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PEERS: An integrated agent-based framework for simulating pedestrians' earthquake evacuation

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ABSTRACT

Traditional seismic risk assessment approaches focus on assessing the damages to the urban fabric and the resultant socio-economic consequences, without adequately incorporating the social component of risk. However, the behaviors people adopt in response to earthquakes, affect their exposure to the threat, and should be considered in quantitative risk assessment studies. This paper proposes an interdisciplinary agent-based modeling framework for simulating pedestrians' evacuation in an urban environment during and in the immediate aftermath of an earthquake. The model is applied to Beirut, Lebanon and integrates geo-spatial, socio-demographic, and quantitative behavioral data corresponding to the study area. Several scenarios are proposed to be explored using this model in order to identify the influence of relevant model parameters. These experiments could contribute to the development of improved emergency management plans and prevention strategies.

Keywords

Seismic risk, human behavior, interdisciplinarity, evacuation, agent-based model.

INTRODUCTION

Earthquakes are high-impact natural hazards characterized by their rapid onset. Although the occurrence of earthquakes is not preventable, a significant reduction in earthquake disasters losses could be achieved through improving infrastructure resilience, emergency preparedness, and response systems (UNISDR 2015).

Various disciplines have analyzed earthquakes from different perspectives. Earth and Engineering Sciences have developed earthquake risk assessment studies, based on the characterization of the earthquake hazard and the assessment of the exposed assets' vulnerability (Erdik 2017). Social scientists have addressed the importance of the social determinants of vulnerability and the behaviors adopted during and immediately after the earthquake on people's exposure, which affect the disasters' the impact and recovery time (Aerts et al. 2018; Rojo et al. 2017). However, human behavior is still rarely included in seismic risk assessments, mainly due to the difficulty in quantifying behaviors into tangible measures that can be integrated into these quantitative methodologies.

Surveys that investigate how people behave in emergencies provide empirical data on human behavior and the decision-making process. Therefore, post-seismic surveys can be a valuable tool for integrating the theories from behavioral sciences into quantitative seismic risk assessments. Recreating earthquake crisis scenarios that integrate social interactions could be achieved through agent-based models (ABM). In these models, agents can represent inanimate objects, such as buildings and debris, and animate objects, such as humans that can move and have complex reasoning abilities. ABMs can also be used to test "what-if" scenarios to explore emergency management strategies through simulations.

This paper presents PEERS (Pedestrians' Evacuation in Earthquake Risk Simulations), an interdisciplinary ABM for simulating pedestrians' earthquake evacuation in an urban environment. The model integrates both the physical and the social aspects of an earthquake crisis. The physical component is taken into account in the realistic estimation of buildings' damages and debris formation. The social aspect is incorporated by the human behaviors

in reaction to the earthquake, represented by the individuals' evacuation and mobility decisions, and the interaction among the individuals resulting in groups formation. PEERS is adapted to the case of Beirut, Lebanon, due to the availability of data related to buildings' seismic damages at building-scale (Salameh et al. 2017), population's vulnerability and reactions to earthquakes (Beck et al. 2018), and on-going surveys on the population's reactions to sudden onset events. The objectives of this paper are to describe the conceptual model adapted to the case of Beirut, its implementation and the proposed experiments plan.

Human Behavior in Seismic Crises

Several social theories exist on human behavior in emergencies. Some examples include Panic theory (Chertkoff and Kushigian 1999) according to which the social response in an emergency would be irrational and chaotic. Normative theory (Chu et al. 2011) argues that the norms that exist in everyday life are maintained in emergencies. However, Emergent Norm Theory (Turner and Killian 1987) suggests that an emergency overrides existing norms and forces people to establish new norms that will guide their behaviors. Social Attachment theory (Mawson 2005) states that in emergencies, individuals seek the proximity of familiar people and places, even if this would mean staying in or approaching dangerous situations. Nevertheless, theories are not sufficient to develop a model of seismic crisis including human behavior. They need to be complemented with quantitative data on the actual adopted behaviors and the factors that influence these behaviors. Post-seismic surveys, which investigate how people behaved when faced with an earthquake, provide data that can be used directly in models.

There is limited research on post-seismic surveys in the literature. The research papers identified (Goltz and Bourque 2017; Jon et al. 2016; Lindell et al. 2016; Prati et al. 2012, 2013; Santos-Reyes and Gouzeva 2020) studied seismic events that occurred in Italy, the USA, New Zealand, Japan and Mexico. These studies seem to agree on the predominant behaviors during earthquakes: evacuating, taking cover, freezing in place and protecting others. However, the frequency of each adopted behavior varies from one earthquake to another, despite very close reported maximum intensities (from VIII to IX) (Table 1). For instance, the percentage of the survey respondents that reported evacuating immediately ranges from below 10% in (Goltz and Bourque 2017) and exceeds 50% in (Santos-Reyes and Gouzeva 2020). Other behaviors such as bracing objects (Goltz and Bourque 2017), information seeking and recovering personal belongings (Prati et al. 2012; Santos-Reyes and Gouzeva 2020) have also been reported during earthquakes.

Table 1. Behaviors adopted during an earthquake. The studied earthquakes are given in brackets

	Earthquake Maximum Intensity	Evacuating Immediately	Taking Cover	Freezing in Place	Reaching/ Protecting Others
Prati et al. 2012* (Umbria-Marche, Italy, 1997)	IX	38%	12%	22%	4%
Prati et al. 2013 (Emilia-Romagna, Italy, 2012)	VIII	36%	30%	33%	No data available
Goltz and Bourque 2017 (Whittier Narrows, USA, 1987)	VIII	6%	39%	35%	6%
Goltz and Bourque 2017 (Loma Prieta, USA, 1989)	IX	8%	25%	37%	11%
Goltz and Bourque 2017 (Northridge, USA, 1994)	IX	8%	27%	39%	17%
Lindell et al. 2016 (Christchurch, New Zealand, 2011)	IX	11%	17%	38%	10%
Lindell et al. 2016 (Tohoku, Japan, 2011)	IX	28%	7%	32%	10%
Santos-Reyes and Gouzeva 2020 (Mexico City, Mexico, 2017)	VIII	53%	14%	2%	17%

* In this survey, the respondents cited all the behaviors they adopted. Therefore, the choices between behaviors were not exclusive

Similarly, the behaviors adopted in the minutes following the shaking are mainly: evacuating, returning home, reuniting with family members or continuing previous activities (Table 2).

Table 2. Behaviors adopted immediately after the earthquake. The studied earthquakes are mentioned between brackets

	Earthquake Maximum Intensity	Evacuating	Returning to house	Reuniting with family members	Continuing previous activities
Prati et al. 2012* (Umbria-Marche, Italy, 1997)	IX	93%	59%	51%	4%
Jon et al. 2016 (Christchurch, New Zealand, 2011)	IX	Going to a public shelter (1%) Going somewhere else (20%)	28%	12%	13%
Jon et al. 2016 (Tohoku, Japan, 2011)	IX	Going to a public shelter (12%) Going somewhere else (11%)	29%	11%	6%
Jon et al. 2016 (Cook Strait, New Zealand, 2013)	VI	Going to a public shelter (12%) Going somewhere else (8%)	10%	10%	54%
Jon et al. 2016 (Lake Grassmere, New Zealand, 2013)	VI	Going to a public shelter (1%) Going somewhere else (13%)	22%	9%	42%
Santos-Reyes and Gouveza 2020 (Mexico City, Mexico, 2017)	VIII	16%	8%	54%	4%

* In this survey, the respondents cited all the behaviors they adopted. Therefore, the choices between behaviors were not exclusive.

Tables 1 and 2, show that the behaviors adopted during and immediately after earthquakes do not follow the same trends in the different studies. These differences could be due to several factors: higher felt intensities were found to be correlated with undertaking protective behaviors (Jon et al. 2016; Lindell et al. 2016), socio-demographic characteristics such as being male made people more prone to evacuate buildings (Goltz and Bourque 2017; Prati et al. 2012, 2013). The cultural context including the society's willingness to adopt earthquake preparedness measures, the reliance on the government and the likelihood to engage in volunteerism were also linked to differences in earthquake behaviors (Palm 1998). This makes it difficult to generalize survey results among different societal contexts. Therefore, in order to model the human response to an earthquake in a society of interest, the best approach is to analyze, within the same culture, the behaviors adopted during events that are relatively similar to the events modeled.

Agent-Based Models for Emergency Evacuation Simulation

ABMs are computational models that model a system as a collection of autonomous IT entities defined in terms of their attributes and behaviors, called agents. Agents are able to operate without direct human intervention and are capable of perceiving and responding to their environment (Wooldridge and Jennings 1995). ABMs have proven to be a powerful tool for modeling and understanding phenomena in several fields such as economics, health care and social sciences (Kravari and Bassiliades 2015).

ABMs are widely used in the simulation of emergency evacuations. This is particularly due to the ABMs' ability to represent the heterogeneity of social agents at the individual level, and the emergent phenomena that result from the interactions among individuals, and between the individuals and their environment (Bonabeau 2002). An important advantage of ABMs is also their capability to include individual-decision making and social behaviors of individuals and groups (Cimellaro et al. 2017). ABMs have been developed to simulate evacuation for non-hazard specific emergencies at both the building scale (Manley 2012; Pan et al. 2007) and the urban scale (Daudé et al. 2019; Zia et al. 2013).

ABMs have also been used for earthquake evacuation simulation in urban environments. AMEL (Beck et al. 2014; Truong et al. 2013) was one of the first models to simulate human behaviors and pedestrian mobility in an urban

area after an earthquake. Derived from survey data, the social agents' behaviors include moving to safe areas, perceiving people and obstacles, and following leaders.

EPES (D'Orazio et al. 2014) relies on behaviors derived from the analysis of earthquake evacuation videos to model pedestrians' evacuation in urban scenarios. EPES also integrates buildings damage estimation and ruins formation inferred from the correlation between the macro-seismic intensity and the probable damage grade. It includes pre-evacuation and evacuation behaviors, and algorithms to calculate paths towards safe areas.

SOLACE (Bañgate et al. 2017, 2018, 2019), based on the social attachment theory to model the human behavior following an earthquake in a city, focuses on the influence of human and social factors, e.g. perception and attachment bonds, and physical factors (intensity of the earthquake, resulting ruins and damages) on successful evacuation.

While PEERS shares similarities with the previously mentioned models, the novelty of PEERS is the integration of physics-based evaluation of damages at the building scale, as well as more complex human behaviors derived from a targeted literature review of human behaviors and adjusted to the local context using detailed survey results.

CONCEPTUAL MODEL

PEERS is a model for simulating pedestrians' mobility and behaviors during, and the following minutes after an earthquake in a city. The model integrates the damages to the buildings, the debris formation and the people's reactions to these sudden onset changes. The model focuses on the city's residents, and integrates the social bonds shared by household members that could influence their behaviors. The model is designed for Beirut (Lebanon) that has faced several destructing earthquakes (Elias et al. 2007) and has recently witnessed a rapid uncontrolled urbanization .

An online questionnaire was conducted to collect data on individuals' responses to previous earthquakes in Lebanon. The questionnaire was designed to collect data needed for the development of an agent-based model for human behavior in earthquakes. It was developed by a multidisciplinary team, and it was iteratively validated between computer and social scientists and tested by domain experts (Beck et al. 2020). The questionnaire covers several aspects including the respondent's earthquake experience: the spatial and social context of the event, the time and intensity of the earthquake, and the behaviors adopted. It also contains questions related to the preparation strategies and knowledge, such as the knowledge of the open spaces, as well as questions related to the socio-demographic characteristics of the respondent. Moreover, the catastrophic explosions that occurred in Beirut's port on August 4 2020 provided valuable observations on the behaviors in rapid onset disaster, namely the influx of people towards hospitals just after the explosion, which resulted in the saturation of Beirut's hospitals. Due to the shared aspect of explosions and earthquake in terms of their sudden onset, another online questionnaire was carried out to collect quantitative data on the behavioral responses to the explosion.

The next sections describe the architecture of the model, the individuals' decision-making process and the formation of groups resulting from people's interactions.

Agents' Description

The architecture of the model is shown in Figure 1. The model consists of an environment that contains five classes: persons, households, buildings, debris zones and open spaces.

Person Agent

The person agent represents the residents of the city. Each person has a home building and belongs to a household. For a day scenario, people can be located either outdoors or indoors, whereas for a night scenario all people are considered to be at home. Person agents can navigate on a continuous topology formed by the area of the environment minus the buildings. They also have a travel speed that depends on their age (Bañgate et al. 2018) and the debris zone they cross. The individuals have socio-demographic attributes related to their age, gender and educational level (see the Implementation section) and have one of the following states: safe when in an open space, in danger if in a debris zone and vulnerable if not in a debris zone nor in an open space. During the earthquake, people might be injured or die if they are inside a building or in a debris zone.

Since the model focuses on pedestrians' mobility, evacuation is the only dynamic behavior modeled for indoor situations. Although other indoor behaviors (collecting belongings and looking for information) are not directly modeled, they are considered as pre-evacuation behaviors and accounted for in the time taken before evacuation. When outdoors, people can follow the recommended behavior and go to the nearest open space or choose to join a family member and thus go to their home to look for their relatives. People might also need to go to a hospital

or can just wander if they have no target destination. The decision-making process behind the behavioral and mobility choices is further explained in this paper.

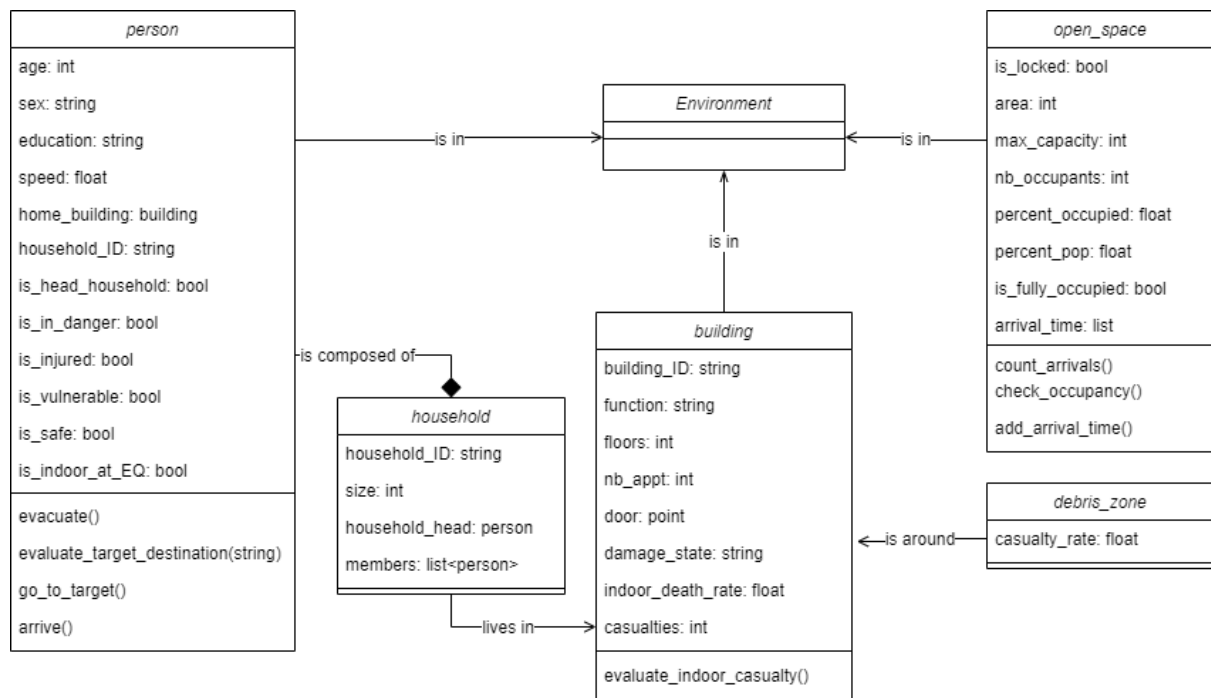


Figure 1. Simplified UML class diagram of the model

Household Agent

People who live in the buildings are organized in households that have different sizes (see the Implementation section). The head of the household is the person who in charge of the household and governs the other household members.

Building Agent

This agent represents the buildings in the city, having one of the following functions: residential, business or hospital (see the Implementation section). The door of the building is a point on one of its edges, from which the inhabitants can enter and leave the building. Buildings have also attributes related to their damage level: a damage state and an indoor casualty rate for the people who are inside the building during the earthquake.

Debris zone Agent

Debris zone agents represent the area created by the debris around each building. Debris constrain the mobility of the people and force them to reduce their speed. A person located in a debris zone is in danger. The casualty rate in a debris zone depends on the building’s physical vulnerability and its damage state.

Open Space Agent

In emergency evacuation plans, open spaces are considered the target destinations of evacuees. The open space agents represent formal open spaces: e.g. parking lots, public gardens and stadiums, and spontaneous open spaces that are free from debris at a certain distance from buildings. A door or a gate can prevent access to designated open spaces that become inaccessible to the population. The area of each open space determines the maximum number of people it can receive.

Decision-Making

Decision-making in ABM can be implemented through several approaches, such as psychosocial and cognitive models, participatory agent-based modeling and empirical or heuristic rules (An 2012). In PEERS, decision-

making is a data-and-assumption-based approach: decisions are based on data derived from the statistical analysis of survey results. When the required data for the model cannot be extracted from the survey results, assumptions based on observations or hypothesis are made. Specifically, the decisions that need to be modeled are the person’s decision to evacuate if they are indoors when the earthquake occurs, and the target destination’s choice in the case of mobility.

Evacuation Decision for People who are Indoors when there is an Earthquake

An approach based on binary logistic regression was used to evaluate a person’s probability of evacuation if they are in a building during the earthquake. This approach allows characterizing the relation between a binary variable, here the evacuation decision, and one or many explanatory variables. The explanatory variables are the factors that influence a person’s evacuation decision obtained from the survey data. Namely, the building’s damage and derived seismic intensity, the sex, age and level of education of the person, their previous earthquake experience, whether the person received earthquake information, and being in the presence of other people.

Using this approach, the probability of evacuation can be calculated for each person *i* as follows:

$$P_{i, \text{evacuation}} = \frac{\exp(\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n)}{1 + \exp(\beta_0 + \beta_1 X_1 + \dots + \beta_n X_n)}$$

with X_1, \dots, X_n being the explanatory variables, and β_0, \dots, β_n the log Odd Ratios obtained from the logistic regression analysis.

Target Destination Decision for People who Adopt Mobility Behaviors

The defined target destinations for person agents are going to the nearest open space, joining a family member at their home, or going to the nearest hospital.

The survey provides the percentage of population that knows the location of open spaces and the percentage of the population that wants to join someone during the earthquake. The probability of being injured can be directly computed during the simulation, whenever a person is in a building or in a debris zone during the earthquake. Therefore, the following assumptions were made in order to fill the data gap:

- If a person agent knows the location of open spaces, its target destination is the nearest open space.
- If a person agent wants to join someone, its target destination is its home.
- If a person agent is injured, its target destination is the nearest hospital.
- If a person agent has more than one of these attributes, its target destination is chosen by a probabilistic approach, with higher priorities to going home and to hospitals rather than an open space. This choice comes from reported evidence in the literature (Alexander 1990).

The probabilities of choosing a target destination depending on the person’s attributes are presented in Table 3. If a person agent does not know the location of open space, and does not want to join someone, and is not injured, it does not have a definite target destination and would just wander around.

Table 3. Target Destination Choice According To a Person’s Attributes

Person’s attributes			Target destination probability choice		
Knows open space location	Wants to join someone	Is injured	Open space	Home	Hospital
Yes	No	No	100%	0	0
No	Yes	No	0	100%	0
No	No	Yes	0	0	100%
Yes	Yes	No	30%	70%	0
Yes	No	Yes	30%	0	70%
No	Yes	Yes	0	50%	50%
Yes	Yes	Yes	20%	40%	40%

Group behavior

As suggested by social theories, in emergencies people try to ensure the safety of their family members. Therefore, families tend to group and evacuate together (Chu et al. 2011). A group is typically characterized by a leader, often in charge of the decision-making. The other group members will follow the group leader in both decision-making and navigation (Kuligowski 2011). Other group behaviors can be seen, such as communication and information sharing (Averill et al. 2005).

In PEERS, people from the same household can form groups, either indoors or outdoors, and navigate together. For indoor situations, if a person, or a group, detects another household member within the same building, the grouping action is then executed. In outdoor scenarios, the grouping action occurs when a person from the same household is nearby.

Once a person is added to a group, they do not leave their group. A group may only lose one of its members if the member dies. Every time a group changes in size, the group leader is reevaluated as follows:

- If the head of the household is in the group, the head of household is the group leader.
- If the head of the household is not in the group, the person with the highest leadership score is assigned as the group leader.

The leadership score is a metric, between 0 and 1, to classify people according to their level of influence on others during emergencies. The metric is calculated for each person as the average of their open space knowledge and age, normalized over 100, which is the maximum age that a person can have in this model. These assumptions come from observations that in Lebanese families, older members, such as parents or older siblings often assume leading roles with respect to other family members. Additionally, it has been observed in previous emergencies that people with a better knowledge of emergency egress routes often lead other evacuees towards safe destinations (Chu and Law 2013).

The group follows the leader's decisions in both indoor and outdoor scenarios. Therefore, if the group is indoors during the earthquake, the group members' decision to evacuate will be the same as the leader. In the case where the group evacuates, all group members evacuate at the same time (Mikami and Ikeda 1985) waiting for the group member that has the longest evacuation delay.

As for navigation, the leader navigates towards its target destination while the followers navigate towards the leader's location. Therefore, all group members navigate towards the target destination of the leader. Group members adapt their speed to the speed of the slowest group member in order to maintain the group cohesion (Proulx 1995).

Group members communicate with each other, and share information about open space locations. Therefore, if one of the group members knows the location of an open space, all group members will gain this knowledge too.

IMPLEMENTATION

PEERS is implemented in GAMA (Taillandier et al. 2018) (Figure 2) an open-source modeling and simulation platform that provides a development environment for building spatially explicit agent-based simulations. GAMA's ability to handle large-scale simulations makes it a suitable platform for simulations at the city-scale. Although, PEERS can run dynamic simulations of residents' evacuation and mobility, it does not directly handle the computation of earthquake damages and related debris, nor the generation of the synthetic population.. Separate models, which need to be executed before the simulations, handle these two aspects and their corresponding outputs are loaded into PEERS.

Processing of Spatial Data

Geo-spatial files of Beirut's buildings and open spaces were retrieved from OpenStreetMap after the digitization of the missing buildings and the characterization of the buildings' functions. The buildings' heights were retrieved from satellite images analysis (Iskandar et al. 2020). A database of buildings obtained from in-situ surveys (Salameh et al. 2017) was used to infer the buildings' vulnerability classes according to their heights; heights having been found as an appropriate proxy of vulnerability classes (Salameh et al. 2017). The computation of the buildings' mean damages for the simulated earthquake scenarios are performed using an approach based on artificial neural networks that predict buildings' damages based on simple indicators of the building's, soil's and earthquake's characteristics (Salameh et al. 2017). The casualty rates caused by buildings damages for indoor and outdoor situations are retrieved from (Federal Emergency Management Agency (FEMA) 2012). Following the assumption that rectangular buildings collapse in a truncated pyramid shape, the footprint of the debris resulting from the buildings damages are computed (Iskandar et al. 2020).

The resulting data are added to the GIS files of buildings, debris zones and open spaces and the corresponding agents in PEERS are directly instantiated from these files.

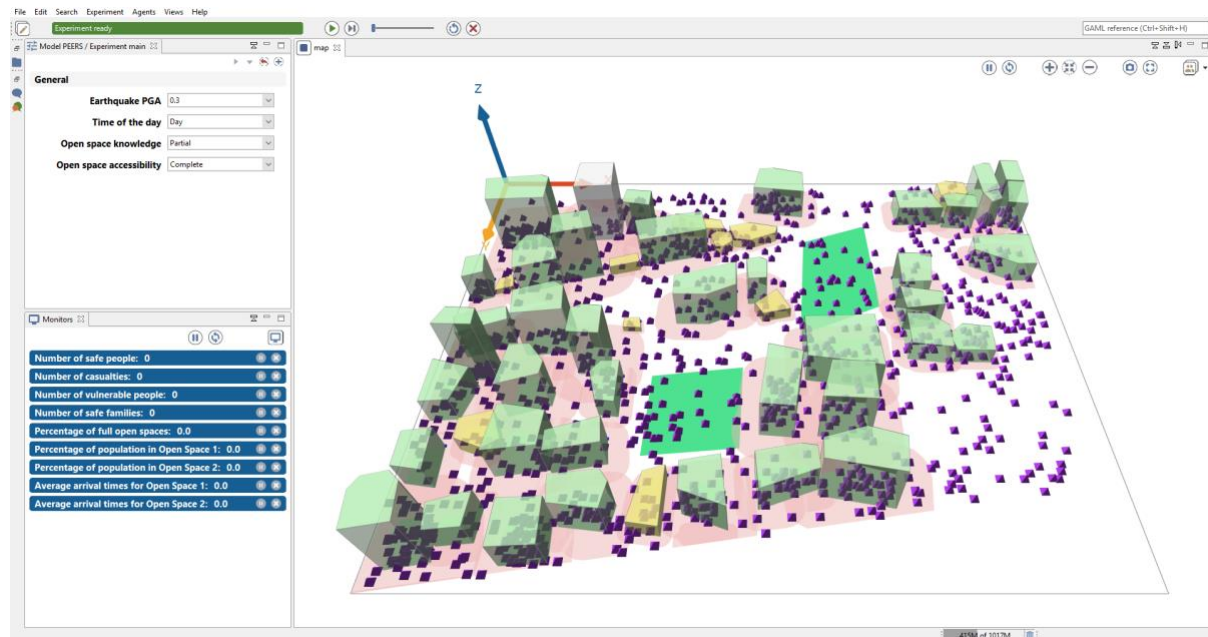


Figure 2. Screenshot of the simulation environment in GAMA

Synthetic Population Generation in GAMA

PEERS is a data-driven model, with social agents having behaviors determined by their individual characteristics. Thus, constructing a synthetic population that represents the population in Beirut as closely as possible is critical for the accuracy of the simulation (Chapuis et al. 2018). Generating synthetic populations is possible within GAMA, using the Gen* plugin (Chapuis et al. 2019).

The Central Administration of Statistics (CAS) in Lebanon provides tables with aggregate data on the distribution of the age, sex and educational level of the Beirut’s residents. The only data that can be found in the CAS database on households’ composition in Lebanon are the distribution of households according to household size, the distribution of the head of households according to their age, sex and household size, and the distribution of residents according to their relation to the head of the household. Due to the sparsity of the available information on households’ composition, an ad hoc methodology was developed (Figure 3) in order to aggregate the generated individuals into households. This methodology is described as follows:

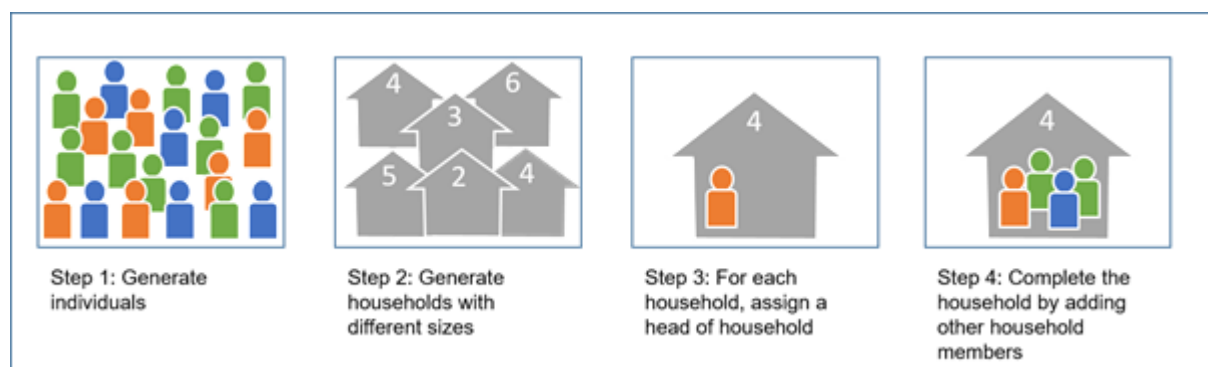


Figure 3. Schematic representation of the methodology used to aggregate individuals into households

Step 1: Individuals are generated using Gen* with attributes of sex, age and educational level according to the distribution of the residents provided by the CAS.

Step 2: Households with different sizes are generated to fit in the number of created individuals while respecting the distribution of household sizes.

Step 3: For each household, a person that satisfies the distribution of the age and gender of the head of the household with respect to this household's size is drawn from the population and assigned as the head of the household.

Step 4: If the household is composed of more than one person, other people are drawn from the pool of individuals and assigned to this household.

For choosing other household members, the role they occupy is chosen according to the distribution of the residents' relations to the head of the household (spouse, child, etc.). The role then gives age and gender constraints according to which a person is drawn.

Steps 3 and 4 are repeated until all households are complete. Finally, the generated households and individuals are then saved into files that can be directly imported in the main model to create the corresponding agents.

Experiments

The simulations can result in outputs related to the populations' safety status. These include the evolution of the numbers of safe and vulnerable people over time, the number of casualties and the number of families with all members safe. The simulations can also track the status of the open spaces and provide indicators such as the percentage of full open spaces at the end of the simulation, the percentage of the population in each open space and the average time taken by the people to reach each open space.

The scenarios planned to be explored have been defined in order to test the influence of some relevant model parameters on the simulation results:

- *The seismic intensity*, defined in the model by the Peak Ground Acceleration (PGA) that control the buildings' damage level and generated debris. Simulations will be run for PGA values of 0.3g, as prescribed by the Lebanese seismic code, and 0.5 g a more pessimistic but still plausible earthquake scenario. This experiment will evaluate the impact of the buildings' damages on the evacuation and the post-seismic mobility.
- *The time of the day*, translated in the model by the distribution of the population. The simulations will cover night scenarios and day scenarios and will allow to evaluate the impact of the population's spatial distribution on the simulation results.
- *The population's knowledge of the locations of the open spaces*, an attribute of the person agents. A scenario where all people know the location of an open space can be implemented and compared to a realistic scenario, based on the survey results. This experiment will evaluate the effect of an information campaign targeted to increase the awareness of the population.
- *The accessibility to open spaces*, an attribute of the open space agents. A scenario where all open spaces are accessible will be compared to a realistic scenario in which some of the open spaces are locked in order to evaluate the influence of having all open spaces accessible.

CONCLUSION

Earthquakes are sudden onset hazards; nevertheless, their impacts could be reduced by improving the seismic risk characterization and establishing effective emergency management plans. Integrating human behavior in seismic risk assessments is a critical factor for increasing their realism. PEERS, an interdisciplinary ABM for the simulation of the physical and the social aspects of a seismic crisis at the city-scale is proposed. PEERS integrates the interaction between individuals and their household members, and the interaction of people with the buildings, the debris and the open spaces in the city. The model takes into account individuals' evacuation and mobility decisions and the formation of groups between household members. PEERS is applied to Beirut (Lebanon), where survey data are collected to feed PEERS with realistic behaviors of individuals. Implemented in GAMA, PEERS also relies on other models to generate real geographic data and a synthetic population. The model has yet to be calibrated with the survey results, once the treatment of the survey data is finalized. Future works will focus on performing a thorough sensitivity analysis to identify the model's sensitivity to the input variables. The simulation results will be then validated by domain experts and practitioners through participatory simulations. Once validated, we would be able to start the experimentation. The planned experiments cover scenarios that test the influence of the earthquake scenario, the time of day, the population's knowledge of the location of open spaces and their accessibility. These simulations will contribute to identify the key factors that control the seismic risk in Beirut, and to test emergency management strategies. Future perspectives include the proposal of a seismic risk index that takes into account the physical and the social components of a seismic crisis, calibrated by the simulation results.

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