SEN1211 Final Project 2023/2024

Adaptation to climate-induced hazards in cities: assessing risks in the multi-actor decision-making context

Dr. Ir. Omar Kammouh, Dr. Ir. Igor Nikolic
Drs. Liz Verbeek, ir. Thorid Wagenblast, Prof. Dr. Tatiana Filatova

1. Background

1.1 Context

In this project, you will model climate change adaptation, in particular against flooding, in an urban context using agent-based modeling. This will allow you to understand the interaction of different actors (households, government, insurance providers, etc.) and how their efforts complement each other to assess the overall preparedness against flooding events in the region. The main indicator for this is the residual damage and how it can be reduced in different setups. Some of the questions you will be able to answer are how the actors interact with each other or whether policies are mitigating the damage.

2. Purpose of the model

2.1 Objective

The goal of your final project is to:

Model a representation of a decision-making process for <u>*a selected actor*</u> *in the context of urban floods and explore the consequences of the selected decisions for damage assessments.*

2.2 Your task & research questions

Design and implement an agent-based model of the flooding adaptation, and develop an in-depth representation of a decision-making of a selected actor and analyze the simulation results to answer the following research questions:

1. *How does the decision of a real actor engaged in climate adaptation get implemented in the code of an agent-based model?*

   <u>*In the report,*</u> *please support your model design choices with:*
   a. *an explanation of the possible real-world behavior of the selected actor;*
   b. *the relevant theoretical/conceptual framework in which you ground the agent behavior in the ABM;*
   c. *a clear hypothesis about the influence of the modeled cause-effect links on the model outcomes.*

2. *What are the model outcomes under various parameterizations?* *In the report, please:*

    a. *Present and discuss the key outputs of interest, including the dynamics of regional residual damages (i.e., remaining damages after adaptation is taken), distribution of damages across the groups of actors and across agents within the same group (e.g. households with different incomes or with different risk perceptions), diffusion of adaptation over time. Feel free to report additional outputs that are most relevant for the actor whose decision-making process you have modeled.*
    b. *Explore the behavior of the model using sensitivity analysis, for example, by employing the EMA workbench or a parameter sweep. Communicate your interpretation of why the results did or did not confirm your initial hypothesis.*

3. Model elements

3.1 Problem description

You will model climate change adaptation of an urban area, particularly the interplay between public and private adaptation. The model consists of households that can make individual adaptation decisions to protect their property against flood damage. These can include the elevation of the house, installing water barriers, but also things like coordinating with neighbors or having emergency supplies ready. These households can exchange information through a social network and can be targeted by different policies.
The area is based on Harris County in Texas, US. This includes the City of Houston (Figure 1) and has a population of about 4.8 million. It is located on the coast of the Gulf of Mexico and has to deal with flooding due to storm surges which can come in combination with very heavy rainfalls when hurricanes hit the city (e.g., hurricane Harvey in 2017).

3.2 The minimal model

You will find a minimal Python model using the Mesa ABM library, which you can use as a starting point. In the given model, we focus on a dynamic urban environment that primarily features households and a network of social connections. Each household, represented as an agent, is situated within the model's spatial layout, reflecting a unique location in the urban setting. These locations determine each household's exposure to flood risks based on real-world geographical data. The households have the ability to adapt to flooding through various measures and share information through their social network, which includes both nearby and distant connections. This network plays a crucial role in influencing adaptation decisions, as households exchange experiences and perceptions about flood risks and protective measures. The model also includes a government agent, currently passive, offering potential scope for policy implementation. The primary focus is on how households respond to flood risks, adapt over time, and how their decisions are shaped by social interactions and external flooding shocks.

Flood Maps and Flood Depths:

The estimated flood depth for each household is derived from pre-loaded flood maps. These maps represent potential flood scenarios, offering a base for calculating potential flood risks in different areas of the city. You don't need to worry about the technicalities of importing or processing these maps; this has been set up for you. The estimated flood depth is then translated into an estimated damage factor for each household.

Shock Event - Actual Flood Depth and Damage:

A flood shock occurs at a predetermined point in the simulation. This shock represents an actual flooding event, affecting all households in the model. Following this event, the actual flood depth at each household location is calculated, deviating from the initial estimates to mimic the unpredictability of real-life flooding. This actual flood depth is then used to compute the actual flood damage.

Note that households use the estimated flood damage, derived from flood maps, to inform their adaptation decisions. This estimated damage serves as an anticipation of potential impacts based on historical data or predictive models. However, the actual damage experienced by households during a flood shock event might differ from this initial estimate.

Calculating estimated and actual Flood Damage:

The household flood damage is based on the flood depth-damage curves for North America by Huizinga et al. (2017) (check page 16) where the actual flood depth is translated into a damage factor, ranging from 0 (no damage) to 1 (maximum damage). The damage factor is influenced by various adaptation measures that households may have implemented, such as elevating their homes or installing flood barriers (not yet implemented in the minimal model). Depending on the adaptation measures the household has taken, the factor is reduced by a percentage. Together with the house size, this can be transferred to monetary damage.

Visualization:

The simulation includes intuitive visualizations (Figure 2). You'll see a geographical map displaying households and floodplains, with color-coded markers indicating adaptation status. A social network diagram also illustrates the social connections between households. Interestingly, information can spread not only through established social network connections but also from spatially proximate households, even if they are not directly connected in the social network.

The description above is not comprehensive. You may also adapt the above description (simplify it or make it more complex) to what makes sense to you and matches your modeling skill level and ambition. You must carefully and explicitly document your assumptions.

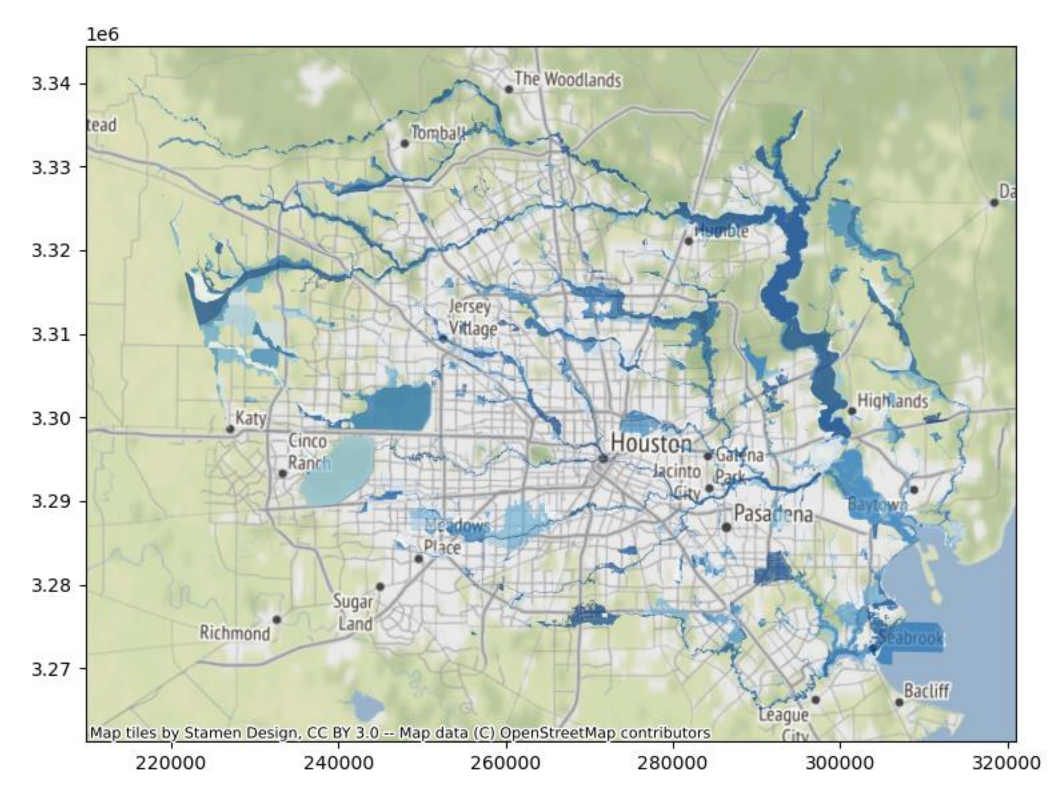

Figure 1 Flood map for coastal Harris County/Houston

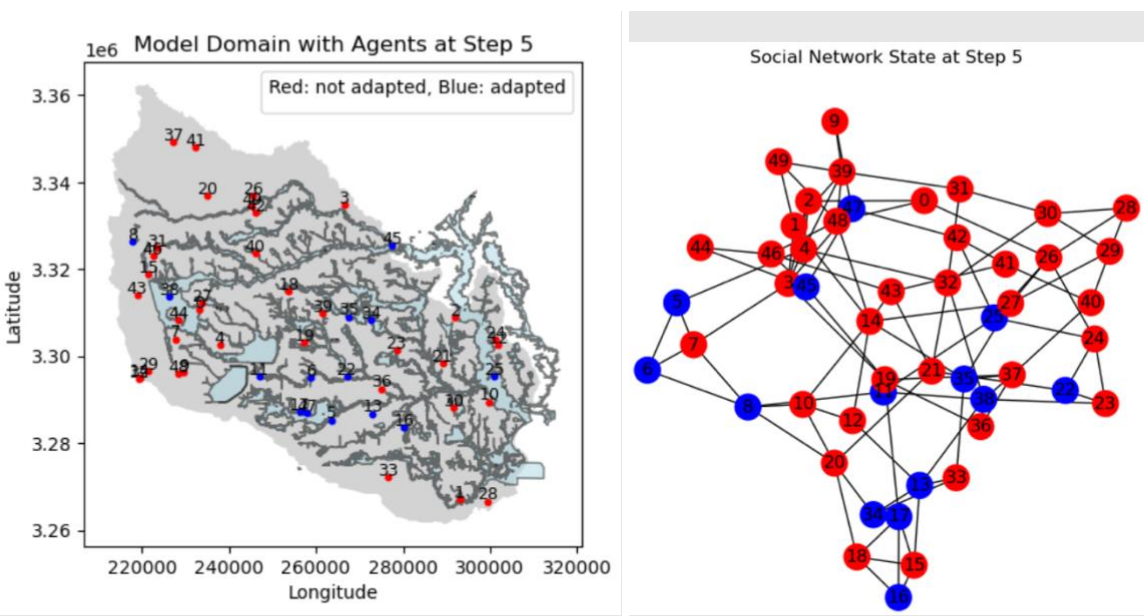

Figure 2 Flood map domain and social network with households' adaptation status

3.3 Agents

Below are suggestions for some agent types to consider. Feel free to consider more/other agents.

Household agent:

- Household agents decide on taking Climate Change Adaptation (CCA) measures based on a certain theory (e.g., Protection Motivation Theory)
- Have: perceptions regarding their flood situation, Desire (or not) to take flood adaptation, Savings, House size, Flood risk
- Do: take adaptation measures, communicate with their connections and update their perception
- At least two alternative theories (can be more) + ref to an article explaining the approach or another ABM that did implement such a decision already
- Optional things to consider

Government agent:

- The government agent can implement certain CCA policies. These could be for example:
    - Information: providing households with information about their flood risk or potential measures they can take.
    - Subsidies: reducing the costs of taking adaptation measures.
    - Regulations: making certain measures compulsory in certain areas e.g. within the floodplain.
    - Infrastructures: building dikes or reservoirs that reduce flood damage in a certain area. *Note that building a dike can be modeled as a reduction of the probability of flooding or a reduction of flood depths instead of modeling an actual physical entity.*
- At least two alternative theories (can be more) + ref to an article explaining the approach or another ABM that did implement such a decision already
- Optional things to consider

Insurance agent:

- The insurance agent might offer insurance to households. They can decide to specifically target households in certain areas.
- Households in certain areas (e.g., within the floodplain) might be required to get insurance. This can also come together with other regulatory measures.
- At least two alternative theories (can be more) + ref to an article explaining the approach or another ABM that did implement such a decision already
- Optional things to consider

3.4 Interaction

Social interactions among Household agents:

- Households are connected with each other in a social network. In this network, they exchange their worries and perceptions surrounding the adaptation decision. Based on the exchange, their own opinion is updated and hence their likelihood to take adaptation measures varies.

- The interaction can be varied in different network structures, and the perceptions that are exchanged.
- At least two alternative theories (can be more) + ref to an article explaining the approach or another ABM that did implement such a decision already
- Optional things to consider

3.5 Other Entities/objects (non-agents)

Natural disaster: flooding

- Can have different magnitudes
- Occurs at a specific time

3.6 Time

- Model runs for 80 ticks
- Time resolution: 1 tick/step = 1 quarter of a year
- In 1 tick/step:
    - Households save money.
    - Households communicate with other households.
    - Households update their perceptions.
    - Households reconsider their adaptation decision.
    - Households take adaptation measures.

Note: the description provided in this section (Section 3) is not meant to be comprehensive. You may adapt the above description (simplify it or make it more complex) to what makes sense to you and matches your modeling skill level and ambition. You should make your own assumptions. For example, which conceptualization of agent decision-making should I choose and why? How does an agent update their risk perceptions? Is adaptation affordable? What other societally relevant outputs are important for understanding how equitable the emerging climate adaptation dynamics is? etc. You must carefully and explicitly document your assumptions.

4. Reusable Building Blocks (RBBS)

Reusable Building Blocks (RBBs) are modular, self-contained components used in agent-based modeling to represent specific processes or mechanisms. They are designed to be easily integrated into larger models, allowing for the efficient construction and adaptation of complex simulations. RBBs enable modelers to reuse established, well-tested components across different projects, ensuring consistency and reducing development time.

Liz Verbeek, one of this year's SEN1211 instructors, has prepared a supplementary information document on RBBs: RBBInstructions (uploaded on Brightspace). Liz will also give a lecture about RBBs during one of the tutorials to provide even more support.

In this project, each student group must develop one RBB for a specific implementation at one level of interaction within the agent-based model, as detailed in Appendix A. The developed RBBs will focus on various aspects of the adaptation process, ranging from individual decision-making theories to broader social and policy influences. This RBB should be a well-defined, modular component that can be integrated into the larger agent-based model of urban flood adaptation.
Please see the last column in Appendix A to know which RBB your group has to develop.
Selected RBBs developed by student groups will go under a review process and potentially be published on a dedicated RBB website: https://www.agentblocks.org More information regarding the submission of your RBB can be found in the RBBInstructions document.

5. Metrics, user interface, parameters, experimental design

Key outputs of interest include the dynamics of regional residual damages (i.e., remaining damages after adaptation is taken), distribution of damages across the groups of actors and across agents within the same group (e.g., households with different incomes or with different risk perceptions), diffusion of adaptation over time. Feel free to report additional outputs that are most relevant for the actor whose decision-making process you have modeled.

5.1 Metrics

In your report, make sure you are explicit about the metrics you will be collecting from your model and how they are relevant to answering the research question.

5.2 User interface

Make sure that the user interface can visualize the dynamics of the system, that the key parameters of the model and the policies are settable and that the metrics you identified can be followed.

5.3 Parameters

Many parameters/numbers for your model are still missing. Please make reasonable assumptions, with a brief explanation of why you are making them. You can also look up data from online sources but please do not spend a lot of time on this!

5.4 Experimental design

Make an experimental design for exploring the model behavior and answering the research questions. Please communicate your experimental design explicitly, with brief reasoning about the choices you made.

6. Guidelines, submission, grading

6.1 Guidelines

The most important thing is to cover all steps of the modeling cycle, from initial conceptualization to reporting on the model. When you are short on time, make the model (much) less complex, but make sure you do all the steps, like verification, analysis, etc. Especially when you are not very experienced in programming, make it simple but sane. *Always prioritize completeness over depth*.

This project description is incomplete! There are many things you will have to decide yourselves; make your own assumption. Make those assumptions and choices very clear, especially when significantly deviating from the base project description. Make it clear what the assumption is, and why you made it. "We had no idea what else to do, this seemed reasonable because…" is a valid reason for your report. Keep in mind, this is a modeling course, not a course on climate change adaptation.

Keep the report short and to the point. It is OK for it to be quite mechanical, you are demonstrating your ability to design a model, make choices, implement, analyze, etc, not write pretty and long reports.

6.2 Submission

You will individually submit your final report during the exam, as an answer to a question. Each member of the group needs to upload the file as an answer to their own exam.

Please follow these requirements for the submission format carefully!

- Make a zip file, with the name and student number of every group member as a filename.
- Name your zip file without spaces in the filename.
    - e.g. **Kammouh_314159_Nikolic_424242.zip**

Inside the zip there is:

- A directory with the same name.
- In that directory:
    - There is a report in PDF format with the name and student number of every group member in the file name: **Report_Kammouh_314159_Nikolic_424242.pdf**
    - Please make sure you use the **"embed all fonts"** option, which is the same as using the PDF/A format, when you generate the pdf
    - Make sure you do not put all of the model code in the report, you can, of course, use snippets if needed for your story
    - A **model/** directory, containing the python/nlogo file(s) of the model and all data needed to run the model.
    - An **output/** directory, containing all the generated result files. Please **zip these files** before adding them to the package
    - An **analysis/** directory, containing all code (R/python/Excel/whatever) that you have used to generate your report, and all output images that you created.
    - Maximum file size is 100 MB. If you have generated more than that you need to reconsider your modelling practices.
    - Submission of RBB: You will develop a complete RBB on the https://www.agentblocks.org website. Also, please submit a PDF file with the name and student number of every group member in the file name:

RBB_Kammouh_314159_Nikolic_424242. The file should include the "Title", "Authors" and "ID" of your RBB. Note that you have to provide the Title and Authors when you submit your RBB, as detailed here. The ID will be assigned there during or after your submission.

6.3 Grading

The grading will be determined based on the following criteria:

- Did you submit your RBB to the website? How complete is it?
- Do you have a concise but complete overview of the conceptual model?
- Do you explain the formalization and implementation of your conceptual model?
- Are all model assumptions clear?
- Did you perform model verification?
    - If yes, how thoroughly?
- How did you set up your simulation experiments?
- How well did you do the analyses?
- How well are you interpreting the data?
- Do you answer the research questions?
- Does your model run?
- Does it break if the parameters are changed?
- Does it generate recognizable criteria?
- How well are you using the Python language?
- Is the report complete, clear, and readable?

Appendix A – RBB concepts, references, and tasks

Level of Interaction	Concept	Implementations with references	Tasks	Groups
Single Agent	Adaptation decision-making (Households)	Protection Motivation Theory Noll et al. (2022) or Haer et al. (2016a)	Develop an RBB that models household flood adaptation decisions based on the Protection Motivation Theory.	1, 16, 31, 46

		Prospect Theory Haer et al. (2016b)	Develop an RBB that incorporates Prospect Theory to represent household risk evaluation and decision-making in flood-prone areas.	2, 17, 32, 47
		Expected Utility Theory Haer et al. (2016b)	Develop an RBB that integrates Expected Utility Theory to model household decision-making processes for flood adaptations.	3, 18, 33, 48
Agent-Agent (Same Class)	Social Influence	Assimilative Social Influence, **Continuous** Opinions (e.g., my connection adapted/ did not adapt) Degroot (1972), Flache et al. (2017) Sections 2.11-13	Develop an RBB using the DeGroot model to simulate the influence of continuous opinion dynamics on flood adaptation within a community of households.	4, 19, 34, 49
		Assimilative Social Influence, **Nominal** Opinions (e.g., my connection adapted/did not adapt) Flache et al. (2017) Sections 2.15-18	Develop an RBB that represents assimilative social influence with nominal opinions affecting flood adaptation behaviors in a neighborhood.	5, 20, 35, 50
		Similarity Bias Flache et al.(2017) Sections 2.24-26	Develop an RBB to model the impact of similarity bias on household decisions regarding flood adaptation in a socially connected community.	6, 21, 36
Agent-Agent (Different Types)	Policy Processes	Multiple Streams Framework Enserink et al. (2022) Section 2.3.2	Develop an RBB employing the Multiple Streams Framework to represent interactions between government policies and household adaptation decisions.	7, 22, 37
		Actor Coalitions Framework Enserink et al. (2022) Section 2.3.4	Develop an RBB using the Actor Coalitions Framework to illustrate collaborative efforts between different actors in creating flood adaptation policies.	8, 23, 38
Not Specified / Dependent on Implementation	Not Specified	Individual Risk Measures Jonkman and Van Gelder (2002)	Develop an RBB that incorporates individual risk measures to assess the impact of flooding on diverse households.	9, 24, 39
		Societal Risk Jonkman and Van Gelder (2002)	Develop an RBB to simulate how societal risk factors influence collective flood adaptation strategies in an urban community.	10, 25, 40
		Economic Risk Jonkman and Van Gelder (2002)	Develop an RBB that integrates economic risk factors in modeling the financial implications of flood adaptation decisions.	11, 26, 41
		Policies: Tools of Government -Treasure Bali et al. (2021) – Conceptual framework - Conceptual framework	Develop an RBB that models how government financial resources (Treasure) can be effectively utilized in flood risk management.	12, 27, 42
		Policies: Tools of Government – Nodality Bali et al. (2021) - Conceptual framework - Conceptual framework	Develop an RBB that simulates the role of government in information dissemination (Nodality) and its influence on public awareness and response to flood risks.	13, 28, 43
		Policies: Tools of Government - Authority Bali et al. (2021) - Conceptual framework - Conceptual framework	Develop an RBB that represents the government's legal power (Authority) in enforcing regulations and policies for flood risk management.	14, 29, 44
		Policies: Tools of Government - Organization Bali et al. (2021) - Conceptual framework - Conceptual framework	Develop an RBB that illustrates the impact of government organizational structures and resources (Organization) on the planning and implementation of flood risk management strategies.	15, 30, 45