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Glossary

Acronym	Full name
ABM	Agent-Based Modelling/ Agent-based model
CHM	Cultural Heritage Management
CNH	Cultural/ Natural Heritage
DRM	Disaster Risk Management

1 Executive summary

Agent-based modelling (ABM) is a method of computational social science used to represent an environment based on the interactions between model represented components. Agents may include entities such as people, the environment, or a hazard itself, whilst their modelled processes are actions which they carry out within the system. For example, travelling, searching for food, or hazard propagating behaviours. The benefit of this type of modelling is its ability to explore the dynamics of many interacting behavioural elements to better understand them, which are otherwise not modellable due to many interacting stochastic processes.

Purpose

A changing climate which poses increasing urban risks is worsening the vulnerability of cultural heritage sites to natural hazards [1]. The purpose of T2.6 is to identify gaps in information about hazards, as well as in current management policies of hazard risk reduction and post-disaster recovery. The use of ABM is developed in this context due to its ability to explore, in a flexible way, options and varying solutions to otherwise difficult to understand environments and their behaviours. Several natural hazards have been explored through the use of ABM to this end, with the final produced and tested models focusing on pluvial flooding and heatwaves. Heatwaves are predicted to increase in their intensity, frequency and duration in the future as a direct consequence of the changing climate [2]. Whilst in the past they have not been associated with structural damage to heritage, this is something which is not studied in great detail and must be monitored [2]. Additionally, the impact of heat on intangible heritage as well as human health is often dangerously overlooked and should not be ignored. The impacts of flooding, which was the second hazard explored in detail, on cultural heritage is clear from past events. Structural damage from large volumes of water and debris associated with fluvial flooding are well known, and this is considered a major hazard in Europe [3]. Pluvial flooding, similarly, is exacerbated in urban areas of heritage due the increased surface runoff of urban areas [4]. The aim of this task was therefore to produce a baseline set of knowledge about possible ways to support regions and cities in reducing hazard risk and improving resilience, by modelling the effectiveness of different proposed interventions before resources and time are committed to implementing them. The purpose of this report is a description of the process of this task, with sufficient detail so as to provide replicability in future ABM works and for allowing further development of the models created.

Methodology

Model selection process - This task began by composing a list of model ideas which covered all Open Labs and hazards addressed by SHELTER. This initially consisted of 25 ideas, which were later narrowed to 17 following inputs from technical partners, and then to 5 based on feedback from open labs. Bilateral meetings followed to clarify expectations and needs and based on this **model concepts** were drawn up in more detail and circulated to the Open Labs once more to clarify expectations. This included an overview of which modelled components the model could consist of, and details of how these could interact. Furthermore, an initial summary of possible data requirements was provided at this stage. At this point, a ‘lighthouse’ and ‘follower’ approach were adopted, whereby each model idea was assigned one Open Lab to primarily focus data and results on, as a ‘lighthouse’. If appropriate, any other Open Lab which had expressed an interest in the model became the ‘follower’ in this approach, indicating its position as a secondary party which the model was not initially run for. At this stage, two more model ideas were excluded due to a lack of interest or difficulties associated with producing the planned model. For the remaining three models, technical notes were drawn up to detail more specifically the possible data requirements and interactions between different parts of the model. Finally, the two most promising and interesting models were developed into code which runs in a Python framework, from which results and graphs were created to provide insight for the Open Labs they were created for.

The two main developed models that were implemented and tested are:

1) Modelling a heatwave preparedness communication plan among vulnerable residents and its impacts on reducing heat stress and mortality.
2) Greening a city for pluvial flood hazard reduction, by improving the rainwater retention capacity through greening.

For each of these two fully-developed models a technical note was drawn up, detailing different components of the model in terms of a task breakdown, the input requirements, a list of processes and background literature reviews explaining the importance of the modelled elements. This was circulated among the Open Labs and a further round of feedback in the form of bilateral meetings helped to further refine the process.

Model development was carried out using the Python library Mesa [5], which was selected as the best software library to code the models in for three main reasons. Firstly, its use of a fully-fledged versatile programming language, Python, meant that any code produced would be universally usable. Secondly, its library extensions for geographic representations were found to be important for displaying visualisation elements of the models. Finally, its cloud-based server format meant there was potential to later integrate the models with the online SHELTER platform under T5.4.

Key findings and Conclusions

Agent-based modelling is a tool which is growing in popularity for the use of exploring complex systems. Its use in disaster risk management as an explorative tool has many benefits, including the ability to test different disaster management interventions before their actual implementation. The first developed model in this task allows for gaining insights in which communication measures are plausibly the most effective for deploying a heatwave communication plan among elderly citizens, to reduce heat stress and mortality. The second developed model allows for gaining an understanding on the impacts of greening parts of a city for reducing the impacts of pluvial flooding. The results from both models can therefore be used to inform planning for local city authorities from a CNH risk reduction perspective.

The model development process was iterative, with several rounds of feedback from Open Labs to inform the model development.

Link with SHELTER Operational Framework

Within the SHELTER project, ABM helps to change the approach to CNH management from a reactive response to a proactive stance under which mitigation provides solutions before disasters force repair. The developed work supports SHELTER's scientific technical objective 3, which is to analyse, test and pilot novel cost-effective solutions and tools. ABM can be used as a rapid assessment tool to examine potential solutions for reducing hazard impact and is thus useful for improving both preparedness and improving recovery and response to hazards. This task also supports scientific technical objective 4 which is to develop collaborative iterative adaptation planning. The ability for heritage managers to foresee how they could respond to a hazard before it occurs, and to learn from the impacts on how to better respond to the next hazard. As it can be seen in Figure 1, the scenario analysis based in ABM is part of the SHELTER operational framework, as one assessment tool for trans-disaster phase.

Lessons learned and EC expectations:

This deliverable provides an insight into the value of ABM as a tool for disaster management. A key lesson learned during the process is the importance of considering the needs of the Open Labs as specifically as possible, to ensure the benefits remain relevant. This is a challenging process in a project like SHELTER due to the wide-ranging scope in developing a broad knowledge set on improving resilience around cultural and natural hazards, which requires multiple discussions and interactions to come to a useful set of concepts for model implementation and utilization.

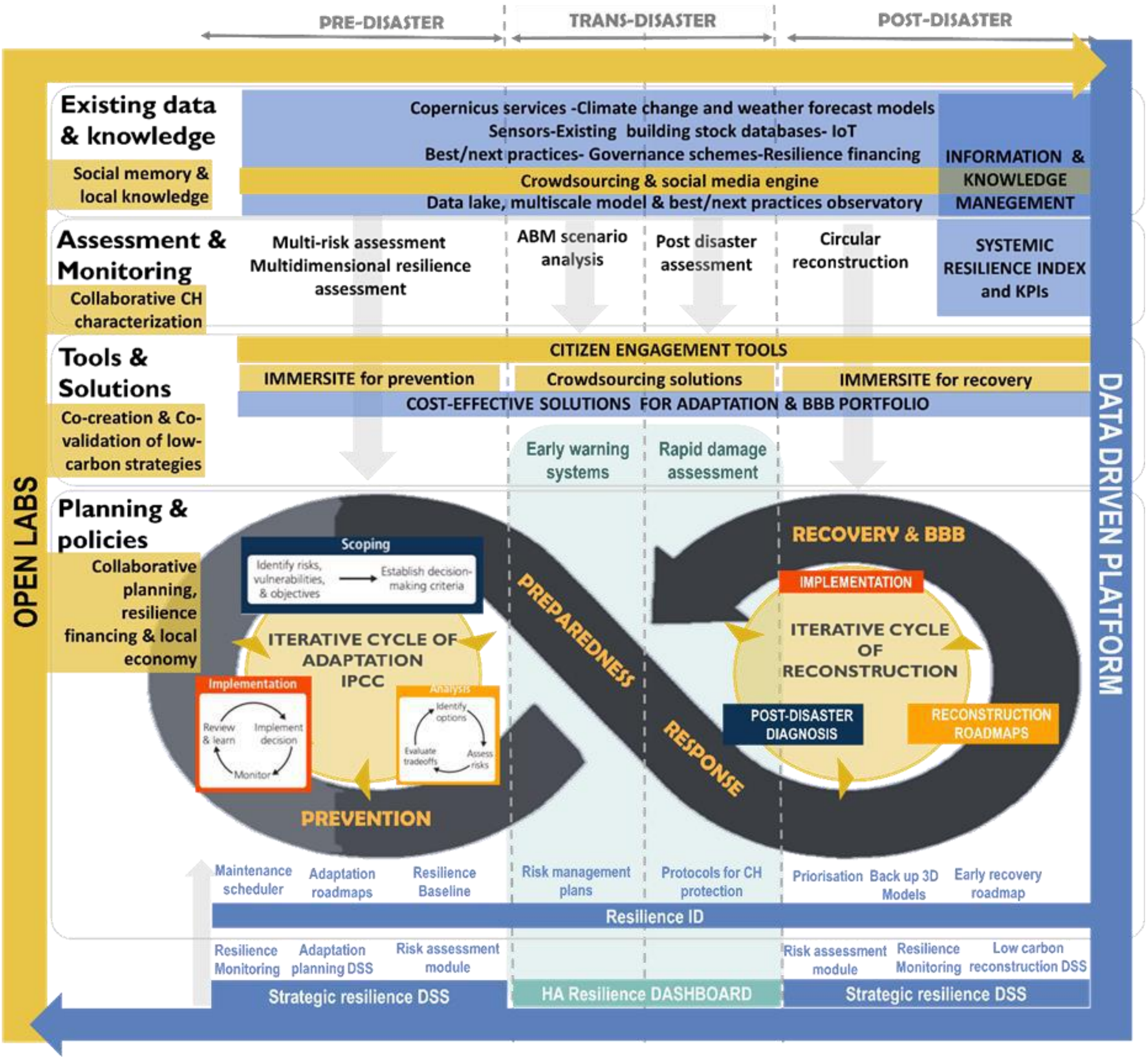


Figure 1: SHELTER Operational knowledge framework

2 Introduction

2.1 Aims and Objectives

The aim of T2.6 is to produce agent-based models which allow insight to improve our ability to protect cultural and natural heritage sites throughout Europe. The models produced allow **exploration** of which interventions are plausibly the most effective, and some amount of quantification of the relative benefits of different measures before resources and time are committed to their implementation. They are **explorative** and not predictive since the developed models are without empirical validation based on local before and after hazard impact observations, as this lies outside of the scope of the task. And the interpretation of what measures are most effective is based on **plausibility** since the developed impacts in the models are based on expert logic and literature where available. Providing an understanding and structure to discuss the likely impacts of hazard risk reduction planning efforts, and a structure to evaluate what insights need to be monitored and evaluated to improve the planning process.

To ensure the task did not deviate from its initial objectives, sentences from the task description are here referred to the sections where they were addressed directly.

Proposal reference	Location
Scenarios regarding the preparedness measures and behaviours forecasted will be set and modelled	Covered in Section **2.8**
The heterogenous behaviour patterns of these agents can be run together, allowing to see interactions, modelled with parameters such as rules set by the scenario measures, infrastructure, citizens' awareness increase on DRM, response and preparedness	Covered in Section **3**
an overview of the behavioural scene following the disaster is displayed instead of forecasts on individual stakeholders.	Covered in Sections **5, 7, 9**
Simulations will be used to determine and compare parameters such as fatality number, injury number, total number of citizens exposed to disaster, financial impact and recovery rate provided and complete recovery time needed after the event.	Covered in Section **10 and 11**
Multiple scenarios will be run and adapted to assist in adaptation roadmaps and Resilience ID definition (WP4) and co-creation and projects results validation in Open labs (WP7).	Covered in Section **10 and 11**

Table 1: Report structure

2.2 Relations to Other Activities in the Project

This task forms an important input for WP5, the objective of which is the creation of an online data-driven platform containing methodologies developed in other tasks. The use of a Python library means that the code developed in this model can be easily integrated into this platform to allow the visualisation server functionality of the models to continue to be available for use.

The insights from the development process in this task will form a direct input for T2.7, the development a cross-scale historic area systemic resilience assessment methodology. This is primarily because the task also included an examination of the requirements from the SHELTER Open Labs in terms of CNH risk reduction management and resilience. This report details the implementation of the model concepts and models developed under T2.6 in the SHELTER project’s framework.

A key input for the technical notes on the model on governance structures and collaborations was the outputs of T6.1, the stakeholder and network mapping within each Open Lab at multiple scales. Actors at every scale were considered by this task and incorporated into this model concept. This allows for the modelling of where intervention measures could improve the effectiveness of information sharing modes during disaster recovery and response.

Finally, the involvement of SHELTER Open Labs in the selection and refinement of the models created was linked to the efforts of WP7 that governs the Open Labs management.

2.3 Report structure

The report takes on the following structure. Chapter 2 introduces the deliverable and its aims whilst setting the task in the context of the wider SHELTER project. Following this, chapter 3 begins by introducing agent-based modelling both conceptually as well as discussing how it can be useful for cultural heritage and natural hazards. This chapter also details the process of deciding which models would be implemented during this task, beginning from the initial ideas phase and the process of narrowing these down and developing their concept and technical notes. Finally, a comparison of ABM platforms available was carried out, in order to justify the selection of Mesa and ensure this was the most appropriate option. Chapter 4 contains the concept and technical notes, as well as results and conclusions, for the heatwave model which was developed for Dordrecht Open Lab. Chapter 5 contains the equivalent information for the second model, the greening city model developed for flood reduction in Ravenna Open Lab. Finally, chapter 6 contains the conclusions and next steps. The appendices contain the concept and technical notes which were written for undeveloped models.

2.4 Contribution of Partners

A number of partners played important roles when developing the models and the deliverable D2.6.

Partner	Chapter	Description
Ekodenge UK (EcoWise)	All	Task leader. Developed the model ideas, technical notes and built them by writing code.
Tecnalia	All	Reviewed technical notes for concepts and provided feedback for selection of early results. Reviewed the deliverable. Chose which models to advance on behalf of Baixa Limia Open Lab
Polito	All	Reviewed deliverable
UNIBO	2.9, 8, 9	Chose which models to advance, and reviewed concept and technical notes for model 6, on behalf of Ravenna Open Lab.
IHED	2.9, 6, 7	Chose which models to advance, and reviewed concept and technical notes for model 4, on behalf of Dordrecht Open Lab

UNESCO	2.9, 4	Chose which models to advance, and reviewed concept note for model 1 on behalf of the International Sava River Basin.
Ekodenge	2.9	Chose which models to advance on behalf of Seferihisar Open Lab

Table 2: contribution of partners

3 Agent-Based Modelling for Cultural and Natural Heritage and Hazards

This chapter justifies the importance of Agent-Based Modelling as a tool for improving our ability to protect cultural and natural heritage and explains the methodology behind its implementation. Section 3.1 outlines what the process is, which is elaborated upon in section 3.2 where the process is linked to its capabilities for improving cultural and natural heritage. Section 3.3 then includes some examples of initial ideas which were considered for the project before any narrowing down processes occurred. This section also outlines the process by which these ideas were decided to ensure the replicability of this methodology.

3.1 What is Agent-Based Modelling?

Agent-Based Modelling (henceforth ABM) is a method of simulating an environment based on interactions between its actors with each other as well as with their surroundings. It models a system's individual components, treating them as unique and able to interact with other components of the system over a period of time [6]. Also known as individual-based modelling, this works by simulating multiple 'agents' contained within a system. These are entities which are independent but connected to each other through networks. Importantly, they are able to make independent decisions based on their environment and behaviour and their interactions with other agents. Furthermore, an ABM can be adaptive, meaning agents can change their behaviours throughout the simulation based on their individual characteristics and interactions [7]. In this way, ABM is able to speculate on emergent behaviour from a system in a way that traditional deterministic modelling techniques are unable to do [8]. An agent in this system may include, for example, a person, animal, building, or anything else capable of having characteristics which can change over time with the environment. In this way, ABM is an example of systems thinking. This is the concept that a whole system has linked components, and in order to understand why an outcome is produced the components of the system must be considered symbiotically.

An agent-based model is used to address problems which arise from systems too complicated to be accurately modelled by traditional methods that fail to account for this complexity. The characteristics of the system's agents are defined, for example an agent which is a person might have the characteristic "hungry" which will have two possible states, hungry or not hungry. "Location" could have multiple different states, depending on whether the person is at work, at home, or elsewhere. There can be any number of states, as long as an understanding remains of how to model the relationship between this and the behaviour which is being modelled. These factors can be represented by a set of rules which determine the actions the agent takes, appropriate to the system being modelled. Decisions which an agent may make can be related to survival instinct, for example when to evacuate following a hazard warning, or economic-based when financial incentives exist. The ABM itself, therefore, consists of a group of agents with defined characteristics alongside a model which makes the agents act. The advantage of modelling behaviour in such a way is that it allows us to observe dynamic components of a system interacting with its individuals. It is possible to model many possible interactions by representing the world from individual agent perspectives. Unlike other model types, which describe a system with variables representing its entire state, this allows a deeper complexity and understanding of how its behaviour is linked to its components individually. ABM is therefore useful for modelling situations where its agents have potentially complex or non-linear interactions [9]. It is therefore suited well to disaster management studies, as these often involve complex situations arising from uncertain conditions which are to an extent unpredictable. The result is modelling in such a way as to simulate changes in the behaviour of agents over a given period of time, to allow an understanding of how different factors can influence hazard vulnerability.

3.2 How can ABM support Cultural and Natural Heritage Resilience?

Cultural and Natural Heritage represents important records of the past which have stood the test of time against historical hazards [10]. However, despite proving historically able to withstand natural hazards, the onset of anthropogenic climate change amongst other factors is increasing hazard occurrence and placing increasing stress on cultural heritage sites, making them vulnerable in novel ways which require new solutions. Through both tangible monuments and intangible tradition, its role in preserving community identity [11] and history has earned it recognition as a key component of resilience [12]. Efforts to encompass it in disaster risk management frameworks are increasingly common. There is no single way to improve the resilience of cultural heritage sites in the face of these new risks – notably those exacerbated by a changing climate – being faced today [13]. The exploratory nature of outputs from ABM thus becomes useful in the face of such uncertainty [8]. Moreover, literature has shown that ABM can address the different of components of resilience (recovery, resistance, and variability) although their multidimensional study is still limited [14].

ABM is particularly useful in this context because it is able to explore the potential impacts of introducing changes to a system. It can therefore enable a structured exploration to examine which interventions are likely to work, and the quantification of the relative benefits of different measures before resources and time are committed to their implementation. The complexity of the multiple interacting parts of any cultural heritage site includes stakeholders at different scales, visitors, residents, and future changes to the physical system itself brought about by climate change. The interplay between these factors often renders CNH sites unsuitable to traditional deterministic modelling methods. The ability of ABM to set behavioural rules and their interactions, and thereby speculate emerging factors into systems is important for understanding this complexity and how it evolves over time. For example, if a natural disaster adversely impacts one community more than a neighbouring one with similar exposures, ABM helps us to structure the social factors that impact vulnerability into model rulesets. For example, on how socio-economic income levels affect availability to resources that allow for swift evacuation or how community structures impact a faster and/or more equitable support response to vulnerable members in the community. The intuitive nature of ABM makes it an especially suitable tool for communication of results [15]. The outputs of ABM can therefore help to structure the discussion around what matters in terms of preparedness planning, by exploring ideas on how particular measures will help (or not) in a combined qualitative and quantitative manner, and thereby inform future policy decisions.

The protection of cultural and natural heritage aspects of places which are vulnerable to hazards is important for a site's social, cultural, economic and historical value. Heritage significance of historic areas is a non-renewable and unique resource that cannot be fully recovered by rebuilding it after a disaster. Thus, protecting important sites which are vulnerable is of paramount importance. Studies have previously confirmed the utility of the ABM approach to simulate stakeholders in intangible cultural and natural heritage studies, for example with an emphasis on ticket prices [16]. In particular, this is where its incorporation of the human behavioural aspect has made ABMs unique in their approach [17] to modelling cultural and natural heritage. This demonstrates the applicability of this type of modelling for the benefit of intangible cultural and natural heritage, which can be furthered to encompass the improvement of resilience by modelling other stakeholders and to different ends. Since so far ABM has been predominantly used for natural heritage issues [7], the work presented in this report is an opportunity in the advancement of ABM for cultural heritage environments.

3.3 Initial ideas for Agent-Based Modelling in Shelter

In the initial stages of the task a large number of ideas were developed with technical partners for potential ABM's that could be modelled in the context of cultural and natural heritage resilience. Table 3 lists the original 25 concepts which were initially under consideration as potential modelling ideas for SHELTER under task 2.6. This involved detailing a broad list encompassing multiple ideas applicable to all the open labs, which was later narrowed down. Ideas included:

- 1 specific idea for subsidence, 2 for heatwaves, 2 for flooding and 3 for wildfires.
- 1 model specifically for the Ravenna Open Lab, 3 for Seferihisar, 3 for Galicia.
- 9 ideas simulating the impact of an improvement of hazard awareness
- 4 ideas simulating ideas of risk mitigation
- 6 ideas representing an improvement of hazard preparedness.
- 6 ideas to model an improved recovery phase

The ideas are displayed in table 3. Based on these 25 ideas a total of 17 were short-listed by the technical team as potentially useful and feasible to implement which are highlighted in yellow for later reference.

Number	Model idea	Category
1	Simulations of how different rates of natural gas extraction impact land subsidence	Risk mitigation
2	Simulating the impact of a heatwave preparedness communication and mitigation programme on mortality, with the programme being targeted to elderly and vulnerable groups	Hazard awareness
3	Simulating the impact of behavioural support on heatwave mortality for visitors at historic sites (e.g., provision of water fountain or shade)	Hazard awareness
4	Simulating for preparedness plans the number of access routes to determine quickly how emergency services could travel after a disaster	Preparedness
5	Simulating how information campaigns targeted/placed in travel corridors to the region could improve visitor awareness of fire prevention actions (billboards, flyers, signage in multiple languages, geolocalised SMS)	Hazard awareness
6	Modelling first responder wildfire detection in local areas, and the speed of informing and coordinating a response	Hazard awareness
7	Simulating how forest management practices can help reduce the spread of wildfires (discontinuous tree layer/open forest areas to slow spread)	Risk mitigation
8	Simulating how virtual site visits combined with replicas of most popular cultural heritage artefacts could form an alternative experience when a hazard implies no access for long periods of time	Risk mitigation
9	Modelling the economic and wellbeing benefits of introducing proactive policies (including fire extinguishers, reinforced foundations) compared with rebuilding post-disaster (specific KPIs would be introduced)	Preparedness
10	Modelling what combinations of a range of disaster-protection mechanisms in a disaster make sense (e.g. 5-6 mechanisms including social and physical such as escape route signposting, reinforced foundations)	Preparedness
11	Simulating how spatially planned hazard-proof sites (shelters, earthquake resistant buildings) can reduce injuries/ faster medical provision and improve the safety of people at culturally significant sites	Preparedness
12	Simulating peoples responses given different amounts of warning time before a flood (variation between days to hours) in interest and ability to respond	Hazard awareness
13	Simulations of greening of a city to improve water retention capacity for flash floods/ impact on reduced overflowing of sewers	Risk mitigation

14	Simulations of how smart phone application early warnings can influence hazard awareness (hazard awareness inclusion in weather apps) (variation due to people with and without digital access)	Hazard awareness
15	How improved signage of on-site evacuation routes impacts awareness and risk	Hazard awareness
16	Simulations of peoples actions and routines in a disaster following the implementation of a regular drill	Hazard awareness
17	Simulating the household dissemination impact of introducing a school hazard education programme	Hazard awareness
18	Modelling how the involvement of multiple stakeholders in key decision making processes can strengthen the preparedness and resilience of HAs. For example perceived value of HA, willingness to contribute to preparation efforts, financial contribution (could model scenarios with low/medium/high preparedness in relation to certain critical decisions and their relation to perceived value, willingness to contribute, financial contribution) (e.g. COVID PPE stocks being underfunded due to changed priorities)	Preparedness
19	Modelling the impact of communications technology in post-disaster recovery in terms of availability and robustness	Recovery
20	Modelling how previous hazard experience and past success/failure in communication/response from authorities influences peoples responses to a hazard	Preparedness
21	Modelling the influence of community support in basic service provision for recovery (e.g. providing food, shelter, water)	Recovery
22	Modelling the ability for recovery efforts to reach people through networks of information linkages by examining a specific parameter, for example if someone has a place to stay	Recovery
23	Modelling humanitarian logistics and infrastructure for post-disaster response for a certain recovery need, e.g. food or water	Recovery
24	Simulating the importance of collaborative information sharing between parties such as NGOs, governments and local people	Recovery
25	Simulating the impact of establishing a citizen first response team. This would train certain members of the community (e.g. nominated 'block leaders') in first-response following a disaster, including first aid, damage assessment, emergency communication, shelter and cultural needs.	Recovery

Table 3: List of original 25 potential model ideas.

3.4 Selection of Models to Implement in Shelter Under T2.6

Due to the aforementioned explorative nature of agent-based modelling, a key part of the model elaboration process is to ensure that appropriate and useful models for the SHELTER Open Labs as end users are developed. To this end care was therefore taken to engage with the Open Labs in feedback cycles to incorporate their opinions and ideas, whilst making sure that the models can be technically developed as well within the task time constraints.

Process description to come to select specific models - The process of selecting models to implement was separated in five stages of evaluation. Each features a different external input from technical partners and open labs. At every stage, progressively fewer model ideas were considered for implementation until the final stage when the remaining models entered conceptual development.

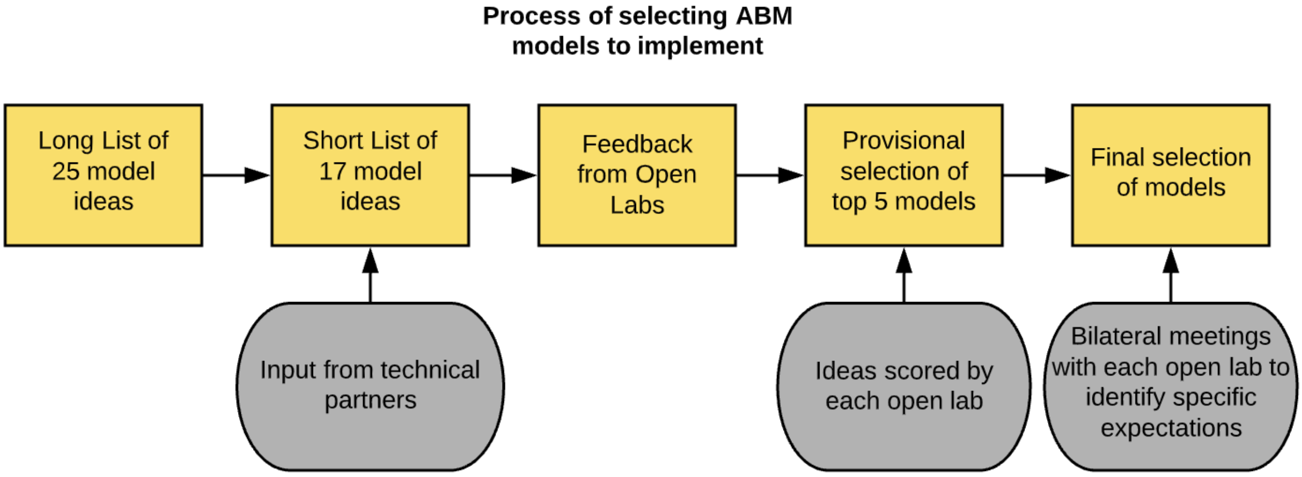
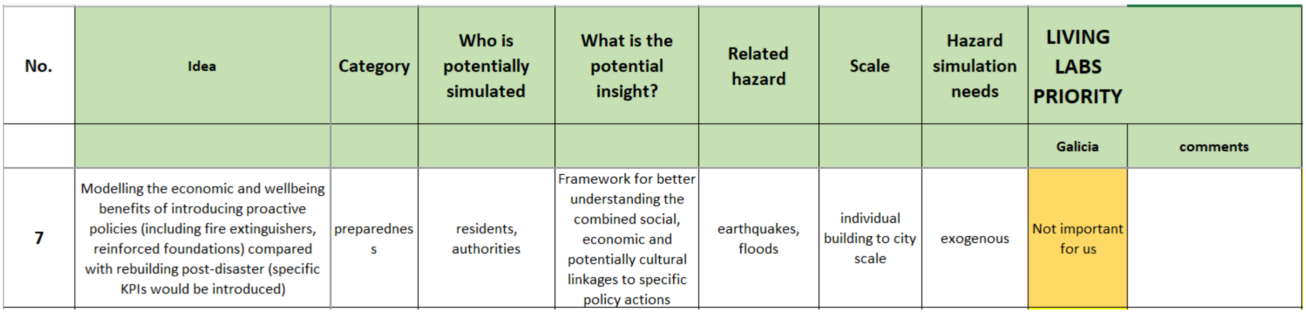


Figure 2: Summary of the five staged model selection process

Generation of the long list - The process began with the generation of a lengthy 'long-list' (table 3), intended to be a very broad and thorough identification of all the potential areas which could be modelled. This led to a total of 25 potential model ideas, covering all Open Labs and natural hazards being considered by SHELTER. The list was kept intentionally broad, to give as much choice of model ideas to the Open Labs as possible.

Narrowing down to a short list - The long list was then narrowed to a list of 17 ideas. This was done by a selection of the top 10 model ideas by the task leaders, as well as a consultation with the technical experts who also selected their top 10 models. Any models which were not selected by either party were eliminated from further analysis, which concluded with 8 of the potential model ideas being eliminated at this stage. Shown in table 3 as the models that are not highlighted. The purpose of this was to remove any overlapping ideas providing similar alternative models, and to eliminate those which were initially less favourable from a CNH perspective. The intention of this was to provide a more simplified list to present to the Open Labs for scoring the models they thought to be potentially most useful, without being overloading with information.

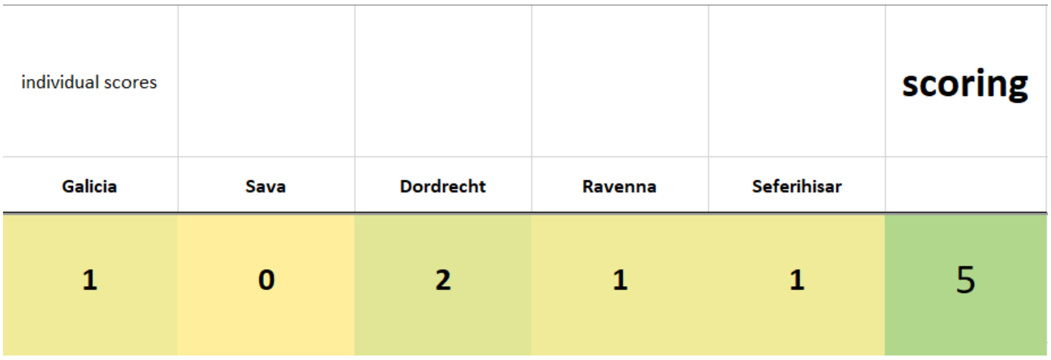
Scoring with Open Labs - Each Open Lab was then provided with the shortlist in the form of an Excel Spreadsheet with columns for their rankings of each idea. Options for rankings included 'most important for us', 'high importance for us', 'low importance for us' and 'not important for us'. Alongside this prioritisation list, there was also a space for each Open Lab to write their ideas of why an idea was relevant or not. This allowed a greater understanding about the priorities of different stakeholders for models which they believed could benefit them. An example row of this form is displayed in figure 3.



No.	Idea	Category	Who is potentially simulated	What is the potential insight?	Related hazard	Scale	Hazard simulation needs	LIVING LABS PRIORITY	
								Galicia	comments
7	Modelling the economic and wellbeing benefits of introducing proactive policies (including fire extinguishers, reinforced foundations) compared with rebuilding post-disaster (specific KPIs would be introduced)	preparedness	residents, authorities	Framework for better understanding the combined social, economic and potentially cultural linkages to specific policy actions	earthquakes, floods	individual building to city scale	exogenous	Not important for us	

Figure 3: Example row of form sent to open labs to prioritise the proposed models.

The results of this feedback form were then combined into one scoring system, with 'most important' correlating to a score of 3, 'high importance' correlating to 2, 'low importance' scoring 1 and 'not important' scoring 0. These scores were then added and totalled, to easily identify the models which scored highly across multiple open labs. Figure 4 is an example of how this scoring was carried out.



individual scores					scoring
Galicia	Sava	Dordrecht	Ravenna	Seferihisar	
1	0	2	1	1	5

Figure 4: Scoring methodology for an example model.
Each Open Lab ranked model ideas by their importance converted to a numerical value.

It should be noted that the models progressed were not simply the top 5 scoring models based on this scoring system alone, however. Following the form being completed, key themes emerged for the priorities of each Open Lab. Whilst in some cases a physical-oriented model was preferable to understand more about the dynamics of the hazard itself, other Open Labs preferred models which focused on how social interventions can impact risk, and which were applicable across multiple Open Labs. The progressed models were therefore a balance between individual priorities and models which suited multiple open labs. Based on this analysis, 5 models were progressed to the next step. These are stated in table 4. Important to note is that ideas 1 and 5 at this stage consisted of two similar ideas which were merged based on conversations with Open Labs.

	Idea	Potential insight	Open labs
1	Simulating the importance of collaborative information sharing for recovery between parties such as NGOs, citizen response teams, governments, and local people Simulating the impact of establishing a citizen first response team by training members of the community in disaster first-response	Understanding what information needs to be shared and why, and understanding how bottom-up responses could improve recovery	All open labs but a focus on Dordrecht and Ravenna
2	Simulating for preparedness plans the number of access routes to determine quickly how emergency services could travel after a disaster	Information for potential measures for logistics planning in wake of a disaster	Sava River Basin and Seferihisar
3	Simulate how wildfire can evolve considering meteorological conditions, soil moisture and species in the area. Simulating how forest management practices can help reduce the spread of wildfires (discontinuous tree layer/open forest areas to slow spread)	Estimating the spread of fires following management interventions, and understanding what physical factors influence wildfire spread and severity	Galicia
4	Simulating the impact of a heatwave preparedness communication and mitigation program on mortality, with the program being targeted to elderly and vulnerable groups	How awareness of preparedness measures can impact vulnerable groups positively (e.g., reduce mortality)	Dordrecht, Seferihisar
5	Model of how multiple stakeholder involvement in decision-making strengthens preparedness, e.g., how do more stakeholders being involved influence perceived value of cultural heritage, willingness to contribute financially and otherwise	Evaluation of how stakeholder involvement changes preparedness and resilience, e.g., willingness to contribute and the perceived value of historic areas.	All open labs

Table 4: Near-final narrowed-down 5 models after Open Lab scoring.

Results from the narrowing down - Following this initial scoring, a bilateral meeting was set up between the Open Labs and technical partners to establish a dialogue on which model ideas would be progressed to form the final selection. Minutes from these conversations can be found in Appendix A. Whilst, at this stage, there was already a fairly clear idea of which models would be used, this allowed open labs to express their opinions about the chosen models and to better explain their specific needs and expectations from the task.

Whilst the format of this was a bilateral meeting, several key questions were formulated following a discussion between the modelling team, for the sake of uniformity with each meeting. These were as follows, for each model applicable to each Open Lab:

1) What are the Open Lab's needs in relation to the presented model?
2) How does the Open Lab see the model outputs as helping?
3) In what format does the Open Lab need the results to help their purpose?

Whilst the discussions as noted in Appendix A typically addressed each of these questions naturally, they were interjected where it was felt that the conversation was not addressing them sufficiently. This ensured that the final chosen models were as appropriate as possible. The discussion also allowed each partner to comment on their specific needs for the exact focus of the model and provide feedback. This allowed the later creation of several "sub-models" within each idea. A write up of the discourse covered in each of these 5 meetings is available as an appendix A. A more general discussion also ensued about which of the models from the short-list of 5 were deemed the best ones for implementation within which Open Lab.

At this stage, to ensure only a manageable number of models were progressed, model ideas 1 and 5 (table 4) were integrated as their objectives were similar, as was suggested by one of the Open Lab partners. Furthermore, following evaluation an extra model was added to the short list, to better suit the needs of the Ravenna Open Lab. This became known as model 6 (see table 5).

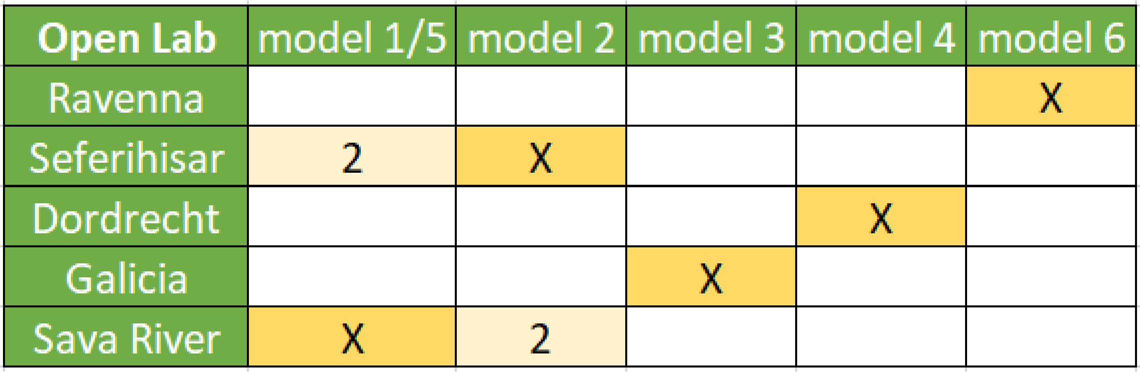
	Idea	**Potential Insight**	**Open Labs**
6	Simulations of greening of a city to improve water retention capacity for flash floods/ impact on reduced overflowing of sewers	Estimating what proportion of public areas need to be greened in order to have a tangible impact on floods	Ravenna

Table 5: Model idea emerging from conversations with Ravenna OL

The potential insight of model 6 is in regard to the percentage green land and flood adaptation capacity. Being ideal at the city scale and smaller, it was deemed most appropriate for the Ravenna Open Lab as a potential help to its flash flooding problem.

3.5 Results from the First Open Lab Evaluation

A 'lighthouse' and 'follower' approach was adopted for the implementation of models. Since several model ideas were suited to and favoured by multiple Open Labs, it was not feasible to apply the model to each example. This would have required extra data and time inputs. Therefore, instead a lead 'lighthouse' Open Lab was adopted for each model which would constitute the main focus of Shelter. Where possible, a 'follower' was also appointed as a secondary aim of the model. Following initial development for the lighthouse Open Lab, where possible the model was unlocked for the following open labs. Table 6 is an indication of which models were lighthouses and which were followers from this point onwards.



Open Lab	model 1/5	model 2	model 3	model 4	model 6
Ravenna					X
Seferihisar	2	X			
Dordrecht				X	
Galicia			X		
Sava River	X	2			

Table 6: Lighthouse (X) Open Labs and follower (2) Open Labs for each model

At this stage there was a clear idea of which models would be implemented, and therefore the next stage was to create a detailed conceptual overview for each model. The conceptual document was sent to each of the Open Labs who had selected these models, to improve their understanding of the implementation stages of the models henceforth, and to facilitate another round of discussion regarding specific details and model focuses.

3.6 Model Concept Notes Development

After the initial presentation of the Open Lab leaders and partners to the selected models, ideas were exchange by each Open Lab which allowed model concepts to be developed in detail. The results are several 10-page concept notes for each model as a next step in the Task 2.6 process. This involved building upon the initial model ideas with detail about why and how its outcomes would be used. The models were made more specific to the discussed needs to refine them to make each model suitable to the needs of the Open Labs. The outcome of this concept development stage is presented in this document, and summarised in table 7:

Based on initial model selections there were several models which were planned for but not subsequently implemented due to a lack of motivation from the Open Labs or due to a lack of time from the modelling team. These are as follows.

Name of model	Open Lab intended for	Type of note developed	Chapters
Model for heatwave communication plan	Dordrecht	Concept and technical	4,5
Model for City Greening for Flash Floods	Ravenna	Concept and technical	6,7
Model for information sharing and recovery response	International Sava River Basin Commission	Concept and technical	Appendix B, C
Model for access routes during emergency	Seferihisar, International Sava River Basin Commission	Concept only	Appendix D
Model for wildfire evolution and management practices	Galicia	Concept only	Appendix E

Table 7: summary of concept and technical notes

The detailed concept note for each model was circulated to the proposed open labs for implementation. Each contained an overview of the ABM process and a timeline of the task to keep the Open Labs informed of the process as well as a detailed description of the model idea along with any variants or sub models being incorporated. User stories were also provided, which are sentences describing actions by users who would be utilising the model results, to contextualise its usefulness. A model schema then outlined the different building blocks that would exist within the model, i.e., the modules which would combine to provide the overall model. The agents within it were then defined, and importantly a preliminary list of data needs was provided, including information about whether this is essential for the model's functioning or an extra need, and its description. Potential results followed, to allow an end goal for during the model's development to ensure the process remains focused. Finally, a bibliography provided some additional resources for each model, which could relate to either similar ABM studies in the past, or other studies relevant to this hazard which could prove useful either for conceptual understanding or identifying useful results.

Outcome of the concept note development - During the process of developing the concept notes, some issues revealed themselves. The nature of model 3 as a physical wildfire model is difficult to work around because, as a result of the fast-paced nature of this task and the other models needing development, there is no feasible way to develop a comprehensive, accurate wildfire model in this timeframe. A review of the literature found no open-sourced wildfire models which would provide the modellers with the functionality required to incorporate into an ABM, however a private sector wildfire model was discovered and a partnership proposed. This was unable to progress however, which posed a significant problem to the development of model 3. Whilst it would be possible to develop an alternative wildfire model, the detail and usefulness of one able to be produced during the timeline of the task is not comparable to the private sector one discovered. At this stage therefore, this model was discounted from the study on the grounds of it being unfeasible.

On a similar note, model 2 was disregarded due to a combination of its lack of usefulness for the Open Lab and the time limits of the task. This therefore resulted in three final models being progressed.

3.7 Summary of the concept notes which did not become fully coded models:

The appendix contains the full concept and technical notes for each model, as outlined in table 7. The below section contains a summary of these concepts.

Model for information sharing and recovery response:

The Sava River Basin spans multiple countries and when flooding occurs in the border region of two or more, communication becomes incredibly important for streamlining the emergency response. However, differing national and regional policies mean this process is not always as coordinated as it could be. As explained in appendices B and C, this model would simulate the information flows between different organisations in the wake of a flood in the Sava River Basin. Specifically, due to the large size of this river basin which crosses several national borders, this model would have explored the processes influencing information flows between organisations within each country. Exploring results from this should allow a better understanding of the factors which influence what makes a communication measure effective. Since this is an abstract model exploration, 5 specific examples of cultural heritage sites at a trans-border flood-prone region in the Basin would have been modelled. A specific recovery metric would have been chosen, for example the repair of the heritage itself, in order to have a specific parameter to model the changes of. This model would also consider the improved resilience for future flood events, and model these in the process. Figure 28 displays this model concept as a series of interacting organisations and information flows.

Model for access routes during emergency:

Following a natural disaster such as an earthquake or flood, it is important for emergency services to have detailed knowledge of where access routes are located and whether they have remained accessible following the hazard. This knowledge is crucial for ensuring a streamlined emergency response which reaches the people who need it as quickly and efficiently as possible. Two variants of this model were foreseen, one specific to the Seferihisar Open Lab and the other to the Sava River Basin. In Seferihisar, the Citadel area has only a few routes into it and not all entrances are large enough for emergency vehicles to enter by, with more being obstructed by market stalls. There is therefore a need to model the travel of people out of the city during an earthquake to points of safety, as well as a need to model the entrance of vehicles to respond to those who cannot exit depending on the severity of disaster. This model would have explored either of these focuses.

The second variant was intended for use by the International Sava River Basin and aimed to address flood hazards which occur in trans-boundary areas. The model aimed to explore the links between cooperation and information flows to identify the benefits of information and resource sharing for the purpose of disaster response, and aimed to address flood hazards which occur in trans-boundary areas. The model aimed to explore the links between cooperation and information flows to identify the benefits of information and resource sharing for the purpose of disaster response One key recovery metric could have been selected, for example the sharing of emergency vehicles.

Model for wildfire evolution and management practices:

The final model concept which was developed was for the Galicia Open Lab, which is subject to wildfires. In order to tangibly address this natural hazard, it is important to understand the physical and human drivers of fire which contribute to their prediction and management. This model concept was therefore to simulate fire spread in Galicia given different conditions, as well as to explore different forest management interventions and the impact these could have on reducing the spread of fire. Its objective was to identify the factors which were most associated with fire spread, to allow managers and citizens to be aware of fire conditions and take precautions when conditions are ripe for one.

3.8 Model Selection and Feedback from Open Labs

From the original 25 model ideas, the two models which were constructed:

1) Simulating the impact of a heatwave preparedness communication and mitigation programme on mortality, with the programme being targeted to elderly and vulnerable groups (Chapters 7, 8, 11)
2) Simulations of greening of a city to improve water retention capacity for flash floods/ impact on reduced overflowing of sewers (Chapters 9, 10, 12)

These two models cover a range of natural hazards facing cultural and natural heritage sites in the Open Labs and more generally across Europe. They were therefore found to be the most representative, and therefore the most suitable, models to move forward with.

3.9 Selection of Platform for Implementation

Prior to the implementation of the models a suitable coding platform had to be selected for the SHELTER works. There are several functional programming tools for writing agent-based modelling codes. Each has different benefits and drawbacks which are summarised in **table 8.** Note that the 10 provided in the table are not an exhaustive list of all potential ABM software, yet the overview covers all software that is widely used. The evaluation is based on a Literature survey and the modeller team's past experience with some of the software.

Name	Language	Description and difficulty	Open source?	Link to software description/download
Mesa	Python	Browser for visualisation; repeatable components.	Yes	Mesa: Agent-based modeling in Python 3+ — Mesa .1 documentation
NetLogo	NetLogo language	Simple/easy interface in NetLogo language. Most widely used and easiest to learn.	Yes	NetLogo Home Page (northwestern.edu)
MASON	Java	Complex to use, fast and efficient	Yes	MASON Multiagent Simulation Toolkit (gmu.edu)
AnyLogic	Java	User friendly graphical interface	No	AnyLogic: Simulation Modeling Software Tools & Solutions for Business
Repast-J	Java/C#	Object-oriented agents, user-friendly graphical output	Yes	Repast Suite Documentation
Swarm	Java	Complex to model. Collection of independent agents	Yes	ABM Resources - Swarm

UrbanSim	Opus with python base language	Moderate difficulty. Intended for land use planning	Yes	UrbanSim.
PDES-MAS	C++	Complex.	Yes	PDES-MAS | Distributed Simulation of Agent-Based Systems)
Mobility Testbed	Java	Moderate difficulty, medium-scale	Yes	GitHub - agents4its/mobilitytestbed: Flexible Mobility Services Testbed
ASCAPE	Java	Flexible, powerful, less code than other tools.	Yes	Ascape 5.6.0 (sourceforge.net)

Table 8: Comparison of ABM platforms based on [7] **and** [18].

After this comparison, **MESA** was decided as being the most appropriate software toolkit for the development of the models under this task in Shelter. The reason is its reusable framework and flexibility in deployment.

There are five main reasons for the selection of MESA:

- The use of the Python coding language provides for an essential advantage compared to the other options considered, which is more versatile and easier to develop code in. Python has a strongly object-oriented form in its approach which makes it more easily understandable for code reading and development.
- The widespread availability of python libraries makes it more versatile in expanding the visualisation of output results, and to integrate geographical GIS information, which are better than other options considered. Specifically, a library has been developed known as Mesa-geo [19]. This has been created for the purpose of extending Mesa to include mapping capabilities. Specifically, this library allows for the uploading of a shapefile to take the form of an agent and replace the standard grid format of other model types such as NetLogo.
- The MESA libraries are also easy to adapt for cloud-based utilisation which provides a key advantage as the models can be more easily integrated in the SHELTER platform. This is as the model is launched as a server which launches in an internet browser, requiring only a cloud shell for online use. Other software requires bespoke specific user interfaces in order to launch and run models.
- Mesa has a feature called batch runner which allows many iterations of models to be run simultaneously and very quickly. The randomness present within systems which are modelled by ABM make repeating model runs very important for reliability.

4 Heatwave Communication Model:

Simulating the impact of a heatwave preparedness communication and mitigation programme on mortality, with the programme being targeted to elderly and vulnerable groups.

4.1 Concept Note

4.1.1 Model Description:

Title: To simulate the impact of a heatwave preparedness communication and mitigation programme on mortality, targeted to elderly groups.

Aim: The aim of this model is to better understand how awareness of proposed heatwave preparedness measures, focusing on communications, can have a positive impact by reducing health risks of people in the population who are aged 70+ (e.g. reduce mortality). This can help to refine such preparedness measures and support calculations of people's wellbeing improvement and healthcare cost reductions.

Context about heatwaves: Heatwave preparedness is of importance because the frequency and duration of spells of hot weather will significantly increase across the 21st century due to climate change. Urban citizens in densely built cities are adversely affected because of the urban heat island effect, which causes locally higher temperatures to occur. Especially vulnerable are those aged 70+ with limited mobility, who have limited means to seek cooling. Heat risk occurs when the body cannot dissipate its excess heat into the environment, resulting in body temperatures to rise above the 37°C average temperature. If humans are in such an environment for too long their body heats up and hyperthermia can occur which can lead to excess heat mortality. These risks are especially relevant for those aged 70+ as these people are more likely to be taking medication which impacts their natural thermoregulation mechanisms, making them especially vulnerable.

Context about preparedness: The specific conditions under which heat wave mortality among elderly occurs was studied by Van der Torren et al. (2006) for the 2003 heatwave in France [20]. A total of 315 mortality cases and 282 control subjects were analysed who lived at home at least 24 hours before death or hospital admission. Living conditions were directly observed and information as obtained from interviews with friends, neighbours and next-of-kin either face to face or by phone. Key risk factors for heat mortality of elderly, established with statistical significance, included:

- Being confined to a bed
- Not leaving the home during heat waves
- Pre-existing medical conditions, especially neurological and mental disorders
- An absence of social activities
- Living in a house constructed before 1975
- Living on the top floor of a building
- Bath or shower frequency (the lower the frequency the higher the risk)

- Quantity of liquids drinking per day (high liquids intake lowers the risk)
- Opening of windows (keeping the windows closed increases risks)
- The quality of house insulation

The model should include the following capabilities:
1) To simulate heatwave scenarios and mortality impacts for elderly groups and vulnerable populations, including long term temperature scenarios.

3) To take into account different sections of the vulnerable population with different characteristics and behaviours, who respond differently to communication campaigns and routes.

2) To simulate communication channels/modes across local population focusing on heatwave preparedness and mitigation by the local authority and relevant local institutions.

4) To take into account both direct and indirect communication efforts to the most vulnerable section of the population across communication channels/modes.

The model should provide the following type of insights:
1) An understanding of the effectiveness of different channels/modes of communication to vulnerable people in a heatwave.

2) A better understanding of why certain sections of the population within vulnerable groups are at a higher vulnerability in a heatwave than others.

3) An exploration of ideas on how to refine the communications in terms of strengthening particular channels/modes and reducing the effort on others.

4) Information that can help to establish the healthcare cost reductions from the communication programmes by reducing mortality.

Model variants - No model variants are currently expected.

User story examples
Several model user's stories have been created to contextualise this model in terms of its utility for end users who will be using its outputs and make it as easily understandable as possible. This list focuses on the key user groups who are likely to be the focus of the model, these are as follows:

- ➔ As a local government heatwave communication team, I want to run the simulation to understand how communications I have in mind could reduce heatwave mortality.
- ➔ As a local government heatwave communication team, I want to gain insights in which communication routes can be most effective for reducing heatwave mortality risks.

- ➔ As a local government heatwave communication team, I want to run the simulation to gain a better understanding of which local actors to involve in the communications to make them more successful in reducing heatwave health risks.
- ➔ As a local government finance team, I want to run the simulation to understand the potential healthcare cost benefits of heatwave mortality reductions.

Model schema and building blocks: context

A model is composed of several building blocks, each has an input, a process, and an output. A set of **building blocks** is called a **'module'**, or a sub-model because it can be run on its own. The combination of all these building blocks results in the combined model. The relationship between all these results in a **model schema**, see for example figure 5.

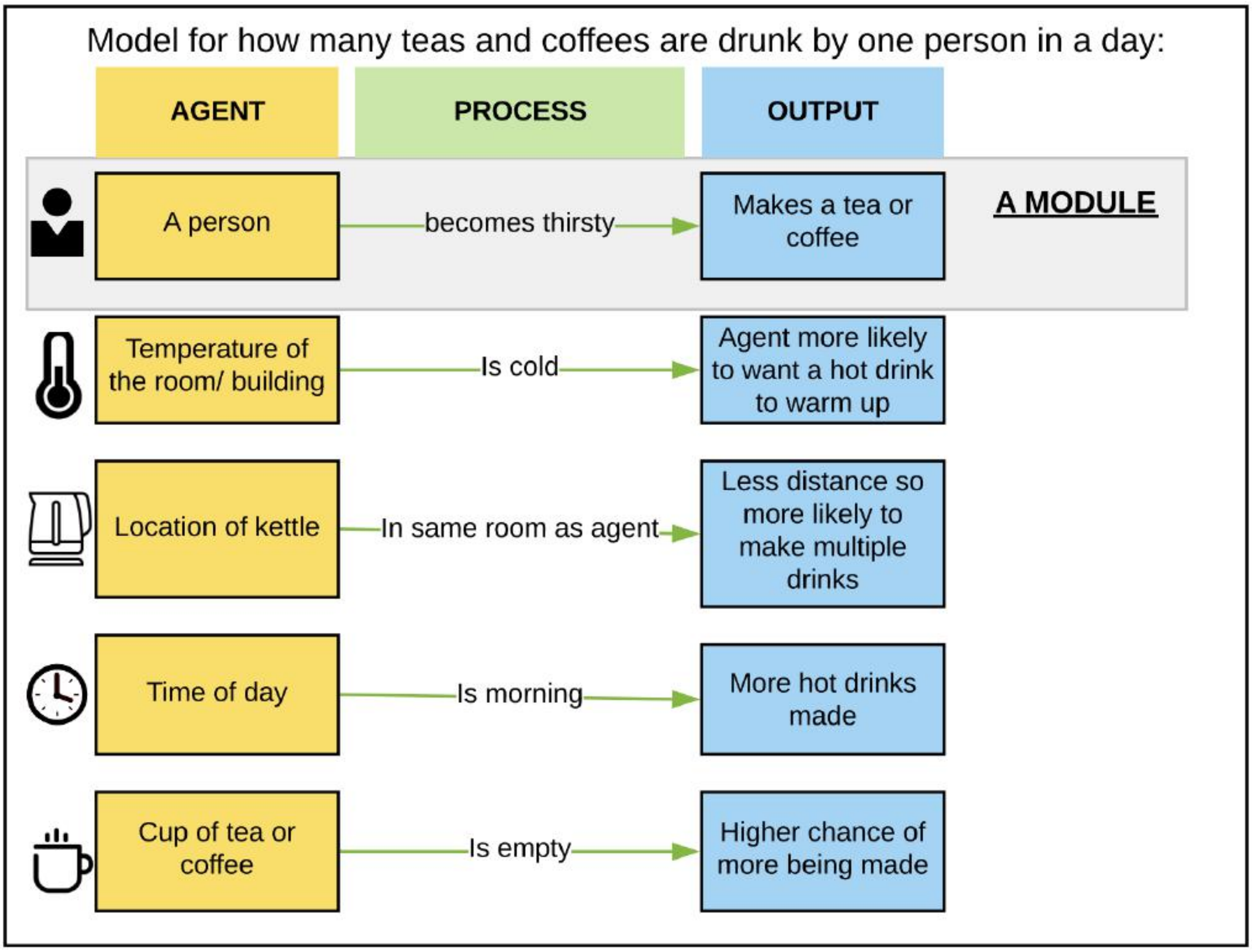


Figure 5: An example of how models are composed of 'submodules'.

These are in turn composed of individual building blocks in an agent → process → outcome form.

This relates to ABM in that a building block has a process where an entity changes over time and or space, for example a person (entity) becomes older when simulating time in a model. The input in the process is starting age, the process is ageing and the output is end age.

Agent-based modelling importantly considers multiple entities which must be defined before the technical development. Each entity exists separately from each other but will be combined in the model runs. This allows simplicity for editing entity features and characteristics at various points in the process.

4.1.2 What are the Proposed Agents in this Model?

Before connections, processes and outcomes can be identified as above in figure 5, it is important firstly to define the agents which are present in the system being modelled. These are specified in the following table along with their possible characteristics and related processes. Important to note is that the actual implemented model will focus on only a few characteristics per agent and related processes; this is to increase both the quality of the model and to only focus on what is really relevant and to make it possible to deliver the task. Table 9 is separated into high and low priority actors, to acknowledge the existence of many stakeholders but also focus the model to actors who are most involved and who the model is primarily targeted towards.

High Priority Model Actors:

Entity	Characteristics	Processes
Local government heatwave coordination team	Communication models/channels, Resource availability (labour effort), residents they are in direct contact with	Communications with local institutions. Communications with residents.
Residents who are not vulnerable	• Age, gender, health status, home location • Network linkage with vulnerable residents	Heatwave impacts, behavioural change from communications, care for vulnerable residents in network
Residents marked as vulnerable	• Age, gender, health status, home location, vulnerability grouping • Network linkage with non-vulnerable residents	Heatwave impacts, behavioural change from communications
Social care institutions	Communication models/channels, resource availability (labour effort), residents they are already in direct contact with	Communications with residents

Low Priority Model Actors:

Entity	Characteristics	Processes
Public institutions with spaces (e.g. museums, transport hubs)	Location, footfall of not vulnerable residents per day, footfall of vulnerable residents per day	Ability to physically place communications and make announcements.

Table 9: Entity characteristics and processes

4.1.3 What Would the Model Look Like?

The model schema consists of a description of the most important sub-modules which it will contain. An overview of these modules can be seen in figure 6, which also describes initial setup on how these are linked by providing information inputs or outputs. Thereby it forms provisional interactions between different entities in this model, with an ‘input, process, output’ format similar to figure 5.

In total five sub-modules are anticipated:

Heatwave simulations: a sub-module that simulates hourly temperature and humidity conditions of the location for a recent year using weather station data as an input. It also can simulate more extreme heat scenarios based on regionalised climate forecasts made by the IPCC by superimposing future average temperature conditions upon historic variations.

Local government heatwave plan coordination scenario: a sub-module that simulates communication modes/channels deployed and the efforts within them including person resource needs and coordination between local government and local institutions involved (e.g., social care organisations, public institutions). Communication modes/channels can focus on vulnerable and/or non-vulnerable residents. The module relies on user inputs selection to select efforts with routes within a person resource budget.

Active and passive communications to resident’s simulation: a sub-module that simulates based on the selected efforts and routes the communications in space and time as they occur, taking into account effectiveness of the communication (e.g., number of residents reached by the communication in an active or passive manner). This will potentially also include the communications between residents.

Residents’ activity and behaviours: a sub-module that simulates the daily activity cycle of residents to understand their location, the relation between communications made and communications reaching the residents, as well as the simulation of specific behaviour that reduce mortality risks (e.g., drinking, showering, opening windows). The sub-module will also include the likelihood that the communication reaching the resident will be acted upon to change the behaviours.

Residents' heatwave risk and mortality: a sub-module that simulates the mortality risk of heatwaves on top of background mortality, with the reduced risk of mortality from changed behaviours.

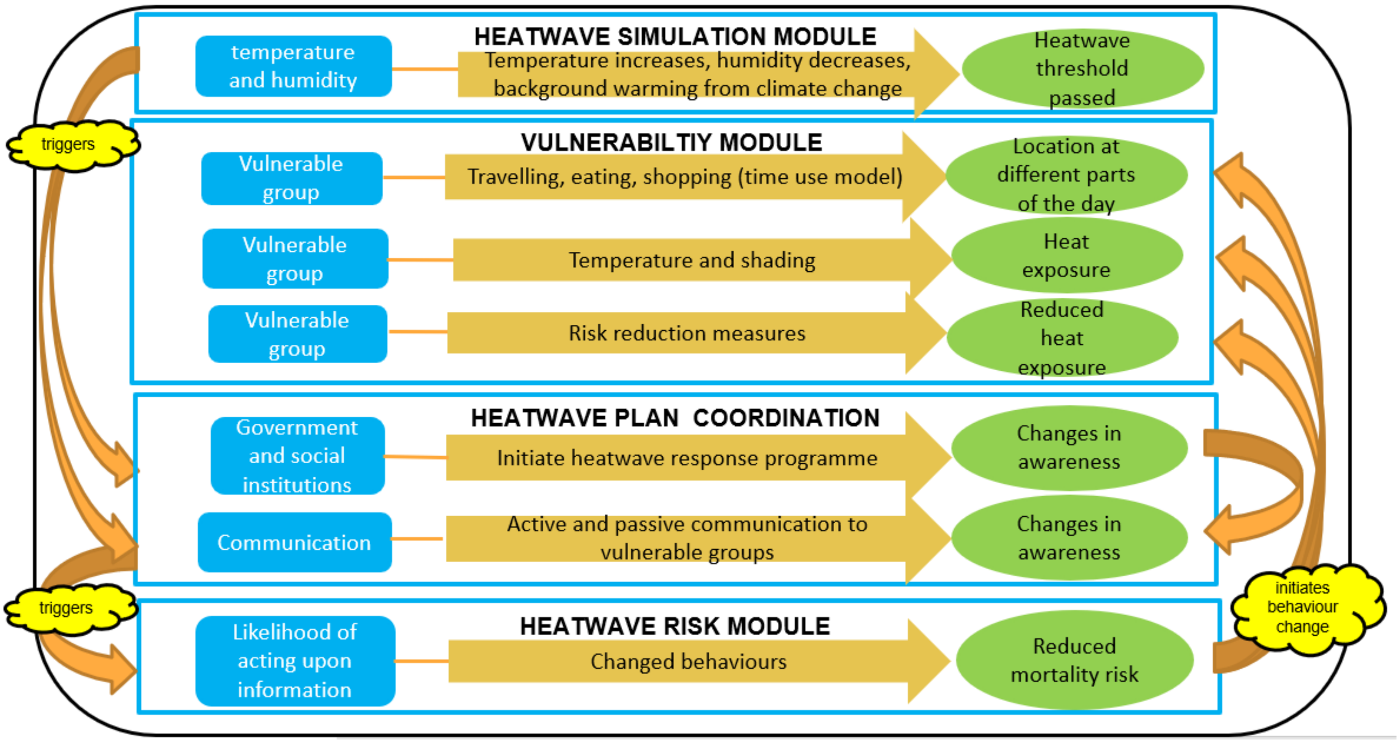


Figure 6: Interactions between entities within model

4.1.4 Preliminary Data Requirements for Open Lab Dordrecht

At this stage, data requirements are broad and not final. Table 10 can therefore be considered as a generalised way of understanding the possible requirements which might be needed for this model. Table 10 also provides an indication of whether its requirement is necessary as a minimum for model construction, or whether it is an ideal additional parameter. Whilst an initial overview is accompanied with whether this data is publicly available and accessible, important to note is that this followed only a preliminary assessment and may not therefore represent the data available to its full extent.

Data	Description (resolution/periodicity)	Minimum requirement	Ideal requirement	Publicly available/source
Map of buildings ideally split between residential and commercial	Per building	X		Discernible from Open Street Map, Esri or similar
Demographics information of local population	Age and gender, ideally split spatially to a fine-grained level	X		Census information or statistics, to identify number of vulnerable people in simulations.
Temperature and humidity data	Hourly level	X		Local weather stations
IPCC regionalised temperature scenario’s	Ideally seasonally/monthly		X	IPCC Models
IPCC regionalised humidity scenario’s	Ideally seasonally/monthly		X	IPCC models
Background mortality data	Annually	X		Publicly available [21].
Health information of elderly population	Information about vulnerabilities of elderly population (TBD)		X	Can be qualitative information, e.g. factors that increase vulnerability.

Table 10: Preliminary data requirements to create the model

4.1.5 Potential Results

Finally, at this stage it is important to understand the potential results which could arise from this model, to tailor the process as it develops. These could include, but are not limited to, the following:

Direct results for model users:

User	Result
Local government heatwave coordination team	To use the model results to understand how effective certain types of heatwave communication could be.
Local government heatwave coordination team	To use the model to identify factors which affect the vulnerability of elderly citizens.

Table 11: Direct results for model users

Indirect results for non-model users:

User	Result
Elderly population	Potential to increase safety during heatwave events.
Social care institution	Potential to reduce the social costs of a heatwave
Healthcare services	Potential to reduce the pressure on healthcare during heatwaves.

Table 12: Indirect results for non-model users

4.2 Technical Documentation

4.2.1 Overall Model Structure

Summary: This is intended to model the impact of improved communication channels on the risk to vulnerable groups during heatwave events in the Dordrecht Open Lab.

Structure: This model contains 5 submodules which will each be explored in turn. Each should be able to run individually as its own model, and also be able to be combined to produce the overall model, by its interactions detailed below by the orange arrows in figure 7. The submodules are as follows:

1) Heatwave simulation module
2) Heatwave plan coordination module (local government scale)
3) Active and passive communications to vulnerable groups
4) Activity and behaviours of residents
5) Residents heatwave risk and mortality

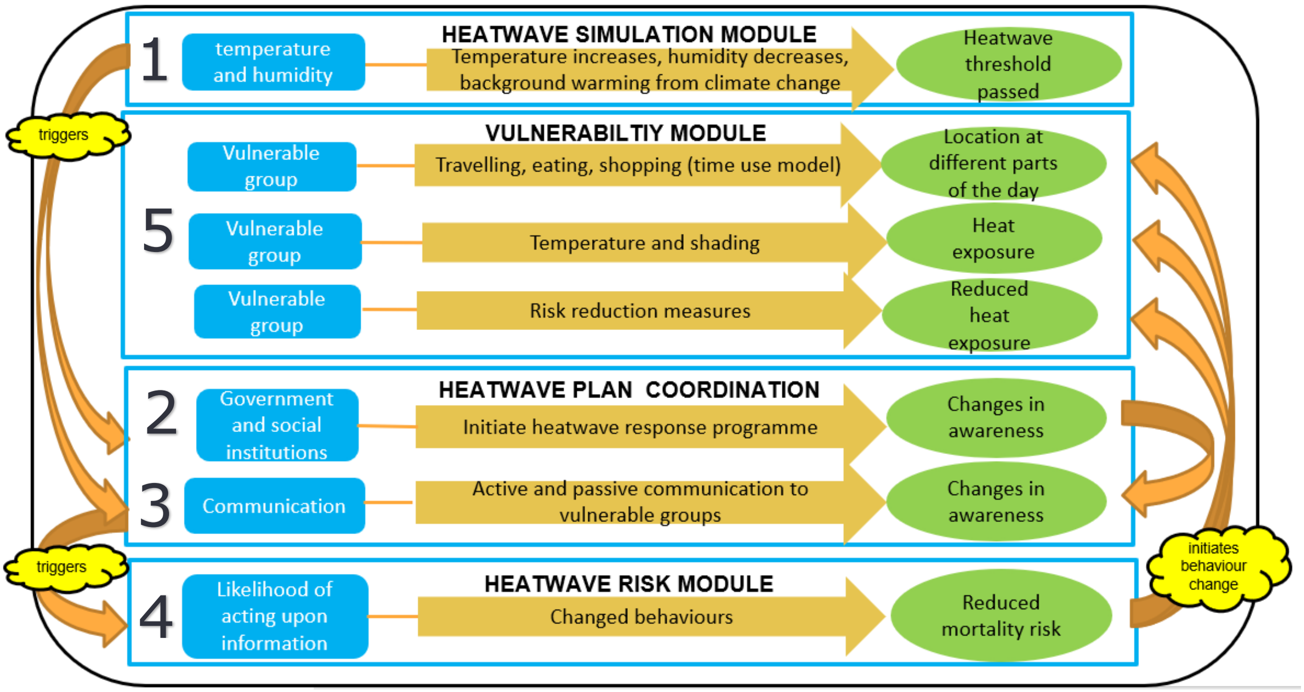


Figure 7: Interactions between entities within model

Model user inputs for initialisation - A brief overview of the mechanistic properties of the various types of agents in this model, as well as the environment which they interact with.

Environment characteristics:

- Selection of current weather from historic datasets (last 10 years), including data from a heatwave event.

The local authority heatwave measures themselves:

- List of actions, both passive and active. User can select different actions and the effort/frequency of this communication effort.
- Measures are deployed after a certain threshold temperature of 25°C.
- E.g. passive communications include posters, sending warning messages.
- Active communication measures include phone calls.

Agent initialisation - The agents are described based on their characteristics, which include both static characteristics (parameters) and dynamic characteristics (variables). Additional characteristics can be added based on what is needed, based on probability/randomly generated numbers.

Agent type 1:

- **Senior members of the population**
  - **Static characteristics:**
    - Age group (70-80, 80-90, 90+) – determined by real population composition of Dordrecht.
    - Social networks – *visits from family, friends, neighbours. Also societies/ clubs/ friend circles.* This is a randomly generated number and between 0 and 3.
    - Self-cooling mechanisms. Once the heat drops below a threshold, for example at night, the agent is able to cool themselves naturally.
  - **Dynamic characteristics:**
    - Location at different parts of the day, determining which communication measures the agent might be subject to.
    - Heat exposure (through a combination of background temperature and linked with where they are (indoors/outdoors)). Simple flag – indoors or outdoors – and severity of impact will vary accordingly.
    - Adoption of risk reduction behaviours – propensity to listen to others and trust messages from local authority. This will be a Likert scale of 1-5 with options ranging from “strongly agree” to “strongly disagree”.
    - Heatwave risk – dependent on the actions undertaken to reduce heat stress. All the other factors listed above feed into this, and this is what determines the background mortality risk foreach individual agent.

Agent type 2:

- **Vulnerable senior members of the population**
  - This group is identical to the former in all characteristics except that they have a poorer self-cooling mechanism ability due to being less able to carry out risk-reducing behaviours.
  - They also cannot leave the house, so their time roll function is always either at home or asleep.

4.2.2 Module for Heatwave Simulations

A sub-module that simulates hourly temperature conditions of the location for heatwave periods, using weather station data as an input.

Background knowledge - Heat risk occurs when the body cannot dissipate its excess heat into the environment, because temperatures are above the body temperature around 37°, resulting in body heat accumulation. If humans are in such an environment for too long their body heats up and hyperthermia can occur.

The concern over heat mortality risks has grown considerably in recent years because such events will become increasingly common due to climate change [22]. Currently about 30% of the world's population is affected by deadly heatwaves for at least 20 days a year, and this percentage is anticipated to increase to about 75% of the world's population under a growing emissions scenario [23]. This is worsened in urban areas because of the urban heat island effect exacerbating this extreme heat [24].

The mortality risk of heatwaves has been analysed at a macro-level by Mora et al. (2017) [23]. Data from 911 heat-wave studies including 1949 case studies was analysed to understand conditions under which heatwaves result in excess mortality, above non-heatwave mortality levels. To do so an equal number of non-heatwave episodes that were considered non-lethal were introduced for the same cities as the meta-literature data. Out of 16 different variables analysed, the two conditions found most relevant were mean daily surface air temperature and relative humidity. Combined these two variables explained at 82% accuracy the occurrence between lethal and non-lethal heat episodes (See Figure 8).

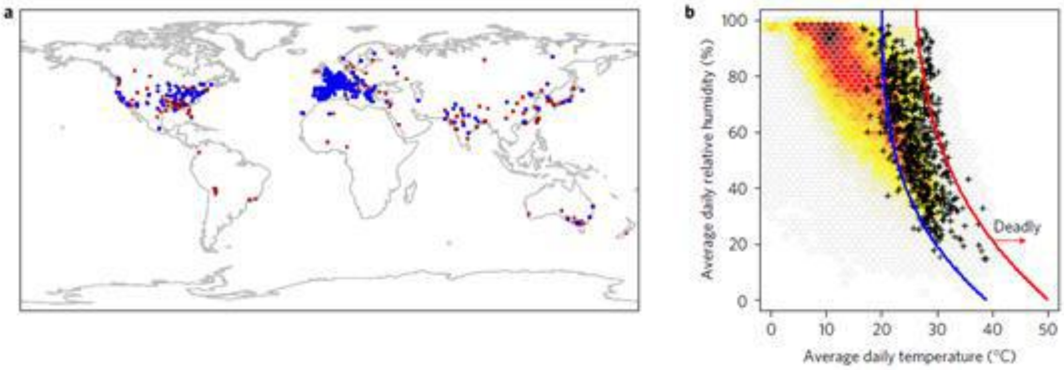


Figure 8: Global Heatwave Risk Plot adopted from Mora et al. (2017) [23]**.**

Based on data assessed from 911 heat-wave studies indicating relationship between heatwave mortality, temperature, and humidity.

The effect of humidity is due to its impact on sweating. Sweating is a key process by which the body dissipates heat, which becomes less effective when the air is very humid. In case of high humidity heat accumulation can thus occur when the temperature is below 37°, as one of the most effective heat dissipation mechanisms is not functioning well. Baccini et al. (2008) investigated the relationship between apparent temperature, a combined measure of temperature and dew point as a proxy for humidity, on heat mortality risk in 15 European cities. They found a 2% to 3% heat mortality increase associated with a 1 degree rise in apparent temperature [25]. Ho et al. (2017) [26] looked at the humidex index, a measure of apparent temperature used in Canada, and its relationship to heat wave mortality from 1998 to 2014. They found that above a humidex cut-off point of 34.4°C there was a significant increase in heat mortality.

Studies have also shown that the duration of heat accumulation is of importance. An analysis of heatwaves for Australian cities by Xu and Tong (2017) found the highest mortality risk when extremely-hot days (the hottest days in a given month) were followed by extremely-hot nights. When extremely-hot days were followed by lower temperature nights (not-extremely-hot) mortality increases were lower. Similarly, when extremely-hot nights were followed by lower temperature (not-extremely-hot days) the effects were much lower [27]. The finding was corroborated by Murage et al. (2017) who studied heat mortality in London from 1993 to 2015. The authors found that hot days followed by hot nights have a higher mortality risk then hot days followed by cooler nights, with the highest risk caused by stroke and heart failure [28].

Baccini et al. (2017) established a greater mortality risk for 65-74 year age-groups, and even greater at 75+ versus 15-64 age groups, associated with a 1°C rise above the apparent temperature mortality thresholds. Specifically, the % change for populations in Mediterranean located cities was 0.92%, 2.13%, and 4.22% for 15-64, 65-74, and 75+ age groups, respectively. The variation for North-Continental cities was established at 1.31%, 1.65%, and 2.07% for the same age groups, with as main causes cardiovascular and respiratory mortality. Rey et al. (2007) analysed the impact of heat waves on all-cause mortality in France for six heatwaves from 1971-2003.[29] They investigated groupings from <35 years, 35-44 years, 45-54 years, and further 10 year groupings up to 95+. Mortality ratios were analysed based on observed mortality during heatwaves, divided by expected mortality based on average mortality per group in the three preceding years. In five out of six heatwaves the Mortality ratio's grow substantially from the age of 55 years and above. Especially populations of 75+ years had a 40%+ higher mortality rate then in the background non-heatwave data. In addition, for this group women had a 5%-28% higher mortality rate than men [29].

List of requirements:

- Hourly temperature data for the duration of a heatwave which has occurred recently in Dordrecht.
    - 2018 was chosen as a representative year, a heatwave occurred during the summer of this year, and this was a particularly long-lasting event.

List of processes with outputs:

- Computer code to read the standardised temperature and humidity data files for the baseline year or baseline average in a CSV format.
- Evaluate based on Dordrecht heatwave thresholds if there is a heatwave (yes/no).

Input requirements:

Data need	Purpose	Dataset used (add link)
Hourly temperature data for a recent year	To have a temperature baseline	Climate Explorer: Select a daily time series (knmi.nl)

Table 13: Input data requirements description tailored to Dordrecht OL.

Development tasks in a user story format:

Type of task	Description	Desired outcome
Input data collection	Collect the recent baseline data from temperature stations	As a modeller I want to be able to feed in data to run my simulation
Input data harmonisation	Setup standardised CSV file for temperature and humidity data	As a modeller I want my model to ingest the data in a standard way so I am sure it will work every time
Process code implementation	Read CSV file	As a modeller I want my model to read the CSV file with the data and store it in my model's memory
Process code implementation	Provide output hourly temperature	As a modeller I want my model to read and provide hourly values for temperature
Visual graph code implementation	Display data in a graph in a sequenced manner per hour for a timeseries of data	As a modeller I want my model to display the hourly values in a fast way to shown changes throughout the chosen time period

Table 14: Task table for heatwave simulations

4.2.3 Module for Local Government Heatwave Plan Coordination Scenario

A sub-module that simulates communication modes/channels deployed and the efforts within them including person resource needs and coordination between local government and local institutions involved (e.g., social care organisations, public institutions). Communication modes/channels can focus on vulnerable and/or non-vulnerable residents. The module relies on user inputs selection to select efforts with routes within a person resource budget, as well as associated institutions to be involved.

Background information/knowledge - A heatwave in the Netherlands is defined as occurring when 5 consecutive days reach 25°C of which three are as high as 30°C [30]. At this point, the national heatwave plan is activated, which warns and communicates effective behavioural methods which people are requested to adopt to improve their wellbeing during a heatwave [31]. Although this study focuses on the heatwave plan's implementation in Amsterdam, the national nature of the plan means these findings are also applicable to Dordrecht. Van Loenhout and colleagues discovered a lack of familiarity of this plan among key care organisations including care homes. It was also found that these plans were not transferrable to the local level, and vulnerable individuals were not sufficiently addressed by it [31].

The Dutch national heatwave plan was most recently updated in 2015. It is coordinated by the National Institute for Public Health and the Environment, with input from other prominent Dutch institutions but notably with a lack of involvement from local level actors including governments, health, and social care institutions [31]. It is possible that this stems from heatwaves as being considered a low-priority public health issue [31]. The same study reported that representatives from organisations listed as involved in the national plan, were unaware of its existence and did not receive warning when conditions were such that there was a need to trigger its activation. There was an attempt to improve this under an updated version of the Dutch National Heatwave Plan, which acknowledged and attempted to clearly state the responsibilities of various organisations [32].

List of requirements:

- Communication channels: ability for user to select.
    - Channels:
        - Active channels: community networks, targeted phone calls.
        - Passive channels: TV adverts, posters in public spaces.
- Number of people targeted by communications

List of processes with outputs:

- Communication events generated:
    - From the heatwave module we receive information if a heatwave is occurring. If yes:
        - Inputs given by user are x communication channels wanting to be deployed.

- Based on these inputs for a given heatwave, the number and type of communication events are effectuated, including their duration.

Input requirements:

Data need	Purpose	Dataset used (add link)
Input data selection options	Identification of all communication channels in place	Dordrecht heatwave communication plan and workshops
Selection of communication measures	Several communication measures are chosen that could potentially be deployed	Estimated by modelling team
Data selection option	Social institution options for municipality to select from which help with communication	Input from the heatwave communication plan.

Table 15: Input requirements for Local government heatwave plan submodule

Breakdown of development tasks in user story format

Type of task	Description	Desired outcome
Input data collection	Identification of the communication channels	As a user I want to be able to select the communication channels I want to use.
Input data collection	Identification of potential institutions for helping with the communications.	As a user I want to be able to select the institutions which will help me with my communications.
Process code implementation	Reading effort/channel table from CSV file	As a modeller I want my model to be able to read a CSV table in a pre-generated format and loaded into memory.
Visual graph code implementation	Draw a scatter plot with resources and communication channels.	As a modeller I want my model to be able to provide a visual output of the results.

Table 16: Breakdown of tasks for Local government heatwave plan submodule

4.2.4 Module for Active and Passive Communications to Resident's Simulation

a sub-module that simulates the communications in space and time as they occur based on the selected efforts and routes, taking into account effectiveness of the communication (e.g., number of residents reached by the communication in an active or passive manner). This will potentially also include the communications between residents.

Note that this submodel refers to the communication process itself, rather than the plan in place. It is also not simulating what happens after the communication, just a yes/no output as to whether something is communicated or not. It may be important for this submodel to determine the difference in impact between passive and active communications and their varying effectiveness and the number of people they attempt to reach.

Background information - Due to the perception of heatwaves as a low-priority public health issue, there have been few observed activities to directly communicate with at-risk groups [31]. This could be due to several factors including the nationally-organised media attention already given to heatwave plans being perceived as sufficient in reaching these groups. Important to note here is that homeless people, classed as an at-risk group, do not fall under a municipality's responsibility, and are therefore excluded from municipal actions [31].

The same study by Van Loenhout and colleagues identify the current heatwave plan in general as non-committal and unclear regarding which organisations have which responsibilities. This is a common theme among European heatwave plans and lessons can be learned from the failings of other countries not previously experiencing frequent heatwaves: in the UK, most recommendations for improving this plan focused on infrastructure changes rather than improving communication [24]. The UK's heatwave plan contains no guidance on how citizens should behave during a heatwave, or how this should be communicated to ensure it reaches the most vulnerable citizens. Like the Netherlands, the UK is also more equipped for dealing with cold weather and does not consider heat stress a high enough priority [24].

List of requirements – For each of the bullet points listed, a way of parameterising or estimating its impact must be specified. The intended requirement is ultimately a probability of the specified channel reaching someone who is vulnerable (e.g., 0.0 – 1.0 chance). These are not mutually exclusive. Someone can receive two communication attempts and thus have two probabilities of adopting behaviour.

- **Passive communication flows (from a local authority perspective):**
    - Leaflets through doors
    - Posters in social spaces such as GP waiting rooms and public transport.
    - Social support network agent communications (Community networks based on information diffusing between friends, family, carers, and neighbours).
    - Website placements with warnings
    - Radio (local) communications.
- **Active communication flows (from a local authority perspective):**

  - Knocking on people doors
  - Phoning people who are vulnerable
  - Automated SMS messages
- Due to the large number of these measures, it was decided to only model 3 measures, to reduce the effect of randomness. These were:
  - Posters in public spaces
  - TV adverts
  - Phone calls
  - Community networks – these were modelled for every agent on every run and so the impact of them was not measurable.

List of processes with outputs:

- The output of this submodel is number of people who all the communication efforts reach, passively or actively.
- Starting points are the communication methods deployed as events from the heatwave communication model.
- Joint probability of communications being successful or not (does it reach the senior member).

$$\mathrm{C} = (p\mathrm{A}) + (p\mathrm{P})$$

Equation 1: Communications probability within population

- **C =** Joint probability of successful communications PER AGENT.
- ***p*A**ctive = number of communication attempts multiplied by probability of success for each active communication channel being adopted, added together. The resulting equation is:
  - ***pA* = *p*A(phone) + *p*A(sms) + *p*A(community) + *p*A(doorstepping)**
- ***p*P**assive = number of communication attempts multiplied by probability of success for each passive communication channel being adopted, added together. The resulting equation is:
  - ***pP* = *p*P(radio) + *p*P(flyer) + *p*P(poster) + *p*P(TV)**

For example:

- *active: 1000 phone calls per week each with a 0.5 probability (someone either does not pick up, picks up and does not listen/hangs up, or listens).*
- *active: 20,000 SMS per week each with 0.7 probability.*
- *note the probability of sms is always 1 – almost failsafe but question is whether agent has a phone, and whether they are on the call list. You can ignore it, but you still receive it.*
- *passive: 100 tv adverts run per week on channel with average audience of 100,000 and probability of 0.1.*
- *passive: 1 poster placed in GP waiting room with weekly footfall of 1000 and probability of 0.4.*
- $\mathrm{C} = (p\mathrm{A}) + (p\mathrm{P})$
- *Successful communications: If all the communication methods above were deployed, the probability of receiving it would be over 100%. But user will select 1 or 2 in the actual model.*

List of secondary communications that support the communication impact:

- The model will also simulate ‘events’ including talking to neighbours, and within this there is a probability that they will talk about the weather, and the need to take actions about the heatwave. But these neighbours won’t be simulated as agents, rather the probability of this communication itself is what is measured.

Input requirements:

Data need	Purpose	Dataset used (add link)
Number of each type of active communications	How many attempts to communicate this way will be made	User input
Probability of each active communication effort being successful	For every person successfully reached how many attempts fail?	Modelling team based on literature information
Probability of each passive communication effort being successful	For every person successfully reached how many attempts fail?	Modelling team based on literature information
Number of people exposed to each passive communication method	How many people will be exposed to this method – e.g. footfall of a public space or viewing audience of TV adverts.	Modelling team based on model mechanics

Table 17: Input requirements for communications submodule

Breakdown of tasks in user story format:

Type of task	Description	Desired outcome
Inputting data - probabilities	Determining the probability of each communication type reaching a channel	As a modeller I want my model to be able to calculate the number of successful communications
Inputting data – number of people	Determining the number of people who will be exposed to the communication	As a modeller I want my model to be able to calculate the number of successful communications
Process code implementation	Equation for calculating the successful communications	As a modeller I want my model to provide a reasonable estimate of the number of successful communications attempted

Table 18: Breakdown of tasks in communications submodule

4.2.5 Module for Residents’ Activity and Behaviours

A sub-module that simulates the daily activity cycle of residents to understand their location, the relation between communications made and communications reaching the residents, as well as the simulation of specific behaviour that reduce mortality risks (e.g. drinking, showering, opening windows). The sub-module will also include the likelihood that the communication reaching the resident will be acted upon to change the behaviours.

Background information / processes - The specific conditions under which heat wave mortality among elderly occurs was studied for elderly people by Van der Torren et al. (2006) for the 2003 heatwave in France [20]. A total of 315 mortality cases and 282 control subjects were analysed who lived at home at least 24 hours before death or hospital admission were analysed across the city based on random selection. Living conditions were directly observed and information as obtained from interviews with friends, neighbours and next-of-kin either face to face or by phone. Specific heat conditions for the houses were obtained from satellite data using Landsat 5 profiles for thermal images and a vegetation index to calculate the surface temperature within a 200 meter around each home.

The average age of the mortality cases was 85.1 years, and that of the control group 82.1 years. Main causes of death for the 315 mortality cases were cited as a cardiovascular cause (37%) and heat (35%) with other causes including cancer (7.5%), respiratory diseases (6.3%) and neurological diseases (4.3%), with about 10% from other causes. The large majority of deaths occurred in the house, with 233 out of 253 cases hospitalised at home.

The results of the study were expressed as an odds ratio which can be interpreted as a risk multiplier versus if the condition did not exist, the higher the greater the risk. Key condition specific risk factors for a univariate analysis (only one condition is analysed), were found to be:

- Being confined to a bed, odds ratio of 7.52
- Pre-existing medical conditions, odds ratio ranging from 1.5 to 5.9 depending on the condition, especially neurological and mental disorders highly increased mortality risks (odds ratio 4.7 and 5.9)
- An absence of social activities whether religious, cultural or leisure, odds ratio of 6.0
- The use of home attendants for cleaning or moving or meal delivery, odds ratio of 3.84, plausibly spurious factor associated with lack of mobility or pre-existing medical conditions or both.
- Living in a house constructed before 1975, odds ratio of 1.83
- Living on the top floor of a building, odds ratio of 2.33
- Living in a house with the bedroom under the roof, odds ratio of 2.16
- The outdoor temperature index in (200-meter radius), odds ratio of 1.21
- Bath or shower frequency
    - More than one per day, odds ratio of 1
    - One per day, odds ratio of 3.14
    - One per 2 days, odds ratio of 12.09
    - One per week, odds ratio of 15.61
    - Never, odds ratio of 20.76
- Quantity of liquids drinking per day

  - One litre or more, odds ratio of 1
  - Between 0.5 and 1 litre, odds ratio of 2.64
  - Less than 0.5 litre, odds ratio of 16.8
- Opening of windows
  - At night, odds ratio of 1
  - Never opening the windows, odds ratio of 2.29
  - Only in the afternoon, odds ratio of 3.27
- Good insulation lowered the risk of mortality, at an odds ratio of 0.48, versus an odds ratio of 1.0 in houses with very bad insulation.

Key condition specific risk factors for the multivariate analysis (all significant conditions were considered in a combined correlation), were found to be:

- Not leaving the home during heat waves, odds ratio of 2.0, versus visiting cooler places, odds ratio of 0.46
- Confined to bed, odds ratio of 9.59
- Not confined to bed but unable to dress and to wash oneself, odds ratio of 4.03
- History of cardiovascular disease, odds ratio of 3.72
- Temperature index (200 m radius), odds ratio of 1.82

The analysis clearly shows that for older age groups, behaviours and conditions that aid in reducing body heat, including showering or bathing, opening windows, living in cooler and better insulated indoor spaces, and being mobile enough to seek cooler conditions, help significantly in reducing mortality.

Interestingly and additionally, another study among care institutions in Amsterdam found that less than 10% of residents' rooms in care institutions were equipped with air conditioning units, indicating the low priority of heat as an issue [31].

List of requirements:

- Factors which influence probability of someone adopting behaviours outlined in a heatwave plan.
- Daily activity cycle for a "standard" citizen. Will be generic and include for example sleeping, working and leisure activities.

Time rolls table for a person in Dordrecht who is over the age of 70 and does not have additional vulnerabilities:

If time is…	Probability of doing …	Is
00:00 – 06:00	Sleeping	1.00
06:00 – 07:00	Sleeping Indoor activities	0.70 0.30
07:00 – 08:00	Sleeping Indoor activities Outdoor activities	0.50 0.30 0.20
08:00 – 10:00	Sleeping Indoor activities Outdoor activities	0.10 0.70 0.30

10:00 – 12:00	Indoor activities Outdoor activities	0.50 0.50
12:00 – 14:00	Outdoor activities Indoor activities	0.50 0.50
14:00 – 16:00	Indoor activities Outdoor activities	0.60 0.40
16:00 – 18:00	Indoor activities Outdoor activities	0.80 0.20
18:00 – 20:00	Sleeping Indoor activities	0.20 0.80
20:00 – 22:00	Sleeping Indoor activities	0.70 0.30
22:00 – 00:00	Sleeping	1.0

Table 19: Time roll of a non-vulnerable elderly agent

For vulnerable agents who do not leave the house, the time roll is different:

If time is…	**Probability of doing …**	**Is**
00:00 – 08:00	Sleeping	1.00
08:00 – 10:00	Sleeping Indoor activities	0.70 0.30
10:00 –12:00	Sleeping Indoor activities	0.10 0.90
12:00 – 13:00	Sleeping Indoor activities	0.10 0.90
13:00 – 17:00	Sleeping Indoor activities	0.10 0.90
17:00 – 19:00	Sleeping Indoor activities	0.20 0.80
19:00 – 00:00	Sleeping	1.00

Table 20: Time roll of a vulnerable agent

List of processes with outputs:

- Calculating a daily activity cycle:
    - Input:
        - Activities include sleeping, working, or going to school, socialising and activities both indoor and outdoor.
        - The number of people reached by communication efforts who act upon them.
        - Government advice in the communication plan and how these changes.
    - Output: a 24-hour repeating sequence for non-heatwave times compared with heatwave times without communication plan

Probabilities of carrying out actions that reduce heatwave risk:

- Probability of adopting behaviours in heatwave plan:
    - Behaviours include opening windows, drinking water, showering more.

  - Factors which may influence adoption: easiness of behavioural change, peer actions, and a person's vulnerability.
- Outcome of this is a profile of a residents' behaviour resulting from the heatwave communication plan.

Input requirements:

Data need	Purpose	Dataset used (add link)
Resident activity cycle	To estimate the actions of users without a heatwave situation	Informed by literature on time use planning
Output from section 3.4 regarding the number of successful communications	To estimate the number of agents who might undergo behavioural change	Comes from model
Estimation of how many behavioural changes will result from successful communications	To estimate the actual behavioural change that will result from successful communications	Comes from model

Table 21: Input requirements for residents' activity submodule

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Process code implementation	Programme agents to have a 24 hour daily cycle of activities.	As a modeller I want to know what a daily cycle of activities looks like for elderly agents and for those who are vulnerable
Process code implementation	Assign actions and probabilities to each time step within the 24 hour period.	As a modeller I want to understand how risk-reducing behaviour may be present within a typical daily schedule
Visual code implementation	Apply a parameter for visualising the adopted behaviours of the agents- e.g., a colour change.	As a modeller I want to view the activity cycle changing throughout the day to understand where and when effective communications could occur.

Table 22: task breakdown for residents' activity submodule

4.2.6 Module for Residents Heatwave Risk and Mortality

A sub-module that brings together the above submodules by simulating the mortality risk of heatwaves on top of background mortality, with the reduced risk of mortality from changed behaviours.

Background knowledge: Risk groups for mortality during heatwave events include primarily elderly people. Additionally, socially vulnerable groups including homeless people are at-risk due to their existence outside of the socially controllable population

[31]. Literacy rates are also important when communicating these risks, as sections of the population including people with learning disabilities and migrants who cannot speak Dutch, are less able to read and understand communications about heatwave risk.

The 2006 European heatwave caused an estimated 1000 deaths in the Netherlands [33] and these hazards cause more negative effects in elderly populations who may have thermoregulatory problems.

List of requirements:

- Total population numbers for each age group
- Annual mortality rates for non-heatwave years, by age group
- Annual mortality rates for heatwave years, by age group
- Probability of adopting heat stress reducing methods following successful communication

List of processes with outputs:

- Calculate the combined risk of the heatwave for the agent based on the actions profile carried out (from previous submodule), and the adjusted heatwave situation.
- Taking into account the risk adjustment and for each age section of the population. Calculate excess heatwave deaths as a percentage change for each age group of the population:

$$p_{Mh} = p_b + \left(\frac{Mh - Mb}{P}\right)$$

Equation 2: Excess heatwave deaths,

- Where Mh is the mortality during a heatwave, Mb is the baseline mortality, P is the total population.
- Equation 1 will be calculated for each age group under consideration.
- There is also a requirement for a function to translate this into an hourly mortality instead of annual.
- Find data determining the probability of behavioural changes being adopted following a successful communication
- Quantifying how behavioural changes reduce excess mortality.
- Working out subsequent excess mortality following behavioural changes.

Input requirements:

Data need	Purpose	Dataset used (add link)
Background mortality rates by age group in the population	To understand background mortality before the effects of a heatwave	Central Bureau statistics office – CBS.nl and/or local Dordrecht health data.

Excess mortality rates during a heatwave by age group	To deduce the additional risk of death caused by a heatwave	Combination of literature analyses of past heatwaves, and if available time series data on mortality of past heatwaves

Table 23: Input requirements for residents heatwave risk submodule

Breakdown of tasks for development:

Type of task	Description	Desired outcome
Process code implementation	Using input data for calculating excess mortality rates.	As a user I want to quantify how heatwaves cause excess mortality
Process code implementation	Using excess mortality rates to extrapolate link between temperature and heat mortality link	As a user I want to understand the relationship between temperature and excess mortality
Process code implementation	Translating communication successes into probability of them causing a behavioural change	As a modeller I need to know how likely someone is to adopt a change in behaviour after a successful communication attempt
Process code implementation	Quantifying impact of behavioural changes on excess mortality for each age group.	As a user I ultimately want to know how the behavioural changes being modelled here can impact mortality rates by age group.
Visualisation code implementation	Creating bar chart which displays mortality outcomes	As a user I want to understand how mortality outcomes change alongside different temperature and communication scenarios

Table 24: Breakdown of tasks for resident's heatwave risk submodule

4.3 Results

4.3.1 Summary of Heatwave Model Mechanics

The following diagram (figure 9) is an overview of the interactions between different parts of the model in its final form. Visually, there are 2 key components of the model which interact. These are the resident activity cycle, which randomly generates an agent’s location at each step of the model based on their characteristics, and the heatwave communication plan which may reach an agent if they are in the correct location.

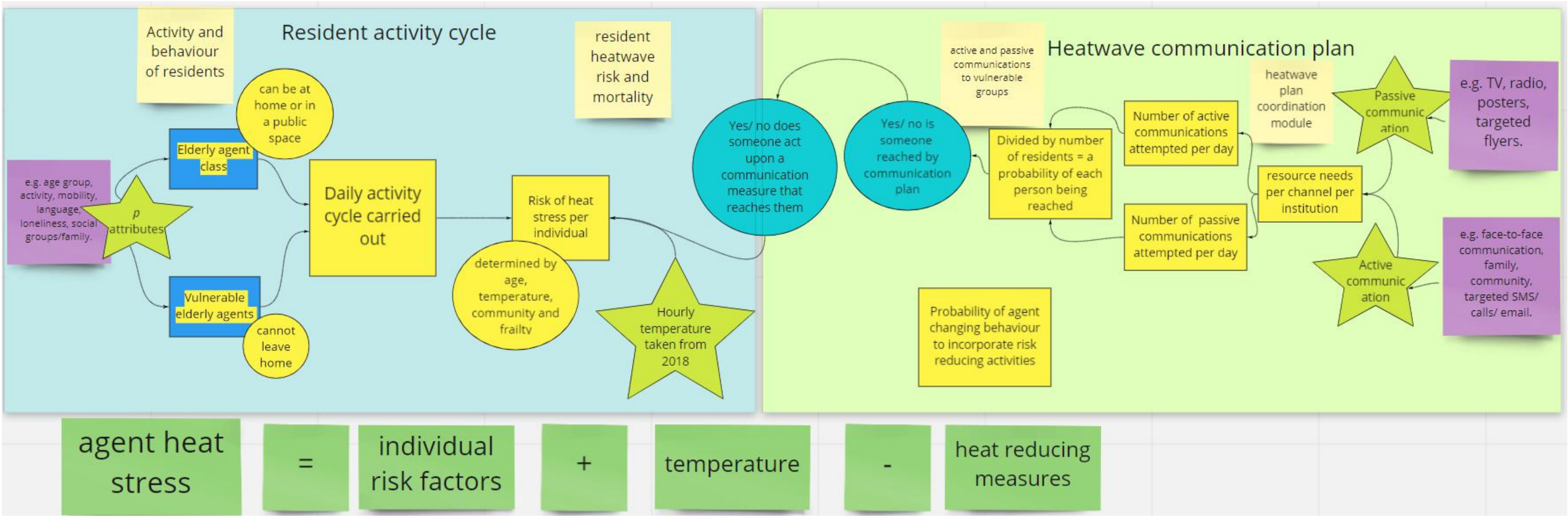


Figure 9: Heatwave model mechanics summary

4.3.2 Model Calibration and Visualisation

The explorative nature of the heatwave model meant that calibration of heatwave mechanics with true temperature and mortality data was an important step to ensure the speculation was based on reality. To this end, after the model's development but before batch running it for results, a calibration step was carried out. An advantage of Mesa is its server visualisation capabilities, which were deemed useful for this step as it allows a user to observe the model results step-by-step. During development phases of the model creation, this allowed a server to be launched with certain model parameters visible as graphs, to allow the modellers to understand how the model mechanics were functioning. Any inconsistencies or unexpected results could therefore be observed. In the case of the heatwave model, agents and poster communication measures were also able to be visualised in a grid, as depicted in figure 10. Here, the colour of the agent corresponds to its heat stress with yellow agents being less stressed and darker red indicating higher stress levels. The size of the agent is also important, with larger dots representing vulnerable agents.

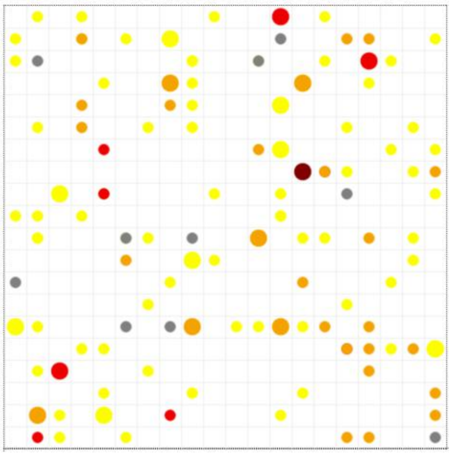


Figure 10: Grid visualisation of model

To calibrate the model, scenarios were firstly run with no heatwave temperatures present, to calibrate the amount of background mortality expected in the model. No heatwave impacts were expected here as the threshold heatwave temperature was not exceeded. This led to a background mortality rate of 14 deaths out of 2000 agents, which was found to be within the expected error range. After this was found to be satisfactory, a scenario was run in which heatwave temperatures were superimposed, but no measures were introduced. This was also calibrated against true heatwave mortality information by age group for the 2018 heatwave event in Dordrecht, and the stress inducing, and natural cooling functions were adjusted accordingly until results observed were realistic. The temperature and average agent stress can be observed from this run:

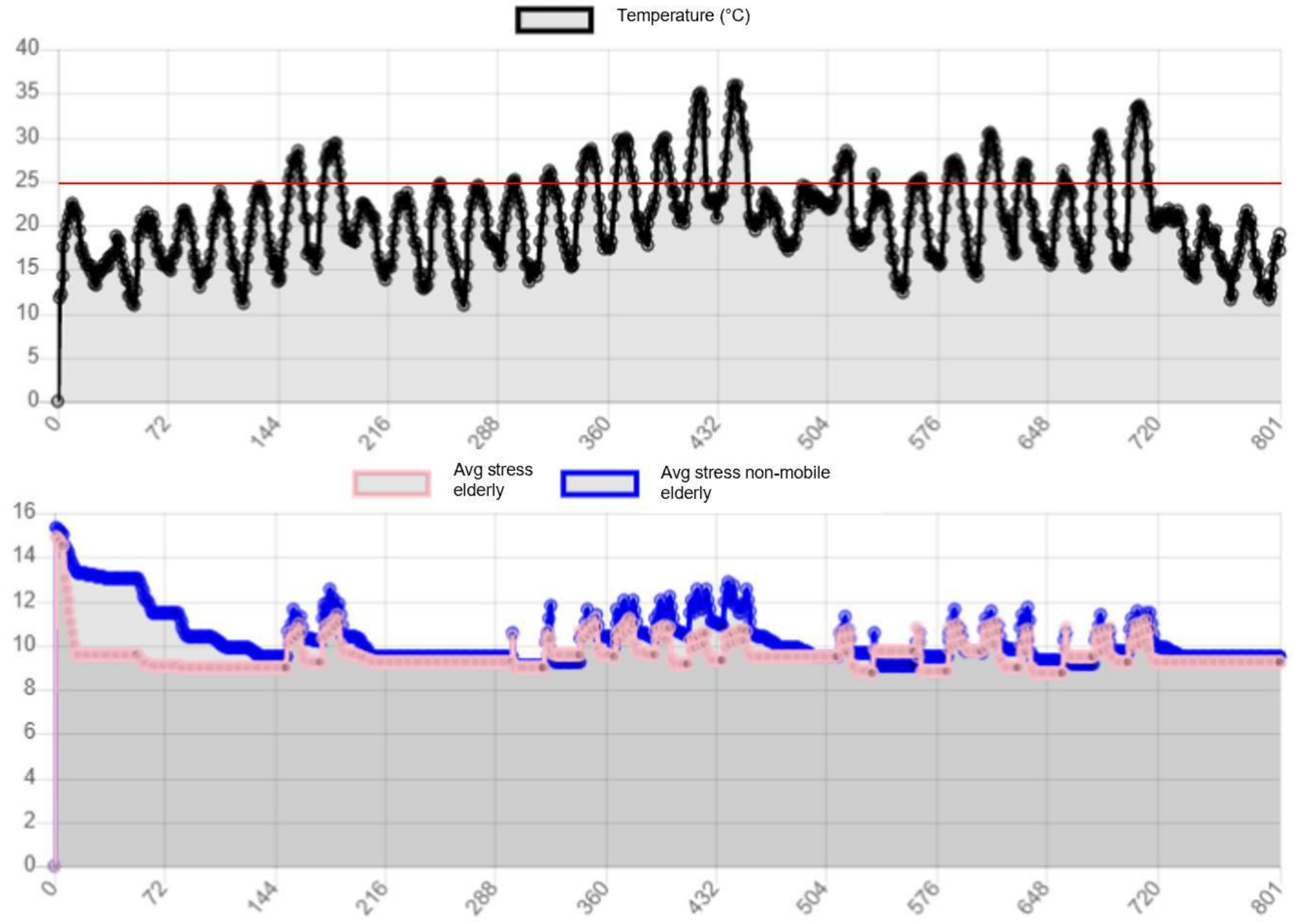


Figure 11: Results from model run post-calibration

The red temperature line visible in the temperature graph (figure 11) indicates the threshold temperature for a heatwave. It should be noted that the stress graph has a minimum stress level, for both agent types, at 10. This is to avoid this value dropping to negative numbers during the night time when temperatures were below the threshold. When compared alongside each other, there is a clear correlation between the spikes in periods of high temperature and periods of high heat stress, particularly for non-mobile agents whose average stress is highest.

Due to the explorative nature of this model, calibration of the effectiveness of various communication measures was not possible. In the future it may be possible to deploy surveys in Dordrecht to gauge the effect of different measures, and thus calibrate the modelled measures in the same way that background mortality and heatwave mortality were calculated. The results which are presented in the following section must therefore be regarded as imperfect and can be altered in the future. The benefit of displaying them at this stage is purely for an understanding of the model mechanics.

Figure 12 is a screenshot of the server capabilities of this model, including the slider parameters which were editable each run.

Current Step: 0

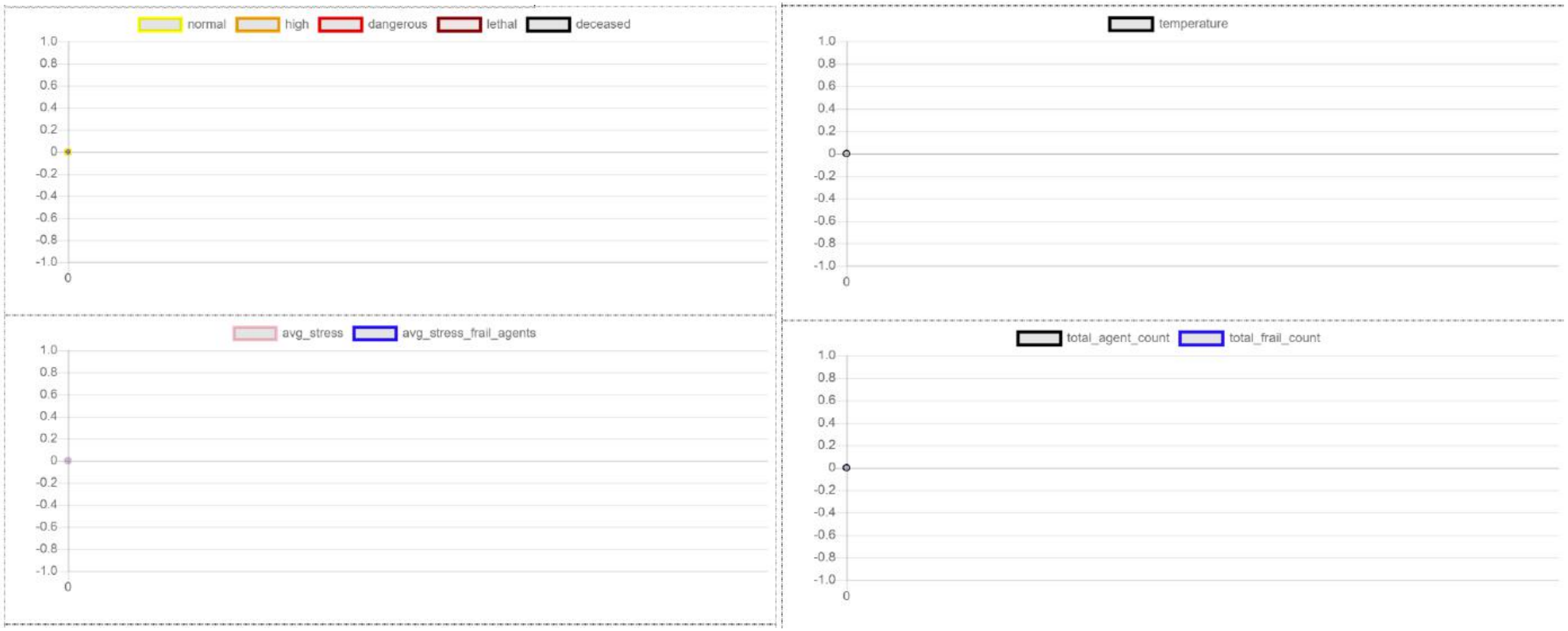


Figure 12: Server element of heatwave model

4.3.3 Scenarios Run for the Model

The model was run as a batch with a series of consistent and variable parameters. Several parameters were also selected as those which would be recorded at the end of every model run. These are as follows.

Fixed parameters:

- The initial population of elderly people in the scenario: **2000.**
- The ratio of vulnerable to non-vulnerable agents in the model: **80:20.**

Variable parameters:

- Number of posters: tested at values of 0, 200, 400, 600, 800 and 1000.
- Number of TV adverts: tested at values of 0, 200, 400, 600, 800 and 1000.
- Number of phone calls: tested at values of 0, 200, 400, 600, 800 and 1000.

Recorded parameters:

- Average stress during heatwave temperatures of non-vulnerable agents.
- Average stress during heatwave temperatures of vulnerable agents.
- Number of remaining non-vulnerable agents in the model.
- Number of remaining vulnerable agents in the model.

For each of these variable parameters, every possible combination of results was run **10** times. Since the 3 variable parameters had 6 combinations each, this meant there were **6,480** model runs carried out.

4.3.4 Results for the Model

The following section outlines the results from this model batch run. Figure 13 compares the average heat stress of agents during heatwave temperatures, with the number of communication measures in total. In the case of both elderly and vulnerable agent types, a clear downward trend in average stress scores correlates with the increasing number of measures in place. In general, the lowest average stress score for elderly agents, of 10.23, coincided with the highest number of communication measures in place. This trend does not seem to tail off but remains constant throughout the model runs. For the average stress of vulnerable agents however, the trend appears to flatten at approximately 2200 total measures.

From figure 13 we can see the functioning of the model mechanics, and the correlation between average stress levels and the number of communications in place. Although at first appearance the values in part A (non-vulnerable agents) appear low, this can be attributed to the fact that the minimum heat stress level at which measures had an impact was 10.0. Given this, the downward trend in stress with increasing measures indicates that the model's mechanics work as intended: for agents whose stress level is greater than 10.0, the heatwave measures are in place and functioning; for those whose stress has fallen to this baseline, the measures do not work until the agent's heat stress increases to the point of dangerous stress. When considering part B of figure 13, the trend is much more pronounced due to these vulnerable agents having a higher average heat stress throughout the model. This trend also appears to flatten somewhat after more than 2200 measures were introduced, which can be attributed to the lack of effectiveness of the posters on this agent type.

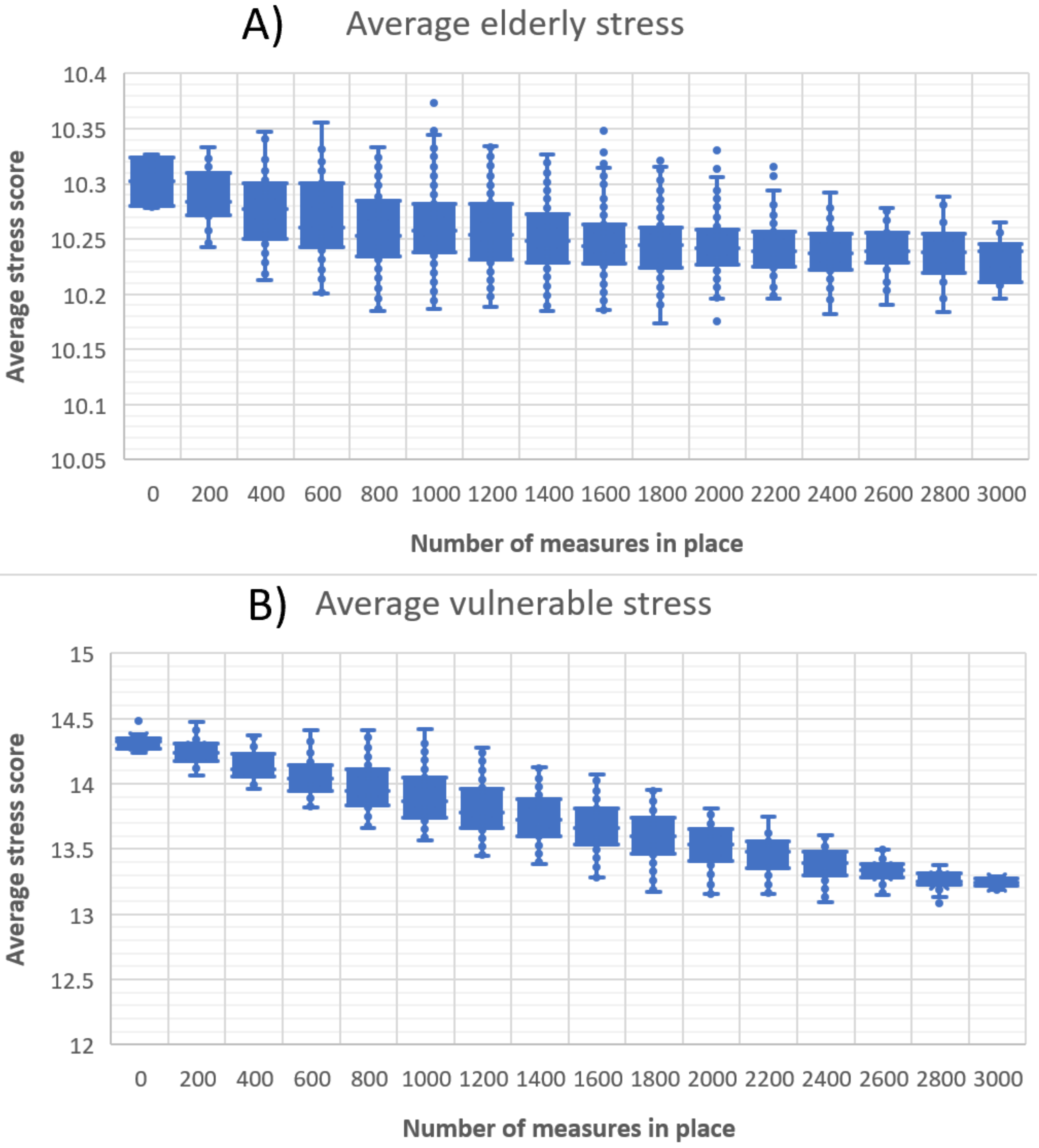


Figure 13: Agent stress against number of measures.

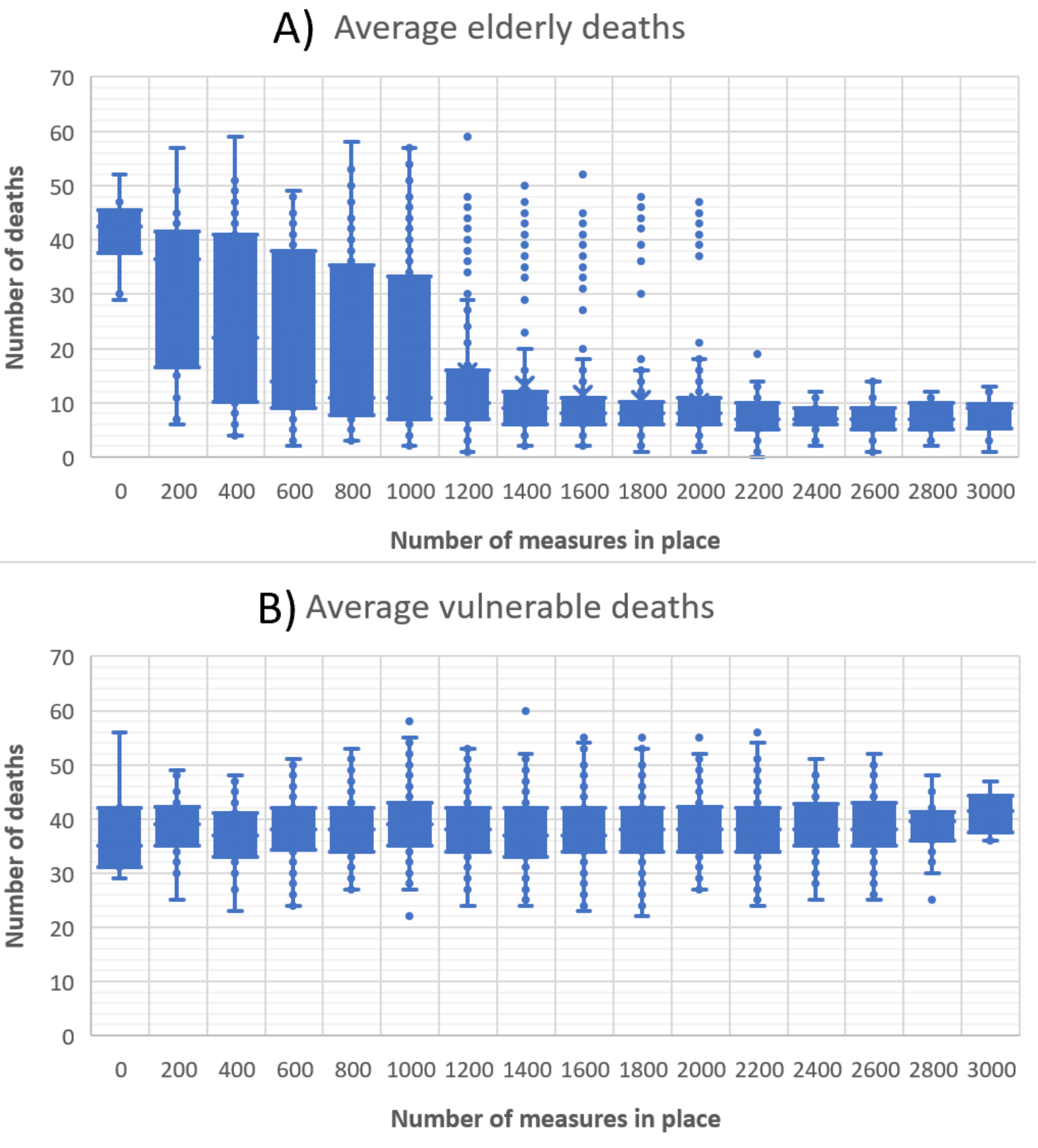


Figure 14: Number of deaths against number of measures

Figure 14a corroborates the trends observed in figure 13a, those which imply that with more heatwave measures in place, the lower the expected death rate. It is worth noting, however, that these trends are not very strong – particularly for the introduction of between 200 and 1000 measures, the quartile range indicated by the filled bar, is very large. Nonetheless there is a clear correlation between deaths and communication measures. Worth noting here is that results from introducing between 1400 and 3000 measures do not vary significantly.

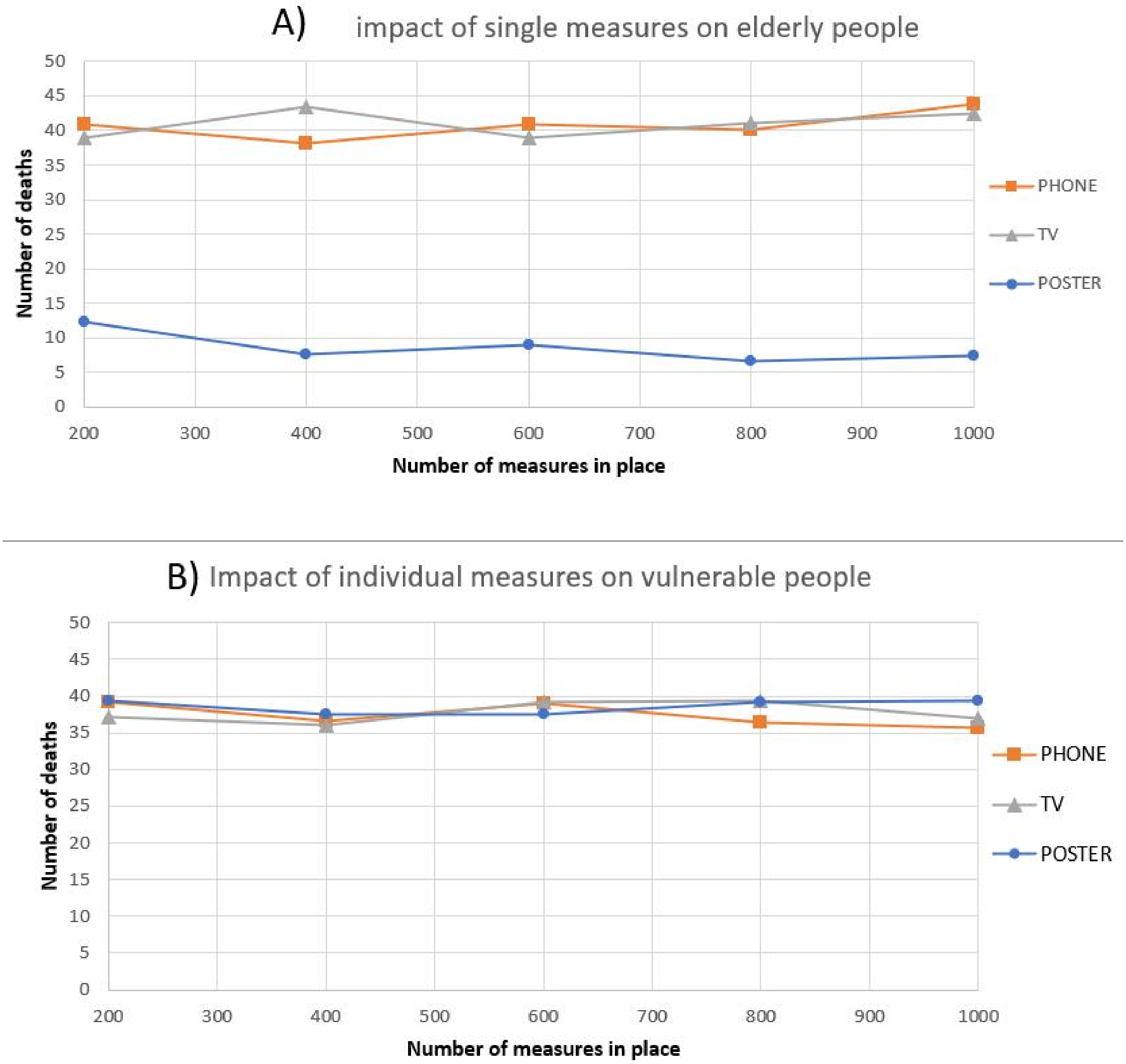


Figure 15: Individual measure impacts

Figure 15 measures only those model runs which considered just a single communication mechanism. Interestingly, part A implies that there is not a huge variation between the number of measures introduced. All three measures produced consistent numbers of mortality despite the numbers of each one introduced. Part B indicates a similar trend despite its numbers being more erratic. Figure 15 further adds to the understanding that vulnerable agents are more susceptible to heat stress.

4.3.5 Discussion and Conclusions

Based on the results we can observe the following:

- Elderly agents who are not vulnerable tend to have a heat stress level that is close to the minimum of 10 (see figure 13) regardless of the number of measures in place.
- Elderly agents do see a reduction in the mortality from about fifty to ten, as there are more combinations of measures in place (see figure 14a), however there are no reductions visible for individual measures (see figure 15).
- Vulnerable agents see a reduction in heat stress levels as more combinations of measures are put in place from an average of 15 towards 13 (see figure 13b).
- Vulnerable agents do not see a reduction in mortality with combined heat stress measures in place despite the overall reduction in heat stress which stays around 35/40. This is also the case for individual measures (see figure 15).

The results appear counter-intuitive in that reduced heat stress from the vulnerable population is not translated into a reduction in mortality from heat stress, whereas fairly stable heat stress for elderly non-vulnerable populations does translate with more measures into reduced mortality. The plausible explanation for this is that the reduction in heat stress for the vulnerable population, whilst substantial with combined measures, is still not enough to reduce dangerous levels of heat accumulation, and that for non-vulnerable elderly the measures have a larger impact and there is a small reduction in heat stress from 10.5-10.3, which means there is a larger marginal impact because the reduction is percentage-wise higher given their heat stress levels without/with measures. As a consequence, the combination of measures for elderly non-vulnerable population has the result of not being in a position of heat stress with no measures at all.

The key uncertainties with these results are as follows:

1. The model assumes that vulnerable agents have more difficulties getting rid of the heat in their bodies than elderly non-vulnerable populations in general. The extent to which this is the case is unknown, and the model makes some educated guesses over a factor of 2 difference.
2. The model assumes that accumulation of heat stress can fairly rapidly lead to mortality. E.g., being in a dangerous level of heat stress can be lethal within 4 hours, thus the window of opportunity for measures in the model to have an impact to prevent this mortality is small.
3. The model assumes that measures have a one-off effect and not a longer-lasting or a short to mid-term effect. In other words, if a communication measure is successful, it will reduce the agent’s stress only once.

To narrow the first uncertainty, significant research is required in relation to peoples’ internal body measurement under different conditions of heat stress and related characterisation of peoples’ underlying health conditions. To this end, it is not possible to improve the model mechanics without further research.

To narrow the second uncertainty, further literature research could be undertaken on the physiological phases of heat-induced mortality. This research would be able to improve the model rules underlying the way heat stress is represented in the model going from low→ medium → high → dangerous → lethal, each related to the duration of certain temperature levels that a person is exposed to. For example, understanding if heat reduction from the body changes depending on the body temperature level in relation to the weather and in relation to the duration of exposure of such weather. Or, if this is a linear process or an exponential-like process in terms of health impacts.

To narrow the third uncertainty, the psychological impacts of heat-mitigation measures would need to be studied. Do such measures have a lasting routine behavioural impact or only a short-term one hat needs repeating during or across heatwaves. The best route for this would be to undertake surveys and interviews under different population segments to understand how different people perceive communication measures as well as interviews.

Knowing these uncertainties and ways of interpretation, the model can be further used with some further evolution as a discussion tool by local authorities. Especially powerful is the differentiation between different population segments among elderly people, and the ability to differentiate between their ability to adapt to cope with heatwaves. As such, we can explore how different measures would affect these different groups differently, observe in reality how the measures have an impact and use this to understand why there are differences in the real-life impacts of heatwaves, based on the model logic and the related discussions on how do heatwaves and mitigation measures impact different groups differently. If we have this type of understanding we can try to plan a heatwave campaign in an improved manner, namely by taking into account the needs of vulnerable populations better as opposed to a more homogenous approach. This should lead to more effective heatwave stress and mortality reductions.

As a key example of this, the population the model is segmented between those who can and those who cannot leave the house (e.g., vulnerable and non-vulnerable agents). According to the study previously referenced by Van der Torren et al. (2006), whether an elderly agent leaves the house or not is one of the key risk factors which needs to be considered in heatwave planning, and thus two of the communication measures modelled were targeted towards vulnerable agents (phone calls and TV adverts). The heatwave communications modelled, thus allows for exploring the critical influence of mobility. The vulnerable agent group consistently had higher stress levels than their less vulnerable counterparts, which can be attributed to their less-effective self-cooling mechanisms and because they are not exposed to outdoor communications measures. This is a factor which the model could be more specifically geared towards in the future, for example by exploring in more detail the natural heat stress variation between being indoors and outdoors. Also taking into account related factors such that people who are typically more indoors also often have more related health issues and/or are more bed-ridden, and thus have less possibilities to seek cooling or reduce their body heat (e.g., they may find it more challenging to shower).

5 City Greening for Flash Floods Model

5.1 Concept Note

5.1.1 Model Description

Title: Simulations of greening of a city to improve water retention capacity for flash floods/ impact on reduced overflowing of sewers

Context and aim: Due to the Santa Croce Church and archaeological site being situated below both street and sea level, subsidence and ground water levels are particularly high in this area of the city of Ravenna. This means that pluvial flooding is a serious issue as water drains into these important areas from the above-ground street. Indeed, the Santa Croce archaeological area relies on a pumping system keeping away the water from the mosaic floor and from the church. The pumping system works continuously, however its functioning runs the risk of being compromised by heavy rains. Greening public parts of the city which have impermeable, manmade surfaces, can help improve rainwater infiltration into the ground and thus reduce surface runoff. This should subsequently reduce the flooding risk of the Santa Croce church and archaeological site, which is more important now than ever before with climate change projected to cause increased precipitation.

This model will attempt to determine scenarios of different amounts of greening in the city, and how much runoff each scenario could prevent. This is to reflect the acknowledgement that whilst greening could potentially be a useful tool, modern Ravenna is built over the remains of the ancient Roman town, and as such is subject to legal policies to protect archaeologically significant remains underfoot. Greening policies, therefore, could not involve the planting of any deep-rooted vegetation which may be invasive to archaeological remains in the subsoil. Furthermore, this places limitations on the areas where greening could occur so a model will be helpful for determining whether or not the amount of greening which could take place, would be a useful policy for the city.

Model variants - There were no model variants or sub-models proposed for this idea, as the main model idea was found to cover the nuances discussed in the Open Lab meeting with Ravenna.

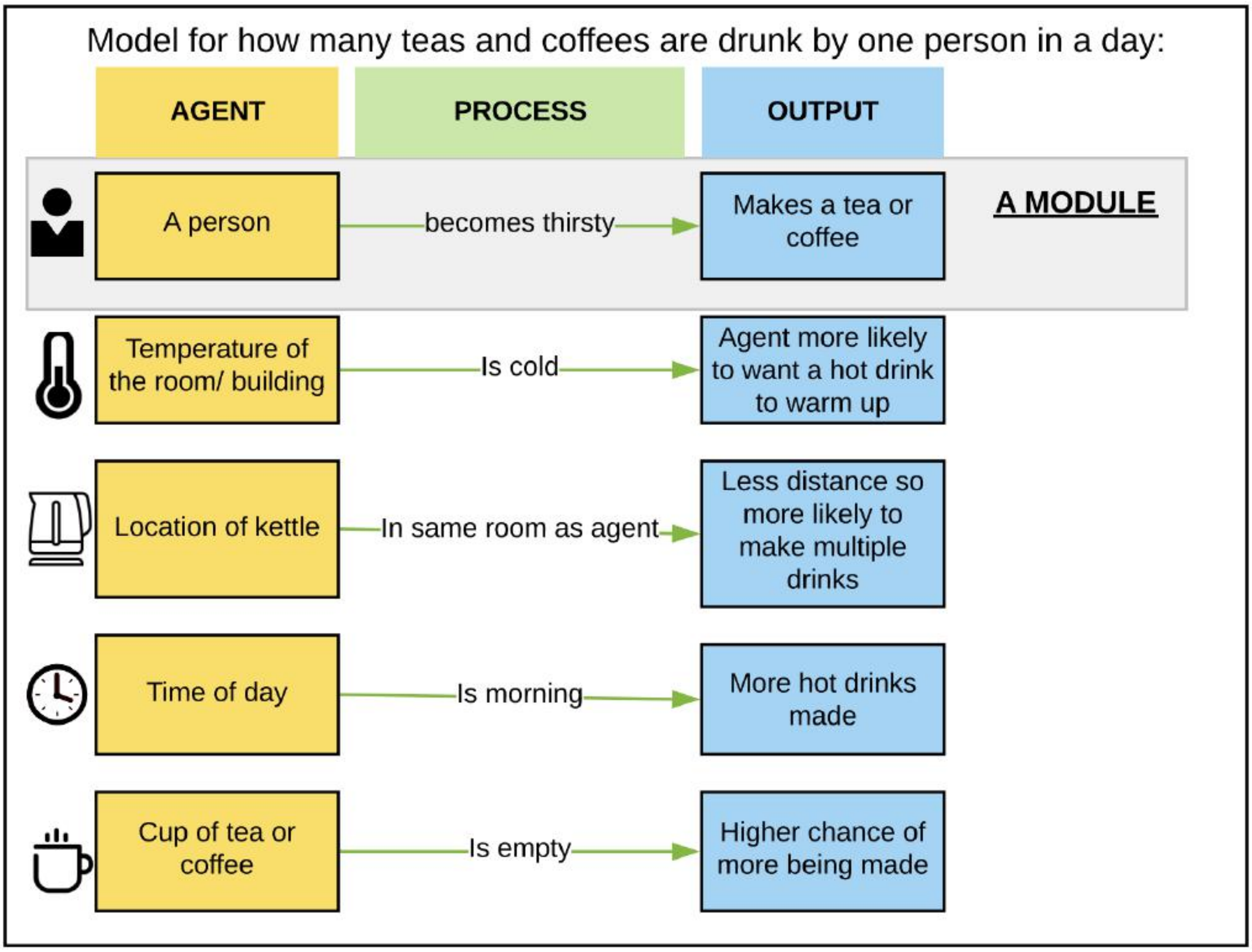
User story examples - Several model user's stories have been created to contextualise this model in terms of its utility for end users who will be using its outputs, and make it as easily understandable as possible. This list focuses on the key user groups who are likely to be the focus of the model, these are as follows:

- ➔ As a member of the Ravenna city authority, I want to use the model results to understand how much greening needs to occur to have an effective reduction in flood impact.

- ➔ As a member of the Ravenna municipality, I want to use the model results regarding effectiveness of greening to evaluate the contribution of private green areas to local flood impact reduction.
- ➔ As a member of the Ravenna city authority, I want to use the model results regarding effectiveness of greening to evaluate specific sites for greening in terms of their local flood impact reduction.
- ➔ As a member of the Ravenna city authority and as an authority managing sites of the city, I want to use the model results to gain an understanding of how climate change could impact the amount of flooding which is already damaging my area’s cultural heritage sites.
- ➔ As a sewage system expert working in Ravenna, I want to use the model to understand how pressure would be reduced on the sewers by greening spaces around the city.

Model schema and building blocks: context

A model is composed of several building blocks, each has an input, a process, and an output. A set of **building blocks** is called a **‘module’**, or a sub-model because it can be run on its own. The combination of all these building blocks results in the combined model. The relationship between all these results in a **model schema**, see for example figure 16.



Model for how many teas and coffees are drunk by one person in a day:

AGENT	PROCESS	OUTPUT
A person	becomes thirsty	Makes a tea or coffee
Temperature of the room/ building	Is cold	Agent more likely to want a hot drink to warm up
Location of kettle	In same room as agent	Less distance so more likely to make multiple drinks
Time of day	Is morning	More hot drinks made
Cup of tea or coffee	Is empty	Higher chance of more being made

Figure 16: An example of how models are composed of 'submodules'.

These in turn are composed of individual building blocks in an agent → process → output form.

This relates to ABM in that a building block has a process where an entity changes over time and or space, for example a person (entity) becomes older when simulating time in a model. The input in the process is starting age, the process is ageing and the output is end age.

Agent-based modelling importantly considers multiple entities which must be defined before the technical development. Each entity exists separately from each other, but will be combined in the model runs. This allows simplicity for editing entity features and characteristics at various points in the process.

5.1.2 What are the Proposed Agents in this Model?

Before connections, processes and outcomes can be identified as above in figure 16, it is important firstly to define the agents which are present in the system being modelled. These are specified in the following table along with their possible characteristics and related processes. Important to note is that the actual implemented model will focus on only a few (2-3) characteristics per agent and related processes; this is to increase both the quality of the model and to only focus on what is really relevant and to make it possible to deliver the task. Table 25 is separated into high and low priority actors, to acknowledge the existence of many stakeholders but also focus the model to the groups who are most involved and who the model is primarily targeted towards. Note that there are significantly few actors for this model, as it is largely a physical model which focuses on the mechanical processes behind city greening.

High priority Actors:

Entity	Characteristics	Processes
Local municipality or the city authority	Low budget for management; ability to initiate hazard warnings. Specific knowledge about local vulnerabilities is high.	Communicating with local communities and individuals. Preparing new urban plan.
Local municipality or the city authority	More parks mean more work and money. But positive trade-offs for wellbeing, floods, air quality etc.	Have to maintain parks, take rubbish etc, and manage budget.

Low priority Actors:

Entity	Characteristics	Processes
Cultural heritage site managers (superintendence)	Rely on car park to bring in tourism revenue; however also have to deal with consequences of flooding.	Repair flooding damage and pump out water.
Flood managers	Care about flood retention but limited budget.	Deal with aftermath of flooding with focus on citizens and town itself

		rather than the cultural heritage.
Local business owners	Rely on tourism so car parks are beneficial to this group.	Require tourism to maintain income.
Visitors	Need car park or park and ride scheme to visit UNESCO Early Christian Monument sites in Ravenna. However, can also benefit from more green areas nearby.	Travel to Ravenna for a day or several days and spend money.

Table 25: Entity characteristics and processes

5.1.3 What Would the Model Look Like?

The high-level model schema consists of a description of several of the most important submodules which it could contain. Whilst having less detail than the entity descriptions in table 25, this is intended to provide a high-level overview of the modules that could be contained within the overall model. An overview of these modules can be seen in figure 17, which also describes some initial ways in which these could link together.

Figure 17 details the provisional interactions between different entities in this model, with an 'input, process, output' format as in figure 16.

The following diagram details the provisional interactions between different entities in this model.

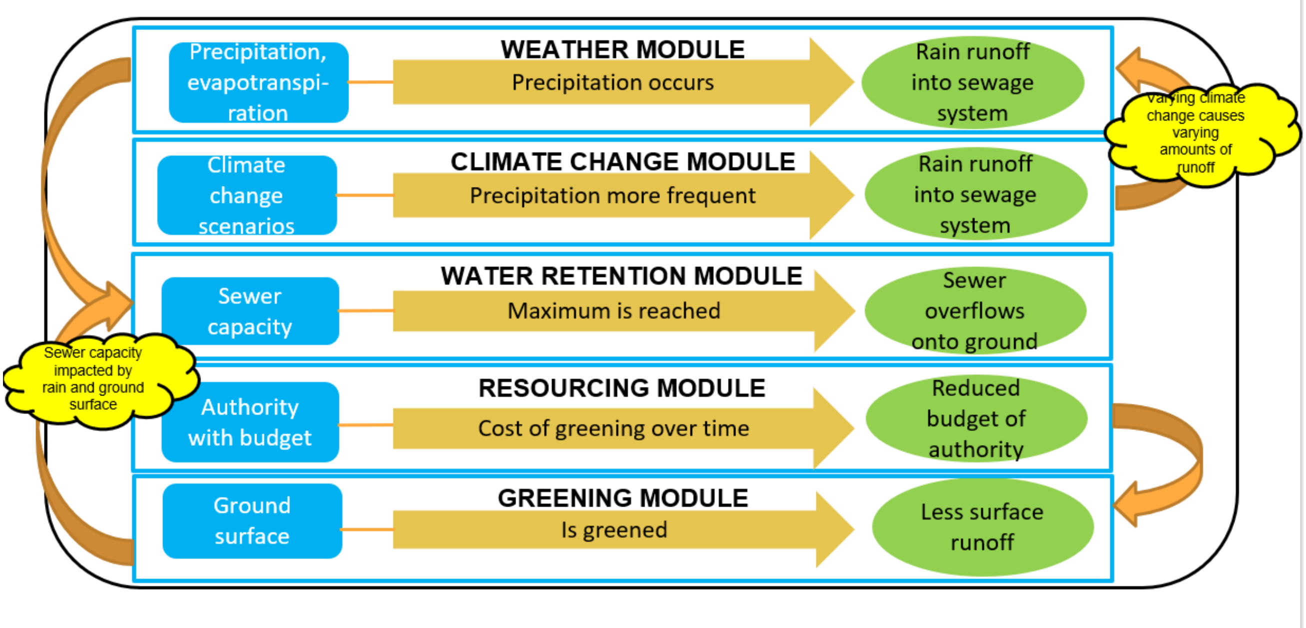


Figure 17: Interactions between entities within model

Module for the weather and the physical drivers of rainfall itself: The model consists of five proposed modules. The first module is regarding the weather and the physical drivers of rainfall itself, which is important for determining the amount of water which the city will have to adapt to in the future and therefore how much greening is required. The input to this is current amounts of precipitation and evapotranspiration, which has the output of the amount of precipitation an area receives and therefore how much will runoff into the sewage system under current amounts of greening.

Module for climate change scenarios: This is linked with the above component of this module regarding weather, and therefore of how this is likely to change in the future given different situations. Precipitation is predicted to become more frequent, which has repercussions for Ravenna, and the output of this relates to rain runoff entering sewage systems.

Module for pluvial flooding and water retention capacity: The third module considered for this model relates to the water retention capacity of the ground surface. The first component of this relates to the physical capacity of the sewers themselves. The process here is when the maximum capacity is reached, which causes sewage overflows on the ground in the city.

Module for city resources: The fourth module relates to the resources of the authority who would be carrying out the greening, mostly financially. Greening a city takes budget, and the process is therefore the cost of greening over time with the output of a reduced budget.

Module for ground surface properties and greening: The module’s final component relates to the ground surface properties which also influences the amount of runoff which eventually leaves the ground surface. If a ground surface is greened, less surface runoff results which is important for water capacity.

Within the weather module, climate change scenarios impact precipitation and evapotranspiration by causing more extreme conditions. Rain runoff may therefore be more severe when this is incorporated into the model. In turn, the severity of precipitation also impacts the sewer capacity component of the water retention module, as sewer capacity is impacted by the speed and volume of rainwater runoff. Within this water retention module, the amount of greening occurring within the model also internally impacts the sewage capacity element, by altering the speed and volume of precipitation which eventually reaches the sewers.

5.1.4 Preliminary Data Requirements for Ravenna Open Lab

At this stage, data requirements are broad and not final. Table 26 can therefore be considered as a generalised way of understanding the possible requirements which might be needed for this model. Table 26 also provides an indication of whether its requirement is necessary as a minimum for model construction, or whether it is an ideal additional parameter. Whilst an initial overview is accompanied with whether this data is publicly available and accessible, important to note is that this followed only a preliminary assessment and may not therefore represent the data available to its full extent.

Data	Description (resolution/periodicity)	Minimum requirement	Ideal requirement	Publicly available/source
Climate change predictions	Local predicted temperature changes given different amounts of climate change		x	IPCC predictions, or more localised scientific papers quantifying this more accurately if they exist
	Local predictions of future precipitation given different amounts of climate change	x		As above
Current climatic data	Monthly temperature mean and maxima	x		Can be gathered from Italian weather services to derive potential evaporation
	Precipitation – monthly averages	x		As above
Current land surface cover	Map of area with land use with urban permeability information and which areas are already greened and to what extent	x		Copernicus Urban Atlas. Enhanced with newer local maps from the municipality where available
	Infiltration estimation based on current land use		x	A function can be created if none exist. Includes land use, green spaces, rainfall, temperature
	Map with topographic features such as buildings		x	e.g. google maps 3D or similar
Past flooding	Inundation data of past flooding events	x		
Sewage capacity	Absorption capacity of the sewage system per m2 or per vector area		x	
Rainfall runoff model	Soil type information for water holding capacity		x	
	Land use runoff		x	Can be estimated if not available from previous modelling studies
	Drainage estimation		x	
	Infiltration percentages		x	

Table 26: Preliminary data requirements to create the model

5.1.5 Potential Results

Finally, at this stage it is important to understand the potential results which could arise from this model, to tailor the process as it develops. These could include, but are not limited to, the following:

Planning results:

User	Result
Local government	To be able to better understand the extent to which green public spaces can contribute to reducing flood impacts.
Local government	To understand the possibilities to mitigate the need for expensive sewer expansions or other measures by improving green space areas.

Table 27: Planning results

Flood response results:

User	Result
Cultural heritage site workers/managers	To estimate the impact of putting in place practices which result in reduced flooding during heavy rainfall events.
Cultural heritage site workers/managers	To estimate the impact of putting in place practices which result in lower damage to cultural heritage sites.
Sewage network workers	An understanding of measures which could be introduced to reduce the speed of runoff from higher infiltration mean less pressure on sewage system so less likely to need repairs.
Local authority workers	An understanding of the measures which could be introduced to lower the need to respond to flooding crisis in the Santa Croce church and archaeological area.

Table 28: Flood response results

5.2 Technical Documentation

5.2.1 Overall Model Structure

Summary: This model will simulate the impact of greening public parts of the city of Ravenna, to evaluate whether this could be an effective solution to flash flooding.

Structure: This model contains 5 submodules which will each be explored in turn. Each should be able to run individually as its own model, and be able to be combined to produce the overall model (Figure 18). The submodules are as follows:

1) Weather module
2) Pluvial flooding and water retention module
3) Resourcing module
4) Greening module

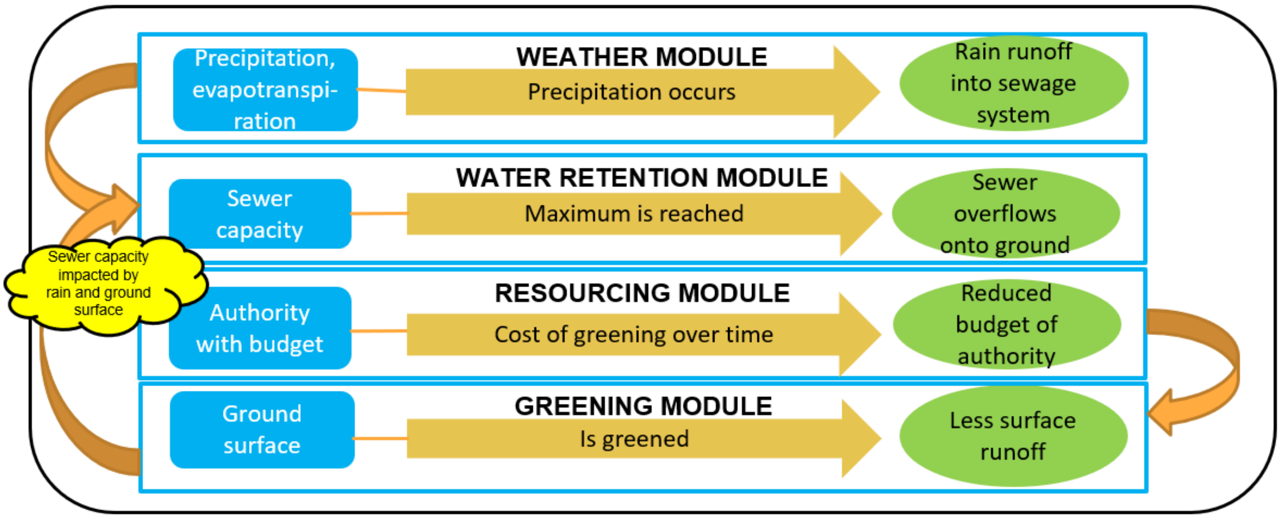


Figure 18: Interactions between entities within model

Model user inputs for initialisation - A brief overview of the mechanistic properties of the various types of agents in this model, as well as the environment which they interact with.

Areas selected by user - The model will have a visual interface of a map of Ravenna which will be divided into areas or 'cells', determined by census data classifications. Each area has characteristics including its current percentage covering of green land, car parks, streets and pedestrianised areas, as well as its area in meters squared. Users will be able to select how many cells will be greened out of those which are eligible.

For a cell to be eligible for greening, it must meet certain criteria, which are as follows:

- Less than 70% of the cell is already greened
- Cell is covered by at least 10% of either car park or street, or at least 5% of a pedestrianised zone

Where a cell met more than one of these criteria, for instance if it was covered by both 10% car park and 5% pedestrian zone, the priority order for the type of greening to occur was determined based on the number of cells in each category. This meant that a cell would firstly be checked for pedestrianised greening, followed by car park greening, and finally street greening.

In total this meant there were **294** cells eligible for greening each run, which were broken down as:

- 231 streets
- 42 car parks
- 21 pedestrian areas

Model initialisation of agents

About the agents: since this is a physical model based on natural processes, the agents in this model represent a simplified version of the actual ground type in Ravenna.

- **Static characteristics:**
    - Area
    - Starting percentage of greened land in each cell
    - Percentage of cell covered by car parks
    - Percentage of cell covered by streets
    - Percentage of cell covered by pedestrian areas
- **Dynamic characteristics:**
    - Overall percentage of greened land in each cell, after greening
    - Whether cell is flooded or not (yes/no)
    - Permeability (a static coefficient which changes depending on the percent of green space in the model

5.2.2 Module for Weather

Background information/knowledge: Prolonged rainfall is a direct cause of pluvial flooding when the land becomes saturated, having absorbed as much water as it possibly can. Heavy periods of rainfall, similarly, prevent water from infiltrating into the ground surface quickly enough to prevent the formation of surface water pools. It is therefore important to understand how much rainfall will lead to flooding issues and therefore how much needs to be absorbed by the ground surface to lessen this problem.

The purpose of this module is to simulate the severity of pluvial flooding given a certain amount of precipitation before any greening has occurred.

List of requirements:

- Daily precipitation totals (taken over two months) during a time period which saw more rainfall than average in Ravenna.
- Current monthly temperature averages for the last 5-10 years (averages taken daily).

List of processes with outputs:

- Computer code to read csv files of rainfall and temperature
- Average rainfall amounts (volume) per m2 area.
- Average and maximum temperature amounts per day
- Calculate potential evapotranspiration (PET) per day

Input requirements:

Data need	Purpose	Dataset used (add link)
Daily temperature mean for a 2 month period	To have a temperature baseline	European Climate Assessment and Dataset (ECA&D)[34].
Daily precipitation totals for a 2 month period	To have an average precipitation amount for a real time period which exp.	European Climate Assessment and Dataset (ECA&D)[34].

Table 29: Input requirements for weather module

Breakdown of tasks in user story format:

Type of task	Description	Desired outcome
Input data collection	Downloading and formatting precipitation and temperature data	As a user I want to view the precipitation and temperature values currently experienced in Ravenna.
PET calculation	Using precipitation and temperature data to calculate PET	As a user I want to know the impact of PET on evapotranspiration rates across greened and urban land.
Process code implementation	Reading temperature, precipitation, and PET as a CSV table	As a modeller I want to feed these parameters into my model

Table 30: Task breakdown for weather module

5.2.3 Module for Pluvial Flooding and Water Retention Module

Background information/knowledge: Urbanisation has negative consequences on rainwater runoff. Rainwater runoff fundamentally differs from natural environments because drainage systems are designed to remove wastewater quickly and efficiently instead of allowing it to naturally drain into the land surface, much of which is impermeable. Figure 19 demonstrates the impact this has on rainfall, which is characterized by a much faster rate of runoff and with a greater quantity of water compared to before urbanisation had occurred.

It is therefore important to quantify the water retention of the combination of these urban surfaces with the drains in place, to determine how much rainfall Ravenna can cope with before excess overland flow results in flood water accumulating in the archaeological site surrounding the Santa Croce church.

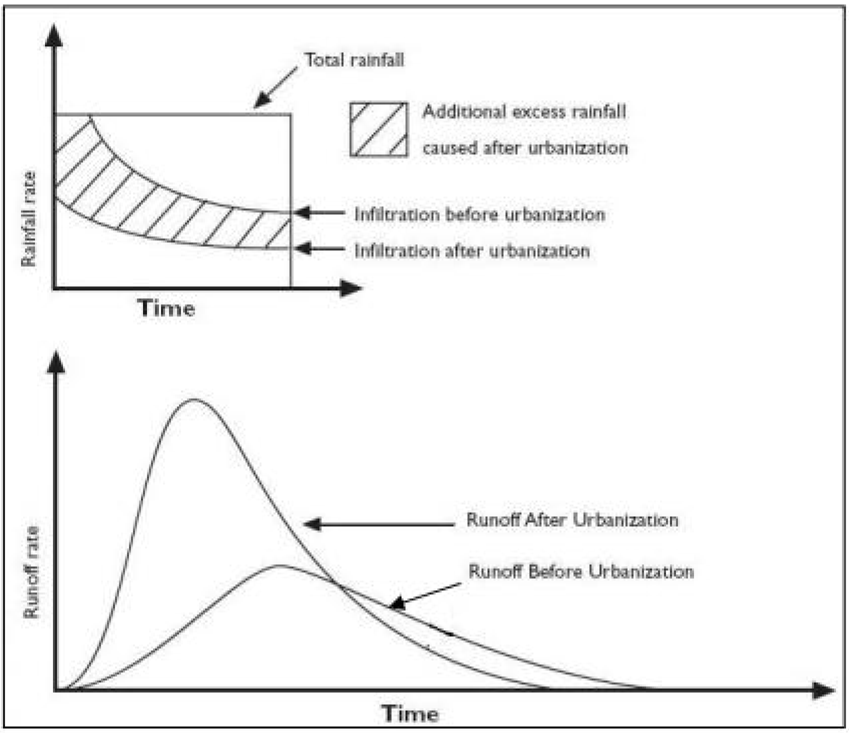


Figure 19: Urban hydrographs.[35]

List of requirements:
- A scale of porousness of ground surface types is needed. This is the same concept as infiltration rates and was made based on runoff coefficients [36].
- A map of Ravenna determining which areas have which ground surface types before greening has taken place.

List of processes with outputs:
- Obtain the precipitation amount from previous modules in mm/m^2 over time.

- Calculate the amount of water pooling and thereby distribution of precipitation across the area of each map subsection based on mapping information.
- Estimate the water retention /saturation of the soil given different amounts of rainfall.
- Estimate the excess water per area after saturation occurs, and the water pooling volume depending on greening percent.

Input requirements:

Data need	Purpose	Dataset used (add link)
Information regarding the permeability of ground surface types in Ravenna.	To calculate current water retention rates through ground types before greening has occurred.	Runoff estimates for different surface types [36]
Map of Ravenna	To combine with permeability information	Data supplied courtesy of Ravenna Open Lab and included shapefiles containing population statistics as well as the location of buildings, car parks, green areas, monuments and pedestrian areas. This was used alongside a base layer from OpenStreetMap[37].

Table 31: Input requirements for pluvial flooding and water retention module

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Identify data inputs	Identify infiltration rates of different surface materials	As a modeler I want to know which surface types have the lowest and highest infiltration rates
Process code implementation	Calculate excess water pooling following different amounts of rainfall	As a user I want to have a model which calculates the excess runoff volume and speed from different rainfall amounts
Visual graph code implementation	Create a graph over time showing how much excess water pooling is present in the model	As a user I want to be able to visualise how rainfall causes flooding volume to differ depending on the ground surface type
Visual map implementation	Create a map which can visualise the areas of the city that have been flooded	As a user I want to be able to visualise how and where rainfall causes flooding in the model

Table 32: Task breakdown for flooding and water retention module

5.2.4 Module for Greening

Background information/knowledge - This module will introduce greening of the city into the rest of the modules to observe how this can change the water retention and therefore flood risk of Ravenna, if carried out in differing amounts [38]. A study into the flood reduction impact of urban greening has shown that among other benefits including cooling and greenhouse gas sequestration, if 1/3rd of the EU's urban surfaces was greened this could transpire an additional $10km^3$ per year of rainwater. At a more local scale, hydrological modelling has demonstrated that green roofs, a similar concept of runoff reduction, could reduce runoff rates by up to 35% in cities. It is therefore worthwhile to explore the possible impact of introducing such measures in Ravenna, to reduce the pressure on sewers during the case of a pluvial flooding event.

This submodule therefore adds to the model the scenario of differing amounts of greening being applied to Ravenna, to determine the impact this would have on water retention.

List of requirements:

- A map representing land use in Ravenna as separated by its areas of different ground surface will form the basis for this module.

List of processes with outputs:

- Create map of Ravenna's land use types.
- For each population zone within the map, calculate the percentage which is green and the percentage which is roads, pedestrian areas or car parks.

Input requirements:

Data need	Purpose	Dataset used (add link)
Map of Ravenna's land use types and associated population	This is from submodule 3.4.	Urban atlas – (ESA), and/or more recent data if available from Ravenna team

Table 33: Input requirements for greening module

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Input data collection	Permeability scores for differently greened surfaces will be established.	As a modeller I need to understand how greening a surface changes its permeability.
Process code implementation	Creation of a code which gives the user the opportunity to select how many areas they choose to green in the model.	As a user I want to select the areas which can most feasibly be greened.
Process code implementation	Feeding the greening permeability values into the hydrograph of submodel 3.5.	As a user I want to understand how greening surfaces changes permeability.

Visual graph code implementation	Draw a map which helps me to visualise which areas I am modelling as greening.	As a modeller I want my model to be able to provide a visual output of the results.

Table 34: Task breakdown for greening module

5.3 Results:

5.3.1 Summary of Flooding Model Mechanics

Before model interpretation can take place there are several factors which must be taken into consideration that may impact the results observed. Whilst pluvial flooding is an important issue in Ravenna, it must be acknowledged that due to subsidence in the region combined with rising sea levels, future estimated implementation of greening will be influenced by other factors as well as rainfall by volume. It was not the intention for this model to construct a detailed hydrological model, but rather to explore specifically the impact of greening as a measure to reduce the impacts of specifically pluvial flooding.

Additionally, the rainfall parameters used in this model are projections based historic events, and thus do not account for climate change scenarios. As occurred in Ravenna in 2015, it is possible for multiple climatic extremes to coincide and worsen the flooding to unpredictable extents. This event consisted of a period of heavy rainfall caused by cyclone Norbert, which coincided with a storm surge [39]. The coincidence of these two events is not uncommon and the occurrence of one in the future could produce flooding beyond what this model considers.

The following diagram is an overview of the key functionalities of the model in its final form. There are 3 key components of the model which interact to form its overall functionality. These are the flooding, rainfall and water retention models.

Figure 22 demonstrates a visual map of the specific areas which were considered for greening.

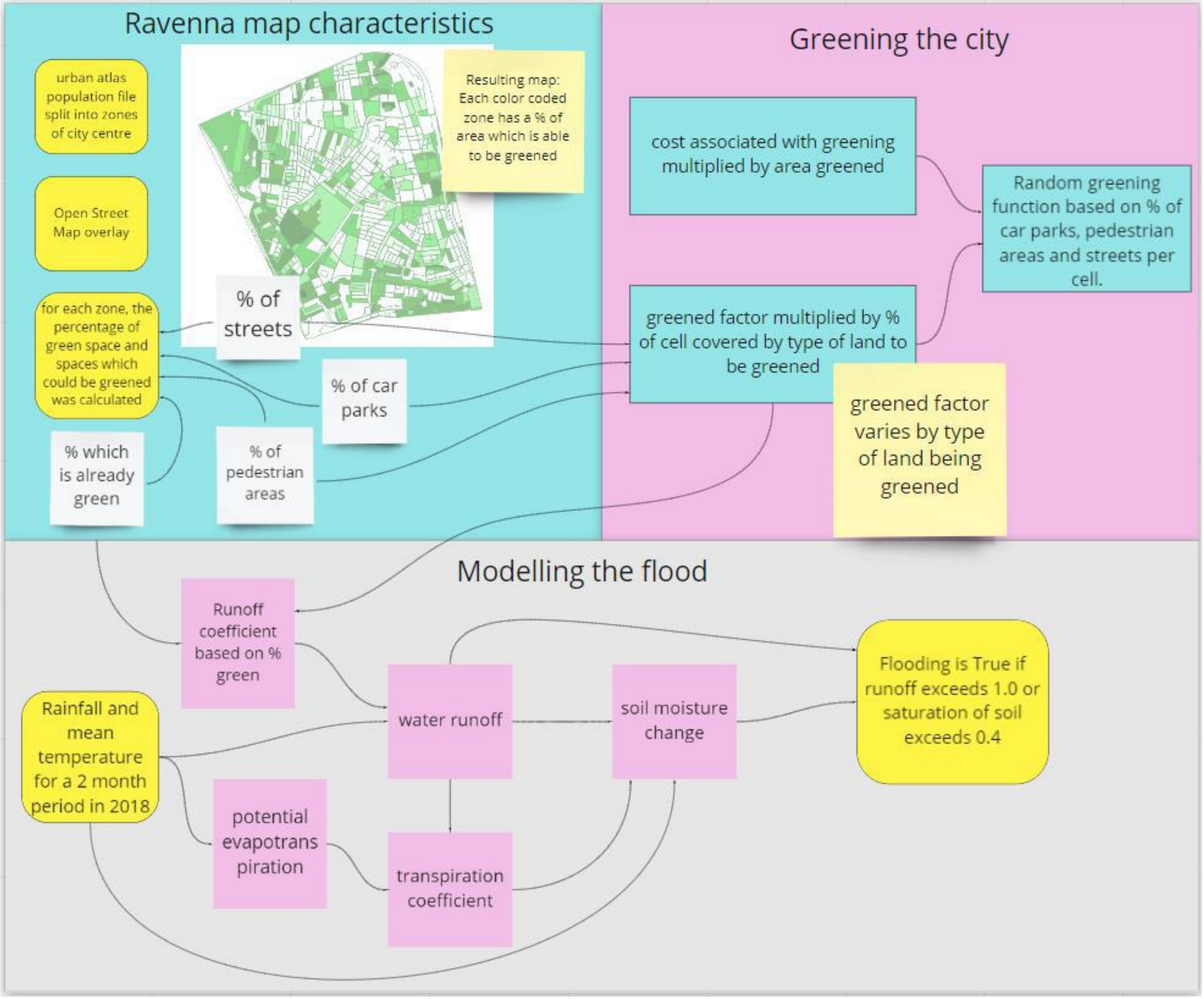


Figure 20: Greening model mechanics

5.3.2 Model Calibration and Visualization

One important advantage of Mesa compared with other ABM tools is it’s use of a server to draw results for individual model runs. Because of the randomness involved with several components of this model, the results presented in this deliverable are the result of a batch run which allows the testing of all possible combinations of a variable. The server results allow the testing of individual model runs and the layout of this server is shown in figure 21. To this end, after the model had been initialised a series of runs were carried out which tested the accuracy of several estimated parameters, including the absorption capacity of cells and their drainage time. Whilst there is no way of backing this up with real data, the model was run several times until the amount of flooding produced consistently plausible results. Whilst this element of the model remains largely an educated guess, importantly it allows for comparison across different amounts of rainfall, which was a real historic dataset, and thus there is potential to calibrate this in the future with real results.


greening city model
About
Stop
Step
Reset
total fund allocation
1000
50000
car_parks_to_green
0
42
streets_to_green
0
231
pedestrian_areas_to_green
0
21
Frames Per Second
0
20
total_money
0
-200000000000
-400000000000
-600000000000
-800000000000
-1000000000000
-1200000000000
0
5
11
17
23
28
34
40
46
51
55
63
current_rainfall
40
35
30
25
20
15
10
5
0
0
5
11
17
23
28
34
40
46
51
55
63

Figure 21: Screenshots of model's visualisation server appearance

5.3.3 Scenarios Run for the Model

The model was run as a batch with a series of consistent and variable parameters. Several parameters were also selected as those which would be recorded at the end of every model run. These are as follows.

Fixed parameters:

- Cost per m2 of greening
- Weather data (per model run)

Variable parameters:

- Number of car parks being greened: Tested at values of 0, 10, 20, 30 and 40.
- Number of pedestrian areas being greened: Tested at values of 0, 5, 10, 15 and 20.
- Number of streets being greened: Tested at values of 0, 50, 100, 150 and 200.

These variables were each run for 5 values, with every combination between the three variables, 100 times. This resulted in **12,500 runs** of the model being carried out.

Recorded parameters

For each of these model runs, 11 parameters were recorded. These are as follows:

- Cost per m2 of greening measures in place
- The number of cells which were greened during a model run
- The total volume of excess flooding in the model.
- The average runoff per cells with less than 5% greened area
- The average runoff per cells which are 6-10% greened area
- The average runoff per cells which are 10-20% greened area
- The average runoff per cells which are 20-30% greened area
- The average runoff per cells which are 30-40% greened area
- The average runoff per cells which are 40-50% greened area
- The average runoff per cells which are 50-60% greened area
- The average runoff per cells which have a greened area greater than 60%.

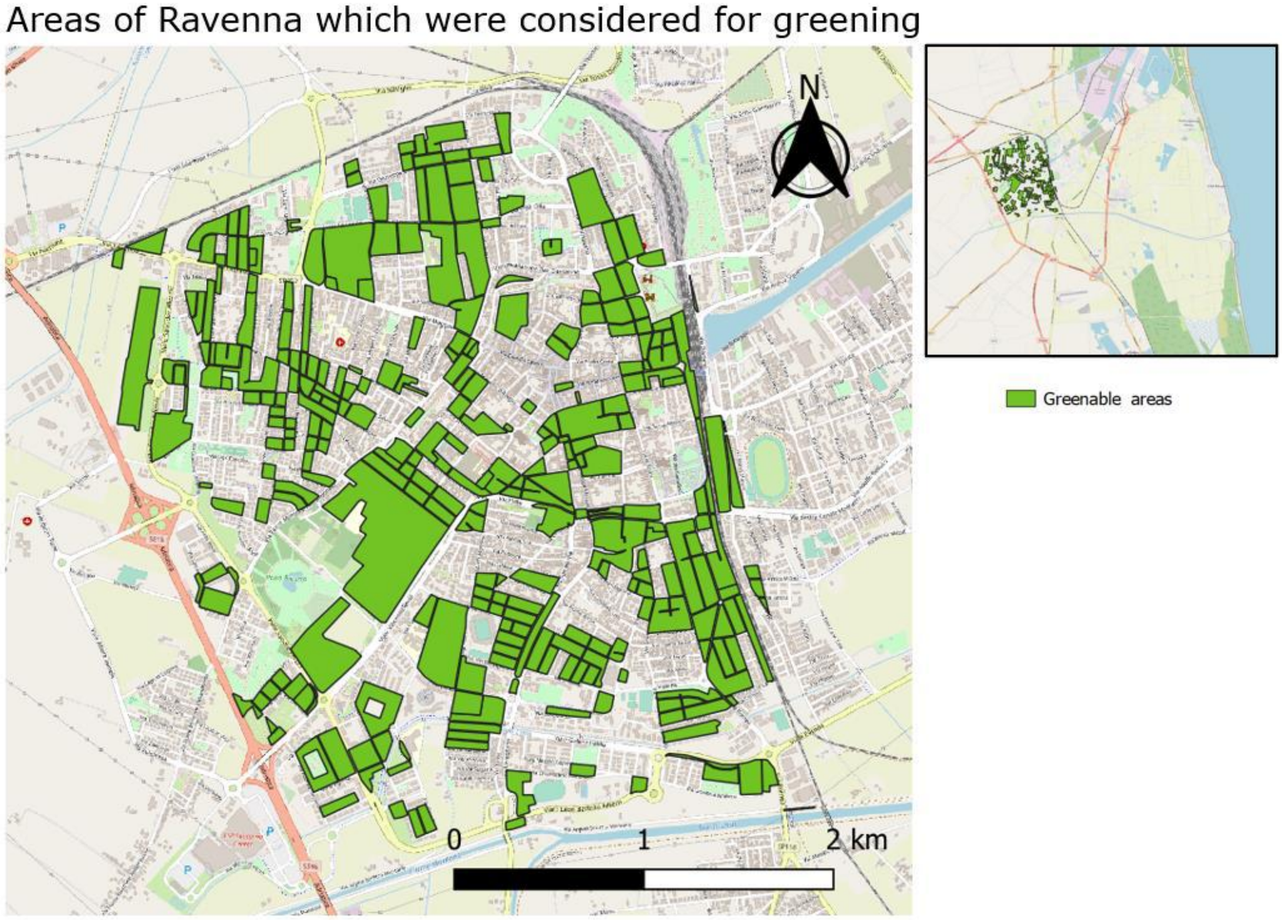


Figure 22: Areas of Ravenna considered for greening

5.3.4 Results for the Model

Figure 22 demonstrates the areas of the city which were modelled for greening. The below series of figures are the main results arising from all of the model runs. Figure 23 demonstrates the main result, of the correlation between the total volume of flooding in the model and the number of greening measures introduced. It points to a clear downward trend with less flooding occurring when more cells have been greened. Figure 24 is the same data but looks specifically at the type of measures introduced to compare the effectiveness of each one. For greened streets there is a strong trend between more of these measures being associated with less flooding, and whilst the trend repeats itself for car park and pedestrian area measures, this is much less pronounced. Figure 25 also models the flooding volume against the number of greened cells, as in figure 23, however results are displayed for each category of percentage greening separately rather than overall. For areas which were 5% greened there is a counter-intuitive negative relationship between flooding and the number of measures in place. For other amounts of greening the trend mirrors that of figure 23, however the strength of this trend varies substantially depending on the category of greening.

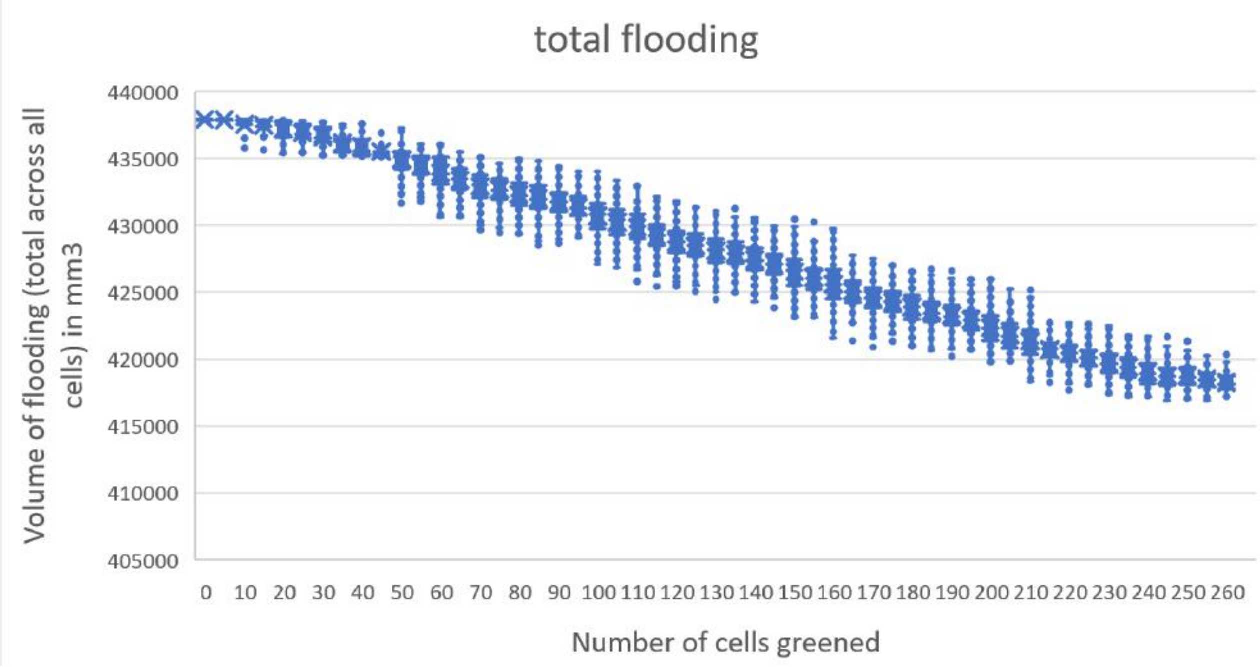


Figure 23: Volume of flooding plotted against number of greening measures

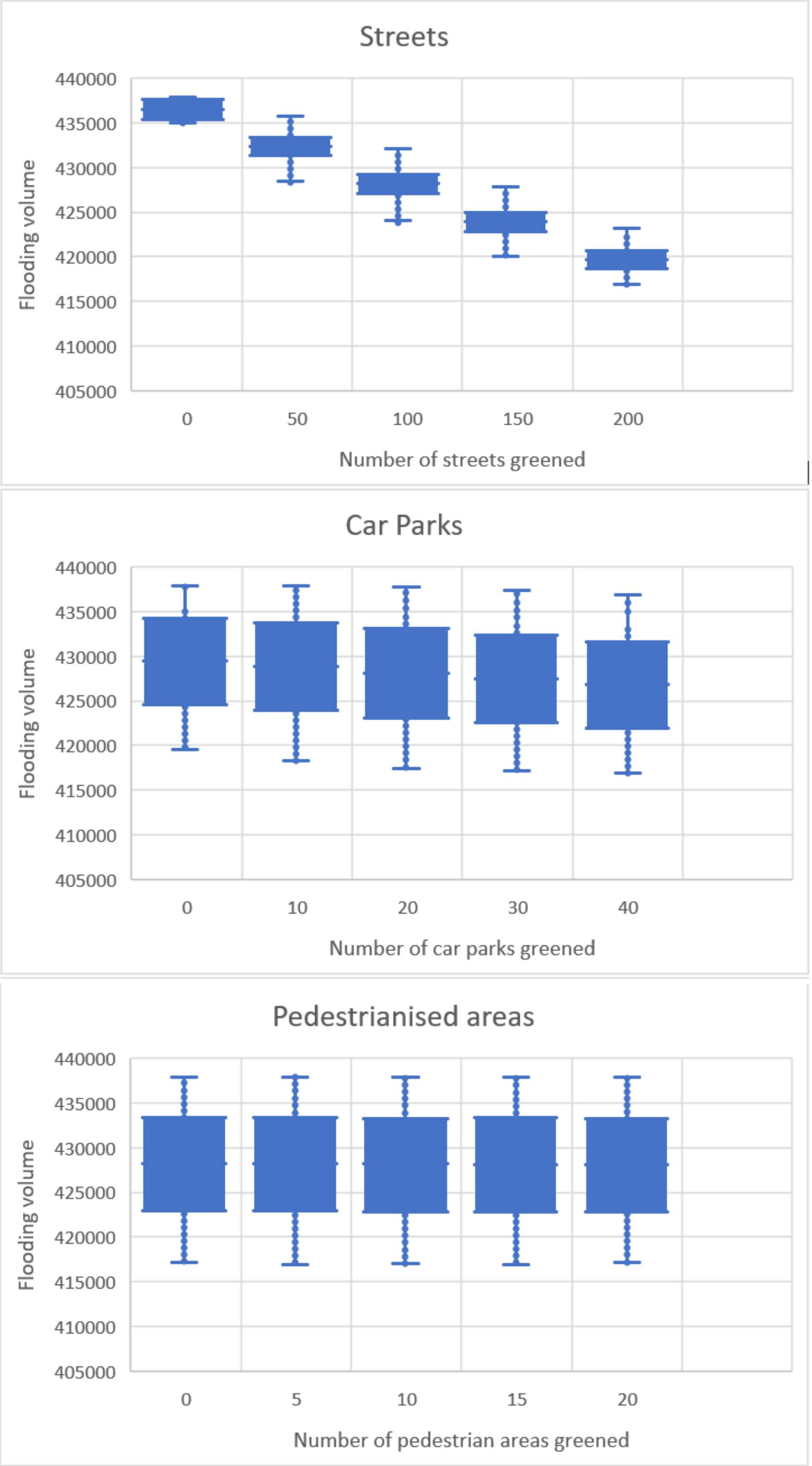
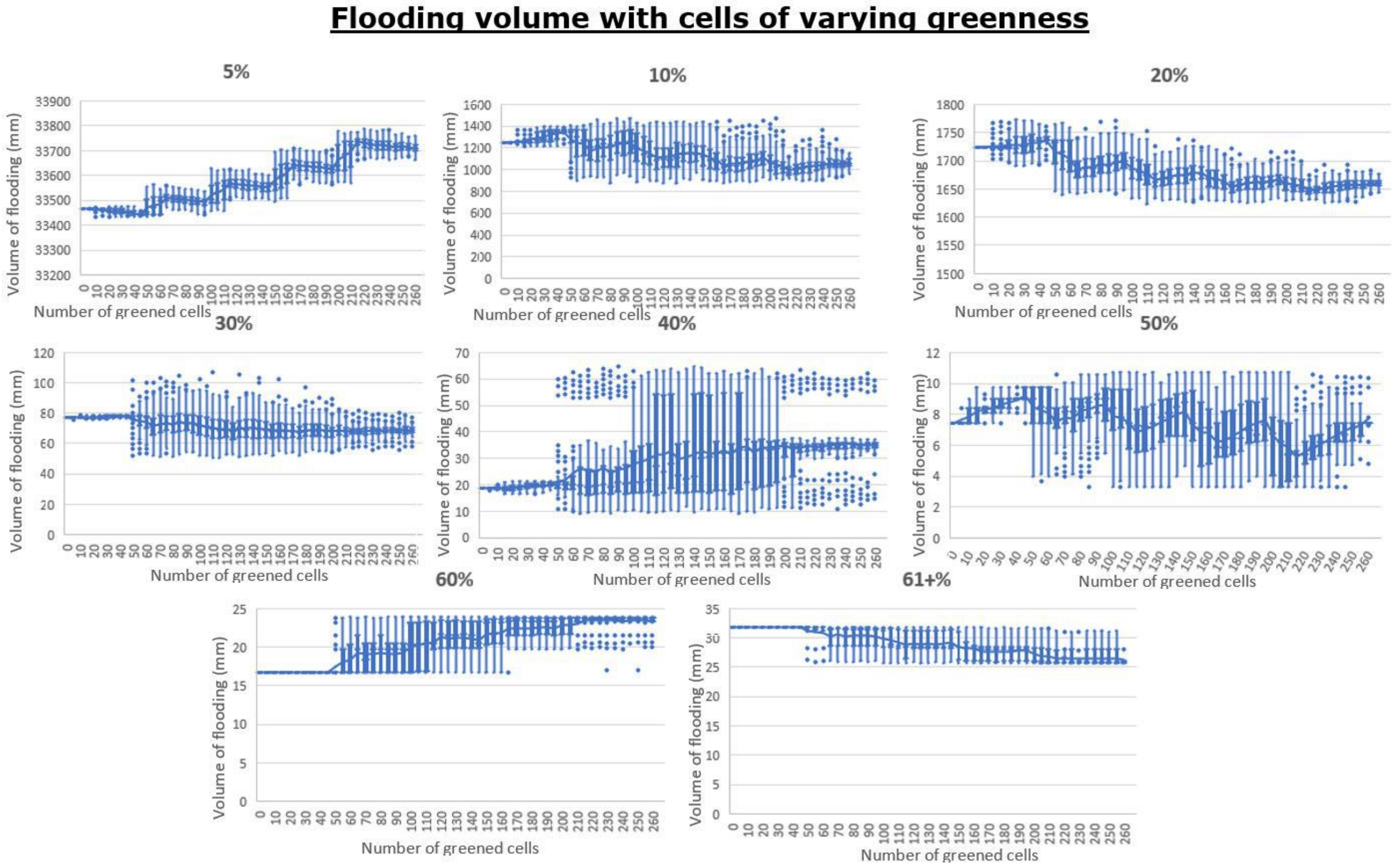


Figure 24: Number of measures introduced compared to flooding volume



Flooding volume with cells of varying greenness

5%

10%

20%

30%

40%

50%

60%

61+%

Figure 25: Flooding volume with cells of a varying greenness

5.3.5 Discussion and Conclusions

Based on these results, several generalised findings can be inferred:

- The more cells have greening measures applied to them, the less excess runoff occurred (see figure 23).
- Cells which have less than 5% of their area greened are more likely to flood with a higher number of greening measures applied to other cells (see 5% graph in figure 25).
- Cells which are over 10% greened benefit from less flooding as more greening measures are introduced (see figure 25).
- There is a greater impact from greening streets than other surfaces (see figure 24).

Figure 23 is clear to point out the trend of decreasing excess rainwater pools with an increase of greening measures. This is because as heavy rainfall occurs, urban surfaces are unable to drain this water away quickly enough before more occurs. Thus as surfaces become on average greener, more drainage can occur and hence less flooding.

Whilst figure 24 is clear in pointing out that greening streets seem to have a much greater impact than the other 2 types of measures, there were a much larger number of cells containing enough of a street to consider this type of greening which can explain this. Despite this, the type of greening modelled for streets was a specific type of greening known as porous roads. This enables a much greater proportion of the potentially-greenable area to be ‘greened’ than on other types of surface – although it is not a typical type of greening since no vegetation is actually planted. Replacing roads of typical materials with porous material such as porous concrete is a very effective way to reduce pooling [40] but comes at a much greater financial cost than typical greening methods explored for other surface types less prevalent in Ravenna.

For cells which had between 0 and 5% of their total area greened, there is a very strong trend which implies that as more measures are applied, more flooding occurs. Although this seems contradictory to the model mechanics, as more measures are introduced elsewhere and land is greened it thus has a higher potential evaporative capacity and coefficient of water pooling. This means that as more rainfall is absorbed across other cells, in cells with little to no greening there is proportionally more water which cannot be absorbed. Where cells experienced a small amount of greening (10-20%), this trend was reversed as visible in figure 25. This can be explained by the small amount of greening which did occur, causing a tangible difference to the cells’ ability to absorb rainfall thus resulting in less excess water. This trend is stronger with cells which were 20% green, as expected for their proportionally higher capacity to absorb water. The graphs which represent cells that were 30-50% greened only slightly indicates this trend which can be accounted for by the relatively fewer observations of cells falling into this category, however important to note is the y axis which points to the much reduced total of flood volume for cells in this category. Whilst the category for 60% greened cells seems anomalous, this can again be attributed to the lack of cells falling into this category, and the trend again returns for cells which were over 60% greened.

The key uncertainties with these results are as follows:

1. The role played by sewage and drainage systems was not accounted for in the model. This could potentially increase the drainage potential of certain parts of the city, for both greened and paved areas. Equally, this could worsen the drainage potential of certain areas due to Ravenna's generally high level of ground water. This varies spatially within Ravenna.
2. There was an assumption of uniformity in the spatial distribution of rainfall. In reality some areas may have experienced more and others less rainfall.
3. Elevation was not considered in this model. In reality, some areas which are higher up or sloped will drain into other areas which are flatter or more low-lying, and the water accumulation in these areas will be greater. This is the reason the archaeological site in the grounds of the Santa Croce Church is at high-risk from flooding, since it is low-lying.
4. The greened factor for different types of land was estimated. This number is the proportion of the green-able area of a cell which was modelled as having had this greening fulfilled. It was modelled as 0.8 for streets, 0.3 for car parks and 0.15 for pedestrian areas.
5. The coefficient of permeability was also estimated. This number is the proportion of the water pool able to be absorbed by different amounts of greening.
6. The specific cells which were greened in each model run were randomly assigned. It seems likely that some of these will either be privately-owned or logistically impossible to green in practice.

The first three of these uncertainties can be narrowed by obtaining more datasets for use in the model, for example a dataset of slope angles can be created from a digital elevation model. Similarly a map of the drainage systems in Ravenna as well as their capacity will be useful. This will require a more advanced technical iteration of the model to incorporate these factors into the flooding mechanics, which was beyond the scope of the task timeline, but would be possible in any future iterations of the model. If carried out this will allow an estimation of runoff to be incorporated to the pooling mechanisms, meaning different pool accumulations in some otherwise identical cells.

To narrow the fourth uncertainty is more difficult as it would require mapping the potentially-greenable areas of Ravenna and calculating how much of their coverage could be greened in practice. This would have to be done for each cell of data specified in the Ravenna map and then averaged for each type of land surface. As well as being time consuming, it is likely that each cell would have large differences among their values for this parameter and thus an average would remain an imperfect way to measure this.

The fifth uncertainty specified could be narrowed by carrying out water runoff experiments with different types of land to represent the numbers more accurately in this coefficient.

To narrow the sixth and final uncertainty, a land survey could be carried out to determine which if the potentially-greenable cells it would be possible to actually green. In the case of private ownership of cell a different type of greening could be modelled, for example involving a private incentive to residents who choose to carry out greening.

This model can potentially be used as a discussion tool for organisations in Ravenna who wish to incentivise the greening of privately-owned land, and for local authorities who are able to bring about the greening of public areas. Importantly, this model demonstrates in an understandable way the positive impact that greening is able to have on flood reduction in Ravenna. It can be used to explore the introduction of differing amounts of greening, and as such to see how many measures would be required to have a tangible difference to the challenge of pluvial flooding in Ravenna.

6 Conclusions and Next Steps

6.1 Conclusions

General conclusions - Cultural and Natural Heritage sites throughout Europe are facing more risks than they have been subjected to in the past, this threatens both man-made and natural sites. ABM is a tool which has great potential to benefit the field of disaster risk management, particularly when dealing with new uncertainties such as climate change. ABM has been shown to be a highly useful explorative tool for modelling the impacts of varying intervention methods prior to their implementation. The long list of agent-based model ideas first introduced in this deliverable evidence the large number of areas in which this type of modelling could be useful in the context of cultural and natural heritage and resilience. This task has explored three of these ideas in technical detail and implemented two in a coded model showcasing the versatility of ABM.

Heatwave Communication model conclusions - The heatwave model produced a structure to explore the expected impacts of heatwave communication measures to improve heatwave planning activities in the future, to reduce heat risk and mortality for vulnerable parts of populations. This is applicable in the implemented Dordrecht Open Lab context as well as elsewhere. It provides a ground for discussion in that the model found that particular communication measures by themselves are not sufficiently impactful, but can be impactful when combined, depending on the degree to which heat stress is reduced by changes in people’s behaviours. The tool also for users to tweak parameters and explore the impacts on heat stress for the elderly, to gain insights in how heat stress operates and leads to mortality, and in doing so provide for recommendations on what research is needed to understand the impacts of heat stress better in terms of its health impacts. For example, the model highlights the need for understanding the physiological differences between different groups of the population and how they can or cannot cope with heat stress, the speed of onset of heat stress to dangerous levels and the gradual or rapid nature in going from heat stress to heatwave mortality.

Whilst it is not possible to determine the accuracy of the various communication measures modelled without empirical validation before and after a hazard, there is potential for the effectiveness of measures to be determined in the future. For example, by carrying out surveys and interviews among the local population. This would enable the model to be transformed from an explorative to a predictive model, as the model rules can be improved, and the parameters can be fully calibrated.

City Greening for pluvial floods model conclusions – The pluvial flooding model explores the interaction between rainfall, surface type and flooding volume in Ravenna, Italy. The relationship between these 3 interacting factors is one which impacts upon the amount of pluvial flooding experienced in Ravenna. As such, their exploration in this model allows an understanding of where intervention in the form of greening impervious surfaces could be carried out in order to reduce this problem. This will reduce the impacts felt by the archaeological site surrounding the Santa Croce Church, which is currently subject to regular flooding in the event of heavy rainfall. As well as providing knowledge about the amount of greening measures which would need to be carried out, the model also speculates about the relative effectiveness of greening different types of land surface. Installing permeable road surfaces, for example, seems to have a much greater impact than greening pedestrian areas. This is partly a result of the quantity of roads eligible for greening, but also arises from the fact that this is a more effective measure than greening other areas, although it comes at a very high cost.

Whilst there remain several difficulties with interpreting this model arising from its uncertainties, there is potential to carry out further work in the future which aims to reduce these uncertainties and improve the model's functionality. This would improve the model's hydrological capabilities and provide more accurate insight into the possibilities of greening the city.

6.2 Future Work

Whilst the task 2.6 has ended in SHELTER concluded the ABM model development, the approach has allowed for reproducibility and extendibility. Depending on the requirements of the Open Labs within and outside of SHELTER it will be possible to further advance the two developed models for future use. Thereby introducing new features and integrating the models in the Open Labs planning efforts. An interesting area of focus for the heatwave model, for example, could be to more explicitly model the impact that leaving the house can have on heat stress, which has been identified in the Literature as one key area which impacts heat stress severely.

Beyond this deliverable there is an intention to publish the results in either an academic conference or journal paper as part of the SHELTER project, which has been discussed between EcoWise and TECNALIA. This as to further the advancement of ABM as a field within the context of cultural and natural heritage resilience. To provide for a further advancement of the body of knowledge coming from the SHELTER project.

There is also potential for the models which are developed to be integrated into the SHELTER online platform, thanks to the use of the MESA code implementation. As part of an API that routes SHELTER project data required for the models (such as GIS files with land use information) to the ABM model server where the user can then operate the models for exploration in a modelling interface. The feasibility of this will be explored as part of task 5.4 in relation to the SHELTER platform development.

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8 Appendix A - SHELTER Task 2.6 OL meeting notes

1 2nd-10th March 2021

8.1 Seferihisar Open Lab meeting

1 and 2 are the primary models of interest and will be discussed further.

They also have an interest in model 3 (wildfires). Although not specifically in the scope of Shelter, it is interesting as the municipality also covers rural areas outside the citadel, which experiences wildfires.

- One fire recently caused damage because it occurred near a beach where cars were parked – frustration that wildfire management is not better.
- Would be higher priority, but protected area means there is uncertainty about the legality of introducing management practices.

Model 4 would also be nice as an extra model but again it is not a priority.

This is based on a stakeholder meeting which assessed two main points relating to the needs of Seferihisar which need addressing:

1) The area is hard to access in emergencies. Streets are narrow and used as a marketplace, so access routes are critical in an emergency.
2) Engaging the inhabitants of the citadel area in the emergency phase. How to collaborate is important here. This is pertaining to vehicle-based emergency services like fire brigades and ambulances.

Model 2: access routes

What are the Open Lab's needs in relation to the presented model?

- Alternative access routes and plans are the interest here.
- Within the citadel there are 1/2 entrances a truck could enter by, and several smaller gates.
    - So based on location of the emergency, the fire brigade/ ambulance would need to be different types of vehicles as some simply do not fit.
- Travel routes of traditional vehicles can be explored. Their paths might be blocked by market tables, signs outside stores etc., so routes might change momentarily.
- e.g., shops putting things outside. Can be described as "street level events".
- So, the focus would be less about rubble generated in a hazard, but more about people's interactions and actions.
- This is especially a problem in touristic areas.

- Alternative routes could be found. Entrances where trucks can enter into the citadel, alongside smaller locations. A key question is whether fire brigades can enter, or if they are too large?
- People alerted when emergency vehicles are travelling so they know to move their belongings which might block its route.

<u>How does the Open Lab see the model outputs as helping?</u>

What are possible results which could help the Open Lab and local populations?

- Could have an output in the form of a warning to remove obstacles from the road, which would know which route is the best and could alert people while the truck was travelling.
- How to evacuate one route as fast as possible
- Not intended to be an emergency management plan. It is more important that the output considers agency of agents – it should consider who is blocking the way, what their capabilities are to move fast, what are they sensitive to.
- This is preferred over the GIS part.
- Need to see how agent behaviour can change.

<u>In what format does the Open Lab need the results to help their purposes?</u>

What form would you like the results to be in? e.g., a report, a presentation.

- Outputs directed at municipality – what should they do, and what hard interventions are feasible (announcement/warning devices, plans).
- A report would be useful to describe which actions could speed up access processes, and how the access routes can be generated based on existing routes.

Model 1: collaborative information sharing

<u>What are the Open Lab's needs in relation to the presented model?</u>

What are your interests and needs for potential models?

- Multi-stakeholder concept is important to gain a clear picture of who is involved.
- Citizen engagement is important for Seferihisar, but alongside this is the need for cooperation between all relevant institutions.
- in Turkey, there is one institution in charge of all disaster actions, called AFAD (Ministry of Disaster and Emergency Management). They do action plans for preparedness, mitigation, planning. **Communication is lacking, however.**
- Additionally, there are NGOs who are really responsive, especially in the first response phase and recovery. They are independent however, with their own decision-making processes.
- Also crowdfunding campaigns. They have no prioritisation or plan, and funds are badly coordinated: some places get too many funds and other places receive none.
- This is especially true given social media – it is not always the person in charge who reaches most people, but rather whoever makes the best use of social media.

- So in theory, one government agent is in charge of everything, but in practice it is many agents who all take charge and do not coordinate.

<u>How does the Open Lab see the model outputs as helping?</u>

What are possible results which could help the Open Lab and local populations?

- Have to acknowledge the difference between first response and recovery:
  - first response includes food provisioning, shelter, finding people.
  - Recovery is about life getting back to normal, providing aid, temporary/permanent housing, rebuilding, financial recovery.
- First response – can relate to the accessibility of the location. For example, a fire brigade will take a long time to reach somewhere remote.
  - A potential help would be an app or means of communication so everyone knows who has what resources (equipment), who has training to intervene (who can someone call for help locally such as a neighbour) – easy, uncomplicated interventions between neighbours.
  - Network of citizen response teams – business owners, hotel staff as citizen first responders. E.g., an app or communication output.
- Recovery – measure of aid reaching the right people.
  - How much time can be saved if there was collaborative information sharing priorities? How could confusion be avoided; could aid be directed efficiently?
- First responder sub-model: Question of how many first responders is needed?
  - *Idea: quantifying the cost of handing out equipment (fire extinguishers, training, compensation) – versus how much disaster recovery could cost?*
  - If a road was blocked, which businesses and locations would be critical? Importance of which buildings are hotels (open all the time, staff can be trained) – e.g., could be about coordinating 20% of area's hotels.

<u>In what format does the Open Lab need the results to help their purposes?</u>

What form would you like the results to be in? e.g., a report, a presentation.

- This is the broad idea – but would be ideal to focus on **first response** – time, proximity vs capability, people vs trees. More meaningful model.
  - (Recovery is a long, complex process with many variables)
- Possibility of reducing damage is output.

Summary of Seferihisar's modelling needs:

Model 2 is the most important for Seferihisar. The citadel area has few entrances, some of which are too small for large fire trucks to enter by, and which are often blocked by markets and other street-level activities. Outputs from this ABM could therefore consider who is blocking the way, and what actions can change their behaviour in an emergency. It is targeted at a municipality partner, so outputs should be tangible and provide suggestions of how emergency travel plans can be improved.

Model 2, on collaborative information sharing, is important as this is fragmented. In theory there is a government agency in charge but in practice response and recovery are uncoordinated. Social media is also important, and an ideal output would be some way to enable people from different parties to communicate with each other. This could be between neighbours in a community. A network could be established of citizen response teams, including hotel and business staff because Seferihisar is a tourist area. First response would be a helpful focus compared to recovery, which is long and complex.

Models 3 and 4 are also potentially relevant but not as important as models 1 and 2.

8.2 Ravenna Open Lab Meeting

Model 1 – collaborative information sharing

- Interesting idea but difficult to provide information for this model because many stakeholders are involved, and it is impossible to be aware of information fluxes.
- Not something they can rely on, as any missed connections potentially mean the final model outputs are misleading.
- They are not directly involved in information sharing which complicates this.

Model 6 – simulations of greening a city

Impact and results are possibly the most useful for this model because municipality are working a lot on the topic. It would build upon a Nature4Cities model which looked at how much runoff is generated from paved vs greened gardens.

A model applied here could have a similar basis but a different focus depending on specific needs: public vs private; different types of greening etc.

What are the Open Lab's needs in relation to the presented model?

What are your interests and needs for potential models?

- The Municipality are already working on the topic of greening the city.
- The problem of soil sealing has been raised. Some areas would need to be de-sealed (*there is an ongoing study on this).*
- This could involve not just the monument, but a larger part of the city
- Municipality is making a new urban plan and greening is one strategy they are putting in place but will need to understand better what data is needed.
  - Greening could be a part of this: PhD thesis of de-paving public sealing.
- action which could enhance the resilience of the historic centre.
  - One team member's research is about the Basilica in Ravenna which is a UNESCO site – there is huge car park which is completely cemented. So one action is to convert this to a green area enhance the water retention.
  - Also, the possibility for modelling greening of streets and public surfaces.
- Bringing conservation into urban planning – more possibility of urban actions.
- Very dense, ancient area so cannot demolish anything or build much.
- Santa Croce is lower than street level so acts like a pool when it rains.
- Also, idea of working with private owners. Not considered by the municipality.

How does the Open Lab see the model outputs as helping?

What are possible results which could help the Open Lab and local populations?

- What scale of greening that needs to happen to have an effective result. What is the specific problem, and what are short/long term challenges (climate scenarios).
- what greening do we propose for this solution because whole area of Ravenna is ancient part of Roman Ravenna so bound by **legal policies.** This means that planting cannot be anything with deep roots.
- 'greening' too invasive for subsoil and archaeological remains.
- Two other options – economic constraints must also be considered, provided the numbers can be found
- Also, perception – do people like car parks have a need for them vs parks
    - Not feasible to just say this is no longer a car park. Must be blended ideas.

<u>In what format does the Open Lab need the results to help their purposes?</u>

What form would you like the results to be in? Who is intended audience?

We have an Italian partner who is involved with sewer systems and we could potentially get some useful information here.

- Working on activities related with financial issues.
- If they have the numbers, it is doable but if we do not then no point.
- Possibility for a climate adaptation plan, as there exists municipal-scale climate change projections. Links to WP4 about policy.

Model 5 - involvement of multiple stakeholders in key decision-making:

- This would aim to be less of a planning instrument, more of a governance information structure.
- Idea is to look at all instruments – how do they work? Who is doing what? Are there any incoherencies with the planning tools?
- If small scale/local actors are involved from the start in a process they are more likely to show an interest and contribute helpfully to its functioning.
- How can this strengthen decision-making?
- Would support in elaborating their governance model with management of CNH.
- Potential to expand area of open lab, subject to an internal discussion.
- Would relate to the risk management and the value of the area

Summary:

Model idea 1 is not suitable for Ravenna because of the difficulty of providing relevant information which is sufficient to ensure the model's reliability. Model 6 is potentially very useful because water retention is a big issue in Ravenna. It also has the possibility of wide engagement. This could potentially involve the large car park next to the Basilica as a case study. The focus of such a model would be more about the greening of public spaces rather than private. Model 5 could also be useful for improving governance models, but potential results need to be specified with more detail to make it feasible. An internal discussion will follow, but it is likely that model 6 will be selected.

8.3 Galicia Open Lab Meeting

Galicia like models 1,2,3 and 5. All are relevant to their emergency department, so the concept notes could be translated into Spanish (Tec has offered to proofread translation). Galicia is keen to know the kind of information which would be needed. Data requirements are important so they can present to emergency department. Quite related with preparation for emergency phase rather than reactions and coordination. Once we send the data requirements, they will ask their boss and tell us if we will go ahead or not.

2nd model is not quite so interesting. Routes which go to the fires are probably totally defined already and cannot be modelled or defined given additional information. Model 5 could focus on the legally involved stakeholders, as when an emergency occurs this means switching to another organogram. Includes citizens, (many) NGOs, private sector.

About fire management in Galicia:

- Legally involved stakeholders – management, partners, etc. Related just with administration; local and national government. There is a specific organigraph for the general management of wildfires, describing how they are officially linked.
- When an emergency occurs, there is a 2nd organigraph which gets deployed – for fire trucks, also from governance administration. This is driven by different stakeholders, but it is still driven by governance but with different departments.
- Important links between citizens and NGOS. Many human driving elements in fire.
    - This is related to fire management – practices they deploy in area are quite specific – involved in forest, economic, tourism in the park, urban elements.
- so private and public management not technically linked. But their behaviour impacts, and depends on, how the fire is going to move.

Model 1: collaborative information sharing

What are the Open Lab's needs in relation to the presented model?

What are your interests and needs for potential models?

- Model 1 is quite related with one of their local solutions and stakeholders.
- This is linked with the 5th model too, which could potentially feed this model 2.
- Interest here is with social capital development and public sector, in the city sense.
- 'Emergency' aspect has not really been checked. In Galicia, feedback must be done carefully as they have specific conditions within their OL.
- Good idea would be to have some information about what data we need.

How does the Open Lab see the model outputs as helping?

What are possible results which could help the Open Lab and local populations?

- Will change with more information making people feel more engaged
- How will decision be making participation impact it? Can be interested unofficially.
- Sum to be involved, engaged and practices of forest management understanding.

- Different contexts mean some not fluent asking another administration officials. Cultural reasons of how things interact between departments.
- Three keyways stakeholders can impact wildfire management
    - 1 – if there is more information, they will be more engaged.
    - 2 – how practical forest management solutions can condition fire evolution
    - 3 – how will participation in decision-making affect management.
        - Only theoretical as cannot impact the actual decision-making process.

<u>**In what format does the Open Lab need the results to help their purposes?**</u>

What form would you like the results to be in? e.g., a report, a presentation.

- Insights could include failure points, and where links are too complicated.
- missing a clear example of how model 5 would work, still an abstract idea.

Model 3: - wildfire

<u>**What are the Open Lab's needs in relation to the presented model?**</u>

What are your interests and needs for potential models?

- Important to know how wildfires move. This is a wish-list activity of the OL.
- Questions about what modelling data is needed. This could be translated and given to emergency services, who coordinate actions in a fire, so it is relevant to them.
- practical elements of management: use of forest given interests and fire evolution.

<u>**How does the Open Lab see the model outputs as helping?**</u>

What are possible results which could help the Open Lab and local populations?

- When fire occurs, physical conditions can be used to predict how it will evolve.
- Where has highest risk of burning? Spatial and temporal aspects.

<u>**In what format does the Open Lab need the results to help their purposes?**</u>

What form would you like the results to be in? e.g., a report, a presentation.

- Physical outputs will be possible.

Summary:

Several of the ideas are relevant for Galicia, in particular models 1 and 3 are the most interesting. The main constraints and concern at this point is whether suitable data is available in Galicia. To remedy this, the next stage moving forwards will be to summarise the data requirements for each model which can be discussed among the Open Lab. All model ideas are more relevant to their emergency department, who they will involve.

8.4 Dordrecht Open Lab Meeting

Models 1, 4 and 6 were marked as relevant. Models 1 and 4 are the most interesting from Dordrecht's point of view. Model 6 is less important as this is already happening within the city so the added value of a model here is unclear.

Model 2 – not important. 2 types of floods in Dordrecht (dyke breaches vs in historical city outside of dyke coverage). 5-6,000 houses flooding 0.5-1m for up to 24h. So, they are already looking at routes there, but it is a very limited area, and if it is the entire area, it does not matter because everywhere is flooded.

Model 3 – tidal nature area but no forest fires.

Model 6 – something Dordrecht are already putting a lot of effort and resources into it, so not sure what added value would be if we did something here as well.

Model 1: collaborative information sharing model.

<u>What are the Open Lab's needs in relation to the presented model?</u>

What are your interests and needs for potential models?

- Complicated but interesting idea
- Netherlands good at prevention but less evolved crisis management ability.
- from perspective of peoples' recovery and the importance of this, and to model the distribution of funds.
- Strengths of decision-making as low/medium/high, or at different tiers (executive decision making, employee who does not have decision-making power), related to decision making with probability it is acted upon, all theoretical.
    - This can be modelled with different inputs and interventions.
- There is the question of whether this would be flood-specific or generally following a shock of any type.
- We would need to decide the recovery metric we want to measure (e.g., peoples' wellbeing, shelter, food, [mental] support). Or this could focus on the distribution of funds – who gets what money for what purpose.
    - It would be feasible to focus on one of these concepts, and it would still be abstract enough for us to focus on multiple hazards.
    - This could focus on the Shelter focus within Dordrecht, which is about the historic part of the city building resilience in a way that allows it to keep its overall historic quality. *Dance between legal considerations.*
    - Or it could be focused on the overall resilience of the wider city area – what would people need to be able to cope if entire city flooded?

Model 2: Heatwave communication

<u>What are the Open Lab's needs in relation to the presented model?</u>

What are your interests and needs for potential models?

- Something being considered much more. Experiencing Southern-European type summers so would be interesting to partner with Turkey.
- In the Netherlands, people are still conditioned to build their houses suitable for cold weather. What is really needed therefore, is a change in mindset.
- Interesting for a preparedness point of view. Dordrecht is developing a heatwave communication plan which will be activated with certain temperature thresholds, so this is an area being looked into as people are not used to this hazard.
- An area of interest is, for example, how to keep buildings cool during the day. Will involve behavioural change, as presently heat is viewed as a good thing and people open windows and go outside, not understanding the dangers.

Summary:

It is hard to see the added value from model 6 so this has been excluded. Models 1 and 4 are very interesting and would like to discuss these further with colleagues in Dordrecht. We will write down all the potential focuses of model 1 to help decide what direction this could go in.

8.5 Sava River Open Lab Meeting

Model 6: greening a city: Sava is not so connected with local scale management so this could be helpful in this regard for strengthening responses on this scale. This model could be interesting and helpful for informing national authority stakeholders cooperating under the Sava Commission. It is not a priority, however.

- likes the approach of modelling as they can be reused.
- The models which were discussed further were 1, 2 and 5.

Model 5: Modelling involvement of multiple stakeholders in key decision-making

- This model is connected with organigraph task 6.3. So, considering they have already given this a lot of their own + stakeholders effort, this model is useful.
- Actions involving people who are not in the decision room. Some information comes from people outside formal structures so may introduce more information which does not feed up to the top level. Less or more willing to do things.
- Could use organigraph and play around with decision links. Supposed to understand what critical processes in decision-making are, and to gain insight.
- Local scope of area/cities and so on – offer the results to our stakeholders.
- Model 1 is supporting for models 5 and 2. Audience involved in model 5 is more like general public who are not really involved. Their people are usually decision-makers. Not just for cultural heritage and emergency in or process.

<u>What are the Open Lab's needs in relation to the presented model?</u>

What are your interests and needs for potential models?

- Sava Commission is internationally responsible for transboundary water management for sustainable development.
- During preparation of project proposal, they defined a local OL objective to **strength and network between the three sectors** responsible for flood risk management. Currently they are only cooperating with one of these.
  - Flood agency is one partner, more on basin-level than national.
  - Also, sector for CNH protection – authorities and ministries in charge of this. Prior to SHELTER, there was no communication here.
  - Third – civil protection for disaster risk management. Some cooperation here, but they do not officially have these authorities under their umbrella.
- Any model which improves the cooperation between these three sectors would be very helpful, especially if there is potential to update this continually.

<u>How does the Open Lab see the model outputs as helping?</u>

What are possible results which could help the Open Lab and local populations?

- Can easily see where there is a lack of involvement – dynamic involvement of stakeholders.

- CNH in each country is not represented enough in decision making so an improvement of this would be ideal.
- Model should give opportunity to organise themselves where they are presently, and that model point out in which part of decision making they should be involved.
- Basic tool for preparedness and each step of DRM cycle, one model which will allow info on same level about endangered CNH and who could assist to protect this CNH – which institution, which sector – who is officially responsible vs who can assist as a volunteer.
- Specific floods – who is closest, where is equipment stored for intervention – who can provide a forecast about the next event?
- **Dynamic and practical**

<u>In what format does the Open Lab need the results to help their purposes?</u>

What form would you like the results to be in? e.g., a report, a presentation.

- SavaGIS provides very formal information – flood maps etc., aimed at technical experts. There is no information for regular citizens to use.
- Hence a model could be useful for the wider public.
- If there is interest from stakeholders in a specific tool, a long-term maintenance and sustainability and use could be offered.
- Sava commission approves this if there is technical interest and decides whether the tool is mature enough to be proposed for further use.
    - Decision making mechanisms: Sava engages as a project partner to facilitate all processes & expert groups. These have nominees selected for each country.

Model 1

<u>What are the Open Lab's needs in relation to the presented model?</u>

What are your interests and needs for potential models?

- Similar expectations to model 5 – involved stakeholders as dynamic, lack of involvement with CNH, so a model to help this sector to give them an opportunity to say where they need to be involved.
- What does recovery mean for Sava?
    - still understood as building back better – always very complicated part of DRM cycle – there is not really anyone specialising in recovery. So, this is often overlooked – people focus more on prevention and preparedness.
    - Mirza acknowledges that DRM should really involve more stages and be complex. Currently, recovery = reconstruction, which he knows should be improved.
- What happens after the floods is still left behind. Recovery badly organised and only about reconstruction but should be much wider.
- peer learnings from other experiences.

- As a starting point in our case recovery equals reconstruction – not a good approach.
- Recovery metrics include insurance policies, clean-up/restoration, financial assistance, drinking water access, environmental recovery.

<u>How does the Open Lab see the model outputs as helping?</u>

What are possible results which could help the Open Lab and local populations?

- Sava commission has no budget so must be models to convince those who do – good non-structural measure.
- Scheme will be dynamic, easily see where we have a lack of involvement – already know that cultural heritage in each country is not involved enough – without an official attitude.
- the model should give opportunity to recognise themselves where they are currently in the decision-making process.
    - It could have the functionality to point out in which part of the decision making they should be involved – back to model 1 – if we have all three sectors – plus non-governmental, citizen, plus local people.
    - Information sharing between all stakeholders is a basic tool for preparedness for recovery at each step of disaster risk management cycle.

<u>In what format does the Open Lab need the results to help their purposes?</u>

What form would you like the results to be in? e.g., a report, a presentation.

- The Sava GIS portal is aimed more at technical partners so some output which is useful for the general public would be helpful.

Model 2

<u>What are the Open Lab's needs in relation to the presented model?</u>

What are your interests and needs for potential models?

- Issue recognised and a crucial turning point was May 2014 – major flood in region – 3 countries were devastated with 79 casualties. In one moment, many countries in the region tried to help each other with humanitarian aid and equipment.
- The **issue with border crossing** was really a problem. So in this sense, preparedness plans for this open lab will be very useful because this issue is one of the official non-structural measures in flood risk management plan
    - document approved by five countries (Albania is 6th but very small portion is in the basin so no official cooperation, although Albania is a member of UNESCO).
    - Albania did not approve the flood risk management plan, but this should not matter because they generally support ideas which they see as useful for them, and they attend the stakeholder workshops.

- So far there has not been any progress in this preparedness plan – just 1 of the measures listed in the plan as obligation of countries in coordination by Sava commission – so SHELTER could be a great opportunity to deal with this.
- There are some reports – standard operational procedures – SOPs– which we could analyse d to see what the experiences are from the past and from 2014.

<u>How does the Open Lab see the model outputs as helping?</u>

What are possible results which could help the Open Lab and local populations?

- *We could look at time response and resourcing – flood disaster in cross-border area – if we have info available on resourcing (vehicles, shelter, food etc) – and model what if they do not collaborate vs what if they do collaborate – and comparisons. Parameters – how long does it take to get to a site, how fast does response need to be.*
- Could involve broken or flooded routes by using a path finder algorithm.
- They have past flood maps for this which are useful, as well as more difficult information including capacities of different countries and where there are resources etc. This information exists.

<u>In what format does the Open Lab need the results to help their purposes?</u>

What form would you like the results to be in? e.g., a report, a presentation.

- Spatial data in the form of maps will be a useful output.
- Aim for it to be in cloud with other platforms, so it can continue to be used after SHELTER ends.
    - Several decision-making mechanisms. As a secretariat, Sava is engaged as a project partner to facilitate projects which then have expert groups and members nominated by each country.

If something get approved, Sava commission acts to provide support and collaborate, after they decide if the tool is mature enough for future use.

Summary:

Sava River see models 1 and 5 as one and the same, perhaps 1 as a sub-model of 5 but both are very useful. They have stressed that decision-making and governance is their top priority, so a technical model should consider this in its outputs. Model 2 is also very important as such, particularly with regards to cross-border communication during emergencies. For this model, there is some relevant data which we could utilise such as maps of previous flood extent. Dynamic, practical results are key for both. Model 6 is also relevant, though less of a priority.

9 Appendix B: Concept Note: Collaborative Information Sharing

9.1 Model Description

Model Title: Simulating the importance of collaborative information sharing for recovery between parties such as NGOs, citizen response teams, governments and local people in relation to key decision-making processes, better preparedness and greater resilience.

Aim: This model aims to improve the understanding of how information flows can either enable or hinder effective disaster recovery, dependent on how effective they are. A better understanding of the processes involved in information sharing should allow an understanding of what enables communication to be more efficient, and ultimately to refine the response process.

Context about information sharing: When a disaster occurs, the speed and efficiency of information spread between multiple organisations can be crucial in organising and executing an effective response. It has been determined by other studies that during a disaster relief workers have a greater concern with receiving information themselves rather than sharing this information onwards[41]. The result is that information is not always shared where and when it needs to be among different actors who have varying priorities. Increasingly, with the involvement of grassroots movements and individual actors in the disaster response process, this is relevant for ensuring coordination between on-site responders and centralised management authorities. Ultimately, all involved partners, governments and actors must be aware of each other's actions, or the result is inefficient disaster response.

Context about decision-making involvement: At the local level, it is important to understand how one player's involvement can strengthen modellable attributes such as enthusiasm to help and knowledge about a topic. Scaled up to regional, national, and even international scales, the same attributes can be modelled for organisations instead of individuals. Ultimately this submodel will examine whether making a person or organisation more involved with a flood management action will improve their willingness and enthusiasm to be involved with it. This feeds into the main model as information sharing may be either hindered if one party decides to take over too much responsibility alone or improved if better involvement and interest facilitates dialogues.

Context for Sava River Basin: As a large region which spans multiple countries, Sava River basin has many different actors involved in its decision-making processes. The communication and collaboration between these multiple actors can prove critical when responding to flooding. The model will therefore particularly involve exploring information sharing between differing national authorities involved to gain insight as to how this can be improved. The Sava River Commission is one example of an international body which helpfully surpasses national-level decision-making, so information from this model could be used to explore how the Commission can inform and improve international flood response, for example by encouraging the sharing of resources between countries.

Example decision-making processes resulting in better preparedness and greater resilience - Four examples of focuses for specific decision-making processes have been outlined. Each of these examples describes a desired outcome in the context of preparedness and resilience. The modelling effort aims to contextualise the information required to achieve the decisions to come to this outcome. In other words, we want to understand or obtain an understanding through the modelling effort on what decisions need to be made and which information needs to be shared among all stakeholders to come to this outcome.

Example 1: Building back better.

In the case of flooding the aim is to make sure the location's resilience is enhanced so that should a similar event occur in the future, steps can be taken to mitigate the same damage from occurring again by ensuring that the damage can be prevented as much as possible by building back better infrastructure which is more flood-proof.

Example 2: Social fabric restoration/resilience.

The aim here is to ensure resilience with regards to the social fabric of a community. The desired outcome is to learn lessons from past disasters and talk to local people to ensure a quick return to normality following a flood. Information shared with regards to this focus would include where and when resources for longer-term recovery are needed (such as building materials and money to reconstruct damaged buildings). Typically, these resources are controlled by authorities in power who need to communicate with individual people and communities, thus the more direct this communication the more effective the response.

Example 3: Knowing what to do in advance

The aim of this focus is to be able to enact an appropriate response to disasters by knowing where resources are and where help is needed. Communication flows here could include, for example, sharing knowledge between countries in the Sava River Basin relating to weather forecasts and flood warning systems. Individual actions can also relate to pre-hazard education and plans in place for how to act during a flood.

Example 4: Sharing resources between countries

The aim of this focus would be to identify where steps can be taken to relieve the pressure on emergency services of one country, by receiving help from across borders. An understanding of the efforts which need to be made is therefore important for reaching the stage where the response to flooding is international and coordinated.

Selected decision-making process by the ISRBC - Based on these different options and the communication with the International Sava River Basin Commission, the following decision-making process was selected as the most relevant and will be taken forward for the model:

The reconstruction and repair of several specific cultural or natural heritage sites. We would set a collaborative recovery effort to be modelled in a part of the Sava River Basin.

- This would take into account improved resilience for future floods, for example by using different material types for reducing vulnerability or constructing flood defences.
- We would model the decision-making process, addressing questions such as who needs to be involved in these processes if the flood occurs in a border area between Croatia, Bosnia and Herzegovina and Serbia. In this way we would explore what collaborative recovery looks like.
- This would involve selecting several sites with different characteristics.
- The modelling would be used as a tool to understand which communications could be needed between different sites.

Model variants - There were no submodules developed for this particular model. The International Sava River Basin Commission have communicated with the modellers the need to study the health impacts of flooding. Due to limited baseline information and limited expertise of the EcoWise team in this area, it was found too high-risk to move forward with this need. The ISRBC have emphasised the relevance and importance of this issue. Therefore, options for further study or evaluation of the health impacts of flooding are recommended both for the SHELTER project and the EU policy agenda in the context of resilience of CNH.

User story examples - The model descriptions of user stories have been prepared for the Sava River Basin but wherever this case study is mentioned it can be replaced with any other cultural heritage site within the SHELTER project.

Several model users' stories have been created to contextualise this model in terms of its utility for end users who will be using its outputs and make it as easily understandable as possible. This list focuses on the key user groups who are likely to be the focus of the model, these are as follows:

- ➔ As a member of the Sava River Commission I want to use the information gained about sharing networks to better understand how to improve cross-border disaster recovery.
- ➔ As a member of the Sava River Commission I want to use the model to simulate how stakeholder engagement can facilitate information sharing between parties in the basin.

- ➔ As a member of a national authority in the Sava River Basin, I want to use the model outputs to understand how working with other nations can provide beneficial outcomes to my nation during an emergency.
- ➔ As an NGO I want to use the model outputs regarding areas for cooperation to understand the information flows I need to carry out to help the greatest number of people in a flood.

Model schema and building blocks: context

A model is composed of several building blocks, each has an input, a process and an output. A set of **building blocks** is called a **'module'**, or a sub-model because it can be run on its own. The combination of all these building blocks results in the combined model. The relationship between all these results in a **model schema**, see for example figure 26.

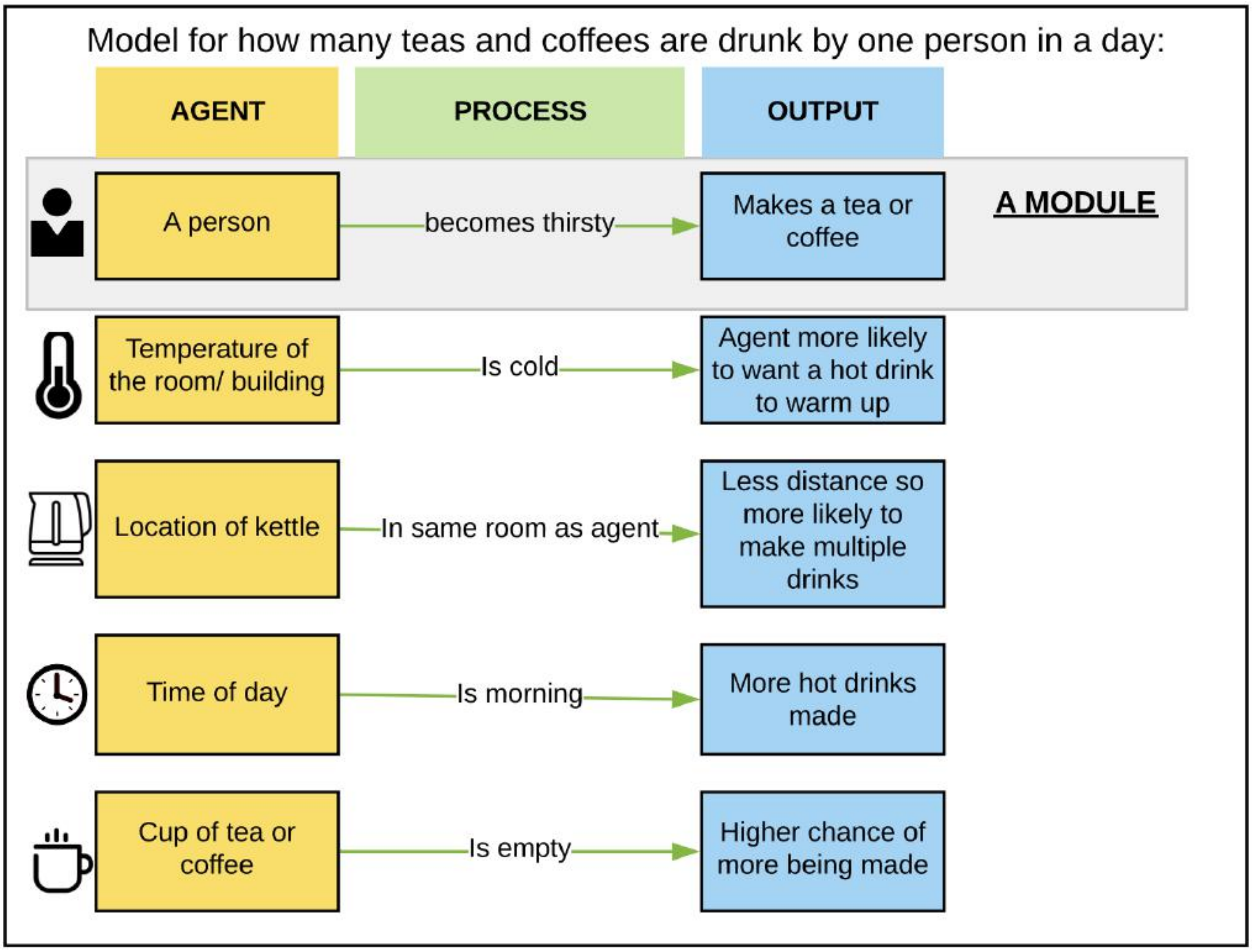


Figure 26: An example of how models are composed of 'submodules'

Figure 26 demonstrates submodules, or modules, which in turn are composed of individual building blocks in an agent → process → outcome form.

This relates to ABM in that a building block has a process where an entity changes over time and or space, for example a person (entity) becomes older when simulating time in a model. The input in the process is starting age, the process is ageing, and the output is end age.

Agent-based modelling importantly considers multiple entities which must be defined before the technical development. Each entity exists separately from each other but will be combined in the model runs. This allows simplicity for editing entity features and characteristics at various points in the process.

9.2 What are the Proposed Agents for this Model?

Before connections, processes and outcomes can be identified as above in figure 26, it is important firstly to define the agents which are present in the system being modelled. These are specified in the following table along with their possible characteristics and related processes. Important to note is that the actual implemented model will focus on only a few (2-3) characteristics per agent and related processes; this is to increase both the quality of the model and to only focus on what is really relevant and to make it possible to deliver the task. Table 40 is separated into high and low priority actors, to acknowledge the existence of many stakeholders but also focus the model to the groups who are most involved and who the model is primarily targeted towards.

High priority Actors:

Entity	Characteristics	Processes
Local government	Low budget for management; ability to initiate hazard warnings. Specific knowledge about local vulnerabilities is high.	Communicating with local communities and individuals
National government	Many other hazards and issues to allocate funding for.	Coordinates response within own country's borders but no international communication
Non-government organisation	No official links to centralised flood responses but need information of this nature.	Respond to flooding
Emergency shelter [example].	[example of a metric that could be measured]. Might also include people rescued, provision of aid parcels etc.	Has other purposes until required, based on communication with authorities.
Sava Commission (or other cultural heritage organiser)	No budget; non-structural measures preferred. In communication with all of the separate national governments.	Facilitates the communication between different governing bodies internationally.

Actors of secondary importance:

Entity	Characteristics	Processes
Citizens (categorise by vulnerability?)	Scale of individual people within flood-prone communities.	Are vulnerable to flooding, experience disaster and respond based on amount of

		hazard education and outside help.

Table 35: Entity characteristics and processes

9.3 What Would the Model Look Like?

The high-level model schema consists of a description of submodules that perform a specific function and provide for an output. An overview of these 5 modules is shown in figure 27, which also describes initial ways to link the proposed sub-models. The 5 submodules include:

Module for top-down recovery response: The first module outlined relates to the response from a top-down perspective. If two or more parties communicate and collaborate effectively, resources and help efforts can be distributed where and when they are required. If communication and collaboration is not effective or not in place however, the hazard response and recovery needs may be overwhelming with too many resources available to one group, area, or region, while other areas, groups or regions may not receive any recovery support.

Module for the flood itself: Each flood occurring in the Sava River Basin does so with differing spatial characteristics and severity. No two events are the same, however the flood itself informs the top-down response, as well as triggering an NGO into action. It may also cause emergency shelter locations to be established as safe points for evacuees to reach. The module takes in historic flood information and allows for selecting different types of flood events.

Module for communication: Communication is the cornerstone of this model idea. It is triggered following events, such as a flooding event itself and recovery event milestones with varying amounts of communication effectiveness between different levels of responders that can be altered in the model (national governments and NGOs for example), resulting in varying levels of success when planning and implementing a recovery effort.

Module for NGO first response (optional, to be evaluated): This module is envisioned as being carried out by non-governmental organisations rather than national emergency services although it is acknowledged that both will be present. Its process of carrying out first response depends on the communication between this organisation and the national 'top-down' first response module. Importantly, these organisations are not controlled by any legislation or agreements which may have been decided, and their actions are mostly independent.

Module for reconstruction and repair resource needs: This module will describe the people and equipment needs for the reconstruction and repair effort as well as any broader recovery needs for temporary rehousing of the local population, if required.

Module for on-site reconstruction and repair effort: Finally, on-site recovery is the module which provides the metric to be examined to determine the effectiveness of the communications and resulting occurring actions, or a lack thereof. This will calculate the speed and effectiveness of recovery given communications and resource availability and sharing. This could also involve rehousing requirements in addition to the reconstruction and repair of the CNH itself. Under each scenario, how quickly these housing sites are allocated, where they are located and how many people are aware of them, can be modelled factors. This will enable an estimation of how the recovery effort is aided by improved information flows.

The following figure 27 details the provisional interactions between different entities in this model.

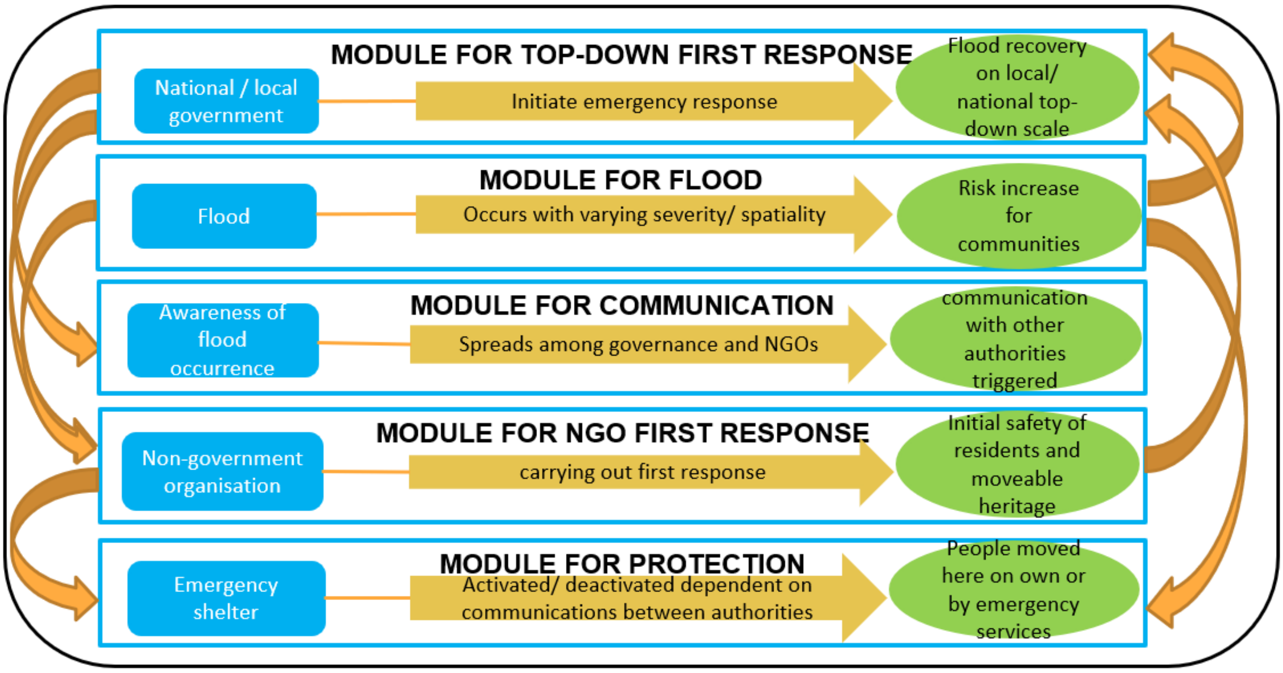


Figure 27: Interactions between entities within model

9.4 Preliminary Data Requirements for Sava River Basin Open Lab

At this stage, data requirements are broad and not final. Table 41 can therefore be considered as a generalised way of understanding the possible requirements e needed for this model. Table 41 also provides an indication of whether its requirement is necessary as a minimum for model construction, or whether it is an ideal dataset that is not needed to implement the model but would be helpful to have. Whilst an initial overview is accompanied with whether this data is publicly available and accessible, important to note is that this followed only a preliminary assessment and may not therefore represent the data available to its full extent.

Data	Description (resolution/periodicity)	Minimum requirement	Ideal requirement	Publicly available/source
Information about stakeholders at different levels	Who is involved	X		Organigraphs from task T6.3
	The governance/ communication links between different parties	X		Organigraphs from task T6.3 can be used to identify who are the key stakeholders for information flows.
Understanding of how authorities receive information	e.g., by news coverage, emergency calls, forecasts.	X		Will likely be qualitative and can be estimated. Needed to understand where information flow starts from.
Attitudes of citizens and disaster knowledge for recovery response	The current attitudes of people in response to knowing what to expect from institutions to recover from a disaster – including hazard education		X	Can be estimated based on qualitative information from the open lab or otherwise using dummy data.
Vulnerability information / affected area's	vulnerability by location relating to elevation, building types and flood defences		X	Does not have to be spatially accurate beyond broad areas.
	Location of past flood events	X		SavaGIS portal.
Population	Number of people per relevant geographic element	X		TBD

Socio-economic information	Socio-economic information relevant for recovery (e.g., housing, employment)		**X**	TBD
Recovery metric baseline information	e.g., location of temporary housing points, to be determined based on needs	**X**		Map-based.

Table 36: Preliminary data requirements to create the model

9.5 Potential Results

It is important to have an idea of what the potential results could arise from this model, both to understand the potential benefits, and to tailor the model development process. These could include, but are not limited to the following:

Planning results:

User	Result
Sava River Commission	To be able to better understand how communication improvements can help disaster response
Sava River Commission	To estimate where the specific communication flows between disaster response parties can be improved, and between whom.
Sava River Commission	To have a model which I can run to view how changing information flows can have an impact on the speed and effectiveness of flood recovery responses.
National governments	To have the potential to improve my disaster response capacity by receiving help from other national governments

Table 37: Potential planning results

Immediate response results:

User	Result
Sava River Commission	To use the model to convince stakeholders to act regarding international emergency border crossing.
Non-government organisations (NGOs)	Potential to be involved in flows of information and related coordinated actions impacting the work I carry out
National governments	To better understand how national governments in the Sava River Basin could help each other during emergencies.

Table 38: Immediate response results

10 Appendix C: Technical Note: Collaborative Information Sharing

10.1 Overall Model Structure

Summary: This model's purpose is to simulate how communications between involved parties can be improved to recover from floods within the Sava River Basin. Recovery needs are selected to explore how several specific cultural heritage sites can be restored which sit in a cross-border region following a flood. The model will allow for a comparison of the response to a hypothetical flood both before and after improved communications and information flows.

Structure: This model contains 5 modules discussed below in detail after an overview of the agents involved in the model (Figure 28). The modules are:

1) **Module for the technical and non-technical resource needs for recovery**
   - Defines required resources needed for the recovery. Potential resources include sandbags, workers, trucks, emergency housing, and special engineering and materials knowledge about CNH rebuilding.
2) **Module for the in-house capacity for supplying recovery needs**
   - Defines the emergency response organisations or similar institutions. To identify in-house capacity such as ownership of trucks, ability to set up emergency houses in a week, engineering knowledge of how to rebuild CNH. This also covers spatial location of the resources in terms of country/region.
3) **Module for communication structure to allocate recovery efforts**
   - Defines the specific communication structure required to activate in-house capacity and allocate it to specific CNH sites.
   - Simulates the communication between organisations and their networks for deploying resources to fill recovery needs.
   - Potentially introduce a negotiation element for resource allocations, to model the communication and allocation between organisations.
4) **Module for hazard resilience**
   - Uses the same communication structure to explore resilience measures including the construction of early warning systems and flood damage minimisation structures.
5) **Module for flood damage**
   - Defines the extent to which the CNH is damaged given a certain flood scenario to inform recovery needs

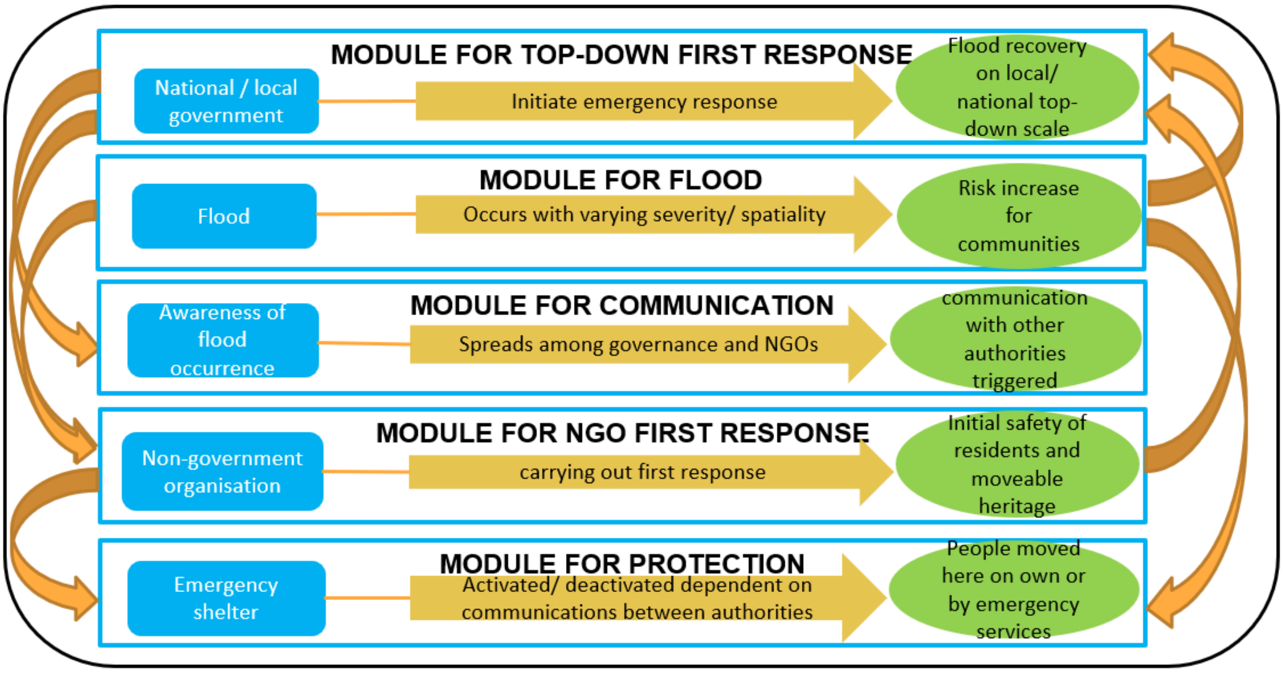


Figure 28: Interactions between entities within model

10.2 Model User Inputs for Initialisation

This section provides an overview of the mechanistic properties of the agent types in this model.

Agent initialisation - This concept simulates agents belonging to large-scale agencies and organisations. Characteristics include which country they belong to.

Agent type 1:

National government:

- A generic type of national government agent, or of an equivalent organisation which has control of flood response.
- Important to note is that individual governments defined as a generic national government agent type. Any differences which arise between the actions of different national government agents, will be the result of randomly generated actions.
- **Static characteristics:**
  - Country of responsibility
  - Communication flows from/to local governments
- **Dynamic characteristics:**
  - Speed of communication channels internally – i.e., how quickly or slowly does information move between different agencies within the larger organisation for activating resources for recovery.

  - Speed of communication channels externally - the speed of resource allocation to and between local governments and their agencies.
  - The amount of communication between national governments of differing countries.
  - Amount of resilience actions taken following the flood event. More resilience actions imply better flood response for the next event.

Agent type 2:

Local government

- This includes city/region governments who are responsible for overseeing the maintenance and repair of CNH sites.
- Within this is a sub-agent type of **the emergency response department.** They are responsible for activating an emergency response.
- **Static characteristics:**
  - CNH site of responsibility within emergency response department.
  - Communication flows internally, and with national governments, and ability to trigger response organisations.
- **Dynamic characteristics**
  - Responds to funding availability from national government but may offer a more localised response to a flood including the deployment of emergency vehicles and shelter.
  - Time taken to communicate their needs to the national government agent type which initiated the funding needed to respond.
  - Time taken for communication with its own country of authority (who in turn communicate with other national authorities)

Agent type 3:

Recovery support organisations (e.g., community organisations / NGOs / local service organisations)

- Has their own independent structure and organisation, and receives information differently compared to national and local government (e.g., organisations with specific knowledge for cultural heritage repair).
- Example roles include immediate responses such as sandbag distribution and first aid provision, or actions more related to long-term recovery
- **Static characteristics:**
    - Location of staff on the ground at the time of the hazard
    - Specific knowledge related to CNH sites and their recovery needs as well as location and risk knowledge.
    - Response time following notification of a hazard occurrence.
    - Interaction with authorities in three possible stages:
        - Full interaction and complete division of recovery efforts
        - Some communication but no division of taskforce
        - No communication
- **Dynamic characteristics:**
    - Response actions
    - Ongoing communication with other parties during hazard response phase

10.3 Module for Protection and Recovery Resource Needs

This submodel focuses on identifying the specific recovery needs for each of the sites being considered, as well as the types of organisations able to provide these needs. It contextualises the model elements of changing recovery communications between different organisations, by defining the end goal of these communications, namely the deployment of resources.

Background information/knowledge:

Three cultural heritage sites have been selected in the tri-border area between Croatia, Bosnia and Herzegovina, and Serbia. They have been selected based on the recommendations of the ISRBC as sites which are covered by the SHELTER project and because of their location. These are each located in a different country and are as follows:

1. Džamija Azizija (Azizija Mosque) in Bosnia and Herzegovina, a religious heritage asset
2. Brodska tvrđava (Fortress in (Slavonski Brod) in Croatia, a military and defence type of asset
3. Spomen kompleks "Sremski front" kod Adaševaca (Memorial complex "Sremski Front" near Adasevac) in Serbia – intangible cultural heritage which relates to memory as well as a physical site in need of protection.

Additionally, a UNESCO site was also selected. This is the Mehmed Paša Sokolović Bridge in Višegrad, situated in Bosnia and Herzegovina and near the border with Serbia.

Whilst each site has overlaps, also due to the differing characteristics of each of these sites, a different recovery effort is needed, with differing technical and non-technical requirements. Different organisations will possess the resources required to repair different CNH sites due to their construction and material makeup.

List of requirements:

- Information regarding the characteristics and vulnerabilities of each of the chosen sites in the Sava River Basin.
- Information/estimations of what each specific site requires for a complete recovery, which may depend on the level of damage experienced.
- Understanding which organisations possess which knowledge and resources to facilitate this post-flood recovery for each site.

List of processes with outputs:

- The speed at which these recoveries will occur depends on the national and local government's communication with organisations who have these resources, and the ability to deploy them.
- This module is therefore influenced by the speed of these communications, which the user specifies under module 4.6.

Input requirements:

Data need	Purpose	Dataset used (add link)
Identification of all sites specific recovery needs	To model what is required for a recovery at each site	N/A
Identification of which organisations have which CNH recovery needs	To understand what communication must take place to enable recovery	N/A
Identification of links between agents with resources and sites in need of protection.	To understand which sites need protecting as well as which organisation has the resources for providing this.	N/A

Table 39: Input requirements for protection module

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Database selection	Selection of 2/3 CNH sites for recovery monitoring along the Sava River Basin which are vulnerable to flooding.	As a user I want to contextualise the model results by visualising the outcome in the format of whether recovery is aided.
Identify specific site recovery needs	Identify and input specific organisations providing recovery needs – technical as well as non-technical – for each site	As a modeller I want to understand the needs of each site for recovery after a flood
Identify necessary communication links in place	Identify the links between national and local governments, with the organisations who have recovery resources.	As a modeller I want to identify the necessary communications which need to take place to begin the process of recovery at each site.
Input data collection	Implementing different levels of communication within recovery process modelled	As a user I want to see how different amounts of communication between different parties can change the effectiveness of disaster response

Table 40: Task breakdown for protection module

10.4 Module for Recovery Resource Capacity

This submodel refers specifically to the response within various organisations at different scales which possess in-house capacity to aid recovery efforts immediately before and after a flood.

Background information/knowledge:

The specialised nature of CNH recovery means that the locations of different recovery resources, and the organisations who supply them, are spread across a geographically large area. Natural disasters, furthermore, are characterised by uncertainty and disruption [42]. Consequently, it is important to identify where emergency recovery supplies originate to speed up the recovery process and maintain communication channels during a flood. As well as to identify redundancy of resources in case of local constraints. This is particularly true when disasters span national borders, as the size of impacts makes it crucial to coordinate communication between different national states each possessing different resources, which may be able to reach the affected area at differing speeds.

List of requirements:

- What are the organisations with the capacity to supply in-house recovery?
  - Organisations with an emergency department for securing the site
  - Organisations with site damage inspection capacity
  - Organisations with water pump deployment capabilities
  - Organisations with engineering reconstruction knowledge
- Following the information of a flood's occurrence reaching a national or local authority (module 4.6), what are the communication flows in place which ensures this knowledge reaches the organisations with the resources to trigger a response.
- Identify whether each organisation considered relies on local or national government organisations to trigger their response.
- What management solutions are put in place when a warning is triggered? (from T3.3 deliverable)
  - **Preparedness phase:**
    - Sandbags
    - Container systems
    - Shields/panels
    - Free-standing and frame barriers
  - **Response phase:**
    - Securing the site
    - Site damage inspection
    - Pumps and check systems
    - Engineering reconstruction

List of processes with outputs:

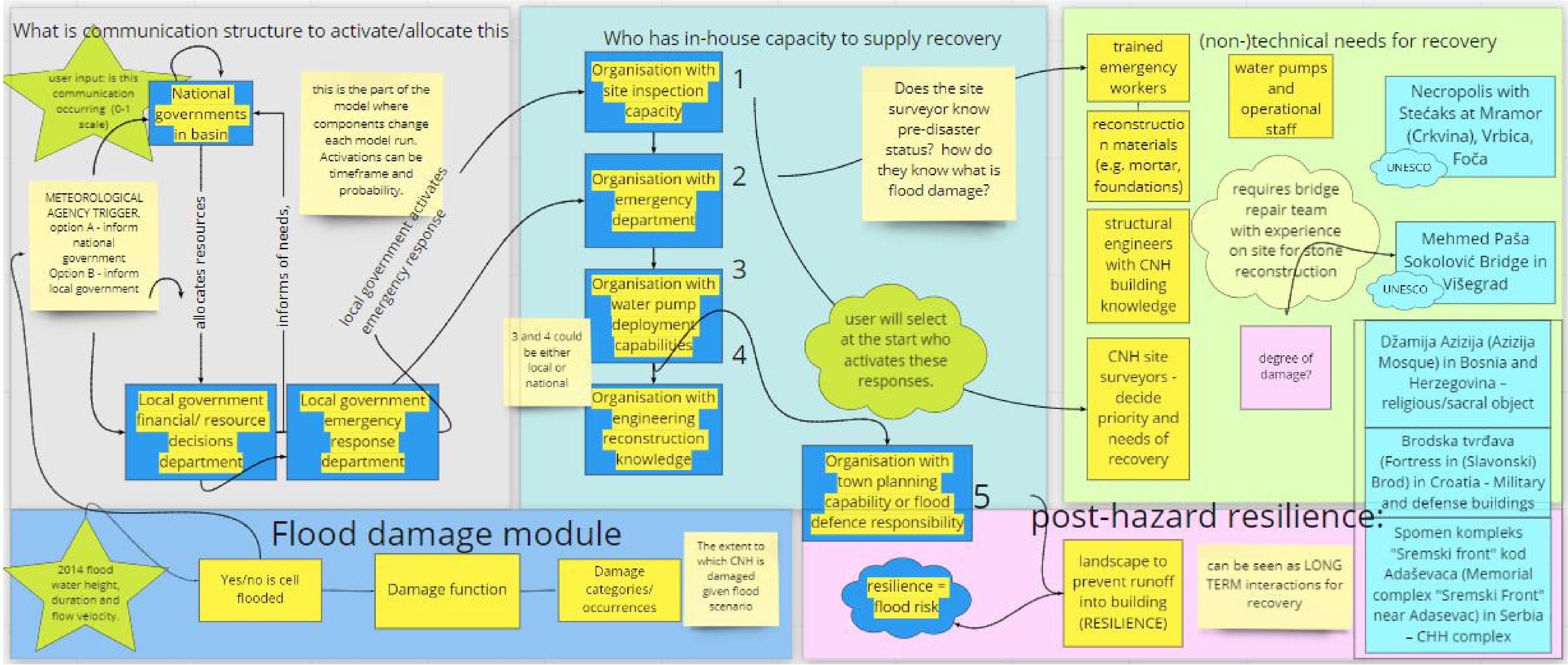
- Identify several organisations involved in site recovery
- Identify the preparedness and response resources available to the organisations

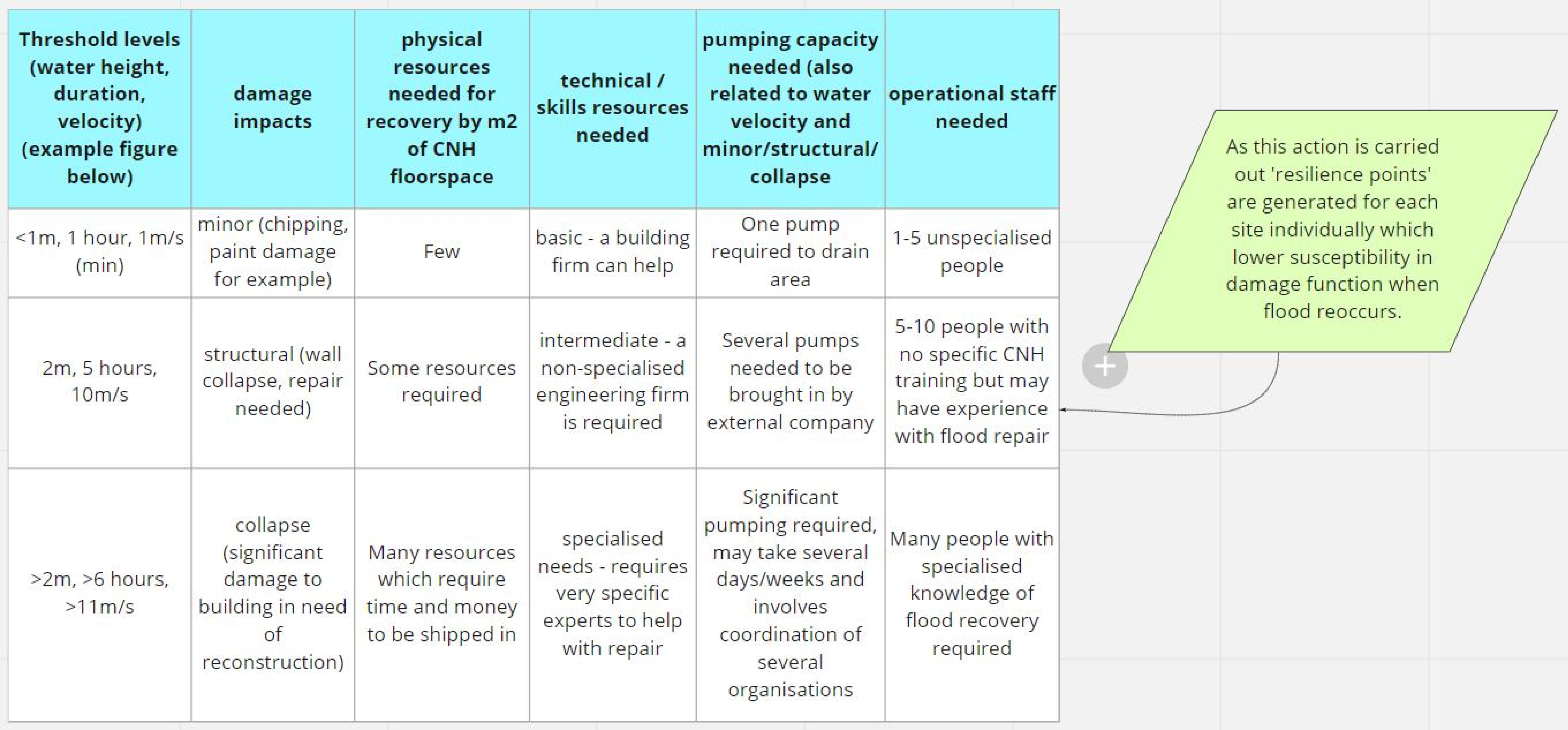
- Identify whether these organisations are triggered by national or local communications
- Identify the relevant communication flows to ensure a response is triggered
- Model the necessary links between CNH sites and the organisations with the resources they require to recover after a flood

Input requirements:

Data need	Purpose	Dataset used (add link)
List of several key organisations involved in site recovery	To model specific flood responses by specific organisations	Not available
Understanding of which specific responses are able to be carried out by which organisations	To determine the communication links that need to be modelled	Not available

Table 41: Input requirements for top-down module


What is communication structure to activate/allocate this
user input: is this communication occurring (0-1 scale)
National governments in basin
this is the part of the model where components change each model run. Activations can be timeframe and probability.
METEOROLOGICAL AGENCY TRIGGER. option A - inform national government Option B - inform local government
allocates resources
informs of needs,
local government activates emergency response
Local government financial/ resource decisions department
Local government emergency response department
Who has in-house capacity to supply recovery
Organisation with site inspection capacity
1
Organisation with emergency department
2
Organisation with water pump deployment capabilities
3
3 and 4 could be either local or national
4
Organisation with engineering reconstruction knowledge
Does the site surveyor know pre-disaster status? how do they know what is flood damage?
user will select at the start who activates these responses.
Organisation with town planning capability or flood defence responsibility
5
(non-)technical needs for recovery
trained emergency workers
reconstruction materials (e.g. mortar, foundations)
structural engineers with CNH building knowledge
CNH site surveyors - decide priority and needs of recovery
water pumps and operational staff
requires bridge repair team with experience on site for stone reconstruction
degree of damage?
Necropolis with Stećaks at Mramor (Crkvina), Vrbica, Foča
UNESCO
Mehmed Paša Sokolović Bridge in Višegrad
UNESCO
Džamija Azizija (Azizija Mosque) in Bosnia and Herzegovina - religious/sacral object
Brodska tvrđava (Fortress in (Slavonski) Brod) in Croatia - Military and defense buildings
Spomen kompleks "Sremski front" kod Adaševaca (Memorial complex "Sremski Front" near Adasevac) in Serbia – CHH complex
Flood damage module
2014 flood water height, duration and flow velocity.
Yes/no is cell flooded
Damage function
Damage categories/ occurrences
The extent to which CNH is damaged given flood scenario
post-hazard resilience:
resilience = flood risk
landscape to prevent runoff into building (RESILIENCE)
can be seen as LONG TERM interactions for recovery



Threshold levels (water height, duration, velocity) (example figure below)	damage impacts	physical resources needed for recovery by m2 of CNH floorspace	technical / skills resources needed	pumping capacity needed (also related to water velocity and minor/structural/ collapse	operational staff needed
<1m, 1 hour, 1m/s (min)	minor (chipping, paint damage for example)	Few	basic - a building firm can help	One pump required to drain area	1-5 unspecialised people
2m, 5 hours, 10m/s	structural (wall collapse, repair needed)	Some resources required	intermediate - a non-specialised engineering firm is required	Several pumps needed to be brought in by external company	5-10 people with no specific CNH training but may have experience with flood repair
>2m, >6 hours, >11m/s	collapse (significant damage to building in need of reconstruction)	Many resources which require time and money to be shipped in	specialised needs - requires very specific experts to help with repair	Significant pumping required, may take several days/weeks and involves coordination of several organisations	Many people with specialised knowledge of flood recovery required

As this action is carried out 'resilience points' are generated for each site individually which lower susceptibility in damage function when flood reoccurs.

Figure 29: Conceptual diagram for interaction between components of model

Note that the table follows on from the module for resilience outlined in the main figure.

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Identify the organisations involved in specific flood responses	To find several key organisations, who may be independent groups or part of national or local governments.	As a user I want to model how higher-level communication flows can impact the responses of these organisations
Identify whether these organisations are triggered by local or national governments	To identify which flows of communication are necessary to trigger the actions of these groups	As a modeller I need to visualise the full picture of flood emergency communication with regards to the recovery aspect.

Table 42: Task breakdown for top-down module

10.5 Module for Communication

When responding to a flood event, decision-makers must address several causes of uncertainty including, for example, the failure of defence structures designed to be relied upon in such a situation. Therefore, each organisation involved in the recovery effort has different priorities resulting in different internal flows of communication. Each organisation may not make the time to consider conveying its own knowledge to other organisations involved, such as other national governments, as each is concerned mostly with its own actions before those of others.

This module will examine the communication links both within organisations as well as between them, during and after a flood. It is the model’s intention to enable these links to vary in terms of their speed and effectiveness, similar to a real-life governance system.

Background information/knowledge: As well as the physical uncertainty about flood event parameters, human behaviour also contributes to the uncertainty around flood risk. Emergency planners must therefore take into account the actions of other such organisations when planning a flood response.

The 2014 Sava river basin flooding event demonstrated what can happen when multiple systems fail. It resulted in a flood event with characteristics that were wholly unexpected. The subsequent breakdown in communications between emergency managers, NGOs and citizens resulted in a greater vulnerability to the residents affected by the flood than would otherwise have been expected by examining physical parameters alone. There were, for example, numerous examples of people refusing to leave their homes following recommendations to evacuate during the 2014 flood. Kekez et al. (2020) speculate the cause of this as not only decision uncertainty, but also as a result of the different perceptions of evacuation effectiveness across decision-makers. As an example of how decision-makers must work collaboratively to improve coordination and therefore flood risk management.

List of requirements:

- Knowledge of all communication channels in place between different agent types.

- Understanding of where these links could be strengthened and improved.
- Links between national and local government in terms of resource provisioning in an emergency.
- Links between differing national governments and local governments who in turn communicate with internal organisations who are indirectly linked in this way.
- An understanding of the chain of communication flow triggered when a flooding event occurs for resource allocation.

List of processes with outputs:

- Links made within and between each agent type, with the ability to turn these connections on and off and to change the degree of their effectiveness, as a user-settable parameter in the model.

Input requirements:

Data need	Purpose	Dataset used (add link)
Input data selection options	Identification of all agents in place	N/A
Process links	To identify all the potential channels of communication between each agent type	N/A
User slider information	To allow the user to change the effectiveness of the communication links with each model run.	N/A

Table 43: Input requirements for communication module

Breakdown of tasks in user story format:

Type of task	Description	Desired outcome
Input data collection	Identification and initialisation of the agent types	As a user I want each type of organisation to be represented
Process links introduced	Creating links between each agent type	As a user I want to visualise the different links that reveal themselves between different organisations
Input user slider	Ability for user to change speed of communications in this structure	As a user I want to determine the consequences of slowing down or speeding up the speed of information sharing in the model.

Table 44: Task breakdown for communication module

10.6 Module for Resilience (pre and post-hazard)

Here we would have a case where an external organisation provides certain resilience services, and we explore whether this is communicated or not. A subsequent flood will then be modelled to allow a comparison before and after the introduction of these measures.

Background information/knowledge - Resilience measures can be strengthened by involving several stakeholders and by communicating actions between different parties of interest. These measures can be implemented both before or after a disaster has occurred, to reduce the impact of future events. For example, flood defences may be installed to prevent banks being overtopped under future conditions, or landscaping may be carried out to reduce the risk to individual buildings.

List of requirements:

- Understanding of which resilience measures would benefit each site being considered in the basin.
- Understanding of how organisations with town planning capability, or flood defence responsibility, or similar, are activated before or during the flood recovery process.

List of processes with outputs:

- Determine which of the resilience measures the relevant organisation could carry out that will be modelled.
- Determine which communication flows need to take place to enact such resilience measures.
- Determine how this resilience could change the recovery process of a further flood event in terms of severity and also the speed of response.

Input requirements:

Data need	Purpose	Dataset used (add link)
Input links between resilience mechanism and organisation in charge of it	To visualise the link between the mechanism and the organisation.	

Table 45: Input requirements for NGO first response module

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Select a resilience measure to implement	Select a resilience mechanism to enable the comparison of the model both with and without this implemented.	As a user I want to understand the impact of introducing resilience measures with reference to different sites. Specifically how would this change the recovery speed and links between agents during a subsequent flooding event.

Table 46: Task breakdown for NGO first response module

10.7 Module for Flood Damage

Background information/knowledge - The Sava River Basin is subject to heavy autumn rainfall periods which cause flash flooding, as well as spring snowmelt causing slower, but equally damaging, flooding. This varies within the basin according to topography and other factors and can be modelled [43]. The 2014 flood event is an example of one in which multiple uncertainties compounded to cause a situation that was both unexpected by decision-makers, and severe [44]. Due in large part to the almost simultaneous overtopping of two dikes, an estimated volume of 80 million m^3 was discharged into the surrounding land in Croatia. Climate change, and other unknown factors, contribute to the uncertainty about how flood events will play out in the Sava River Basin, now as well as into the future.

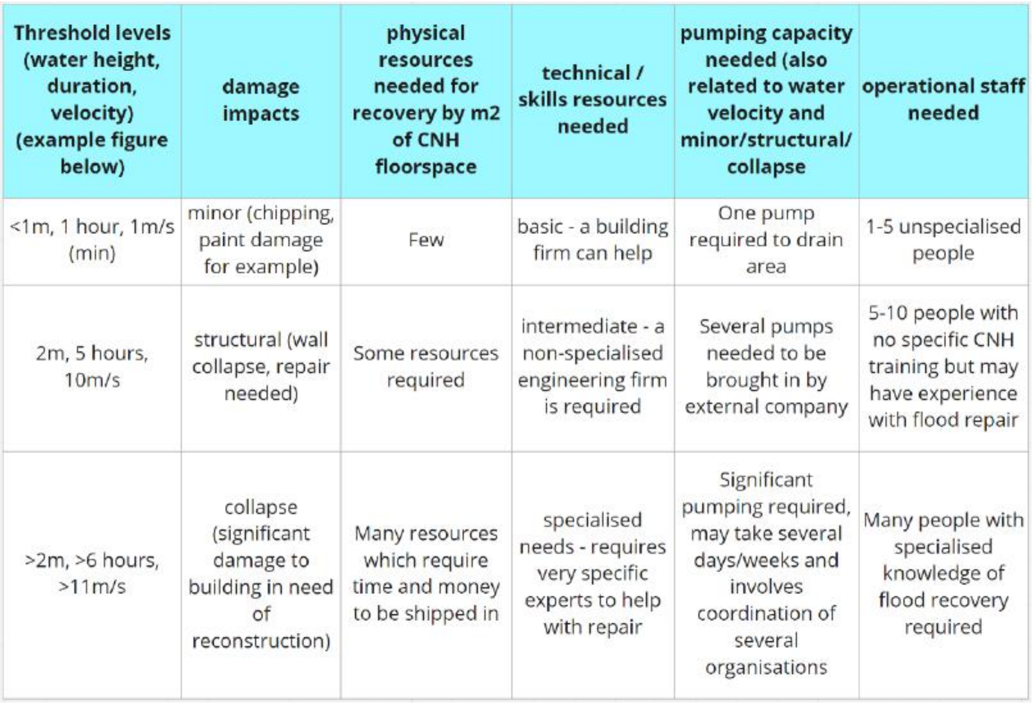
Flood modelling has become increasingly advanced, and complex, in recent decades and as such there exists many ways to transform historic flooding data with land use and ground type information into potential future floods [45]. These include 2d shallow-water models, drainage network coupled urban surface models, and hydrological models coupled to hydrodynamic urban flood models, all of which have varying levels of computational intensity. Given the purpose of this model within the SHELTER context is to understand recovery from flooding, and not the flooding process in itself, it was decided that a more general damage function is sufficient in relation to past flood events. It was therefore decided to translate damage for parameters from the 2014 flood event into potential damage for other locations along the Sava River, should a similarly devastating event occur again.

List of requirements:

- Flood parameters for the 2014 Sava River flood event.
- Depth-damage function for flood.

List of processes with outputs:

- Computer code to read CSV files of flood depth at different locations on the Sava River to determine yes/no if a cell is flooded or not.
- Computer code to superimpose future climate change scenarios on present conditions.
- Overlaying of flood scenarios onto a map of the Sava River Basin which demonstrates the location of both flood defences and cultural heritage sites.
- CH damage function applied to flood depth information to determine how much damage can be expected at each site.
- CH damage divided into three categories depending on its extent (minor, structural, collapse), according to table below.



Threshold levels (water height, duration, velocity) (example figure below)	damage impacts	physical resources needed for recovery by m2 of CNH floorspace	technical / skills resources needed	pumping capacity needed (also related to water velocity and minor/structural/ collapse	operational staff needed
<1m, 1 hour, 1m/s (min)	minor (chipping, paint damage for example)	Few	basic - a building firm can help	One pump required to drain area	1-5 unspecialised people
2m, 5 hours, 10m/s	structural (wall collapse, repair needed)	Some resources required	intermediate - a non-specialised engineering firm is required	Several pumps needed to be brought in by external company	5-10 people with no specific CNH training but may have experience with flood repair
>2m, >6 hours, >11m/s	collapse (significant damage to building in need of reconstruction)	Many resources which require time and money to be shipped in	specialised needs - requires very specific experts to help with repair	Significant pumping required, may take several days/weeks and involves coordination of several organisations	Many people with specialised knowledge of flood recovery required

Figure 30: Damage categories

Input requirements:

Data need	Purpose	Dataset used (add link)
Historic flooding data from 2014 event for Sava River basin	To understand what parameters caused severe flooding historically in the Sava River Basin	
Topographical map of Sava River Basin tri-border area	To superimpose flooding information onto the area of CNH interest	
Damage function for flooding extent	To assign a damage score to each CNH site that is marked as inundated under flood conditions	

Table 47: Input requirements for flood module

Breakdown of development tasks in user story format:

Type of task	Description	Desired outcome
Input data collection	Reading a csv file which contains flood depth information for 2014 flood event	As a modeller I want my model to be able to read a pre-formatted CSV file
Perform damage function	Using a pre-defined depth/damage function to determine a damage score for each CNH site in the tri-border region	As a modeller I want a damage score to be applied to my model to determine the severity of impact.
Damage categorisation	Assigning a score threshold for three levels of damage.	As a modeller I want a simplified way to simulate a building being damaged from a flood

Table 48: Task breakdown for flood module

11 Appendix D: Concept Note: Access Routes

Introduction

After the initial presentation of the Open Lab leaders and partners to the 6 selected models, ideas were exchange by each Open Lab which allowed model concepts to be developed in detail. The result is a 10-page concept note for each model as a next step in the Task 2.6 process. This involved building upon the initial model ideas with detail about why and how its outcomes would be used. The models were made more specific to the discussed needs to refine them to make each model suitable to the needs of the Open Labs. The outcome of this concept development stage is presented in this document.

Concept stage rationale

This document provides one of the five developed model concepts for the task. The reason to develop these concepts is that it is important before development to gain an overview of how a model will work, along with proposed data inputs and resulting outputs, to ensure a structure and productive model implementation process. This also allows the Open Labs to ensure that the model is within their expected vision, and to propose changes where they see it as relevant to do so. Furthermore, whilst descriptions and data requirements listed here are not comprehensive or set in stone, this should allow an Open Lab to initially think through the data sources which are available to them and determine what could be useful for the model implementation. Equally, if a data source is deemed essential and not available either open source through the internet, or through the Open Lab, then a data restructure will be required before the next step of developing the model's technical overview.

SHELTER context

Task 2.6 contributes to the SHELTER objective of improving resilience by using an operational knowledge framework within vulnerable areas of cultural and natural heritage. The models which will be created for the purpose of this task, while using at times imperfect data, will contribute to the knowledge framework objective of SHELTER. In specific, they do so by operationalising concepts of preparedness and resilience for different model use cases, by establishing qualitative, semi-qualitative and quantitative insights that can be acted upon. The outputs of the models developed are aimed primarily at the Open Labs and associated local and regional government stakeholders, to create visibility on potential improvements in current operational frameworks.

Models and open Lab context

Initially 6 models were selected for potential implementation based on the discussions with the Open Labs as follows:

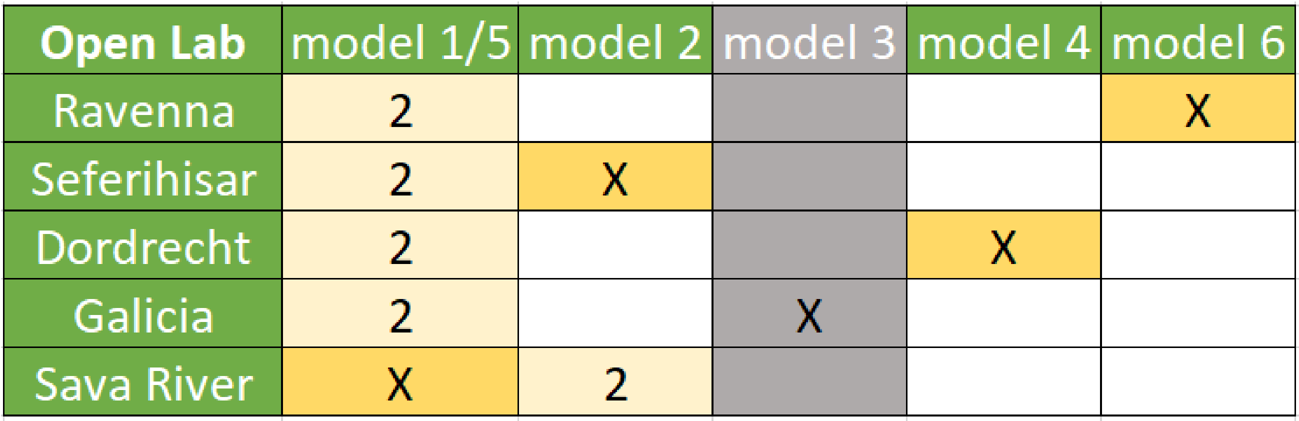
- Model 1: collaborative information sharing and recovery response
- Model 2: access routes for emergency services
- Model 3: wildfire evolution and management practices

- Model 4: heatwave communication and mitigation for preparedness
- Model 5: Involvement of different users and willingness to act
- Model 6: Greening a city for flood reduction

Based on an iterative evaluation it has been decided to merge the model concepts for model 5 and model 1 due to large similarities in the concepts. It also has been decided to currently put on hold the development of model 3 following discussions with Tecnalia and Galicia Open Lab, given changes in the requirements.

Out of the remaining four models (model 1 + 5), model 2, model 4, and model 6, this concept note outlines details model 2.

This concept note is for model 2 and based on discussions with Seferihisar as the lead 'lighthouse' open lab proposed for this model, and the other Open Labs as 'followers'. Here borrowing from the lighthouse-follower cities concept from H2020 Smart Cities and Communities, where the lighthouse city implements a use case, and the follower cities co-learn from it. As such, this document is tailored to Seferihisar from a data requirement perspective. Table 1 demonstrates the lighthouse models, shaded in yellow, who the models will be primarily directed towards.



Open Lab	model 1/5	model 2	model 3	model 4	model 6
Ravenna	2				X
Seferihisar	2	X			
Dordrecht	2			X	
Galicia	2		X		
Sava River	X	2			

Table 49: Open Lab model preferences

In table 49, a cross indicates a top priority model, the number 2 implies a model will be a secondary development later on in the Shelter process. Darker yellow shading is the lighthouse Open Lab. Model 3 is greyed out as it is currently on hold following discussions with Tecnalia and the Galicia Open Lab.

Timeline of task

Figure 31 provides an overview of the task process, from the development of these model concept documents until the end of the task action period. The most important periods are the technical specification of models which will begin development following feedback between April and May 2021.

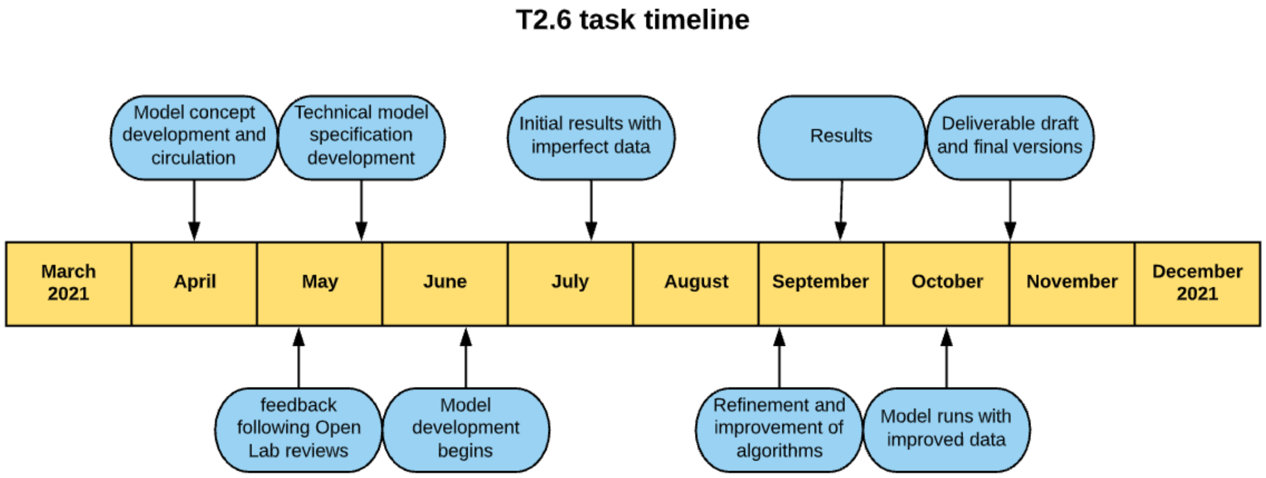


Figure 31: An outline of the timeline for this task

11.1 Model Description:

Title: Simulating for preparedness plans the number of access routes to determine how emergency services could travel after a disaster.

Aim: An understanding of where access routes are located, whether they are accessible and low-risk to traverse after a disaster as well as their characteristics such as road size, is important for disaster response. It is critical to have an understanding of which routes are most accessible following a disaster, as well as local effects which could render certain routes impassable. This is to ensure emergency vehicles travel to where they need to be as quickly and efficiently as possible, which does not always mean taking the fastest route.

Model variants

In addition to the core model outlined above, based on discussions with each Open Lab as to what they find useful, two sub-models have also been specified as particular focuses for this model. They are as follows:

**** It is important to note at this stage that, because of the tailoring of model 1/5 to the needs of Sava River, this model will firstly be carried out using variant A, specific to Seferihisar. Later on in the Shelter timeline, if there is possibility, the model will be tailored to Sava River using model variant B. ****

11.2 Model Variant A – Specific to Seferihisar

Context: In Seferihisar, the Citadel area has only a few routes into it and not all entrances are large enough for emergency vehicles to enter by. Furthermore, local activities such as market stalls may be blocking the way of these vehicles. There is a need to determine the fastest routes that are cleared and can directly be travelled through for emergency vehicles entering the citadel. Equally, given a disaster within the citadel itself, the limited exits could prove hazardous for those inside who respond differently when trying to escape to safer ground.

Variant: This sub-model has two potential focuses, of which one will be modelled. Firstly, this could focus on the movement of emergency vehicles into the citadel. The results of a model could help to inform alerts, for example, to be received by local people who own market stalls, in order to tell them to move out of the way before the arrival of a large emergency vehicle so as not to hinder its progress. This also involves the idea of a first responder team, which could be modelled to understand how information can flow in a community between nominated “street leaders” and their neighbours/tourists in the vicinity. They could provide status updates, for example detailing the risk of secondary hazards such as tsunami risk and therefore whether there is a need to evacuate the citadel or not.

Secondly, the model could instead explore the exit of people from the city following a disaster such as an earthquake in the citadel itself. Two scenarios could be modelled, firstly with a moderate or low intensity earthquake where people stop their actions momentarily, or secondly a severe event which causes people to try to leave the citadel area. The historic nature of the citadel, including city walls vulnerable to collapse and secondary hazards such as fire outbreaks and tsunami, may encourage people to want to escape to higher or more open spaces. People act differently when in danger, and this will vary depending on those around them and their hazard knowledge, among other factors. Exit times from the citadel therefore vary, and this can be modelled to inform planning and evacuation decisions.

11.3 Model Variant B – Specific to Sava River Basin

Context: Within the Sava River Basin, international borders prove an issue when coordinating flood response between different countries. Particularly when a flood event spans multiple countries in the Basin, or when an event occurs near to a border, international communication and cooperation can prove instrumental to an effective flood response.

Variant: The sub-model will centre around one key response effort. This will be selected after a consultation with the Open Lab, but could include for example rescuing people, providing emergency shelter, or bringing resources such as sand bags or food. Within this, emergency planners could exist at various scales ranging from regional, to national as well as international organisations. The model would explore the links between cooperation and information flows to identify the benefits of information and resource sharing for the purpose of disaster response (for example the sharing of emergency vehicles).

User story examples

Several model user stories have been created to contextualise this model in terms of its utility for end users who will be using its outputs, and make it as easily understandable as possible. This list focuses on the key user groups who are likely to be the focus of the model, these are as follows:

Variant A user stories – specific to Seferihisar

- ➔ **User stories for model users:**
- ➔ As the municipality of Seferihisar, I want to use the model outputs regarding emergency alarm triggers to ensure my citizens react appropriately to minimise response times of emergency vehicles.
- ➔ As the fire department of Seferihisar, I want to use first responders to help spread information about a hazard and status updates as quickly and efficiently as possible.
- ➔ **User stories for indirect model users:**
- ➔ As a market stall owner in Seferihisar, I want to be able to use an emergency warning result so as not to hinder vehicles responding to an emergency situation.
- ➔ As the local transport police, I want to close roads entering the citadel to non-emergency vehicles if the need arises during an emergency.

- As a first responder, I want to inform my neighbours of when secondary hazard risk is low, or when it is high and they should leave the area.
- As someone who lives or works in the Citadel, I want to respond appropriately when a disaster occurs.

Variant B user stories – specific to Sava River Basin

- As a national/regional emergency planner, I want to use information generated about response times of emergency vehicles and the availability of routes to best plan evacuation routes and prepare citizens for this situation.
- As an international organisation in charge of basin-level disaster response coordination, I want to use information about collaboration to involve all important stakeholders in disaster response as well as mobilising resources internationally when the need arises.
- As an emergency vehicle driver, I want to use the information about which routes are available to be able to respond as efficiently as I can to an emergency situation, wherever it may be.

Model schema and building blocks: context

A model is composed of several building blocks, each has an input, a process and an output. A set of **building blocks** is called a **'module'**, or a sub-model because it can be run on its own. The combination of all these building blocks results in the combined model. The relationship between all these results in a **model schema**, see for example figure 32.

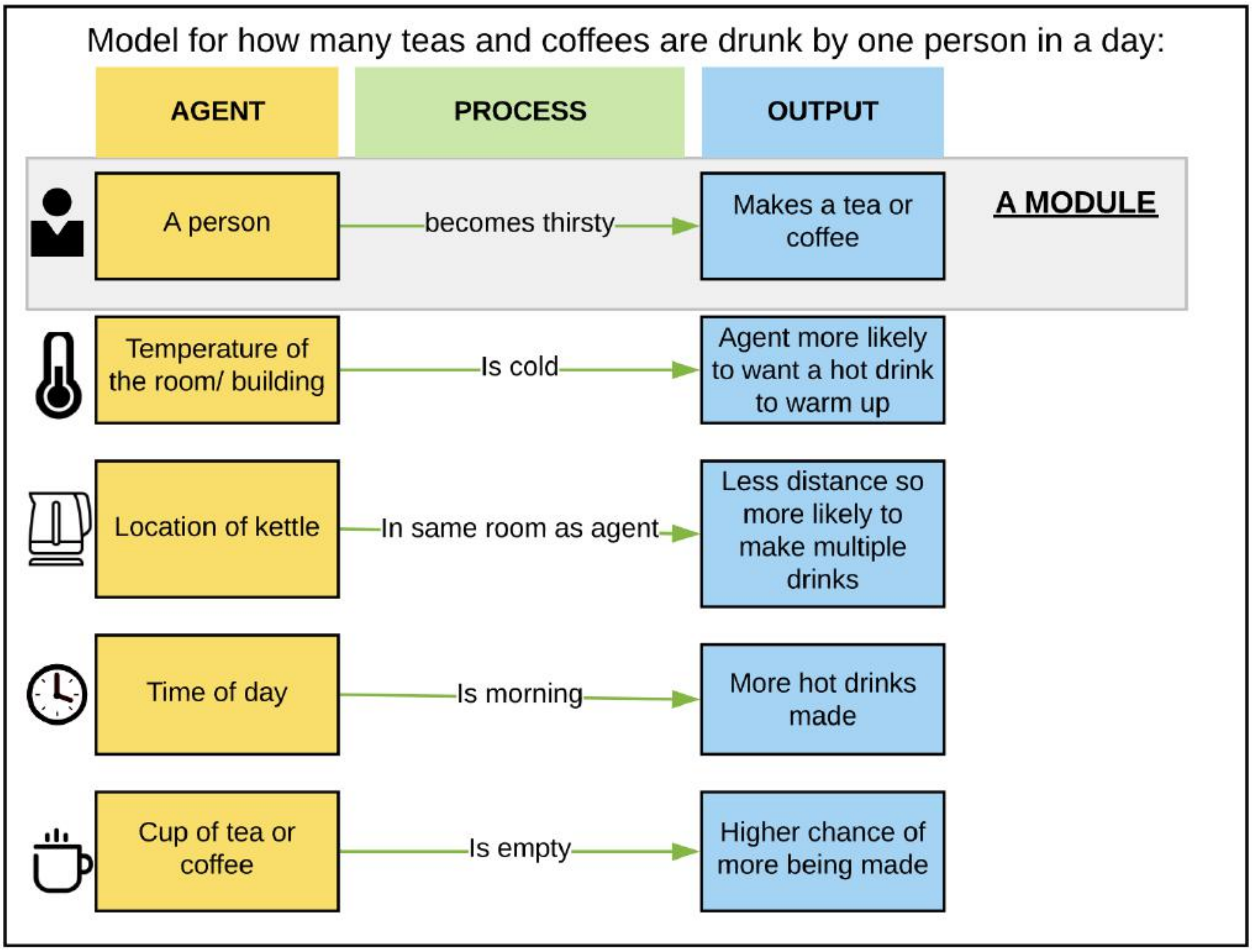


Figure 32: An example of how models are composed of 'submodels', or modules

This relates to ABM in that a building block has a process where an entity changes over time and or space, for example a person (entity) becomes older when simulating time in a model. The input in the process is starting age, the process is ageing and the output is end age.

Agent-based modelling importantly considers multiple entities which must be defined before the technical development. Each entity exists separately from each other, but will be combined in the model runs. This allows simplicity for editing entity features and characteristics at various points in the process.

What are the agents in this model?

Before connections, processes and outcomes can be identified as above in figure 32, it is important firstly to define the agents which are present in the system being modelled. These are specified in the following table along with their possible characteristics and related processes. Important to note is that the actual implemented model will focus on only a few (2-3) characteristics per agent and related processes; this is to increase both the quality of the model and to only focus on what is really relevant and to make it possible to deliver the task.

Sub-model A actors:

Seferihisar:

Entity	Characteristics	Processes
market stall owners	Composed of individuals, but messages can spread via word of mouth. Carry out day-to-day activities such as opening and closing market stalls.	Act individually to respond to alarms and move items blocking road or exit citadel.
Emergency services	Respond from fixed locations and require citadel access for vehicles such as fire trucks.	Move from a fixed point into the citadel when a trigger occurs, e.g. an emergency phone call or an earthquake.
Emergency planners – AFAD (ministry of disaster and emergency management)	Low budget as have to plan for all types of hazards. High knowledge about hazards and processes. Low communication which is often an issue.	Bring into force emergency preparedness plans and contribute to modes of emergency communication.
Visitors*	Not necessarily tourists; just someone who is on the street at the moment of disaster. In public space.	May be unaware when risk is high so participate in normal activities such as tours, museum visits, dining out and shopping.
Citizen first responders	Trusted members of the community such as market stall owners. Roughly 1 per street	Receive text updates during emergency, e.g. informing of secondary hazards. Also trained in first response to help those around them.

**Visitors is a potential agent but this complexity may not be necessary or feasible. Currently this is just speculation that their responses to emergencies are different.*

Sub-model B actors:

Sava River Basin:

Entity	Characteristics	Processes
Regional government emergency planning department	Low budget for management; ability to initiate hazard warnings. Specific knowledge about local vulnerabilities, and what can be done.	Communicating with local communities and individuals, hard intervention measures.
Emergency services (vehicle drivers,	Respond from fixed locations Require road access	Move from a fixed point. Potential for movement

boots on ground response teams)		across borders with the right cooperation.
International scale emergency coordinators	Know what resources there are, have a technical understanding of the hazard, and potential response needs and support identification of which resources need to be pooled together to respond adequately.	Communication and coordination; also permission seeking. Agreements to be able to talk to the right people/governments.

Table 50: Entity characteristics and processes for each sub-model

11.4 What would the Model Look Like?

The high level model schema consists of a description of several of the most important submodels which it could contain. Whilst having less detail than the entity descriptions in table 50, this is intended to provide a high-level overview of the modules that could be contained within the overall model. An overview of these modules can be seen in figures 332 and 34, which also describes some initial ways in which these could link together.

Figures 33 and 34 details the provisional interactions between different entities in this model, with an 'input, process, output' format as in figure 32.

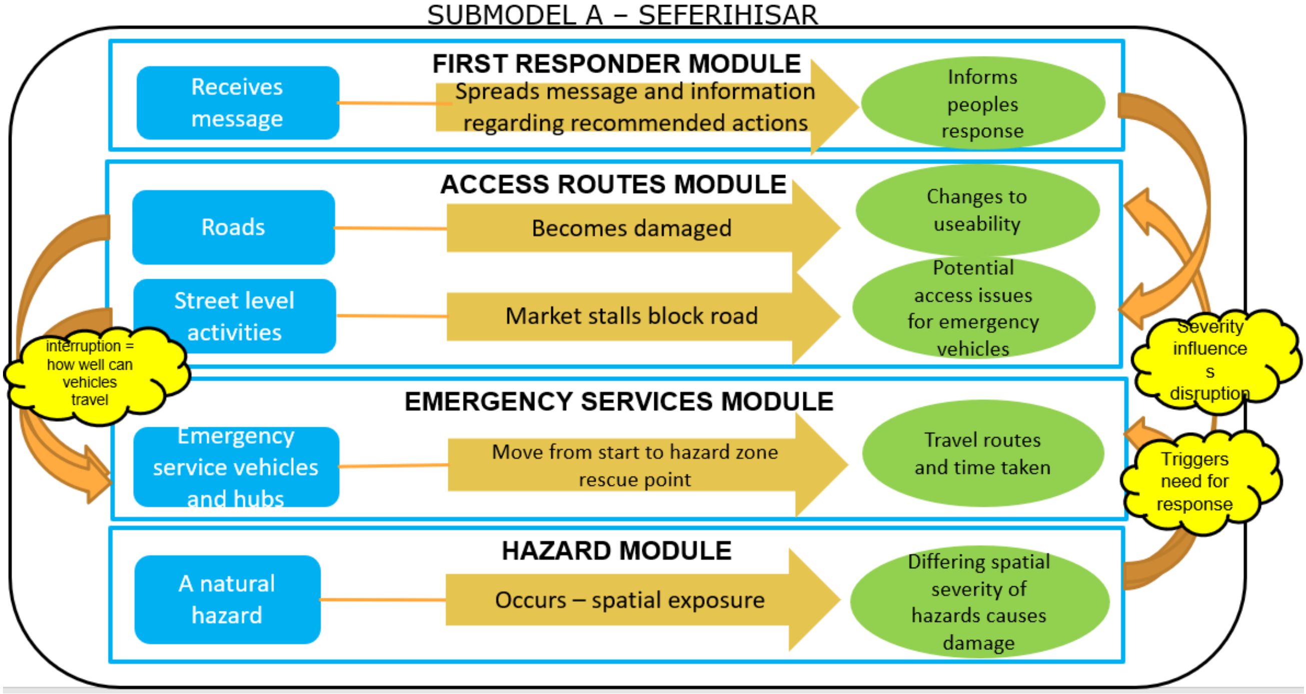


Figure 33: Interactions between entities within sub-model A.

SEFERIHISAR MODEL:

Module for first responders: Within this proposed model, the first module described is the citizen first responder, who receives a message and alerts people nearby. This could be one per street or more, however it is suggested to be members of the community who are trusted such as market owners. The outcome of this module is people being informed in their responses when a hazard occurs, such as whether to move for emergency vehicles to enter the citadel, or whether there is a risk of a secondary hazard such as fires or tsunami following earthquakes. This in turn influences whether people try to evacuate the city or if they carry on with day-to-day activities.

Module for access routes: The second module relates to access routes. It is important to understand what the potential routes and blockages are within the Sığacık Citadel, which could pose access issues during an emergency event. Within this module there are two components, one pertaining to the roads and routes themselves and the other relating instead to the street level activities which could cause these blockages. The roads themselves may become damaged and blocked with debris, and this module will also explore the size of different entrances to the Citadel in relation to the size of emergency vehicles to determine when access would be an issue. This ultimately relates to changes in the useability of the roads. Secondly, street-level activities are an important component of this module because market stalls, tourist activities, parked cars etc. can pose a threat to accessibility. The process here is therefore market stalls (among other factors) blocking the road, and the outcome is potential access issues for emergency vehicles which will be explored through this part of the model. Alternatively, if it is preferred by the Open Lab, this module can instead focus on roads and street-level activities with the focus of how it impacts people trying to exit the citadel in an emergency.

Module for emergency services: Thirdly, the emergency service module will investigate the movement of the emergency vehicles themselves once an alarm or phone call triggers their action during a hazardous event or its aftermath. These vehicles begin at a fixed location, for example ambulances are deployed from hospitals nearby whilst fire vehicles are deployed from fire stations. Following this starting point, a route is then determined based on which roads are the most direct, where blockages occur, and other factors depending on situation specificity. These factors all eventually culminate in the travel routes and the time it takes for the vehicles to reach the area where they are needed.

Module for a hazard: Finally the hazard module explores the hazard itself which the vehicles are responding to. This could include, in the case of Seferihisar, an earthquake and/ or subsequent tsunamis or landslides; heat exhaustion due to a heatwave requiring medical assistance; or wildfires breaking out outside of the Citadel itself. The process considered in this module is the hazard occurring itself, with details relating to its spatial exposure and temporal nature. This leads to an output which is an understanding of the severity of hazards causing varying amounts of damage, depending on factors specific to the hazard itself. The hazard module triggers the need to activate the emergency service response module.

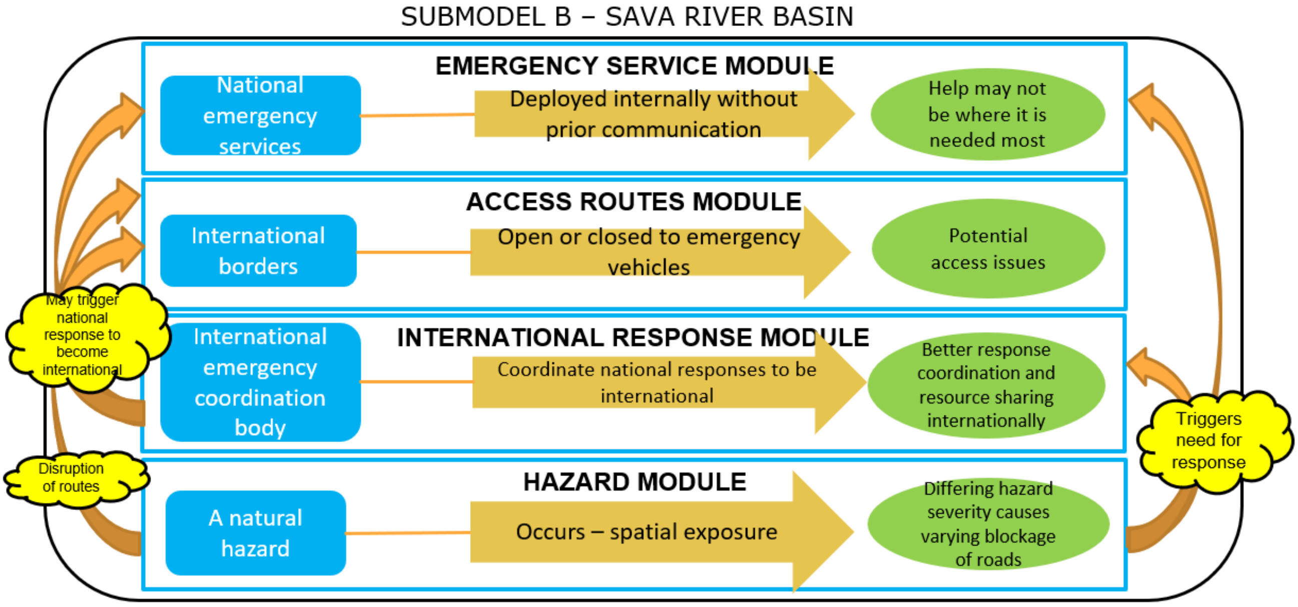


Figure 34: Interactions between entities within submodel B.

SAVA RIVER BASIN MODEL:

Module for emergency services: Within the sub-model intended for the Sava River Basin, the first module is that of emergency services, on a national or regional scale. Upon the occurrence of a disaster, these are deployed nationally at first, as primarily they respond to their own citizens. Without any international coordination, these follow the process of being deployed internally and provides the outcome of helping people not necessarily in the most effective way which makes use of international resources. For example, if a flood occurred in the border regions of one country but the nearest emergency service station was in another country across the border, the response would be more effective if both countries' resources were coordinated to enable a response as quickly as possible.

Module for access routes: Secondly, the access routes module describes international borders themselves which are generally either open or closed and thus can hinder movement even when this communication does occur, leading to potential access issues.

Module for international response: Thirdly, the international response module consists of an agent which is an international emergency body spanning the interests of multiple countries in the region. They are seen as a body which is aware of emergency situations wherever they may break out, and which can therefore inform national-level responses. This may involve making recommendations based on where a disaster occurs, where resources are, and where help is needed. This therefore acts as a trigger for activating the models relating to emergency service deployment, as well as the need for access route involvement.

Module for the hazard: The final module considered within this submodel is the hazard module itself, which occurs over a spatial area and causes differing severity based on where it occurs. This module interacts with the international response module as the hazard itself is what determines the need of international involvement and coordination of national responses. The hazard module also feeds into national-scale responses, for the same reason, before they can be coordinated internationally.

11.5 Preliminary Data Requirements for Seferihisar and Sava River Open Labs

At this stage, data requirements are broad and not final. Tables 51 and 52 can therefore be considered as a generalised way of understanding the possible requirements which might be needed for this model. Tables 51 and 52 also provides an indication of whether its requirement is necessary as a minimum for model construction, or whether it is an ideal additional parameter. Whilst an initial overview is accompanied with whether this data is publicly available and accessible, important to note is that this followed only a preliminary assessment and may not therefore represent the data available to its full extent.

Table 3a: Preliminary data requirements for Seferihisar Open Lab, for model variant A.

SEFERIHISAR

Data	Description (resolution/periodicity)	Minimum requirement	Ideal requirement	Publicly available/source
Access routes	Map of routes into the citadel	**X**		Discernible using google maps.
	Detailed map of the citadel area including roads in and out, and entrance locations.		**X**	If one is not publicly available it can be created.
	Information about the size of different entrances		**X**	Measurements from internet. To be able to determine whether fire trucks/ ambulances can easily pass through.
Location of emergency vehicles	Locations to use as the start point for the path finding algorithm	**X**		Not publicly available but could be estimated using google maps and local knowledge.
	Locations of vehicles plus how many emergency vehicles there are		**X**	Not public knowledge.
	Information about vehicle size	**X**		Could be supplied by emergency services themselves or found online.
Knowledge of the current warning action	Information about how people currently react when a warning is issued or when there is a hazard	**X**		May be qualitative.
	Knowledge of the current warning measures in place	**X**		Qualitative. e.g. sirens, phone alerts when a disaster occurs or when a vehicle needs Citadel access?
Local activities (daily/ weekly event schedule	Repeated events such as market days which could block entrances		**X**	Internet, word of mouth.
	Estimation of number of people who would be in the Citadel at different times of day/year.		**X**	Tourism sites, local knowledge and estimates. Does not need to be exact.

Hazard knowledge	Location of past disaster events in Seferihisar		X	Hazard databases such as CRED disaster database: EM-DAT | The international disasters database.

Table 51: Preliminary data requirements to create variant for Seferihisar

Table 3b: Preliminary data requirements for Sava River Basin Open Lab, for model variant B.

SAVA RIVER BASIN

Data	Description (resolution/periodicity)	Minimum requirement	Ideal requirement	Publicly available/source
Access routes	Map of routes between borders.	X		Discernible using google maps, SavaGIS and similar.
	Detailed map of the region, including roads and locations of fire vehicle stations, ambulances etc.		X	Ideally in digital format to be incorporated into the model.
Location of emergency vehicles	Locations to use as the start point for the path finding algorithm.	X		Not publicly available but could be estimated using google maps and local knowledge.
	Locations of vehicles plus information about how many emergency vehicles there are.		X	Not public knowledge.
Hazard knowledge	Location of past disaster events in the Sava River Basin.	X		Hazard databases such as CRED: EM-DAT | The international disasters database. Also Sava GIS Geoportal.
National disaster responses	Qualitative understanding of how communication flows between play out internally within a country.	X		Qualitative
International communication	Qualitative understanding of how different countries communicate their disaster responses across borders.		X	Qualitative – could use examples of how communication plays out elsewhere with other hazards.

Table 52: Preliminary data requirements to create variant for Sava River Basin

11.6 Potential Results

Finally, at this stage it is important to recognise the potential results which could arise from this model, to tailor the process as it develops. These could include, but are not limited to, the following:

Potential results for model A:

Seferihisar

User	Result	Type of result
Local residents and business owners	Potential to change behaviour during an emergency so as not to hinder response processes.	Simulated behavioural change
Local residents and business owners	Estimate of impacts of improved awareness of disaster severity and secondary hazards. Knowing when to evacuate citadel, based on citizen first responders.	Simulated improved awareness
Fire trucks responding to emergency	Potential to understand measures which could be introduced in order to travel more easily during an emergency and reduce response times.	Simulated timing impact
Emergency planners	The impact of triggering of an alarm system between people in the citadel and emergency service vehicles	Estimated impact
Emergency planners	An understanding of how many first responders are needed for responding to a situation	Estimated impact
Emergency planners	A better understanding of how emergency vehicle access can vary during a hazard and its immediate aftermath, and how this might impact recovery.	Simulated improved understanding
Municipality	Intended users of the output report, to inform what potential interventions could be useful.	Secondary beneficiaries

Potential results for model B:

Sava River Basin

User	Result	Type of result
Fire trucks responding to emergency	Knowledge of measures which could be introduced to be able to reduce response times and collaborate with emergency responders from other national forces.	Simulated improved understanding
Fire trucks responding to emergency	Improved estimates of time taken travel across borders unhindered when the need arises, to aid emergency response.	Simulated benefits of international cooperation
National Emergency planners	Understanding of how to coordinate with other national responses to most effectively provide relief to flooding disasters.	Simulated benefits of international cooperation

International disaster coordination bodies	Estimate of improved communication between different national responses, and an overview picture of the impacts of a flood.	Estimated impact
Citizens in border region experiencing floods	Intended not as users, but as recipients of improved response times. Receive help faster and more efficiently in an emergency.	Secondary beneficiaries

Table 53: Potential results arising from this model

11.7 Conclusions

To conclude, the present development of this concept template is neither final nor particularly comprehensive. Its intention has been to provide the reader with an overview of how the modelling process is likely to look, with room for intervention from the Open Labs at this stage to further specify their interests. We hope that this is a useful document for improving understanding of agent based modelling and how it will work within the SHELTER context. Henceforth, the next stage is to draw up a more specific note on data requirements for this model, to ensure this is available before the modelling begins.

12 Appendix E: Concept Note: Wildfire Evolution and Management

Introduction

Following the initial introduction of the Open Lab leaders and partners to the 6 narrowed-down model ideas, preferences were stated by each Open Lab which allowed model concepts to be developed in more detail. This involved building upon the initial model ideas with detail about why and how its outcomes would be used, to make the models more specific to the discussed needs and to decide finally which models were most suited to which Open Labs. The outcome of this stage is presented in this deliverable.

Project rationale

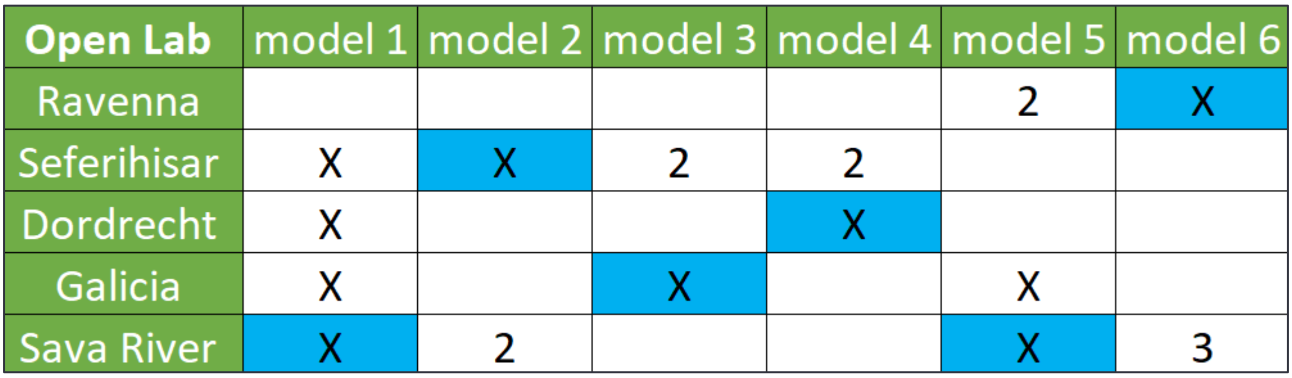
This document provides one of the five initially developed model concepts for the task. It is important to gain an overview of how the model will work, along with its proposed data inputs and result outputs, before development begins. This allows the Open Labs to decide if the model is as they expected, and to propose changes where they see it as relevant to do so. Furthermore, whilst data requirements listed here are not comprehensive or set in stone, this should allow an Open Lab to initially think through the data sources which are available to them and determine what could be useful. Equally, if a data source is deemed essential and not available either open source through the internet, or through the Open Lab, then a data restructure will be required before the next step of developing the model’s technical overview.

SHELTER context

Task 2.6 contributes to the SHELTER objective of improving resilience by using an operational knowledge framework within vulnerable areas of cultural and natural heritage. The models which will be created for the purpose of this task, while using at times imperfect data, will contribute to the knowledge framework objective of SHELTER. The outputs of the models developed are aimed at policy-makers, to demonstrate both areas of weakness as well as success in current operational frameworks, and thus to aid understanding of where developments could be made.

Open Lab context

This concept note is for model 3 and based on discussions we have established Galicia as the lead “lighthouse” open lab. As such, this document is tailored to Galicia from a data requirement perspective. This is not to say this is not useful to other Open Labs, however because of resource constraints, the intention is to try to get a first working demonstration version during this task based on the Galicia Open Lab. After this, where feasible, the aim will be to try and unlock this model for other Open Labs as an extra piece of work outside of the task report. Table 54 demonstrates the lighthouse models, shaded in blue, who the models will be primarily directed towards.



Open Lab	model 1	model 2	model 3	model 4	model 5	model 6
Ravenna					2	X
Seferihisar	X	X	2	2		
Dordrecht	X			X		
Galicia	X		X		X	
Sava River	X	2			X	3

Table 54: Open Lab model preferences.

A cross indicates a top priority model, the number 2 implies a second choice model and the number 3 implies a third choice. Blue shading is the lighthouse Open Lab.

Timeline of task

Figure 35 provides an overview of the task process, from the development of these model concept documents until the end of the task action period. The most important periods are the technical specification of models which will begin development following feedback between April and May 2021.

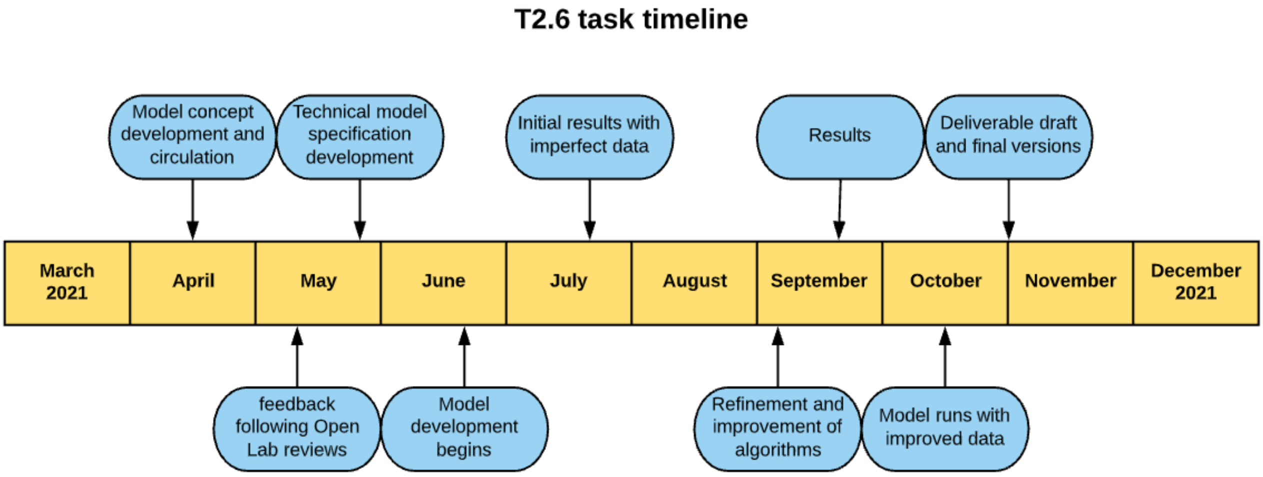


Figure 35: An outline of the timeline for this task

12.1 Model Description:

Simulating how wildfire can evolve considering meteorological conditions, soil moisture and species in the area.

Understanding the various physical and human factors which contribute to fire danger is incredibly important for the prediction and management of this damaging hazard. Particularly given varying amounts of climate change, the increased occurrence of wildfires is now more important to understand and predict than ever. Improved knowledge of these factors increases the accuracy with which prediction can be carried out, with respect to both the spatial and temporal dynamics of wildfire. Better being able to predict a fire event, or to understand when conditions are such that a fire is likely, in turn allows better capacity to evacuate and inform local people before and during a wildfire event.

This model attempts to provide a useful output by simulating fire spread given different conditions. In this way the model aims to identify the most significant factors for causing fire spread, to allow fire managers and citizens to be aware of fire conditions and take necessary precautions. Furthermore, the outcome of modelling different types of forest management interventions is helpful from a management perspective, for informing future options about risk reduction.

Model variants

In addition to the core model outlined above, based on discussions with each Open Lab as to what they find useful, a sub-model has also been specified as particular focus for this model. It is as follows:

Simulating how forest management practices can help reduce the spread of wildfires (discontinuous tree layer/open forest areas to slow spread).

This sub-model was presented to Open Labs to inform the specific focus of the model and ensure its relevance remained high to all who selected it. It adds to the importance of the main model by attempting to examine how human intervention within the process of wildfire spread can attempt to curtail their development. Since there are many options here which have varying degrees of effectiveness, this sub-model allows their comparison to determine which intervention methods are likely to be the most helpful.

User story examples

Several model user stories have been created to contextualise this model in terms of its utility for end users who will be using its outputs, and make it as easily understandable as possible. This list focuses on the key user groups who are likely to be the focus of the model, these are as follows:

- ➔ As a member of the emergency planning department, I want to use the temporal fire spread outputs of the model to develop warnings which can keep citizens safe.

- ➔ As a member of the local government, I want to use the improved understanding of where and when fires spread to improve warning capabilities.
- ➔ As a firefighter, I want to use the spatial outputs of the fire spread predictions to know where I am needed in my community.
- ➔ As a member of regional government, I want to use the improved understanding of fire spread intervention measures to ensure large scale management of the area is as effective as possible.

Model schema and building blocks: context

A model is composed of several building blocks, each has an input, a process and an output. A set of building blocks is called a ‘module’, or a submodel because it can be run on its own. The combination of all these building blocks results in the combined model. The relationship between all these results in a model schema, see for example figure 36.

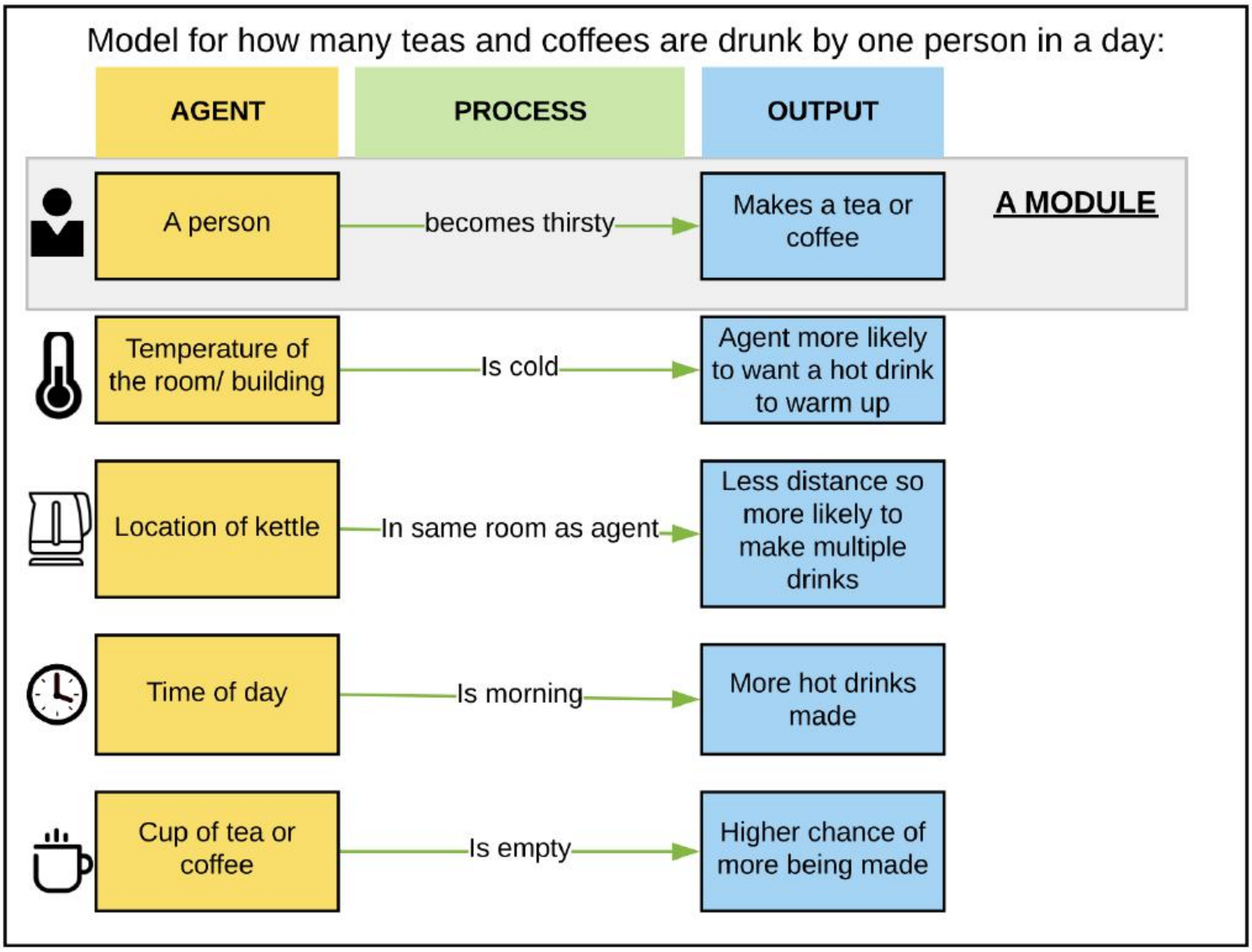


Figure 36: An example of how models are composed of ‘submodels’, or modules

This relates to ABM in that a building block has a process where an entity changes over time and or space, for example a person (entity) becomes older when simulating time in a model. The input in the process is starting age, the process is ageing and the output is end age.

Agent-based modelling importantly considers multiple entities which must be defined before the technical development. Each entity exists separately from each other, but will be combined in the model runs. This allows simplicity for editing entity features and characteristics at various points in the process.

12.2 What are the Agents in this Model?

Before connections, processes and outcomes can be identified as above in figure 36, it is important firstly to define the agents which are present in the system being modelled. These are specified in the following table along with their possible characteristics and related processes. Important to note is that the actual implemented model will focus on only a few (2-3) characteristics per agent and related processes; this is to increase both the quality of the model and to only focus on what is really relevant and to make it possible to deliver the task. Table 2 is separated into high and low priority actors, to acknowledge the existence of many stakeholders but also focus the model to the groups who are most involved and who the model is primarily targeted towards.

High priority actors:

Entity	Characteristics	Processes
Local government	Low budget for management; ability to initiate hazard warnings. Specific knowledge about local vulnerabilities is high.	Communicating with local communities and individuals
Regional government	Detached from specific local processes and information flows but have funding which can be redirected.	Redirect funding for long-term management and planning.
Emergency planners and first responding firefighters	At the city/regional level. Likely to have low funding, as have to plan for other disasters and hazards as well. High knowledge about vulnerabilities and the hazard itself.	Bring into force plans in advance of a disaster, in terms of early warnings, modes of emergency communication.

Low priority actors:

Entity	Characteristics	Processes
Non-government organisation	Has a budget and volunteers. Physical resources may not be available in Galicia however, so action may not be immediate.	Raise funds, provide emergency accommodation and food etc.
Citizens (if relevant, possible to categorise by vulnerability)	Varying vulnerabilities influence citizens differently. Their response is small-scale, ranging from individual to community-level actions.	Warning neighbours in an event, community networks important. Access to warnings can vary.
Visitors to national park	Poor hazard awareness if foreign visitors, therefore high vulnerability. Fire awareness likely higher if	Human triggers to wildfires can be carried out by tourists, may also

	visitors are Spanish or from other countries experiencing high wildfire risk.	not be aware when risk is high.
First responders – fire fighters (linked with emergency planners)	Are stationed at fire stations but have the ability to move quickly.	Attending scene and attempting to put out and control fires.
First responders - ambulances	Are stationed at hospitals but have the ability to move quickly.	When people are involved in a fire, attending scene.

Table 55: Entity characteristics and processes

12.3 What Would the Model Look Like?

The high level model schema consists of a description of several of the most important submodels which it could contain. Whilst having less detail than the entity descriptions in table 55, this is intended to provide a high-level overview of the modules that could be contained within the overall model. An overview of these modules can be seen in figure 37, which also describes some initial ways in which these could link together.

Figure 37 details the provisional interactions between different entities in this model, with an 'input, process, output' format as in figure 36.

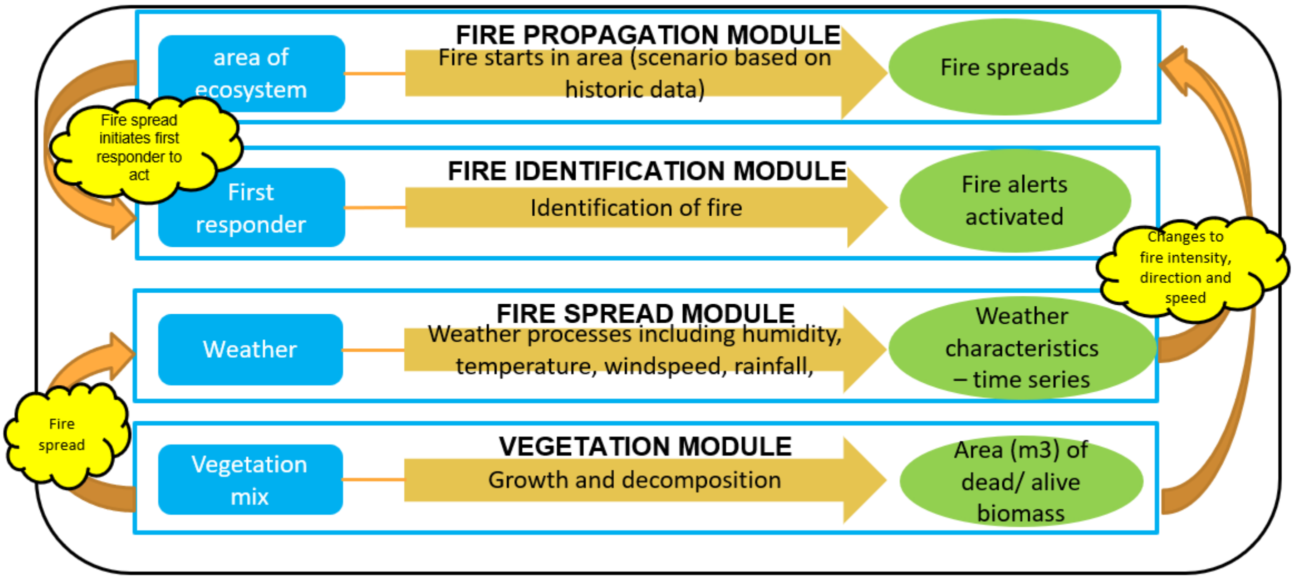


Figure 37: Interactions between entities within the model

The first module within this proposed model is fire propagation. Before we can determine specific factors which may make land more or less susceptible to fire outbreak and spread, this is a crucial element for testing these ideas and identifying how fire spreads. It consists of an ecosystem area, with the process of this catching fire. The output is therefore that the fire spreads.

The fire identification module is important for determining how spread is altered after an event is identified and reported. This determines the speed at which a response is mobilised, and varies depending on factors such as the mobile signal in an area to make an emergency call, the remoteness of an area affecting how quickly it is identified, etc. Ultimately the process is the fire being identified and the outcome is alerts being activated.

Thirdly, the fire spread module aims to categorise all the physical environmental processes which can impact fire spread. This is a physical module which depends on the weather. Within this, the processes include windspeed and direction, temperature and rainfall among other processes. The output is an idea of how the fire could develop spatially given different conditions, which informs the likelihood of fire spreading once a trigger occurs.

Similarly to the fire spread module, the other factor influencing this is the vegetation mix thus giving rise to module 4, the vegetation module. This is the precondition for a fire to develop, since it is this which combines with the correct weather conditions to produce damaging wildfires. It determines the biomass fuel present which influences fire outbreak. The output is the area of dead and alive biomass, correlating to the fuel potential of different areas of forest.

These four modules interact in several ways to produce the overall model idea. As mentioned, it is the combination of weather and vegetation mix which contribute to the conditions ripe for a wildfire. These two modules therefore interact via fire spread itself. Both of these factors together feed into the fire propagation module by altering the physical ways in which the hazard develops. From here, fire propagation influences fire identification by initiating the need for it to happen. Furthermore, the severity and height of the smoke cloud arising from wildfire influences the chances of it being spotted.

12.4 Preliminary Data Requirements for Galicia Open Lab

At this stage, data requirements are broad and not final. Table 56 can therefore be considered as a generalised way of understanding the possible requirements which might be needed for this model. Table 56 also provides an indication of whether its requirement is necessary as a minimum for model construction, or whether it is an ideal additional parameter. Whilst an initial overview is accompanied with whether this data is publicly available and accessible, important to note is that this followed only a preliminary assessment and may not therefore represent the data available to its full extent.

Data	Description (resolution/periodicity)	Minimum requirement	Ideal requirement	Publicly available/source
Land cover map	CORINE contains 44 classes of land cover, at the specificity level of 10-30m per pixel.	X		EU Copernicus CORINE landcover map 2018. Available at : CLC 2018 — Copernicus Land Monitoring Service
	Regional authorities rent a drone and photographs are converted into map		X	Private drone provider would be required if not already in existence.
Topography	Slope	X		Digital elevation model freely available from Copernicus
	Aspect		X	Calculable from slope using GIS software
	Elevation		X	Information about elevation also available in digital elevation model from Copernicus
Vegetation	Fuel model types	X		Stand inventory of trees in Galicia (potential to acquire this from satellite imagery) and Prometheus classification of fuel potential of each one.
	Dryness		X	
	Forest density	X		Potential to use NDVI computations, freely available at resolutions of 10m per pixel.
Weather data	daily mean/ maximum temperature	X		Most of this information is available on the internet, or calculable based on information which is available.
	Wind speed	X		
	Wind direction	X		
	Precipitation	X		
Forest density	To understand how density of trees impacts spread.		X	Potential to use NDVI computations, freely available at resolutions of 10m per pixel.
management techniques	Different methods with parameters – likely qualitative		X	Could be based on a review of the Literature.

Historical fire regimes	Historical fire occurrence log with date and size causes	x		GIS files ideal, or record information (speed, spread)
	Historical fire map of spread		x	

Table 56: Preliminary data requirements to create the model

12.5 Potential Results

Finally, at this stage it is important to understand the potential results which could arise from this model, to tailor the process as it develops. These could include, but are not limited to, the following ideas.

Planning results:

User	Result
Emergency planning department	A better understanding of how wildfire spreads and develops both spatially and temporally.
Emergency planning department	A better understanding of how physical parameters influence wildfire spread.
Local government	an improved understanding of how fire spread can be managed by human intervention, and of which methods work well to do this.
Regional government	Quantifications of how different climate change scenarios could impact the future of wildfire development.

Immediate response results:

User	Result
1st responding fire fighters, as part of emergency planning department	Spatial maps developed to identify patterns of fire spread to allow pre-emptive knowledge of where fire is likely to spread.
Emergency planning department	Aids emergency decision-making, such as whether to get external fire-fighting help from neighbouring regions.

Conclusions

To conclude, the present development of this concept template is neither final nor particularly comprehensive. Its intention has been to provide the reader with an overview of how the modelling process is likely to look, with room for intervention from the Open Labs at this stage to further specify their interests. We hope that this is a useful document for improving understanding of agent based modelling and how it will work within the SHELTER context. Moving forwards, the next stage is to draw up a more specific note on data requirements for this model, to ensure this is available before the modelling begins.