An agent-based model to simulate inhabitants' behavior during a flood event

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SiFlo: An Agent-based Model to simulate inhabitants' behavior during a flood event

ODD Model Description

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1. Overview

1.1 Purpose

SiFlo is an ABM dedicated to simulate flood events in urban areas. It considers the water flowing and the reaction of the inhabitants. The inhabitants would be able to perform different actions regarding the flood: protection (protect their house, their equipment and furniture…), evacuation (considering traffic model), get and give information (considering imperfect knowledge), etc. A special care was taken to model the inhabitant behavior: the inhabitants should be able to build complex reasoning, to have emotions, to follow or not instructions, to have incomplete knowledge about the flood, to interfere with other inhabitants, to find their way on the road network. The model integrates the closure of roads and the danger a flooded road can represent. Furthermore, it considers the state of the infrastructures and notably protection infrastructures as dyke. Then, it allows to simulate a dyke breaking.

The model intends to be generic and flexible whereas provide a fine geographic description of the case study. In this perspective, the model is able to directly import GIS data to reproduce any territory. The following sections expose the main elements of the model.

1.2 Entities, state variables, and scales

SiFlo considers 9 types of Agent (Figure 1):

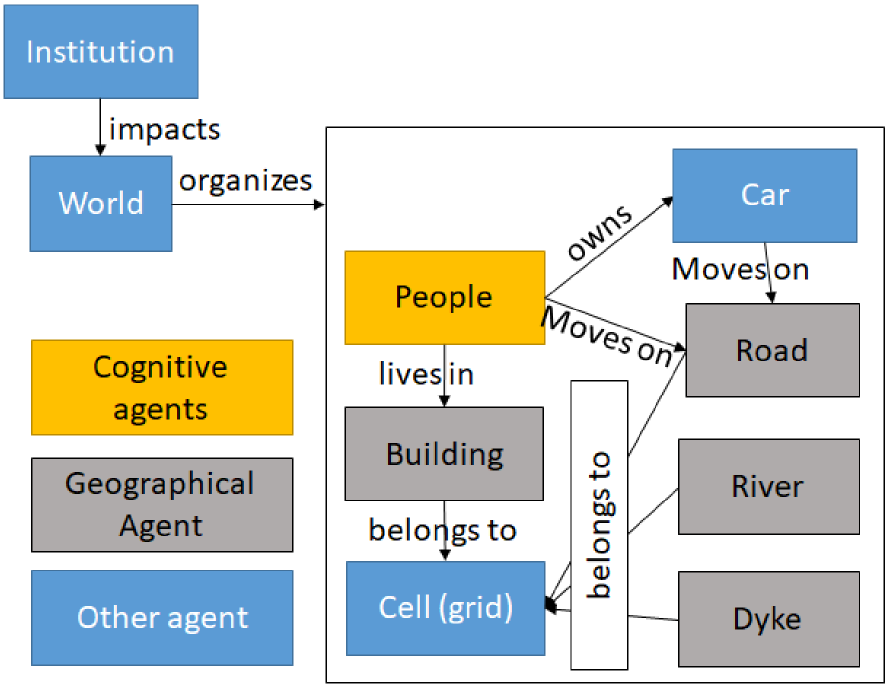

Fig 1. Si-Flo Agents

People: Each people agent corresponds to a household. They are the only cognitive agents in the model. They are built on the BEN architecture (Bourgais et al., 2020). BEN provides a BDI (Belief-Desire-Intention) cognitive model as a core component. The BDI model, which is particularly interesting in social simulation (Adam et al., 2017), proposes a formalization of the human reasoning through three concepts: beliefs, desires and intentions. Beliefs represent the agent knowledge on the world. Desires are what it want to do. Intention is what the agent intends to do (the desire it wants to perform). Each of these concepts correspond in the BDI model to a database that dynamically evolves during the simulation. In addition to these three databases, BEN provides an additional database, uncertainty, which represents uncertain information about the world - note that in the BDI model a belief represents information that is completely certain for the agent. In the SiFlo model, at each time step, a people agent will “perceive” its environment and acquire information (e.g. “flood is coming”, “water in my house”…). These information will modify its belief base (see Table 2 for a description of all the beliefs considered). Based on its beliefs, the agent will express desires (e.g. “evacuate”, “secure my car”…) from a set of rules. Based on the desire base and on the strength it gives to them, the agent chooses one intention and finally realizes it under the form of a plan. A plan can be composed of several actions performed by the agent. The use of BEN offers several benefits (Micolier et al., 2019): in addition to its native integration to the GAMA platform (which was used to implement this model), BEN is easy to use, enable distributed computation (Taillandier et al., 2017), and provide a direct link to social relation, emotion and norm engines. The behavior of the People agent is detailed in the section 6.2.

Grid: It is the support of the simulated world. It provides notably the topography information directly imported from GIS data. During the simulation, the cells of the grid will potentially fill with water, impacting the agents present (road, inhabitant...) on the cell. The size of each cell and the number of cells are of the model parameters which can be adapted to the considered case-study.

Building: This agent represents the buildings in the considered territory and all their furniture. It is defined at the beginning of the simulation from the GIS data (position and shape). Its behavior is directly induced by the environment's evolution and the inhabitants actions. For instance, they can be deteriorated depending on the presence of water in the building and its height, or inhabitants can turn off electricity and gas in their house in order to limit the danger.

Road: This agent is also built from the GIS data. The roads constitute the network on which the inhabitants will travel (by car or on foot). The presence of water on the road can lead to a reduction in the speed of traffic on the road, or even make it unusable.

River: This static agent is defined at the beginning of the simulation based on GIS data directly imported (OSM). In addition to imported geographical data, some information related to the territory management is added, such as the state of the river bed which can directly impact the flow of water.

Dyke: The dyke agent corresponds to all structures which aim to stop or limit the passage of water. During the flowing process, the dyke limits the flow of the water from a cell to another. In the model, the dykes are characterized by their location, their height, their strength and their state. The water pressure can cause them to break, resulting in a spill of water downstream.

Car: Each household can have one or more cars (but also none). It is the main means of moving for people whereas walking is always possible. We assumed that during the flood event, no public transport is usable in the flooded sector. Car is not only a way to travel fast but can be a source of risk. Indeed, accidents can happen when people try to secure their car or when they use it during the flood event. In their analyses of the causes and circumstances of flood disaster deaths, (Jonkman and Kelman, 2005) showed that drowning in a vehicle was the main circumstance of death in the analyzed flood events.

World (global agent): The world agent manages the evolution of the environment and the global mechanisms. Notably, it initiates the flood process by determining the rain and the water entering the system, and by organizing the flowing between cells.

Figure 2 provides the UML diagram of the SiFlo model.

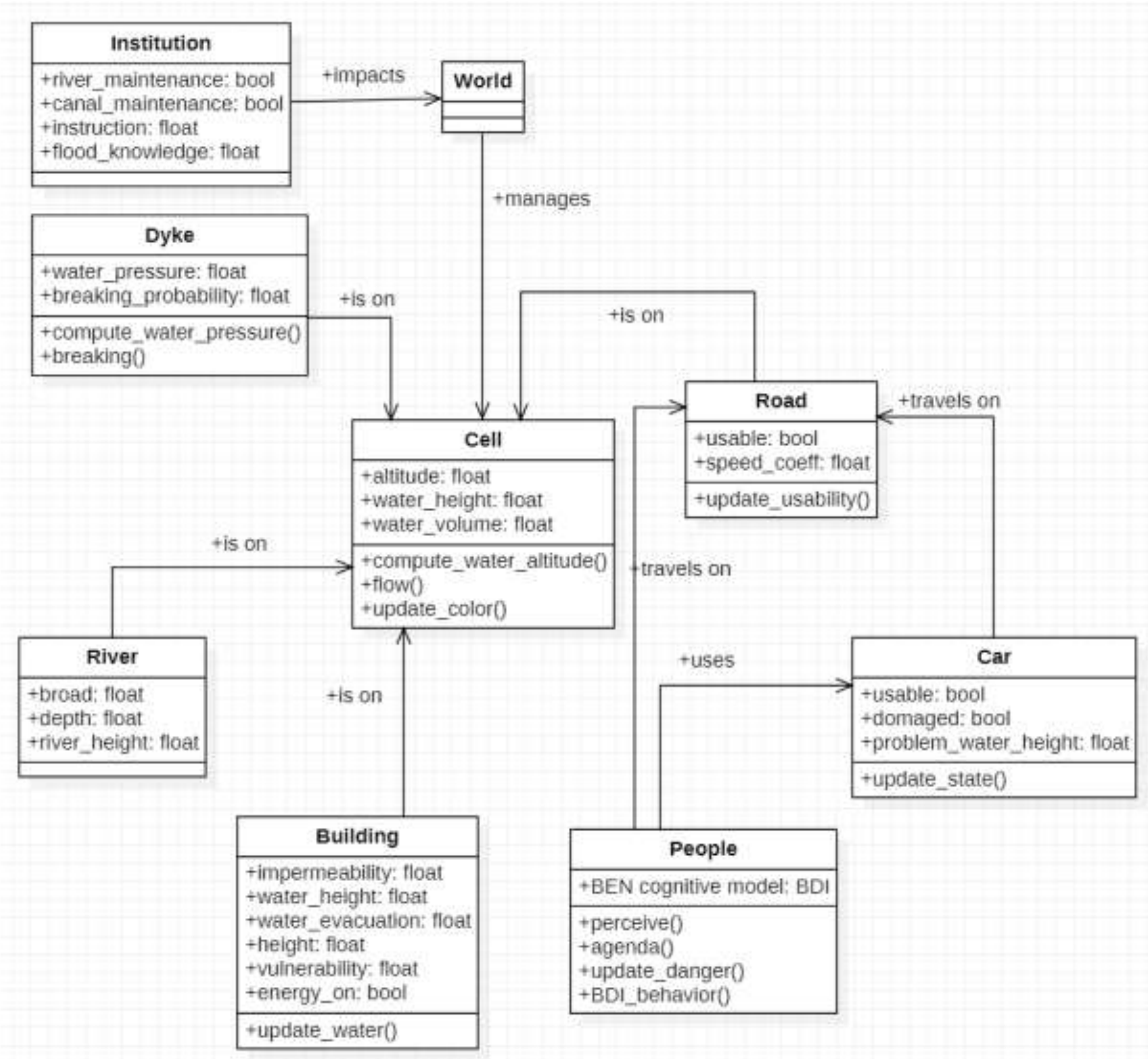

Fig 2. UML of the SiFlo model

Scales

The simulations are executed at the scale of a town or a part of it (the part impacted by the flood) with an explicit representation of the buildings, roads, rivers and dykes. The simulations are not launched from a specific starting date, but rather from the beginning of a flood event and will run until the end of the flood event (when all the water has been evacuated). By default, the time step is set up to 1 minute, but it is a parameter which can be modified.

1.3 Process overview and scheduling

Each simulation step follows the same process (Figure 3).

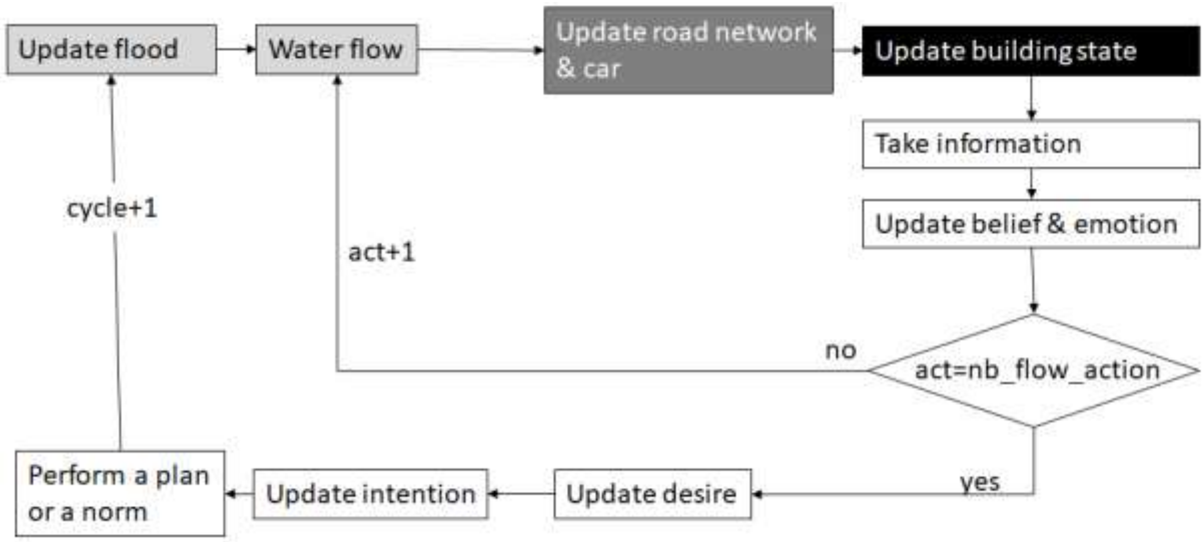

Figure 3: SiFlo process

Firstly, the world agent updates the environmental data (e.g. upstream water, rain) from imported data. It allows to define the new input of water in the system. Then, a flowing model is used to simulate the water flow. The water flow loop (including assessing flood damage) can be repeated according to the water speed, the simulation step and the cell size; this mechanism is more precisely described in Section 6.1.

The flowing action results in an updated water level on each cell of the territory grid. From these water levels, SiFlo computes the state of the road; roads with water can slow the speed of vehicles, be dangerous, or be unusable. Furthermore, the state of the road degrades with water inducing material damage, which will have to be repaired after the flood. After the road, SiFlo updates the building state. Depending on the building permeability, the water on the cell can more or less penetrate into the building. The water can also flow from the building if the water level outside is lower that the inside level. The permeability and water evacuation can evolve during the simulation depending on the people behavior. As for the road, the water in the building can cause damage (e.g. deterioration of furniture, floor coverings, etc.) and induce a danger for inhabitants.

Then, Agent people will act. In a first step, they "perceive" their environment. They get information about the presence or absence of water in their building, near or farther away. In addition, if an agent perceives another who is subjected to an emotion of fear, it may also, depending on its personality, be subject to an emotion of fear. This information modifies their belief and emotion bases. It has to be noted that belief is an internal knowledge for the agent which can be false. The different beliefs and emotions can active desires based on rules. Based on the priority of each desire, the agent chooses one intention and finally realizes the corresponding plan. A plan can be composed of several actions performed by the agent. In parallel, if the people agent knows the instructions to follow (assimilated to a norm in BEN), it can, according to its obedience, rather choose to follow them than to choose the action that his normal behavior would lead it to do.

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2. Design concepts

Basic principles. The main issue of the model is to confront the course of a flood with the behavior of the inhabitants of the area. The model simulates the flooding event (i.e. arrival and propagation of water), step by step, with its damages. Faced with the flood, the model simulates the behavior of the people who will act (e.g. protect their house) or not, follow or not the instructions of the authorities (if they know them), may be afraid, influencing their behavior, etc. By these two elements, the SiFlo model allows to evaluate the material and human consequences of different flooding scenarios and different mitigation strategies.

Emergence. The main emergent (or at least complex to predict) results concern the behavior of people, notably due to the trade-off between different components: the knowledge and the obedience related to the suggested behavior (modeled as a norm), the emotion of fear (with the emotion contagion) and the normal behavior of the people.

Adaptation. Inhabitants behavior is based on BEN BDI architecture. It allows them to perceive their environment (belief base), to update their desire regarding it and finally to adapt their behavior regarding their feeling.

Sensing. Inhabitants perceive their environment and have their own feeling on its. These perceptions allow them to acquire beliefs and emotions (here, fear). These beliefs and emotions have an impact on their behavior.

Interaction. Different kinds of interactions are used in the model (social, physical…). For instance, SiFlo considers interactions between inhabitants (information sharing, emotion contagion…), interactions between inhabitants and building (protect their properties, turn-off energy…), between inhabitants and car (i.e. inhabitants can use their car to travel faster), etc.

Stochasticity. The model uses different random variables and draws in order to compensate the lack of some initialization information (for instance the number of cars by people) and to consider complex phenomena such as dyke breaking dynamics. Stochasticity is also used to simulate the people behavior in order to consider the heterogeneity of the possible behaviors.

Observation. The model has for outputs two types of data: a direct graphical output at each simulation step and the final CSV files available at the end of the simulation. In the graphical mode, several variables evolving at each simulation step are available. These elements are described in section 5 dedicated to the model outputs.

3. Initialization

The simulation begins by creating the geographical agents (cell, river, road, building) from the GIS data. Based on the topography data, the altitude of each cell and the slope between neighbor cells are computed. Then the Institution agent is created and applies its strategy regarding risk management (e.g. river maintenance). Two specific groups of cells are defined; the escaping areas which corresponds to the cells from which people can escape and the active cells which are those considered in the flooding model; indeed, in order to limit the number of considered cells, the user can specify a distance to the river she/he want to consider and only the cells in this perimeter are considered as active.

After, the people agent are created from a shapefile. This shapefile can be built by a synthetic population generator as Gen* (Chapuis et al., 2019). The generation of the synthetic population is outside the SiFlo model and have to be performed before. All the people are instantiate according to their knowledge on the instructions, on the flood, to their OCEAN personality and their social relation. We defined also for each people agent if it owns (or not) one or several cars. The car is randomly park close to the people home.

4. Input data

The input data concerns three domains (table 1):

(a) Geographic data (GIS file)
(b) Social data (synthetic population)
(c) Water data (CSV files)

Table 1. Overview of the input data

Data file	Data type	Description	Source
Mnt.asc	GIS mnt file	The considered area topography	IGN
building.shp	GIS shapefile	All the building geometries, with type and attributes	OpenStreetMap
road.shp	GIS shapefile	All the road geometries, with type and attributes	OpenStreetMap
waterways.shp	GIS shapefile	All the waterways geometries, with type and attributes	OpenStreetMap
dyke.shp	GIS shapefile	All the dyke geometries, with type and attributes	OpenStreetMap
population.shp	GIS shapefile	Population generated by synthetic population generator	Gen* - generated from French national census data (INSEE)
rain.csv	Csv tabular file	Rain data	Meteorological data
water_input.csv	Csv tabular file	Data on water coming from upstream	Hydrologic computation

Synthetic population

For the people, a synthetic population was generated according to the created building. In order to simplify the problem, we consider only one Agent People per household considering that the behavior of the people of the same household are identical. The generation of the initial population is a classical ABM problem and many tools to build synthetic population is available, for instance Mobisim (Antoni and Vuidel, 2010) or Gen* (Chapuis et al., 2019). In this work, we used Gen* to generate the population. Gen* has the advantage of allowing both population generation and spatialization (Chapuis et al., 2018). Unlike Mobisim, Gen* also has the advantage of being directly usable with different types of data and does not require data to be pre-formatted in a particular format. Finally, there is a plug-in that allows Gen* to be used directly from GAMA. In the case of our model where the characteristics of individuals (age, employment, etc.) are not taken into account, only the geographic data of buildings are mandatory. Nevertheless, it is possible to add optional data such as administrative breakdowns with population data (number of inhabitants in each zone), max number of households for each household, Gen* managing the integration of these data to refine the spatialization of the population. In addition to these attributes, the model requires to define a set of other parameters for the people agents concerning their personality (OCEAN), their choice of plan, and their perception of the environment. More precisely, a value between 0 and 1 must be given to each agent for the 5 dimensions of the OCEAN model. For the choice of activities, the strength assigned to the different plans is defined by a random draw (uniform distribution) using the intervals of values given in Table 3. Finally, we consider that there is heterogeneity in the impact of water on people. To represent this, we have defined 2 variables corresponding to the height of water that can represent a danger to the person on foot (*"water_height_danger_walk"*) and in car (*"water_height_danger_car"*). Based on existing studies, we defined these values by a random draw between 10 cm and 40 cm for car travel and between 10 cm and 1m for foot travel.

5. Output data

As output, SiFlo provides different information/data depending on the simulation mode; indeed, the SiFlo models provides two simulation modes: a visual mode and a batch mode.

The visual mode provides a map allowing to follow the simulation process. It ensures the user to follow the flood process. In addition to the map, the model provides as output, different information:

The number of injured people: people who have suffered physical damage, but also people in a state of psychological shock because their life has been threatened; in the model, it is any People agent which has found itself in a situation of danger.

If the agent is inside a building, the level of danger will be defined by:

- if the electricity is on:

$$Danger = \frac{\text{water\_height} - \text{water\_height\_danger\_inside\_energy\_on}}{\text{water\_height\_danger\_inside\_energy\_on}}$$

- if it is off:

$$Danger = \frac{\text{water\_height} - \text{water\_height\_danger\_inside\_energy\_off}}{\text{water\_height\_danger\_inside\_energy\_off}}$$

If the agent is outside:

- if it is using a car:

$$Danger = \frac{\text{water\_height} - \text{water\_height\_danger\_car}}{\text{water\_height\_danger\_car}}$$

- otherwise:

$$Danger = \frac{\text{water\_height} - \text{water\_height\_danger\_walk}}{\text{water\_height\_danger\_walk}}$$

The number of dead people: people who died due to the flood; these deaths can be in buildings (electrocution, drowning...) or outside (mainly by drowning, especially in car). A People agent in a situation of danger has a probability of dying according to the importance of the danger. A draw is then made on this probability to determine if it is dead or alive (injured).

The number of flooded buildings: building where the water height inside exceeded 30 cm during the simulation.

The number of flooded cars: cars that during the simulation are in an area where the water height exceeded a certain threshold. For each car, this threshold is drawn (uniform law) between 10 and 30 cm.

The state of the building: value from 0 (extremely bad condition) to 1 (perfect state) describing the state of the building, considering the properties. It is set to 1.0 at the beginning of the simulation and may decrease with the presence of water in the building and depending on the people behavior (e.g. if people protect their properties).

The proportion of each people performing each plan.

Figure 4 illustrates the SiFlo interface of the visual mode. On the left screen, two graph provides the current proportion of people following each plan, and the number of dead, injured and evacuated people. On the right screen, the territory is represented, with the river (blue line), the flooded cells (blue cells), the road (in grey), the building (white to red square depending on the water level), the cars (in green) and the people (pink cylinders).

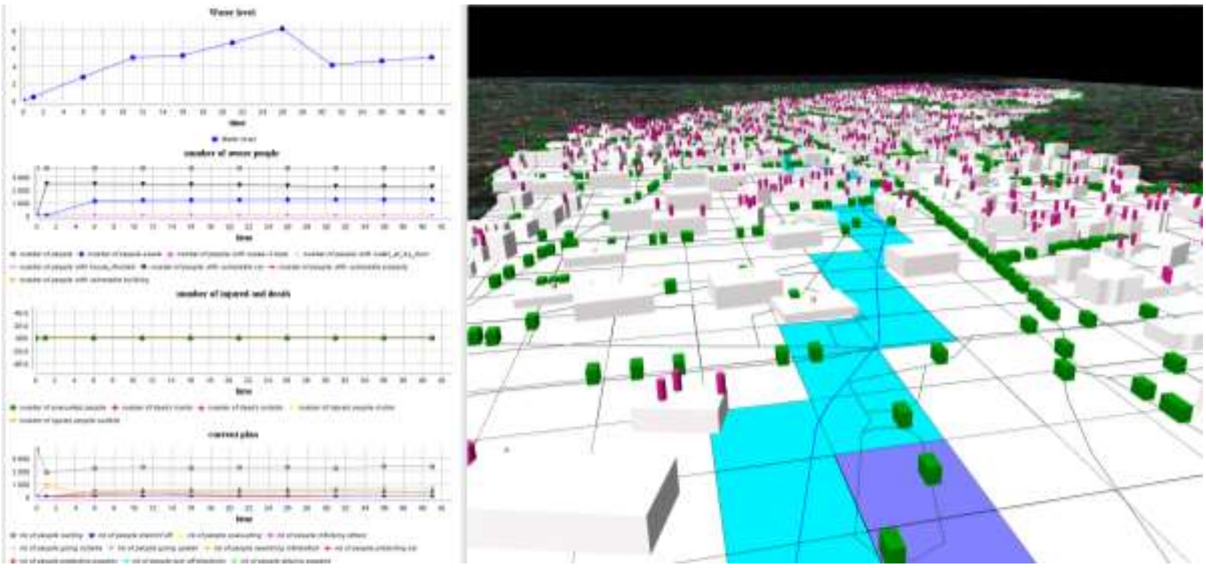

Figure 4. Snapshot of a simulation (with the GAMA platform)

The batch mode allows to perform a simulation without the graphical interface. It accelerates the simulation and allows to create several simulations in parallel. It is necessary because the model is stochastic: some elements are randomly set up (e.g. social links) and different draws are performed during the simulation (e.g. choosing evacuation in case of fear emotion). The batch mode outputs are similar to those of the visual mode, but for the two last outputs (i.e. state of the building and action plans) only the average values are given.

6. Submodels

6.1. Flood model

The flood model is based on a flowing mechanism. At each step, depending on the step, the cell size and the considered maximum speed of the flow (by default 3 m/s), the flowing action can be performed one or several times:

$$\text{nb\_flow\_action} = \text{round\_sup}\left(\frac{\text{max\_speed\_water}}{\text{cell\_size}} \times step\right)$$

with: *nb_flow_action* the number of the flow action at each step, *max_speed_water*, the considered maximum speed of the water, *step* the used step time for the simulation and *cell_size*, the length of the smallest side of a cell.

For instance, considering a *max_speed_water=3 m/s*, *cell_size=15m*, *step=60s*, the *nb_flow_action* is *12*.

At each flow action, the water flows to the lower neighbor cells (considering topography, water height, river bed and dyke). The quantity of water flowing (Qf) depends on the water volume (Wv) and the proportion of the water which flows(Prop). This proportion depends on the distance covered by the water in one flow action (Dist) and the cell size. This distance can be computed by the water speed (WS), the chosen step and the number of flow actions by step (nb_flow_action). The water speed is computed with the Manning-Strickler formula:

$$Qf = \mathrm{Wv} \times \mathrm{Prop}$$

With:

$$Prop = \frac{Dist - cell\_size}{cell\_size}$$

With:

$$Dist = \frac{WS \times step}{nb\_flow\_action}$$

With:

$$WS = K \times HR^{2/3} \times S^{1/2}$$

With *K*, the Strickler coefficient and *HR*, the hydraulic radius, S: slope

$$HR = \frac{wa}{wp}$$

With *wa*, the water area (section) and *wp*, the water perimeter (section).

The flow is possible to one cell to a neighbor cell only if this cell has already flowed (the flow occurs from the lower cells to higher cells) and if the water altitude of the flowing cell is higher than the water altitude and dyke altitude (of the top of the dyke) of the destination cell ; the possible destination cells are referenced as *flow_cells*.

The flow is distributed to the *flow_cells* according to the slope: the greater the slope between the flowing cell and the *flow_cell*, the greater the part of water flowing. The volume of flowed water is subtracted from the initial volume of water of the cell. The water altitude of the cell is then recomputed. An action ("*compute_water_altitude*") allows to compute the water altitude of a cell from the volume of water, the cell dimension, and the characteristics of the river (if any).

The model considers the capacity of the dyke to stop water by adding the dyke height to its belonging cell in the flowing process. But, at each flow action, the dyke may collapse due to the water pressure. The breaking probability is a parameter relative to a dyke; it is defined from its design, its composition, its condition... A broken dyke is considered as no dyke. However, it can lead to a massive flow (all the water retained by the dyke). The water may penetrate into the building located on flooded cells, depending on the difference of water level between inside and outside and the impermeability of the building. On the other hand, if the height of water in a building is greater than the height of its cells, some of its water may spill out.

At the end of each flow action, we check the state of the buildings and the state of the roads. The presence of water may deteriorate buildings. The deterioration of buildings is a function of the height of water and their vulnerability; vulnerability here refers to structural elements but also to furniture and goods present in the building. Roads can become impassable (reduced speed) or even unusable depending on the height of water present.

6.2. Inhabitant behavior model

At each time step, a people agent will “perceive” its environment and acquire information (e.g. “flood is coming”, “water in my house”…). These information will modify its belief base (see Table 2 for a description of all the beliefs considered). Based on its beliefs, the agent will express desires (e.g. “evacuate”, “secure my car”…) from a set of rules. Based on the desire base and on the strength it gives to them, the agent chooses one intention and finally realizes it under the form of a plan. A plan can be composed of several actions performed by the agent. Table 3 exposes the different modeled plans.

Table 2. *People* agent’s beliefs

Belief	Object	Acquired when
Water is coming	knowledge that a flood is in progress	The agent inquires about a possible flood or receives the information from another agent. We also consider that at the beginning of the simulation, a certain number of agents start with this belief (they know about the coming flood)
Water is here	There is water (in significant quantities) where I am.	The agent perceives water in quantity (above the threshold water_height_perception) in its current location (cell or building) or in its direct neighborhood.

Water at my door	There is water (in significant quantities) near my house.	The agent perceives water in quantity (above the threshold water_height_perception) where its house is located or in its surroundings.
House flooded	There is water (in significant quantities) in my house.	The agent perceives water in quantity (above the threshold water_height_problem) in its house
Vulnerable car	My car is in a place that could be flooded.	Defined at the beginning of the simulation. If the car is in a flood zone.
Vulnerable properties	Some elements in my house (furniture, appliances...) could be damaged by the flood.	The water level in the house exceeds a the threshold water_height_problem
Vulnerable building	The house could be damaged by the flood.	The water level in the house exceeds the threshold water_height_problem
Property protected	all the elements of my house that I could put under protected were.	The agent can no longer improve the protection of its properties, i.e. the building vulnerability level has already been decreased by max_vulnerability_building_decrease
Building protected	The waterproofing of the house can no longer be improved	The agent can no longer improve the impermeability of the house, i.e. the impermeability level has already been increased by max_impermeability_building_increase
Energy on	The electricity is on (it has not been switched off).	We assume that the electricity is on at the beginning of the simulation for all houses.
Energy is dangerous	Knowledge that leaving the electricity on during a flood can be dangerous.	Defined at the beginning of the simulation for a certain proportion of the agents.
Need to go outside	I have things to do outside (seeing friends, shopping, etc.)	With a certain probability tested every 15 to 30 minutes.

Table 3. *People* agent's plans

Plan	Trigger	Effect	Strength
Do nothing	Default plan, when the agent does not engage in any particular activity related to the flood (and is not outside).	People don't do anything special outside of their usual activities in their homes. This plan has no effect in the simulation	0.25
Go outside	Beliefs: "*need to go outside*" and not "*water*	People take their car to go somewhere (e.g. shop, go	[0.0,1.0]

	at my door" or *"house flooded"*	at work…)	
Drain-off water	Beliefs: *"house flooded"* and not *"water at my door"*	People perform action to drain-off water (or accelerate it)	[0.0,0.5] + fear level
Evacuate	Emotion: *"fear"* with an intensity higher than a certain threshold (*"threshold_fear_level"*)	People try to leave the flooded area using roads. If they have a car, they try to use it.	[0.0,0.5] + fear level
Give information	Beliefs: *"water is coming"* and there is still at least one person in its social circle who needs to be warned.	People give information to another people in its social circle regarding the flood. each time an agent has given information to another, we consider that its desire to give information to another decreases.	[-0.5,0.5] + fear level - strength_information_ decrement * number of agents already warned.
Go upstairs	The agent has not already gone upstairs and there are several floors in its house and Beliefs: *"water at my door"* or *"house flooded"* and Emotion: fear with an intensity higher than a certain threshold (*"threshold_fear_level"*)	People go upstairs in their building if it is possible	[0.0,1.0] + fear level
Inquire information	Beliefs: not *"water is coming"*	People get information from another people, TV, radio…	[-0.5,0.5] + fear level
Secure my car	Belief: *"vulnerable car"* and *"water is coming"* or *"water is here"* or *"water at my door"* or *"house flooded"*	People try to protect their car (e.g. moving it to a safer position)	[0.0,1.0] + fear level
Protect my properties	Beliefs: *"vulnerable properties"* or *"water is coming"* or *"water is here"* and not *"property protected"*	People try to protect their property and belongings.	[0.0,1.0] + fear level
Weather-strip house	Beliefs: *"vulnerable building"* or *"water is coming"* or *"water is here"* and not *"property protected"*	People try to limit the permeability of their house	[0.0,1.0] + fear level

Turn-off energy	Beliefs: "energy is on" and energy is dangerous" and "water at my door" or "house flooded" or "water is coming"	People turn-off electricity and/or gas in order to avoid risk link to them	[0.0,1.0] + fear level

In addition to the BDI architecture, we used the social norm architecture provided by BEN. A social norm is a set of actions that people know that they should execute. A norm is close to a plan, but an agent can disobey it and do not execute it while it should. Each agent has an obedient value and each norm has a threshold; if the obedient value of the agent is above the threshold, the norm is executed. SiFlo modeled one norm, which corresponds to the behavior advocated by authorities. The implemented social norm corresponds to the French context. It integrates four actions: to protect properties, to turnoff energy in house, go upstairs (if possible) and inquire information on the flood event. These recommendations can be (or not) known by the people. This norm is triggered by the beliefs "*know instructions*" and "*water is coming*", and according to the people obedience. Moreover, BEN allows to model social relation between people via the model of interpersonal relationships of Svennevig (Svennevig, 2000) using 4 dimensions: the liking, the dominance, the solidarity and the familiarity. The relation between people is model as an oriented vector (i.e. the relationship between people A and B can be different form the relationship between B and A). Each dimension is assed from -1 to 1 representing the strength of the dimension in the relation. For instance, a dominance at -1 means that a people is completely dominated by another (full obedience), and at the opposite +1 means that she/he has a complete control on another. The social relations are used in the SiFlo model for the information sharing action. Obviously, the more an agent will like another agent of its social network and the more it will feel solidarity towards it, the more it will wish to warn it in priority.

SiFlo also uses the emotional architecture from BEN in order to consider the fear emotion. Indeed, BEN integrates an emotional model based on the OCC theory of emotions (Colby et al., 1989) and an emotion generation engine based on the work of (Adam, 2007). In BEN, emotion is close to a belief and can modify the desire of the agent (and then the intention and plan). The model considers one emotion, the fear, which can lead, if the fear emotion has an intensity high enough, to two plans: evacuate and go upstairs. It is important in order to be able to model non-rational behavior (Bourgais et al., 2018). For instance, rapid flooding can cause fear and that may make some to want to escape, which is not the recommended behavior. More precisely, we consider that all agents have the desire to preserve their life. In flooding condition (Beliefs: "water is coming", "water at my door", 'house flooded"), the agent will gain the certitude (uncertainty) that its live is at stake. From these desire and uncertainty, BEN automatically generates a fear emotion of which the intensity is directly depends on the certitude that the agent is in danger (certainty that its live is at stake) and on the agent personality. Indeed, BEN integrate the notion of personality and use for that the OCEAN model (McCrae and John, 1992). In SiFlo, 4 dimensions of these OCEAN model are used: the level of neuroticism (capacity to manage negative emotions), the degree of agreeableness and consciousness which allow to define the degree of obedience of the agent (i.e. its propensity to follow the established rules) and the degree of extroversion: our hypothesis is that the more extroverted a person is, the more important his/her social network will be (i.e. the number of people to warn if he/she is aware of the flooding). Concerning obedience, our hypothesis is also that this value depends on the degree of fear: a person having no fear for his/her life will be less likely to follow the safety rules not being aware of the danger. Similarly, a person who is totally afraid will not necessarily think about following the safety rules. Based on the definition given by (Bourgais et al., 2020), we propose as a value for the obedience at time t:

$$obedience(t) = \sqrt{\frac{A+C}{2.0}} - 0.2 \times |0.5 - fear\ level(t)|$$

With A, the agreeableness and C, the consciousness. The fear level at time t is a real number between 0 and 1, which is calculated as follow (using the equation proposed by (Bourgais et al., 2020) :

$$fear\ level(t) = fear\ level\ (t_0) + U(life\ at\ stake, t, t') \times (1 + (0.5 - N) - 0.1$$

With N, the neuroticism and U(life at stake, t,t'), the evolution of the level of uncertainty between t_0 and t (expressed in minutes).

$$U(life\ at\ stake, t, t_0) = (t - t_0) \times (coeff_{wi} \times \max(0.0, (W_t - W_{t0})) + has_{bel(\text{water here})} \times coeff_{wh} + has_{bel(\text{water at my door})} \times coeff_{wd} + has_{bel(\text{house flooded})} \times coeff_{hf}$$

With has_be(B) = 1 if the agent has the belief *B*; 0 otherwise. $coeff_{wh}$, $coeff_{wd}$, $coeff_{hf}$, $coeff_{wi}$, coefficients between 0 and 1 and W_t, the quantity of water observed at time t.

The assumption behind this formula is that the certainty that one's life is at stake depends first of all on the rise of the water level, but also on the knowledge that there is a significant water level outside (water here), next to the house (water at my door) or inside the house (house flooded).

Concerning the social network, i.e. the list of agents who an agent will be susceptible to warn, it is defined as follows. First each agent determines the number of relationships it has. This number is defined by the agent's extroversion and by a parameter max_number_to_inform: number of agents to warn = max_number_to_inform × extroversion (rounded to the nearest integer). Then each agent chooses the required number from the agents the list of agents who still have relationships to define. For each of these relationships, the level of solidarity and appreciation is drawn with a uniform law between 0.0 (neutral) and 1.0 (high solidarity/appreciation).

Finally, we use the BEN emotional contagion engine which is a simplified version of the ASCRIBE model (Bosse et al., 2009). In SiFlo, the fear emotion can be propagated in 2 ways: direct propagation when an agent sees another agent subjected to a fear emotion (distance defined by the parameter fear_contagion_distance) and by the telephone when an agent having a fear emotion will warn one of its contacts. For this we used the mechanisms provided by BEN. More precisely, in order for the agent to transmit an emotion to another, its level of charisma (which corresponds by default to the level of extroversion) must be higher than the level of receptivity of the one who will receive the emotion. The level of receptivity is equal by default to 1 – N, with N the level of neuroticism of the agent. If an agent i propagate its fear emotion to an agent j, the level of fear of agent i will be:

$$fear\ level_i = fear\ level_i + fear\ level_j \times charisma_j \times receptivity_i$$

7. References

Adam, C., 2007. Emotions: from psychological theories to logical formalization and implementation in a BDI agent.

Adam, C., Taillandier, P., Dugdale, J., Gaudou, B., 2017. BDI vs FSM Agents in Social Simulations for Raising Awareness in Disasters: A Case Study in Melbourne Bushfires. Int. J. Inf. Syst. Crisis Response Manag. 9, 27–44. https://doi.org/10.4018/IJISCRAM.2017010103

Antoni, J.-P., Vuidel, G., 2010. MobiSim : un modèle multi-agents et multi-scalaire pour simuler les mobilités urbaines, in: Antoni, J.P. (Ed.), Modéliser La Ville. Forme Urbaine et Politiques de Transport. Economica, pp. 50–77.

Bosse, T., Duell, R., Memon, Z.A., Treur, J., van der Wal, C.N., 2009. A Multi-agent Model for Emotion Contagion Spirals Integrated within a Supporting Ambient Agent Model, in: Yang, J.-J., Yokoo, M., Ito, T., Jin, Z., Scerri, P. (Eds.), Principles of Practice in Multi-Agent Systems, Lecture Notes in Computer Science. Springer, Berlin, Heidelberg, pp. 48–67. https://doi.org/10.1007/978-3-642-11161-7_4

Bourgais, M., Taillandier, P., Vercouter, L., 2020. BEN: An Architecture for the Behavior of Social Agents. J. Artif. Soc. Soc. Simul. 23, 12. https://doi.org/10.18564/jasss.4437

Bourgais, M., Taillandier, P., Vercouter, L., Adam, C., 2018. Emotion Modeling in Social Simulation: A Survey. J. Artif. Soc. Soc. Simul. 21, 5. https://doi.org/10.18564/jasss.3681

Chapuis, K., Taillandier, P., Renaud, M., Drogoul, A., 2018. Gen*: a generic toolkit to generate spatially explicit synthetic populations. Int. J. Geogr. Inf. Sci. 32, 1194–1210. https://doi.org/10.1080/13658816.2018.1440563

Chapuis, K., Thiriot, S., Taillandier, P., Gaudou, B., Amblard, F., 2019. Gen*: an integrated tool for realistic agent population synthesis.

Colby, B.N., Ortony, A., Clore, G.L., Collins, A., 1989. The Cognitive Structure of Emotions. Contemp. Sociol. 18, 957. https://doi.org/10.2307/2074241

Jonkman, S.N., Kelman, I., 2005. An Analysis of the Causes and Circumstances of Flood Disaster Deaths. Disasters 29, 75–97. https://doi.org/10.1111/j.0361-3666.2005.00275.x

McCrae, R., John, O., 1992. An introduction to the five-factor model and its applications. J. Pers. https://doi.org/10.1111/J.1467-6494.1992.TB00970.X

Micolier, A., Taillandier, F., Taillandier, P., Bos, F., 2019. Li-BIM, an agent-based approach to simulate occupant-building interaction from the Building-Information Modelling. Eng. Appl. Artif. Intell. 82, 44–59. https://doi.org/10.1016/j.engappai.2019.03.008

Svennevig, J., 2000. Getting Acquainted in Conversation. John Benjamins. https://doi.org/10.1075/pbns.64

Taillandier, P., Bourgais, M., Caillou, P., Adam, C., Gaudou, B., 2017. A BDI Agent Architecture for the GAMA Modeling and Simulation Platform, in: Nardin, L.G., Antunes, L. (Eds.), Multi-Agent Based Simulation XVII, Lecture Notes in Computer Science. Springer International Publishing, Cham, pp. 3–23. https://doi.org/10.1007/978-3-319-67477-3_1