Waiting areas have insufficient capacity. It concerns points 1 and 2 of Table 4, and the techniques are aimed at eliminating obstacles as much as possible (for example bulky street furniture, damaged pavement, vehicles/parking, etc.), to effectively redesign the shape of the waiting areas (also in terms of its architecture), while maintaining urban quality.
2. Escape routes have insufficient capacity. It concerns points 1, 2 and 3 of Table 4. In this case, the techniques, as for the previous point, tend to eliminate obstacles, improve the evacuation road network both in terms of grid and shape and increase accessibility and therefore reduce times by avoiding too many turns.
3. Lack of performance of the urban shape. In this case, the techniques are a combination of the previous points and are aimed at optimizing waiting areas. This means verifying the possibility of identifying new areas and for this research, of identifying micro-waiting areas as close as possible to the escape routes. The role of these micro-areas is even more important the greater the urban density, such as historic centres, and the less there are large areas to use.

The definition of UDS-b techniques in this research is in the initial phase, since up to now it has been concentrated on the simulation model that will still be improved in the next steps. Therefore, in the previous points we have limited to a qualitative description.

## 7. Conclusion

The article illustrated the results of research in the development phase that concerns the creation of an integrated model to simulate urban evacuation in case of disasters.

The model combines the representation of the urban space with the simulation of crowd behaviour, including random variables such as the appearance of obstacles. The final goal is to create a simulation tool useful for identifying critical issues during evacuation and for applying innovative urban design techniques oriented towards safety and optimization of the urban shape to make the city more resilient and consequently reduce urban risks.

The simulation was carried out using software based on the Gama Platform, a development environment for agent-based simulations. The results obtained from the application of the simulation to the case study demonstrate that three types of critical issues occur in the urban context of reference: 1. Waiting areas insufficient capacity, due to the presence of obstacles and their shape; 2. Escape routes have insufficient capacity, for the same reasons as point 1 and for reduced accessibility; 3. Lack of performance of the urban shape, due to a disorganized urban configuration in terms of safety. Furthermore, they demonstrate that it is necessary to intervene with a redesign of public and open urban spaces to make the related context more resilient by reducing urban risk. Ultimately, they demonstrate that the issue of safety is central in the control of the urban shape and underline the need to define a specific field of research on the techniques of Urban Design and Urban Planning Safety-Based, for which the study presented in this article represents the incipit.

It is necessary to highlight that the model applied in this paper has some limitations. First, the agents-people were simulated as if they were fully aware of the evacuation plans, ignoring the chaotic behaviour typical of panic situations. Furthermore, the differences between social groups that could significantly affect the evacuation were not considered. These limitations will be overcome with the subsequent development of the research. The next steps will focus on these aspects, improving the differentiation of the agents and introducing a 3D geographic model.

The final goal is to develop new techniques of Urban Design Safety-Based, specific for natural and anthropogenic disasters, considering not only the seismic hazard, as for the study described in this paper, but also other types of hazards.

**Author Contributions**

Donato Di Ludovico contributed to sections 1, 2, 4, 6 and 7, and supervised the paper. Federico Eugeni contributed to sections 2, 3, 4 and 5, and Gennaro Zanfardino contributed to Sections 2, 3, and 5.

**Funding**

The research described in this paper received funding from the following projects in which the University of L’Aquila is a partner:

- SICURA Project – “caSa Intelligente delle teCnologie per la sicURezza - L’Aquila”, FSC 2014-2020 - Axis I. Research Programme: Safe City: urban design and technologies for urban safety.
- PNRR ICSC National Research Centre for High Performance Computing, Big Data and Quantum Computing (CN00000013), under the NRRP MUR program funded by the NextGenerationEU. Spoke 9 “Digital Society & SMart Cities”.
- Territori Aperti, a research project funded by Fondo Territori Lavoro Conoscenza - CGIL CISL UIL (https://territoriaperti.univaq.it/).
- NextGenerationEU - National Recovery and Resilience Plan (PNRR) - Project: “SoBigData.it - Strengthening the Italian RI for Social Mining and Big Data Analytics” - Prot. IR0000013.

**Acknowledgements**

For support on data science and open data topics, we thank Prof. Antinisca Di Marco, Department of Information Engineering, Computer Science and Mathematics, University of L’Aquila, Italy.

The data relating to residents and the Municipal Emergency Plan (PEC) used for the simulation were provided by the Municipality of Atri (Abruzzo Region, IT).

**Conflicts of Interest**

The authors declare no conflict of interest.

**Originality**

The authors declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere, in English or any other language. The manuscript has been read and approved by all named authors and there are no other persons who satisfied the criteria for authorship but are not listed. The authors also declare to have obtained the permission to reproduce in this manuscript any text, illustrations, charts, tables, photographs, or other material from previously published sources (journals, books, websites, etc).

**Use of generative AI and AI-assisted technologies**

The authors declare that they did not use AI and AI-assisted technologies in the writing of the manuscript; this declaration only refers to the writing process, and not to the use of AI tools to analyse and draw insights from data as part of the research process. They also did not use AI or AI-assisted tools to create or alter images and this may include enhancing, obscuring, moving, removing, or introducing a specific feature within an image or figure, or eliminating any information present in the original.

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