Urban Safety and Resilience: Agent-Based Modelling Simulations for Pre-disaster Planning

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Abstract. One of the issues that today's urban planner is probably called upon to question is the ability to succeed in shaping a dynamic approach to be able to deal with the challenges and events that contemporary life presents us with by placing oneself in a position that is not always easy and trying to develop methodologies and implement innovative tools that can support planning practice. The research presented in this article addresses, in this context, the issue of pre-disaster planning and focuses on simulation regarding crowd movement at the urban level (and beyond, as will be expounded more extensively in the text) based on algorithmically determined risk scenarios. The methodology is based on the use of an agent-oriented programming language that offers the possibility to build integrated models with different modelling paradigms, explore parameter space, calibrate them, and perform virtual experiments by integrating vector and raster geospatial data. The goal is thus to verify, downstream of these simulations, performance characteristics and endowments of parts of cities about their ability to respond to the occurrence of a natural disaster, but above all, it will be to define new urban design techniques oriented toward safety and thus increasing the resilience of our cities. The article presents the first results of the research about a case study on which the methodology being developed was applied.

Keywords: Simulation · Agent-based · Programming language · Geodata · Pre-disaster planning

1 Introduction

One of the issues on which today's urban planner is probably called upon to question himself is the ability to succeed in shaping a dynamic approach to face the challenges and events that contemporary life presents us with, placing himself in a position that is not always simple, trying to elaborate methodologies and implement innovative tools that can support planning practice. It seems clear, given the continuous occurrence of natural calamitous events on the Italian territory (and not only) [1], how the need to assess a priori the possible effects of such events is of common interest not only for its theoretical-scientific implications but also and above all for its practical ones. Implementing complex simulated models capable of describing the reality around us could, in fact, result in a

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higher degree of preparedness and awareness on the part of society at all levels. A fundamental part of this practice, however, lies in the virtual representation of conditions, behaviour and risk scenarios in order to plan, communicate and inform citizens, public administrations and stakeholders living in the territories, regardless of their disaster history. The changes taking place on a global scale in fact require new investigation methodologies that cannot only be based on the consideration of recurrent past events. From an extensive, growing, bibliographic analysis, the subject of simulation concerning natural disasters is widely discussed in the field of events in Europe and the world, but not in Italy. The reason for this is not clear, but it is possible to make some assumptions. The availability of geospatial data on urban realities, which is fundamental for carrying out analyses and assessments of this type, is not homogeneous throughout the country. The physical conformation of the same, in its natural and anthropic components (think for example of the inter-neighboring mountainous areas and small historical centers), entails quite a few problems at an analytical level. Perhaps these are two of the reasons behind the apparent disenchantment with the issues introduced. On the other hand, research and practice concerning pre-disaster planning now have solid foundations, as models and practices have been built up over time based on the well-established occurrence of calamitous events on the national territory. In this context, the study presented in this article focuses on the development of crowd movement simulation techniques at an urban scale, in relation to the Urban Digital Twin (Urban Digital Twin) and territorial paradigm, capable of acting as support and verification tools for pre-disaster planning and bridging the gap between the two issues. The case study is an area in the first suburbs of the city of L'Aquila, in Abruzzo, currently in the final stages of the reconstruction of private buildings begun following the earthquake events that occurred in April 2009 [2]. As will be explained later, the techniques used are aimed at verifying the capacity to respond effectively to the occurrence of a natural disaster (not only of a seismic nature but also of other types). In this way, it will be possible to define new urban planning and design practices oriented towards the safety of the city's people and thus increase the cities' resilience. The methodology applied to the study is based on the analysis of tridimensional geospatial data within agent-based modelling software [3]. Both data available online, on the geoportal of the Abruzzo Region, and data derived within the software itself are used, thanks to the writing of a code capable, for now in a simplified manner, of implementing a simulation of crowd movement at an urban scale. Although in its embryonic phase, the proposed research is part of a broader scenario of activities carried out by the working group, integrating some of its aspects. Reference is made to the elaboration of Territorial Information Platforms [4] relating to the theme of new forms and tools of urban and territorial planning that relate to the needs of contemporaneity and the spaces in which it manifests itself and develops. Furthermore, it is useful to mention the experiments related to the Digital Twin [5] and City Information Modeling [6]: complex systems of information aimed at building dynamic and open models of three-dimensional representation of the phenomena taking place on an urban and territorial scale. The study is part of two research projects in which the University of L'Aquila is a partner. In particular, these are the SICURA Project - "Intelligent house of technologies for safety - L'Aquila" - Emerging Technologies Support Programme (FSC 2014–2020) - Axis I "Case of Emerging Technologies", Research Programme: Safe city: urban design and technologies for urban safety, and the National Centre for HPC, Big Data and Quantum Computing - PNRR Project, funded by the European Union - Next Generation EU, Spoke 9 - WP6 Socio-economic, T6.1 - Urban and Territorial Safety. Following the introduction of the general purposes of the research, explored in depth in this first section, the state of the art regarding previous research and experience related to the topic is now explored (Sect. 2). In the third section, on the other hand, the methodology followed to construct the algorithm that instructs the three-dimensional simulation environment is described in the fourth section, conclusions are, finally, drawn, and future developments of the research are outlined.

2 Scientific Reference Context

In the international literature, there are several experiences with using and experimenting with simulation systems on an urban scale using the logic of agent-based modelling of phenomena. These are a class of computational models aimed at the digital simulation of actions and interactions of self-named agents to assess their effects on the system. The term agent can be used to identify any element of a system whose behavioural characteristics can be described (people, buildings, roads, traffic, etc.). The literature research was accompanied by an in-depth analysis of simulation software (both commercial and free) based on the scientific models they refer to (most use agent-based simulation methods), their 2D or 3D visualization capability, the use of graphs or grids for urban analysis and the visualization of results, and the number of agents that can be used. The chosen software is Gama Platform [7–9]: a modelling and simulation development environment for the construction of spatially explicit agent-based simulations. Models are built using a Java-based programming language. It is also possible to import and visualize shapefiles (which contain georeferenced data) with which to conduct analyses at different spatial levels and scales of representation. Although GAMA provides a scientific approach to constructing and exploring models, it was also developed for use by researchers outside the field of data science. To place the research in a scientific context of reference, it is considered useful to cite some experiences in which similar methodologies were developed on a different scale and with boundary conditions quite different from a possible Italian case study.

2.1 CityScope

CityScope is a tangible and digital platform, developed at the MIT Media Lab, dedicated to solving the challenges of spatial design and urban planning through tools ranging from simulations that quantify the impact of design (physical and intangible) in cities to collaborative communication applications. Through CityScope, these tools are distributed globally through a network called ‘CityScience’, maintaining open-source databases for most implementations. In this context, GAMA was used to implement an agent-based simulation platform for research projects aimed at understanding behavioural patterns related to housing and mobility patterns in the design of urban policies.

2.2 ESCAPE

ESCAPE [10] aims to implement an operational research system on crowd evacuation at the urban scale. The project is based on the relationship between geographic information systems, multiscale modelling of ongoing phenomena at the urban scale and digitized simulation tools aimed at exploring these models. The system is implemented and validated on real case studies to generate realistic simulations to test evacuation strategies by state bodies dealing directly with emergencies. By combining sources such as spatial information (land use, transport networks, sprawl, and hazards), and demographic data, with simulators for mobility and traffic management (cars, bicycles, pedestrians, public transport) it can visualize different evacuation strategies (partial or complete, wave or synchronous) and providing measures of evacuation times in different crisis zones.

2.3 ACTEUR

The aim of the ACTEUR project is to develop a platform that helps modellers, in particular geographers and town planners, to design and calibrate through a graphical language a cognitive agent capable of acting in a complex spatial environment. The platform also has the ambition to support model discussion - participatory modelling - between the different stakeholders (geographers, sociologists, urban planners, decision-makers, etc.). These tools are integrated in the GAMA platform, which allows users to build large-scale models with thousands of agents and has already been used to develop models with cognitive agents.

3 Methodology and First Results

As already explained in part 2, the methodology proposed in this article is based on the use of a programming language in a digital environment with which it is possible to describe the behaviour of agents at an urban scale. The software chosen is the GAMA Platform [11, 12]. The choice was mainly oriented by the open-source nature of the software itself and the fact that within it is possible to use geospatial data (thus manageable in a GIS environment, a classic planning tool) in both two and three dimensions. As mentioned, in GAMA, processing can be implemented thanks to a programming language (based on Java) in which it is possible to define variables of different types related to each other. The variables defined in this way represent the heart of the algorithm in that they explain the fundamental components of the simulations, called experiments, the parameters of which make it possible to display results in various forms (animated maps, 3D models, graphs, etc.). It is also possible to import data of different types, both geospatial and geometric (both two- and three-dimensional), which are displayed. The structure of the script, which is currently very lean and affected by some limitations that will be mentioned later, is presented below.

```
global {
	//Importa shapefile
	file shape_file_streets <- file("../includes/area pedonabile.shp");
	file shape_file_buildings <- shape_file("../includes/edifici prova.shp");
	file shape_file_arrive <- shape_file("../includes/punti destina-
zione.shp");
	int abitanti;
   int volume;
   int nb_people <- abitanti;
   float people_size <-1.0;

	graph the_graph;

	geometry shape <- envelope(shape_file_streets);

	init {
		create object from: shape_file_streets ;
		object the_object <- first(object);

		//triangulation of the object to get the different triangles of the
polygons
		list<geometry> triangles <- list(triangulate(the_object, 0.01));

		loop trig over: triangles {
			create triangle_obj {
				shape <- trig;
			}
		}

		//creation of a list of skeleton from the object
		list<geometry> skeletons <- list(skeletonize(the_object,
0.01));

		//Split of the skeletons list according to their intersection points
		list<geometry> skeletons_split  <- split_lines(skeletons);
		loop sk over: skeletons_split {
			create skeleton {
				shape <- sk;
			}
		}

		//Creation of the graph using the edges resulting of the splitted
skeleton
		 the_graph <- as_edge_graph(skeleton);


		create goal  {
			 location <- any_location_in (one_of(skeleton));
		}
		create building from: shape_file_buildings
with:[height::float(get("CR359_UN_2")), inhabitants::int(get("abitanti"))];
     loop b over: building {
	create people number:b.inhabitants{
		location <- any_location_in(b);
		target <- one_of (goal);
	}
     }
	}
}
```

```
species object  {
	aspect default {
		draw shape color: #lightgray border:#black;
	}
}

species triangle_obj  {
	rgb color <- rgb(150 +rnd(100),150 + rnd(100),150 + rnd(100));
	aspect default {
		draw shape color: color ;
	}
}

species skeleton  {
	aspect default {
		draw shape + 0.2 color: #red ;
	}
}
species building {
   float height;
   int inhabitants;
   string type;
   rgb color <- type = "Edificio civile" ? #pink : #gray;
   aspect default {
      draw shape depth: height color: color border:#black;
   }
}

species goal {
	aspect default {
		draw circle(3) color:#red;
	}
}

species people skills: [moving] {
	goal target;
	path my_path;

	reflex goto {
		do goto on:the_graph target:target speed:1.0;
	}
	aspect sphere3D {
		draw sphere(1) color: #blue;
	}
}

experiment prova_poligonalizzazione type: gui {
	output {
		display objects_display type: opengl {
			species object aspect: default ;
			species triangle_obj aspect: default ;
			species skeleton aspect: default ;
			species building aspect: default ;
			species people aspect: sphere3D ;
			species goal aspect: default ;
		}
	}
}
```

In particular, the first section, called ‘global’, concerns the general parameters of the simulation, to which the contents of the other two refer. In fact, this section defines the first actions that, once the simulation is launched, are carried out by the software, such as the import of databases and basic files, in this case of a geospatial type, their processing and the strategy for using these data. The second section, on the other hand, concerns the definition of the different types of agents, called ‘species’, which play the role of protagonists in the simulation. In this case, four types of species are defined: street graphs, buildings, arrival points, people. For the latter, the actions, or reflexes, that the agents representing them must have, once the simulation is launched, are defined in relation to the other species (e.g., here we define the type of movement they must perform following the road graph). In the third section, currently the shortest, we define the outputs of the experiment, which will then be displayed graphically in real-time as the simulation runs its course.

The data useful for the development of the analysis are available on the open-data geoportal of the Abruzzo Region (http://opendata.regione.abruzzo.it/). In particular, the CTR available in the regional territorial database (DBTR) updated to 2007 (the most

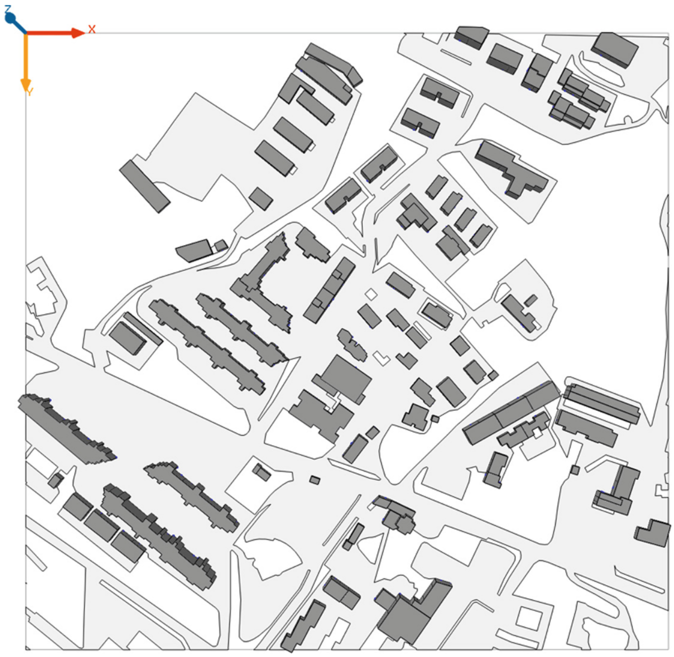

Fig. 1. Base 3D map implemented in the visualizer.

up-to-date official data available) was used, in which there is a shapefile containing geometries concerning the road system. The choice to use these data was guided by their completeness regarding the area under study. The open-source data on L'Aquila (such as those found on OpenStreetMaps https://www.openstreetmap.org/), in fact, do not provide any data regarding building height (a key parameter in the methodology presented here for reasons explored more fully below). Before using the shapefiles within GAMA, it is necessary to prepare them in a GIS (QGIS was used for the same reasons as above). To carry out crowd simulations, it is necessary to calculate the number of theoretical residents in each building. Since information of this kind is not directly available on institutional portals or local information systems, this operation was carried out by considering 1 inhabitant per 100 cubic meters (law standards in Italy for residential buildings). The shapefiles of the buildings in fact contain height values above ground level. Based on the intrinsic geometric characteristics of the buildings and by performing a simple division (in a sequential and automated manner for each building) it is then possible to calculate the theoretical number of inhabitants. The shapefiles are imported into the simulation software. The first result (Fig. 1) is not very different from that obtainable with a normal GIS, as it is possible to visualize the urban environment in three dimensions. According to the inherent functioning of the simulation software, the operations punctuated by the code are sequential in nature. The order of operations becomes, in fact, crucial to the success of the simulation. To carry out a crowd simulation, it is necessary, according to the most used practices in the field, to have a road graph representing the flows that the agents representing the residents must follow to reach one or more specific points. Since these simulations are related to emergencies linked to natural disasters, the point that is considered indicates the location of a hotspot where citizens can be accessed and receive first aid. To calculate the road graph from the polygonal geometries describing the road network, the latter were automatically triangulated in GAMA. The red line in Fig. 2 represents the graph calculated in this way. The red dot has been placed, for the time being, randomly on the graph itself as, in its current state, the study is in the testing phase to better understand the capabilities and properties of the programming language and the possibilities of describing through it the behavior of the crowd with an increasing degree of detail.

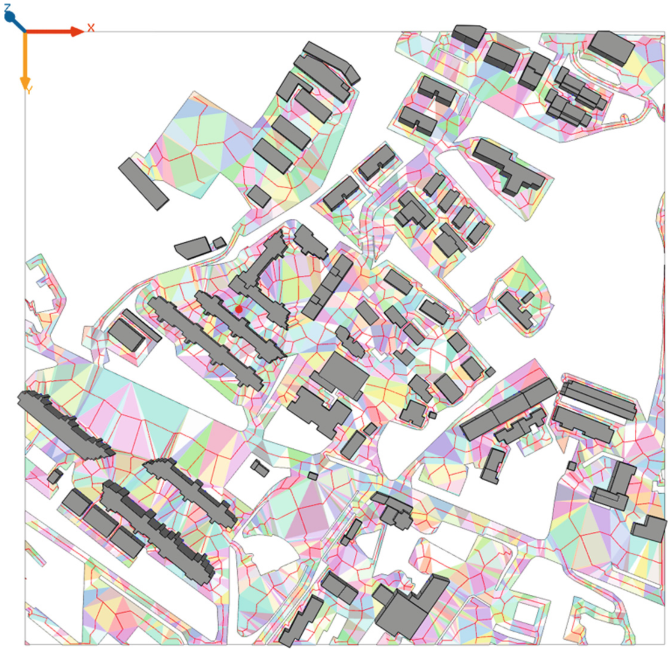

Fig. 2. Graph calculated from the polygonal road shapefile.

Agents representing the theoretical residents of each building are then generated algorithmically. At the start of the simulation, the agents ‘exit’ the buildings and head towards the red point following the shortest path. Now, the agents, represented by the small blue spheres in Fig. 3, move one after the other on the red graph and converge towards the red point representing the hotspot.

It is worth emphasizing that the research currently includes a few approximations (such as the crowd movement) on which further experimentation is underway.

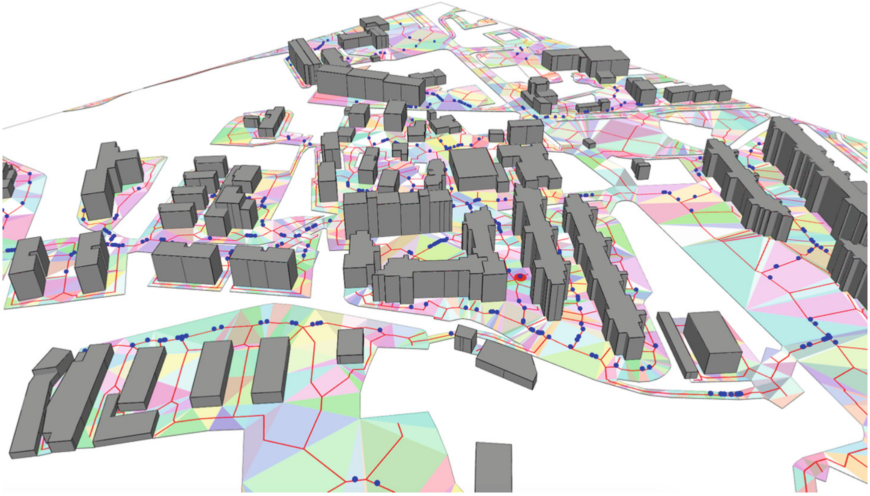

Fig. 3. 3D model of the running simulation where agents converge on the hotspot (the red dot in the middle of the picture. (Color figure online)

4 Conclusions

The methodology proposed here is part of the panorama of techniques for analyzing urban centres in support of planning and programming concerning the theme of simulating the reaction of the crowd to the occurrence of natural disasters about that of pre-disaster planning.

A simulation such as the one shown in the previous paragraph is thus capable of verifying the city's endowments in response to catastrophic events of various kinds (whose implications, conditions, and effects on crowd movement have yet to be implemented in the script and are already the subject of further investigation). At present, the points at which the population converges are randomly arranged on the street graph, and this is certainly a limitation of the methodology. A close collaboration, already underway, of the working group with the Civil Protection Department will make it possible to fill this gap by identifying in the case study the gathering points identified in the current planning.

Further research will focus on implementing the algorithm (script) regarding crowd behavior and how to verify urban standards towards a pre-disaster planning effective simulation (since now the only explored dimension is the movement of the crowd towards a point representing a possible hotspot). Now, as already mentioned, the agents converge towards the collection point in an orderly manner and are aligned following the street graph. It is easy to understand that this is too high an approximation since, especially in the occurrence of unpredictable calamitous events, crowds assume non-linear (or wandering) behavior as they are affected by panic, disorientation, lack of adequate preparation for the eventuality and an instinctive need to save themselves.

The first results of the research in any case make it possible to visualize an initial example of a risk scenario and response by the theoretical resident population. The objective is, therefore, to extend the area of analysis to the entire built-up area (having tested and validated the methodology on smaller and therefore more controllable case studies) by constructing risk (and multi-risk) scenarios with different intensities to build reliable planning support tool capable of verifying a priori planning choices. Moreover, the data used are available for most of the Italian territory, making this method and its protocols applicable and repeatable in other contexts.

Authors Contribution. Part 1 and 4 are by Prof. Donato Di Ludovico. Part 2 and 3 are by Federico Eugeni and Sara Sacco.

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