Technical Manual

How we have built Inond'Act

V1 - 18/06/2025

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Introduction

What is Inond'Act

Inond'Act is an open-source experimental model that evaluates the costs of flood damages to residential buildings. It uses a component-by-component approach: a building is broken down into its features (walls, floorings, heating system, electricity grid, etc.) and an associated cost of damage is estimated for each feature. The sum of these costs determines the total amount of economic costs.

Not only does Inond'Act evaluate damage, but it also takes into account flood adaptation measures. Adaptation lowers the extent of damage each component has, leading to a lower total cost. The model performs a cost-benefit analysis of different adaptation scenarios and suggests the most cost-effective one to the user.

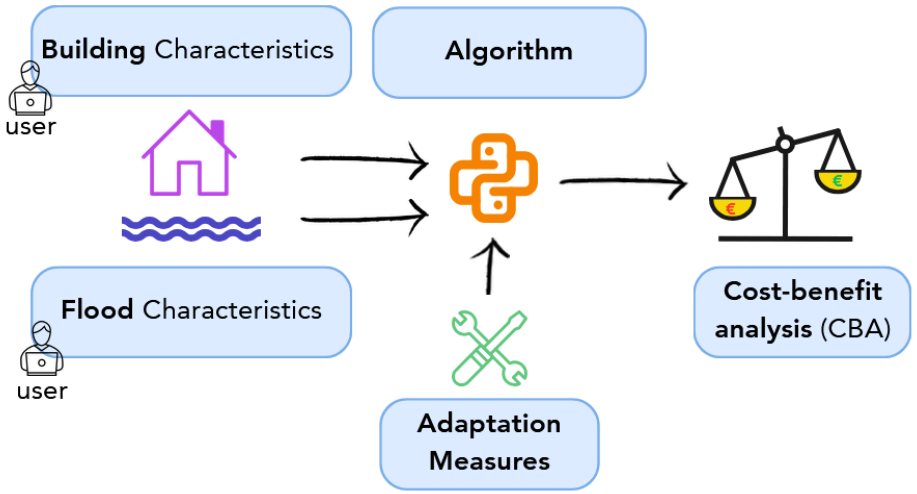
How it works: approach, flood and building data

The component-by-component approach is a well-established method for damage evaluation. Inond'Act largely relies on damage curves (functions representing the probability of a component of being damaged and by how much) elaborated by INSYDE, a study done by Politecnico di Milano and other Italian universities, as well as on Floodam, a damage model created by French public researchers, and on probabilistic studies carried out by the Centre Européen de Prévention du Risque d'Inondation (CEPRI).

Inond'Act has four different flood scenarios: runoff, slow overflowing, quick overflowing and rising groundwater. Each scenario has specific values for height and velocity of water, duration, presence of sediments and, if any, pollutants. Géorisques France is the main source used to determine the characteristics of each type of flood, together with data collected during case studies in Nord-Pas-de-Calais, Bologna (Italy) and Apt (Provence-Alpes-Côte d'Azur).

To assess the presence of certain components within a building and the latter's construction characteristics, Inond'Act relies foremost upon the user's entries. Should they be incomplete, the model relies upon the mandatory questions required to run the model (gross floor area, year of construction, type of heating system, etc.) to automatically fill in omitted fields with statistical information provided by building typologies. Hereby, Inond'act is relying on 41 typologies of residential buildings. Data on real estate in France are provided by Pro'Réno (French information platform on real estate) and are divided into 24 types of collective buildings and 17 individual houses. For each building 33 functions are determined, each

describing a physical characteristic (type of heating system, wall material, flooring, doors and windows, etc.), how it can be damaged and protected.



Schematic overview of Inond'act

Damage and cost calculation

The central element of the model is its algorithm, which puts together all the different damage functions and calculates the total cost. Each damage function has specific parameters, but all of them are composed of two elements: extension of damages and costs.

- The extension of damage is composed by the condition of damage, the threshold over which the component in question is affected by water (e.g. doors are damaged when a flood lasts 2 days or more), and the extent of damage, that is the portion or scope of damages relative to the component (e.g. with the flood attaining 2m, the facade will need to be repainted on up to that point).
- The cost is based on a combination of French gross price lists for building works and empirics (reparation costs shared by flooded households in our case studies). It includes the cost of removal of the damaged components, the supply of new materials and labor.

To calculate the cost of flood damage, Inond'Act multiplies the extension of damage per component by the measurement unit (unit, m^2, m^3). There are 3 main damage families: *preliminary measures*, such as cleaning, dehumidifying, etc; *secondary works*, which include flooring, plaster, paint, doors, etc; and *structural damages*. By adding up the different families, the model calculates a final total cost of flood damage at the building scale.

Adaptation measures

How does adaptation enter the calculation? It does so by acting on the extension of damage. Whenever adaptation measures are implemented, both the condition and extent of damage are modified. For example, if regular cofferdams are installed on a building's openings, Inond'Act assumes that there is no substantial damage for height of water lower than 80 cm, thus changing the extension of damage of flooring, screed, electrical system, plaster, etc.

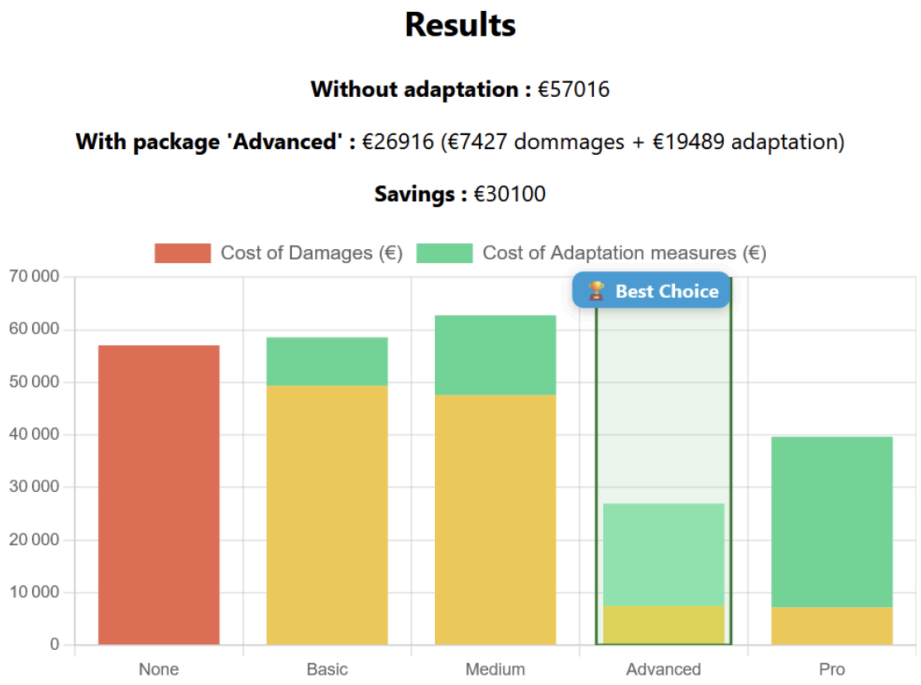
Adaptation measures are not useful if evaluated one-by-one. They need to be grouped to be effective in preventing flood damage, that's why Inond'Act includes 4 packages of adaptation measures:

1. Adaptation BASIC: water pump, cofferdams, walls impermeability, non-return valves
2. Adaptation MEDIUM: BASIC + elevating plugs and other electrical installations up the wall, moving the heating system to higher ground
3. Adaptation ADVANCED: MEDIUM + elevating electrical radiators, creating a downstream power network or two separate electricity networks, changing floorings at the ground floor and in the basement.
4. Adaptation PRO: ADVANCED + raising the windows, installing impermeable doors and windows, impermeable or removable partition walls, impermeable wall coating

Each package is designed to build upon the previous one, making the four incremental both in protection level and cost. The different packages were elaborated by taking into account information provided by *Plans de Prevention du Risque Inondation* in France, consulting firms specialized in flood protection, as well as field work.

Cost-benefit analysis

Inond'Act final output is a cost benefit analysis of flood adaptation. The model presents a comparison between cost of damage with no adaptation and the cost of adaptation plus the cost of residual damages for each adaptation package. By performing a cost-benefit analysis, the model suggests to the user which is the most cost-effective adaptation package for their selected flood and building.



Results for a slow overflowing on a typical Hausmannian building. Inond'Act

The technical manual

The structure of the technical manual aligns with that of our model, progressing from the user's inputs to the algorithm's outputs. Chapters are consequential, with each section building upon the previous one. Composed of eight main chapters, the manual unfolds as follows:

1. **Flood characteristics :** the chapter outlines the flood characteristics, as well as the selectable scenarios reflecting representative flood events.
2. **Building characteristics** : the chapter details how buildings are modeled based on the user's inputs.
3. **Geometric parameters** : this section present Inond'Act's understanding of a building and a flood. Using flood and building characteristics, the chapter introduces key recurrent functions that define the building's geometry (e.g. a dwelling is assumed to have square shape, the basement is half the size of the ground floor) and delineate how the floodwater penetrates and affects the built structure (e.g. translating flood height into affected storeys).
4. **General Assumptions***:* this section regroups Inond'Act's global assumptions and the general principles that set the frame of the model functioning. The chapter explains whether, and in what way, major building elements are included in the model, in what case and how they are affected by water (e.g. the basement is assumed fully flooded when water height exceeds ground level).

5. **Adaptation measures** : this chapter explains how the adaptation measures and packages are implemented, by detailing their cost and clarifying how they affect the model's core functions.

6. **Core functions**: this chapter spells out the 33 functions at the heart of our model by building upon previous assumptions and explanations. It is divided into three subsections that follow the chronological order of repairs after a flood. First, *Preliminary measures* are interventions like water-pumping, cleaning, dehumidifying and disposing waste. Second, *Components* are a wide range of finishing works and gear within a building likely to be damaged by a flood (flooring, plaster, paint, electrical, plumbing and heating systems). Lastly, the *Structure* subsection deals with structural damages to foundations, pillars or to the facade.

7. **Costs**: this section details the cost of every element listed in the core functions chapter.

8. **Glossary of variables used** : Synthetic overview of all used functions and parameters (flood characteristics, building characteristics, geometric parameters and core functions) throughout our model.

Flood characteristics

Estimating flood related building damages required simulating the type of flood it might be exposed to. To do so, we chose to focus on 5 main parameters, based on INSYDE work :

Symbol	FLOOD CHARACTERISTICS		Unit
He	External height of water above ground surface	Float, >=0	m
ve	External velocity of water	Float, >=0	m/s
se	Sediment concentration	String, {No, Low, Medium, High}	Qualitative
d	Flood duration	Float, >=0	h
q	Water quality, pollution	Boolean, {0-not polluted, 1-polluted}	Qualitative

However, to simplify the user experience, we decided to create flood scenarios with default values for those 5 characteristics.

All floods present unique characteristics, shaped by local geography, weather, land use and many other factors. While Inond'act is intended to eventually account for these specificities automatically through georeferencialisation of the user's building address, this functionality is not yet available at the current stage of the project. Still eager to make our model as user-friendly as possible, we grouped above-stated flood characteristics in 4 main flooding scenarios from which the user can choose :

1. **Runoff floods (Pluvial)** – Caused by intense rainfall that overwhelm the ground's ability to absorb water, leading to water accumulation and runoff at the surface.
2. **River overflow floods (Fluvial)** – Occur when rivers or streams exceed their banks due to heavy rain or snowmelt. Can be slow or quick.
3. **Rising groundwater floods** – Result from the water table rising above the surface after prolonged wet periods.
4. ***Coastal floods*** – Caused by storm surges, high tides, or sea-level rise affecting coastal areas. *Inond'Act only takes into consideration the first three floods, as coastal flooding adds a parameter we have yet to model – salt water.*

Although multiple flood types usually occur simultaneously, Inond'Act requires that you specify the one your house is most likely to face.

Here are the flood parameters we used to modelize the different flood scenarios. We know that these values can vary a lot and that each flood is unique, but these parameters currently serve as default values until these five main flood characteristics can be identified more accurately through the geo-localisation of the model.

Type of flood	Properties and intensity of the event	Localization	**He**	**Ve**	**se**	**d**	**q**
Runoff	Watershed Pluvial origin	Not necessarily next to a stream	Very high (to the roof)	Fast	Very high	Low	Presence
			2m	1m/s	high (0.1)	12h	1
Quick and Slow Overflowing	Fast (or flash overflow, torrent overflow, "épisodes cévénols")	Mountainous spaces or storm prone territories	Elevated	Very fast	Very fast	Low	Presence
			1m	2m/s	high (0.1)	3h	1
	Slow (or flood within a plain)	Plains	Elevated	Slow	Average	Elevated	Présence
			1m	0.2m/s	low (0.05)	72h	1
Rising Groundwater	/	Limited in artificialized area	Low	Nul	Nul	Very elevated	Absence
			0.3m	0m/s	no	100h	0

Building characteristics

Mandatory questions

In order to determine required parameters of building and flood, the user needs to answer 8 mandatory questions in the form :

- **Type of flood** : flood scenario chosen and most probable, string, {Runoff, Quick Overflowing, Slow Overflowing, Rising groundwater} – **flood_type**
- **Internal area** : Total usable area of the building, float, [m²] – **Ai**
- **Number of floors** : including basement, int – **Nf**
- **Presence of basement** : boolean, {0-no, 1-yes} – **Pb**
- **Housing structure**: general geometry of the building, boolean {0-individual housing, 1-collective housing} – **Sh**
- **Type of boiler** system : boolean, {0-collective boiler, 1-distributed boiler} – **Db**
- **Year of construction** : int – **Yc**
- **Structure juxtaposition** : number of adjoined buildings, int {2-adjoined with 2 sides exposed, 4-separated with 4 sides exposed} – **Sj**

Optional questions

To obtain a more precise analysis of the building costs, more information can be added by the user filling the optional questions :

- **Height of one floor** : including ceiling, float [m] – **Hf**
- **Material of the facade** : int, {1-stone, 2-concrete, 3-brick) – **Sb**
- **Quality of the construction** : string, {low, medium, high} – **Qc**
- **Area of one dwelling** : for collective housing, number of apartments, int, [m²] – **Ad**
- **Elevation of building** : surelevation due to slab, height of ground level, float, [m²] – **Hg**
- **Type of ground pavement** : int, {1-wood, 2-porcelain stoneware, 3-natural materials or marble} – **Sp**
- **Year of last major renovation** : int – **Yr**
- **Presence of elevator** : boolean, {0-no, 1-yes} – **Pe**
- **Quality of maintenance** : boolean, {0-low, 1-high} – **Qm**

In case some or all optional questions are not filled by the user, we attribute a typology to the building according to the Pro'Réno typologies, filling optional parameters by realistic and probable characteristics.

	MANDATORY QUESTIONS					
	Structure of Housing	**Year of construction**	**Number of floors**	**Structure Juxtaposition**	**Distribution of boiler**	**Existence of basement**
	1 - Collective 0 - individual			**2 - 4 faces exposed**	**1 - Distributed 0 - Centralized**	**1 - Basement 0 - No basement**
Typo	**Sh**	**YY**	**Nf**	**Sj**	**Db**	**Eb**
LC-1	1	<1915	5	4	1	1
LC-2	1	<1915	4	2	1	1
LC-3	1	<1915	4	2	0	1
LC-4	1	<1915	5	2	1	1
LC-5	1	1915≤x≤1945	5	4	1	1
LC-6/7	1	1915≤x≤1945	6	2	1	1
LC-8	1	1915≤x≤1945	8	4	0	1
LC-9	1	1946≤x≤1968	2	2	1	1
LC-10	1	1946≤x≤1968	5	4	0	1
LC-11	1	1946≤x≤1968	12	4	0	1
LC-12	1	1969≤x≤1974	3	4	1	0
LC-13	1	1969≤x≤1974	11	4	0	1
LC-14	1	1969≤x≤1974	10	4	0	1
LC-15	1	1975≤x≤1981	5	4	1	0
LC-16	1	1975≤x≤1981	5	4	0	0
LC-17	1	1975≤x≤1981	10	4	0	1
LC-18	1	1982≤x≤1989	3	4	1	1
LC-19	1	1982≤x≤1989	6	4	1	1
LC-20	1	1982≤x≤1989	7	4	0	1
LC-21	1	1990≤x≤2000	3	4	1	1
LC-22	1	1990≤x≤2000	8	4	1	1

LC-23	1	2001≤x≤2005	4	4	1	1
LC-24	1	>2005	4	4	1	1
MI-1 - MI-3	0	<1915	2	4	0	0
MI-2	0	<1915	2	4	0	1
MI-4	0	<1915	2	2	0	0
MI-5 - MI-6	0	1915≤x≤1945	2	4	0	1
MI-7	0	1915≤x≤1945	2	2	0	1
MI-8	0	1946≤x≤1968	2	4	0	1
MI-9	0	1946≤x≤1968	2	2	0	1
MI-10	0	1969≤x≤1974	2	4	0	0
MI-11	0	1969≤x≤1974	2	2	0	0
MI-12	0	1975≤x≤1981	2	4	0	0
MI-13	0	1975≤x≤1981	2	2	0	1
MI-14	0	1982≤x≤1989	2	4	0	0
MI-15	0	1990≤x≤2000	2	4	0	0
MI-16	0	2001≤x≤2005	2	4	0	0
MI-17	0	>2005	2	4	0	0

More precision is also obtained through the typologies : we obtain new variables such as **Height of Basement** (float, [m], **Hb**), **Thickness of walls** (float, [cm], **Tw**), **Existence of electrical radiators** (boolean, {0-no, 1-yes}, **Er**) and **Height of crawl space** (float, [m], **Hcs**)

	GEOMETRY				EQUIPMENTS AND MATERIALS					
	Area of one dwelling	**Height of floor**	**Height of basement**	**Height of ground**	**Structure of building**	**Structure of Pavement**	**Thick-ness of walls**	**Existence of elevator**	**Existence of electrical radiator**	**Height of crawl space**
	m2	**m**	**m**	**m**	**1 - Brick 2 - Concrete 3 - Stone**	**1 - wood / 2 - porcelain stoneware 3 - marble / natural**	**cm**	**1 - Elevator 0 - No elevator**	**1 - Electrical Radiators 0 - No electrical Radiators**	**m**
Typo	**Ad**	**Hf**	**Hb**	**Hg**	**Sb**	**Sp**	**Tw**	**Ee**	**Er**	**Hcs**

LC-1	80	3.3	2.3	0.1	3	3	45	0	1	0
LC-2	60	3.3	2.3	0.1	3	3	45	0	1	0
LC-3	50	3.4	2.3	0.1	3	3	45	0	0	0
LC-4	50	3.4	2.3	0.1	3	3	45	0	1	0
LC-5	60	3.6	2.3	0.1	3	3	35	0	1	0
LC-6/7	50	3.6	2.3	0.1	3	3	35	0	0	0
LC-8	45	3.2	2.3	0.1	1	3	22	1	0	0
LC-9	60	3.2	2.3	0.1	2	3	20	0	0	0
LC-10	65	3.2	2.3	0.1	2	3	20	1	0	0
LC-11	50	3.2	2.3	0.1	2	3	20	1	0	0
LC-12	65	3	2.3	0.1	2	3	20	0	1	1.2
LC-13	65	2.9	2.3	0.1	2	3	20	1	0	0
LC-14	50	2.9	2.3	0.1	2	3	20	1	0	0
LC-15	65	2.9	2.3	0.1	2	3	25	0	1	1.2
LC-16	65	2.9	2.3	0.1	2	3	25	1	0	1.2
LC-17	50	2.9	2.3	0.1	2	3	25	1	0	0
LC-18	65	3	2.3	0.1	2	2	25	1	1	0
LC-19	65	3	2.3	0.1	2	2	25	1	1	0
LC-20	50	3	2.3	0.1	2	2	25	1	0	0
LC-21	60	3	2.3	0.1	2	2	30	1	1	0
LC-22	55	3	2.3	0.1	2	2	25	1	1	0
LC-23	60	3	2.3	0.1	2	2	28	0	1	0
LC-24	60	3	2.3	0.1	2	2	28	0	1	0
MI-1 - MI-3	90	3.2	2	0.1	3	1	45	0	1	0
MI-2	200	3.7	2	0.1	3	1	45	0	1	0
MI-4	120	3.4	2	0.1	3	1	45	0	1	0
MI-5 - MI-6	130	3.1	2	0.1	1	1	22	0	0	0
MI-7	110	3.1	2	0.1	1	1	22	0	0	0
MI-8	100	3.1	2	0.1	1	1	22	0	0	0
MI-9	100	3.1	2	0.1	2	1	30	0	0	0

MI-10	95	3	2	0.1	2	1	23	0	0	0
MI-11	100	3	2	0.1	2	1	23	0	0	0
MI-12	120	3	2	0.1	2	1	28	0	0	0.2
MI-13	120	3	2	0.1	2	1	27	0	0	0
MI-14	100	3	2	0.1	2	2	30	0	0	0
MI-15	105	3	2	0.1	2	2	30	0	0	0
MI-16	110	3	2	0.1	2	2	31	0	0	0.2
MI-17	110	3	2	0.1	2	2	30	0	0	0.2

Attributing typologies

To attribute a typology to the user's building, we attribute a weight to certain classifying mandatory questions :

- **Sh** (Structure Housing) : 10
- **Yc** (Year of construction) : 8
- **Nf** (Number of floors) : 5
- **Sj** (Structure juxtaposition) : 4
- **Db** (Distribution of boiler) : 3
- **Eb** (Existence of basement) : 1

We can thus for each typology calculate a score : the sum for each classifying column of the difference between the user's answers and the default value ponderated by the weight. We then attribute the user' building to the typology with the smallest score.

Finally, once the typology is attributed, we get the missing values (not filled by the user) from the tables and use them as building characteristics for the calculation of the costs. For the Quality of construction it is fixed to Medium when not filled by the user. For the Quality of maintenance, it is fixed to 0-low if the Year of construction of the building is <2005, 1-high else.

More information on how we build these tables and chose per default values

- **Height of Basement** : default height of basement has been extracted by expert interviews, from two SETEC engineers and technical expert Etienne Boucart

- **Height of crawl space** : according to the year of construction and the typology, we assume or not the presence of a crawl space. If there is no crawl space, the variable Height of Crawl Space Hcs is fixed to 0. Else, it is fixed at 0.2m for individual housing and 1.2m for collective housing.
- **Quality of construction** : if not filled by the user, the quality of construction is automatically filled at the ‘medium’ level.
- **Quality of maintenance** : if not filled by the user, the quality of maintenance is automatically fixed at 0-low if the year of construction is before 2005 and 1-high else.

Geometric Parameters

Now that we have obtained basic flood and building characteristics through the user's answers, we model the building and the flood inside of it. To do so, we conceive the building as a simple square with basic assumptions on its geometry.

This section explains the different geometrical elements and how the building is flooded according to the building and flood scenario. Each geometrical element is obtained through the previously defined building parameters. To facilitate the formula's comprehension, the parameters involved in each function will be specified beneath.

Storey Geometry

Af - Area of one floor [m²]

This function determines the global net usable area throughout one storey, the surface area of one floor.

Af = Ai / Nf

List of used parameters :

- **Ai (Internal Area, float) [m²]:**[1] Refers to the total net usable area, available for practical use throughout a building. Put simply, the sum of 'usable' floor surface areas of one building. Filled by the user.
- **Nf (Number of floors, integer) [unit]:** Refers to the number of storeys throughout a building, including the ground floor. Filled by the user.

Pf - Perimeter of facade [m]

Refers to the surrounding perimeter throughout one storey, only including the lengths of the 4 structural walls, the facade (de facto excluding lengths of interior walls).

Pf = 4 * sqrt (Af)

List of used parameters :

- **Af (Area of one floor, float) [m]** : calculated above

Assumption :

[1] Translation (fr): surface utile brute

- **4 [unit]:** Derives from our general assumption that our building is a square.

Basement Geometry

Ab - Area of basement [m²]

Refers to the net usable area available for practical use throughout a basement. Put simply, the sum of floor surface areas of the basement.

Ab = 0,5 * Af * Eb

List of used parameters :

- **Af (Area of one floor, float) [m²]** : calculated above
- **Eb (Existence of basement, boolean) :** Determines the presence of a basement in the building. Inferred from the 'Building characteristics table' the presence of a basement is associated to 1, and the absence of a basement to 0.

Assumption :

- **0,5 [%]:** We assume the basement to account for 50% of the area of one floor.[2]

Pb - Perimeter of a basement [m]

Refers to the surrounding perimeter throughout one storey, only including the lengths of the 4 structural walls (de facto excluding lengths of interior walls).

Pb = 4 * sqrt(Ab)

Used parameter :

- **Ab (Area of basement, float) [m2]** : calculated above

Assumption :

- **4 [unit]:** Derives from our general assumption that our building is a square.

[2] Based on INSYDE, main paper, Table 3 P.5

Walls Geometry

Pw - Perimeter of Walls [m²]

Refers to the total perimeter throughout one storey by summing lengths of all types of walls. In clearer terms, it consists in summing the lengths of the 4 structural walls and the lengths of interior walls (bearing walls, partitions etc.).

Pw = 2,5 * Pf

Used parameter :

- **Pf (Perimeter of facade, float) [m]** : calculated above

Assumption :

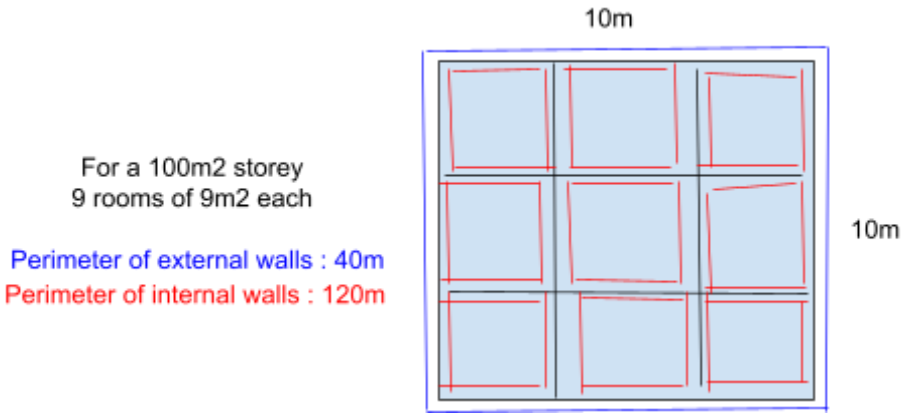
- **2,5 [unit]:** Based on scientific expertise, we consider the interior wall perimeter equating to multiplying the external walls times 2,5. Three interlinked assumptions underpin this figure:

  First, note the characteristic of interior walls having double surfaces. Once a storey is flooded, both faces of interior walls generate repair costs (front and back). This does not apply to the external side of structural walls, as their backside is exposed to the outside and thus not accounted for.

  Secondly, this assumption also accounts for the number of rooms within the storey, as each room implies the presence of walls. For a reference floor area of 100 m², the estimated number of rooms is approximately 9.

  Lastly, we consider the thickness of interior walls tantamount to 0, since adding wall thickness might add additional complexity that would interfere with the perimeter of walls variable (Pw).

  All things combined, the double surface counting, the number of rooms (9 for 100 m²), as well as their wall thickness equating to 0, should lead us to estimate the perimeter of interior walls at approximately 3.
  However, considering that parts of these interior walls consist of partitions, which in our model are accounted for separately (avoiding double counting), the interior wall perimeter coefficient is adjusted to 2.5.



Explanatory scheme of the above-stated assumption

Ad - Area of one dwelling [m²]

Refers to the surface area (m²) of a single dwelling unit. This parameter applies only to collective housing.

Ad = int(Sh==0) * Ai + int(Sh==1) * [int(Ad>Af) * Af + int(Ad<=Af) * Ad]

For individual houses, Ad is equal to Ai.
For collective housing, users can fill in Inond'Act their dwelling Area. If the input value exceeds the area of one floor (Af), the dwelling unit area is set equal to that of the floor (Af). Otherwise, the entered value is retained.

List of used parameters :

- **Sh (Structure of housing, boolean) :** refers to the structure of the housing, 0 meaning individual houses and 1 collective housing.
- **Ai (Internal Area, float) [m²]:**[3] Refers to the total net usable area, available for practical use throughout a building. Put simply, the sum of 'usable' floor surface areas of one building. Filled by the user.
- **Ad (Dwelling Area) [m²]:** Refers to the meter square area of one dwelling. It is filled by the user for collective housing.
- **Af (Area of one floor, float) [m²]** : calculated above

Flood extent Geometry

Hi - Internal height [m]

Refers to the water level, in height, present in the building. Main parameter in assessing water damages.

Hi = max(0, He - Hg)

[3] Translation (fr) : surface utile brute

if adaptation is 'Basic' or 'Medium', Hi = int(Hi>0.8) * Hi
if adaptation is 'Advanced' or 'Pro', Hi = int(Hi>1) * Hi

In case of adaptation measures, internal height is put to 0 if the external height of water is inferior to height of barriers, fixed at 0.8m for Basic and Medium packages, and at 1m for Advanced and Pro packages.

List of used parameters :

- **He (External height of water, float) [m] :** Flood height according to the selected scenario.
- **Hg (Height of ground storey level, float) [m]** : Refers to the elevation of the ground storey relative to the exterior natural ground level. It can be negative in case the building is partially underground or to represent inclined fields. If not filled by the user, it is in our model set at 10 cm, the traditional thickness of a slab.

List of assumptions :

- All adaptation scenarios include cofferdams and non-return valves. Those protection measures protect the dwelling from any water damage inside the building :
    - up to 0.8 m of internal water height (Hi) for Basic to Medium adaptation packages
    - up to 1 m of internal water height (Hi) for Advanced to Pro adaptation packages

Vu - Volume flooded [m^3]

Refers to the amount of residual floodwater present within the building (basement, crawl space and storeys) after the flood. This function is specifically designed to address flood sludge, and is therefore used exclusively for waste-related costs.

Vu = Hb * Ab + Hcs * Af + Hi * Af

- **Flooded volume of basement :** The residual water volume in the basement directly corresponds to the basement's volume.
- **Flooded volume of crawl space :** Refers to the residual water volume present in the crawl space.
- **Flooded volume of storeys :** Refers to the residual water volume present in the first storey. Drawing on existing studies, we only consider the first storey, presenting elements subject to waste disposal.

List of used parameters

- **Hb (Height of Basement, float) [m]:** Refers to the basement's height. It is obtained from our 'building characteristic' table, where collective housing basement height is set at 2,3m and individual housing basement height at 2m.

- **Hcs (Height of Crawl Space, float, {0; 0,2; 1,2) [m]:** Refers to the height of the crawl space. It is considered a fixed input in our model, derived from our 'building characteristic' table. It is important to note that our dataset includes buildings with and without crawl spaces, in regard to their typology. For buildings with crawl spaces, the height is set at 0.2m for individual housing and at 1.2m for collective housing.
- **Af (Area of one floor, float) [m²]** : calculated above
- **Ab (Area of basement, float) [m²]** : calculated above
- **Hi (Internal Height, float) [m] :** calculated above

Assumption :

- **fully flooded :** Derives from our general assumption, that in the event of floods, the basement is considered entirely flooded.

Nfu - Number of floors underwater [unit]

Refers to the number of storeys affected by floodwater. Bear in mind that this assumption considers the storey to be fully flooded. Therefore, this assumption will be adjusted in specific ‘core functions’.

Nfu = int(Hi/Hf) + 1

List of used parameters :

- **Hi (Internal Height, float) [m] :** calculated above
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling and obtained from the building characteristics table.

Assumption :

- **+1 [unit]:** If the height of the water (Hi) exceeds the combined height of the preceding storeys, the floodwater is considered to reach the subsequent storey

Nd - Number of dwellings [unit]

Determines the number of dwellings in the housing. Bear in mind that this function is based on the general assumption that one dwelling corresponds to 100 m². This function is intended exclusively for housing of the collective buildings. Since subsequent operations require an integer, the result of this function is rounded accordingly.

Nd = round(Ai/Ad) * Sh + (1 - Sh)

List of used parameters

- **Ai (Internal Area, float) [m²]:**[4] Refers to the total net usable area, available for practical use throughout a building. Put simply, the sum of 'usable' floor surface areas of one building. Filled by the user.
- **Ad (Dwelling Area) [m²]:** Refers to the meter square area of one dwelling. It is filled by the user for collective housing.
- **Sh (Structure of housing, boolean) :** refers to the structure of the housing, 0 meaning individual houses and 1 collective housing.

Ndf - Number of dwellings per floor[unit]

This function distributes the number of dwellings evenly across the different storeys throughout the building.

Ndf = round (Nd/Nf)

List of used parameters :

- **Nf (Number of floors, integer) [unit]:** Refers to the number of storeys throughout a building, including the ground floor. Filled by the user.
- **Nd (Number of dwellings, integer) [unit] :** calculated above

Ndfu - Number of dwellings per floors underwater [unit]

Refers to the number of dwellings affected by flood water per storey.

Ndfu = Nfu * Ndf

List of used parameters :

- **Nfu (Number of floors underwater, integer) [unit]:** calculated above
- **Ndf (Number of dwellings per floor, integer) [unit] :** calculated above

[4] Translation (fr) : surface utile brute

General Assumptions

This part lists down general assumptions made for our model. They are considered ‘general’ given that they influence all functions of the model independently.

Model assumptions

Assumption “Costs” [qualitative] :

Our unit prices include the cost of component removal and replacement, taking into account workforce. Potential additional costs, such as those related to waste disposal, are not accounted for in our model.

Moreover, our unitary prices or costs of removal and replacement, are considered only as material costs, with no consideration of market prices or other prices.

Considering the economy of scales, we reduce the total cost by 10% to take them into account.

Building characteristics assumptions

Assumption “Squared Housing Unit” [qualitative][5] :

In line with existing studies and to enhance the clarity and standardization of our model, we assume dwellings to be square shaped. This assumption is at the center of all functions linked to the geometrical parameters.

Assumption “Amount of Housing Unit per floor” [qualitative] :

Dwellings refer to the apartments. Their number of units varies according to housing structure (**Sh, individual or collective housing**).

- When considered individual housing - one housing unit is attributed per storey.
- When considered collective housing - housing units per storey are determined by the user or from our dataset.

[5] Translation (fr) : logements

Assumption “Ceiling Thickness” [qualitative] :

The thickness of the ceiling is not considered.

Flood characteristics assumptions

Assumption “Water drain” [qualitative]:

The Floodwater is post event, expected to drain naturally from the building, without requiring technical intervention. Excluded from this assumption are closed spaces (basement, crawl space & elevator shaft) as well as flood sludge (waste).

Assumption “Covered type of floods” [qualitative] :

Our analysis does not consider the impact of rainfall on building structures (e.g., roof damage), nor the specific forces resulting from groundwater upwelling or surface runoff flooding. We will strictly consider the water level rise (he).

Assumption, “Basement Flood” [qualitative]:

We assume that the basement will become fully flooded as soon as there is a flood ie. He > 0. Even if the water does not enter the building (Hi = 0 or Hi inferior to the elevation of ground Hg), if He>0, the basement is flooded.

Adaptation measures

This chapter details the different suggested adaptation measures reducing the building's flood vulnerability. As it is not effective to assess them separately, we choose to regroup adaptation measures into packages of complementary measures that are incremental in terms of protection and cost of implementation. Bear in mind that our presented adaptation measures are non-exhaustive. Plenty of studies make more and further adapted suggestions. The presented measures are the ones we were able to attach a cost to.

Detail of adaptation packages & associated price

The four adaptation packages are

- Basic
- Medium
- Advanced
- Pro

The table below (in French) displays the different adaptation measures included in each package, as well as their respective price :

MESURES	PRIX	Pro	Advanced	Medium	Basic
Essentiel					
Disposer d'une pompe pour évacuer les eaux d'infiltration.	PA1 = 700€	V	V	V	V
Résister: barrières					
Mettre en place des batardeaux (porte simple).	PA2 = 900€	V	V	V	V
Mettre en place des batardeaux (porte double, de garage ou baie vitrée).	PA3 = 3000€	V	V	V	V
Protéger la chaudière avec une barrière ou une estrade permanente.	PA4 = 1 000€	V	V	V	V
Etanchéité des murs					
Occulter les aérations situées en dessous de la côte (type capot amovible).	PA5 = 480€	V	V	V	V
Traiter les fissures sur la façade du bâtiment.	PA6 = 400€	V	V	V	V

Réseau électrique et chauffage					
Colmater les vides entre les gaines et les tuyaux.	PA7 = 600€	V	V	V	X
Rehausser les tableaux et coffrets au-dessus de la côte	PA8 = 1 500€	V	V	V	X
Rehausser au maximum les interrupteurs, si possible au-dessus de la côte	PA9 = 1200€	V	V	V	X
Rehausser au maximum les prises, si possible au-dessus de la côte. En cas d'impossibilité technique, prévoir une installation insensible à l'eau (laiton par exemple).	PA10 = 1200€	V	V	V	X
Rehausser la chaudière au-dessus de la côte	PA11 = 1500€	V	V	V	X
Rehausser au maximum les convecteurs, si possible au-dessus de la côte	PA12 = 1 200€	V	V	X	X
Créer un réseau électrique descendant (en parapluie).	PA13 = 3000€	V	V	X	X
Réseau d'eau et d'égouts					
Installer un clapet anti-retour sur le réseau d'eaux usées (+ regard avec tampon verrouillable).	PA14 = 1 000€	V	V	V	V
Verrouiller les tampons des réseaux enterrés.	PA15 = 600€	V	V	V	V
Travaux second oeuvre					
Rehausser les allèges.	PA16 = 109€ / m2	V	V	X	X
Remplacer les revêtements muraux identifiées comme vulnérables par des matériaux peu sensibles à l'eau (type enduit mortier ciment + chaux)	PA17 = 90€ /m2	V	X	X	X
Remplacer les portes intérieures identifiées comme vulnérables par des matériaux peu sensibles à l'eau (type porte alvéolaire avec huisserie métal)	PA18 = 200€ /unit	V	X	X	X
Remplacer les fenêtres identifiées comme vulnérables par des matériaux peu sensibles à l'eau (type PVC ou aluminium, double vitrage)	PA19 = 689€ /unit	V	X	X	X
Remplacer la porte d'entrée identifiée comme vulnérable par des matériaux peu sensibles à l'eau (type PVC ou aluminium)	PA20 = 2300€ / unit	V	X	X	X
Remplacer les cloisons identifiées comme vulnérables par des cloisons pouvant être démontées et privilégier les carreaux hydrofuges ou matériaux peu sensibles à l'eau	PA21 = 90€ /m2	V	X	X	X
Se protéger					
Arrimer les équipements contenant des produits dangereux / objets flottants	PA22 = 200€	V	V	V	V

In our model

These 4 adaptation measure packages affect our model in two ways. First, their implementation comes with a cost, which is included in the total amount. Second and most importantly, they improve the housing's building characteristics, thus reducing sustained damages and therefore economic costs related to floods.

Cost of adaptation measures

For each adaptation measure X, we compute it's CA(x) (cost of adaptation) by multiplying the unit cost of adaptation PA(x) (price of adaptation) times the required quantity (count, surface) that is being provided by the building characteristics table. This calculation is performed simultaneously for each adaptation package, using the corresponding set of adaptation measures. Our algorithm, being a CBA, ultimately identifies and outputs the most cost-effective adaptation package. Find, hereunder, the detailed code covering the implementation of adaptation measures :

- **CA1 = PA1 * int(package!=None)**
- **CA2 = PA2 * 0,2 * int(package!=None)**
- **CA3 = PA3 * int(package!=None)**
- **CA4 = PA4 * int(package!=None)**
- **CA5 = PA5 * Af/100 * int(package!=None)**
- **CA6 = PA6 * Af/100 * int(package!=None)**
- **CA7 = PA7 * Af/100 * int(package!=None) * int(package!=Basic)**
- **CA8 = PA8 * Af/100 * int(package!=None) * int(package!=Basic)**
- **CA9 = PA9 * Af/100 * int(package!=None) * int(package!=Basic)**
- **CA10 = PA10 * Af/100 * int(package!=None) * int(package!=Basic)**
- **CA11 = PA11 * Af/100 * int(package!=None) * int(package!=Basic)**
- **CA12 = PA12 * Af/100 * int(package!=None) * int(package!=Basic) * int(package!=Medium)**
- **CA13 = PA13 * Af/100 * int(package!=None) * int(package!=Basic) * int(package!=Medium)**
- **CA14 = PA14 * int(package!=None)**
- **CA15 = PA15 * int(package!=None)**
- **CA16 = PA16 * Af/100 * int(package==Advanced) * int(package==Pro)**
- **CA17 = PA17 * Af/100 * int(package==Pro)**
- **CA18 = PA18 * 0,09 * Af * int(package==Pro)**
- **CA19 = PA19 * 0,09 * Af * int(package==Pro)**
- **CA20 = PA20 * 0,02 * Af * int(package==Pro)**
- **CA21 = PA21 * Hf * Af/100 * int(package==Pro)**
- **CA22 = PA22 * Af/100 * int(package!=None)**

Adaptation measure improvements

Additionally, adaptation measures modify the damage extensions of our core functions, thus reducing the cost of damages. The most effective adaptation measure is the inclusion of cofferdams and non-return valves, present throughout the four adaptation packages.

These measures protect the building from water coming inside and thus from any internal cost :

- up to 0.8 m of internal water height (Hi) for Basic to Medium adaptation packages
- up to 1 m of internal water height (Hi) for Advanced to Pro adaptation packages

Added to that come adaptation measures specific to certain functions, which are indicated in the code through the 'adaptation' parameter.

Description of the core functions

This chapter details the core functions used in the algorithm to estimate the costs associated with each building feature. The following guide provides clarifications on how to read and interpret them.

Reading guide

The chapter's structure :

This section of the algorithm organizes our functions into three main categories, reflecting the sequencing of post-flood repairs:

- **p** for Preliminary measures: Sanitation procedures following floodwater withdrawal
- **c** for Components: Finishing works and equipments
- **s** for Structural damages: repairs associated with foundations and structural damages of the building.

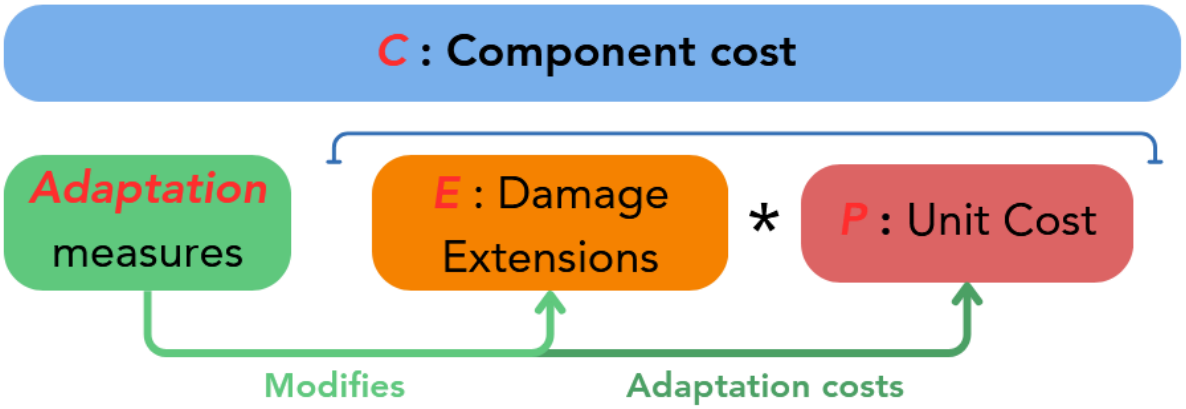
Accordingly, the second letter of each function will be either p, c or s, specifying to which category they belong.

Regrouped within these 3 great categories are 23 components (cleaning, screed, doors) to which are attached 1 - 3 functions. In fact, some components present complexities that must be addressed through dedicated functions. For instance, the door component is split in three different functions covering interior doors, entry doors, and the entry door's lock.

The function's structure:

Each function is composed of a lot of different and varying parameters (Height of the Floor, water height, flood velocity etc.). Nevertheless, each of the 33 functions follow the same structure:

The cost C of one element X is obtained by multiplying the extension of the damage E(x) with the replacement price of the component P(x). These letters will be the first letter of the function's name. To these main elements are added adaptation measures that will strongly modify the E(x) to reduce damages, while also presenting some extra costs.



Schematic structure of the component

In addition to defining the structure, this part also names the functions. Combined with the previous explanation of the 3 great categories, the function names are as follows :

- **E** for Extension of damages : Ep (preliminary), Ec (component), Es (structural)
- **C** for Cost of the component (final cost) : Cp (preliminary), Cc (component), Cs (structural)
- **P** for the price (unitary cost) : Pp (preliminary), Pc (component), Ps (structural).

Additionally, a number is added according to their chronological order.

Color code of parameters:

As mentioned a little earlier, all functions are composed of a lot of different parameters. To facilitate understanding, several descriptive elements are added.

- First, a brief description directly below, breaking down each function and clarifying what each part refers to.
- Second, *List of used building characteristics,* which will specify all parameters used in the functions. Some have been explained earlier in the 'Geometric Parameters' chapter; others will be clearly detailed here
- Third, *List of assumptions :* compiles all of the assumptions we made use of in the function.

Additionally, we made use of a color code to facilitate orientation.

- **Orange :** Building characteristics, covering the extent of potential damages
- **Blue :** Flood characteristics, covering the conditions and thresholds for the component to be damaged
- **Green** : Adaptation measures
- **Red** : Unit cost of the component

Our sources can be sorted in the following way :

- Models : INSYDE main technical manual, it's supplement and floodam
- Studies: CEPRI 'Le bâtiment face à l'inondation'
- Empirics : Field observations and private data handed in by private individuals and local authorities
- ITW: Interviews with experts of various disciplines
- Personal insights: Knowledge based on secondary sources

Preliminary Measures

Ep1 - Pumping [m^3]

This function estimates post-flood pumping costs by including those in the basement, crawl space, and elevator shaft.

Ep1 = (Ab * Hb + Hcs * Af + Ee * 8) * int(adaptation=="None")
Cp1 = Ep1 * catalogue["Pp1"]

- **Pumping in the basement:** Refers to the pumping costs induced by water accumulation in the basement.
- **Pumping in the crawl space:** Refers to the pumping costs induced by water accumulation in the crawl space.
- **Pumping in the elevator shaft:** Refers to the pumping costs due to water accumulation in the elevator shaft.
- **Adaptation measures :** Our 'basic' adaptation measures include the use of pumps during and after the event, canceling all pumping related costs.
- **Unit cost of pumping :** Refers to the pumping cost per m^3, which is in our model set at 5 €.

List of used building characteristics :

- **Hb (Height of Basement, float) [m]:** Refers to the basement's height. It is obtained from our 'building characteristic' table, where collective housing basement height is set at 2,3m and individual housing basement height at 2m.
- **Ab (Area of basement, float) [m^2]** : calculated in geometric parameters
- **Hcs (Height of Crawl Space, float, {0; 0,2; 1,2) [m]:** Refers to the height of the crawl space. It is considered a fixed input in our model, derived from our 'building characteristic' table. It is important to note that our dataset includes buildings with and without crawl spaces, in regard to their typology. For buildings with crawl spaces, the height is set at 0.2m for individual housing and at 1.2m for collective housing.
- **Af (Area of one floor, float) [m^2]** : calculated in geometric parameters
- **Ee (Existence of elevator) [boolean]:** Refers to the presence of an elevator in the building. It is considered a fixed input in our model, derived from our 'building characteristic' table. It must be noted that this input follows a binary scenario, attributing the value of 0 to the absence of an elevator, and the value of 1 to the presence of an elevator.

List of assumptions :

- **Water drain [qualitative]:** The water within the storeys is not regarded as pumping cost as it is above ground level and will flow outside naturally through the openings without the requirement of any technical intervention.

- **8 [m^3]:** Refers to the elevator shaft's volume, set at $8m^3$.[6]

Ep2 - Waste disposal [m^3]

This function covers waste costs generated by the flood, specifically flood sludge, which typically consist of mud and clay deposits. In the absence of any sediments the function remains inactive.

Ep2 = [Vu * (20 * int(se=="high") + 5 * int(se=="medium") + int(se=="low"/1000)) * (1 + q * 0,4)] * [int(adaptation=="None") + 0.5 * int(adaptation!="None")]

Cp2 = Ep2 * catalogue["Pp2"]

- **Extent of generated waste volume :** Captures the waste volume generated by the floodwater by accounting for waste costs generated throughout the basement, the crawl space and the storeys.
- **Impact of sediment concentration:** The presence of sediments triggers waste disposal costs that are rising progressively according to their concentration. The progression adheres to the following scale:
  - "High" sediment concentration leads to 20 times higher costs
  - "Medium" sediment concentration leads to 5 times higher costs
  - "Low" sediment concentration doesn't lead to any extra costs.
  - No cost is associated in case of No sediment concentration

  These numbers have been chosen to reflect prices observed during case studies.
- **Impact of water quality :** The presence of water pollutants contribute to an extra 40% cost increase. It must be noted that pollutants are only taken into account once sediments are detected.
- **Adaptation measures :** Our 'basic' adaptation package includes the use of pumps during and after the event, which decreases waste disposal related costs by 50%.
- **Unit cost of waste disposal** : Refers to the pumping cost per m^3, which is in our model set at 200 €.

List of used parameters

- **Vu (volume underwater, float) [m^3] :** calculated in geometric parameters
- **se (sediment concentration, string) [qualitative]:** estimates the concentration of sediment in the water[7]
- **q (water quality, boolean)** : Determines the presence of pollution in the water

List of assumptions

- **Water drain [qualitative]:** The water within the storeys is not regarded as pumping cost as it is above ground level and will flow outside naturally through the openings without the requirement of any technical intervention.

[6] Based on an interview with engineers (SETEC)
[7] Based on an interview with a hydrogeology expert & personal insights

- **0,4 [%] :** Pollutant presence in the water triggers a 40% increase in waste disposal costs[8].
- **0,5 [%] :** Active pumping prevents half of cleaning and preliminary measures costs.[9]

Ep3 - Cleaning [m²]

This function measures cleaning costs related to the basement, and each flooded storey.

$$Ep3 = [\ 2 * Ab + Hb * Pb + (Hi * Pw + 2 * Af * Nfu - Af)\ ] * int(Hi>0)\ ] * (1 + q * 0,4) * [\ int(adaptation=="None") + 0.5 * int(adaptation!="None")\ ]$$

$$Cp3 = Ep3 * catalogue["Pp3"]$$

- **Extent of cleaning required in the basement:** Includes all floodwater affected surfaces throughout the basement.
- **Extent of cleaning required across all storeys:** Includes all floodwater affected surfaces throughout all of the storeys within the building, i.e. floors, ceiling, walls. It must be noted that, int(Hi>0) serves as a control variable for Nfu, given to automatically take the value of 1 when activated.
- **Impact of water quality:** A strong determinant of the cleaning costs resides in the presence of pollutants within the floodwater, which increases costs by 40%.
- **Adaptation measures :** Our 'basic' adaptation package includes the use of pumps during and after the event, which decreases cleaning related costs by 50%.
- **Unit cost of cleaning** : Refers to the cleaning costs per m², which is in our model set at 8 €.

List of used building characteristics :

- **Hb (Height of Basement, float) [m]:** Refers to the basement's height. It is obtained from our 'building characteristic' table, where collective housing basement height is set at 2,3m and individual housing basement height at 2m.
- **Ab (Area of basement, float) [m²]** : calculated in geometric parameters
- **Pb (Perimeter of basement, float) [m]** : calculated in geometric parameters
- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Pw (Perimeter of walls, float) [m]** : calculated in geometric parameters
- **q (water quality, boolean)** : Determines the presence of pollution in the water

List of assumptions

- **0 < He < Hg** : Basement is flooded while the interior of the building is not flooded
- **Af (Area of a floor, float) [m²] :** We assume that the flood water height within the building rarely reaches the last ceiling. Thus, we subtract the area of the last ceiling[10].

[8] Based on INSYDE Supplement, p.2
[9] Based on empirics & CEPRI : "Liste des mesures de réduction de la vulnérabilité" p.47-53
[10] Based on personal expertise

- **0,4 [%] :** Pollutant presence in the water triggers a 40% increase in waste disposal costs[11].
- **0,5 [%] :** Active pumping halves cleaning costs.[12]

Ep4 - Dehumidification [m³]

This function covers costs associated with the dehumidification process following a flooding event. Included are dehumidification costs pertaining to basement and upper storeys.

Ep4 = [Ab * Hb + Af * Hf * Nfu * int(Hi>0)] * (0,2 * int(d>=12) + 0,8 * int(d>=24) + 0,2 * int(d>=50)) * [int(adaptation=="None") + 0.5 * int(adaptation!="None")]

Cp4 = Ep4 * catalogue["Pp4"]

- **Basement dehumidification:** Refers to the volume subject to dehumidification in the basement.
- **Extent of storey dehumidification:** Refers to the volume subject to dehumidification in all floodwater affected storeys. It must be noted that, int(Hi>0) serves as a control variable for Nfu, given to automatically take the value of 1 when activated.
- **Impact of flood duration :** Dehumidification costs vary depending on the duration of water retention within the building. These costs are associated to the following thresholds :
    - 20%, if the duration exceeds 12h.
    - 80%, if the duration exceeds 24h.
    - 120%, if the duration exceeds 50h.[13]
- **Adaptation measures :** Our 'basic' adaptation measures include the use of pumps during and after the event, which decrease dehumidification related costs by 50%.
- **Unit price of dehumidification** : Refers to the price of cleaning costs per m^3, which is in our model set at 18 €.

List of used building characteristics :

- **Hb (Height of Basement, float) [m]:** Refers to the basement's height. It is obtained from our 'building characteristic' table, where collective housing basement height is set at 2,3m and individual housing basement height at 2m.
- **Ab (Area of basement, float) [m²]** : calculated in geometric parameters
- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling and obtained from the building characteristics table.
- **d (flood duration, integer) [h]** : measures duration of the water inside the building

Assumption :

[11] Based on INSYDE Supplement, p.2
[12] Based on empirics
[13] Based on INSYDE Supplement, p.3 and empirics

- **0,5 [%] :** An active pumping halves dehumidification costs.[14]

Finishing work & equipment components

Ec1- Pavement [m²][15]

This section calculates pavement costs by dividing them into 3 types : wood (Ec1a), porcelain stoneware (Ec1b), and marble or natural material (Ec1c). Our model assumes that adaptation measures influence the various pavement functions similarly, at least to a certain extent. Consequently, adaptation improvements are addressed towards the end of this section.

Ec1a - Wood Pavement [m²]

This function estimates costs associated with wood pavements.

Ec1a = int(Sp==1) * (Af * Nfu * int(Hi>0)) * int(d>24)

Cc1a = Ec1a * catalogue["Pc1a"][Qc]

- **Extent of pavement damage :** Refers to the pavement surface affected by the flood throughout the building, which is obtained by multiplying the area of one floor by the number of flooded storeys. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration :** Pavement costs are triggered once the flood's retention time exceeds 24 hours.
- **Unit cost of Wood Pavement :** Refers to the Ec1a pavement m² cost, which in our model varies according to the component's quality Qc. Consequently costs are : 99 € for both low and medium quality, and 141 € for high quality.

List of used building characteristics :

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Sp (Structure of ground pavement) [unit] :** This parameter determines the pavement's material. It follows a trinary scenario where 1 is associated to a wood pavement, 2 equals to a porcelain and stoneware pavement and 3 associated to a marble or other organic materials.
- **d (flood duration, integer) [h]** : measures duration of the water inside the building[16]

[14] Based on empirics & CEPRI : "Liste des mesures de réduction de la vulnérabilité" p.47-53
[15] Translation (fr) : revêtement
[16] Based on interviews with several floor structure & flood damage specialists

- **Qc (Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

Ec1b - porcelain stoneware pavement

This function estimates costs associated with pavements made of porcelain stoneware.

$$\text{Ec1b} = \text{int(Sp==2)} * (\text{Af} * \text{Nfu} * \text{int(Hi>0)}) * [\ \text{int(Yc<=1990)} * (0.2 + \text{int(d>24)} * 0.4) + \text{int(Yc=>1990)} * \text{int(d>48)} * 0.2\ ]$$

$$\text{Cc1b} = \text{Ec1b} * \text{catalogue["Pc1b"][Qc]}$$

- **Extent of pavement damages:** Refers to the pavement surface affected by the flood throughout the building, which is obtained by multiplying the area of one floor by the number of flooded storeys. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration and construction date :** This component, being more resistant than the previous *Ec1a* pavement, presents lower costs, with destruction ranging from 20% to 60%. The variation is due to the existence of two types of porcelain stoneware pavements, one installed before 1990 and a more resistant version implemented afterwards.
  Thus, if the dwelling was built before the 1990s, it is assumed to feature a more fragile porcelain stoneware, resulting in 20% damage cost if water retention is under 24 hours, and in 60% damage costs if it exceeds 48 hours. The more resistant version installed from the 1990s onward only leads to 20% damage costs when flood retention exceeds 48 hours[17].
- **Unit cost of Porcelain Stoneware Pavement :** Refers to the Ec1b pavement m² cost, which in our model varies according to the component's quality Qc: 109€ for both low and medium quality, and 0€ for high quality. Premium porcelain or stoneware pavements present no costs, as they naturally repel water.

List of used building characteristics :

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Sp (Structure of ground pavement) [unit] :** This parameter determines the pavement's material. It follows a trinary scenario where 1 is associated to a wood pavement, 2 equals to a porcelain and stoneware pavement and 3 associated to a marble or other organic materials.
- **Yc (Year of construction) [unit]:** Refers to the building's construction year, allowing to derive characteristics of the structural features from it.
- **d (flood duration, integer) [h]** : measures duration of the water inside the building[18]

[17] Based on interviews with several floor structure & flood damage specialists
[18] *Ibid*

- Qc **(Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

Ec1c - Marble or other natural materials

This function estimates costs associated with pavements made of marble or other organic materials.

$$Ec1c = int(Sp==3) * Af * Nfu * int(Hi>0) * q * 0.2 * int(d>=72)$$
$$Cc1c = Ec1c * catalogue["Pc1c"][Qc]$$

- **Extent of pavement damages :** Refers to the pavement surface affected by the flood throughout the building, which is obtained by multiplying the area of one floor by the number of flooded storeys. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration and water quality :** Marble and other pavements made entirely of natural materials are largely unaffected by flooding, except for one scenario, where the water is polluted and remains in the dwelling longer than 72 hours, causing it to erode the pavement. Under this condition, damage costs are set to 20%.[19]
- **Unit cost of marble or other natural materials :** Refers to the Ec1c pavement m² cost, which in our model varies according to the component's quality, that is determined by Qc : 111 € for both low and medium quality, and of 200 € for high quality.

List of used building characteristics :

- Af **(Area of one floor, float) [m²]** : calculated in geometric parameters
- Nfu **(Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- Hi **(internal Height of water, float) [m]:** calculated in geometric parameters
- Sp **(Structure of ground pavement, boolean) :** This parameter determines the pavement's material. It follows a trinary scenario where 1 is associated to a wood pavement, 2 equals to a porcelain and stoneware pavement and 3 associated to a marble or other organic materials.
- d **(flood duration, integer) [h]** : measures duration of the water inside the building
- q **(water quality, boolean)** : Determines the presence of pollution in the water
- Qc **(Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

$$Cc1 = (Cc1a + Cc1b + Cc1c) * (1 - int(adaptation=="Advanced") - int(adaptation=="Pro"))$$

- **Associated component costs of the different pavement types :** This part regroups the costs associated with each pavement type (Ec1a , Ec1b, Ec1c).

[19] Based on interviews with several floor structure & flood damage specialists

- **Adaptation measures :** The three types of pavement can be improved and replaced by flood resistant pavement's, which are canceling any flood damage related costs. This is only the case for 'Advanced' and 'Pro' adaptation packages.[20]

Ec2 - Screed [m²][21]

This function estimates the costs associated with the screed, which is the floor layer situated beneath the pavement.

$$Ec2 = Af * Nfu * int(Hi>0) * (1-Qm) * int(d>=12)$$
$$Cc2 = Ec2 * catalogue["Pc2"]$$

- **Surface of damaged screed :** Refers to the screed surface affected by the flood throughout the building, obtained by multiplying the area of one floor by the number of flooded storeys. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration and quality of maintenance :** The screed is considered damaged if the flood duration exceeds 12 hours and maintenance is poor.[22]
- **Unit cost of screed :** Refers to the Ec2 screed m² cost, which in our model is set at 25€.

List of used building characteristics :

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **d (flood duration, integer) [h]** : measures duration of the water inside the building
- **Qm (Quality of maintenance) [unit]:** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.

Ec3 - Baseboard [m][23]

This function estimates costs associated with baseboards.

$$Ec3 = Pw * Nfu * int(Hi>0) * (1-int(Sp==1)) * int(d>=24)$$
$$Cc3 = Ec3 * catalogue["Pc3"]$$

[20] Based on empirical data, CEPRI : "Liste des mesures de réduction de la vulnérabilité" p.47-53 & interviews with several floor structure & flood specialists
[21] Translation (fr) : chape
[22] Based on interviews with several floor structure & flood damage specialists
[23] Translation (fr) : plinthe.

- **Length of damaged baseboards :** Takes into account the baseboards affected by the flood throughout the building and is obtained by multiplying the perimeter of walls of one floor by the number of flooded storeys. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration and pavement type :** baseboards costs are already accounted for if the pavement is made of wood (Sp==1) as wood pavement replacement costs already include baseboards. Baseboards are damaged if the flood duration exceeds 24 hours.[24]
- **Unit cost of baseboards :** Refers to the Ec3 baseboard cost per meter length, which in our model is set at 12 €, provided the pavement is not made of wood (Ec1a).

List of used building characteristics :

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Pw (Perimeter of walls, float) [m]** : calculated in geometric parameters
- **Sp (Structure of ground pavement) [unit] :** This parameter determines the pavement's material. It follows a trinary scenario where 1 is associated to a wood pavement, 2 equals to a porcelain and stoneware pavement and 3 associated to a marble or other organic materials.
- **d (flood duration, integer) [h]** : measures duration of the water inside the building[25]

Ec4 - Partition [m²][26]

This function estimates costs specifically associated with partition walls.

Ec4 = Pw * Hf * Nfu * 0,5 * [int(d>=48) *0.5 + int(d>=72)*0.5] * int(Hi>=1.6) * int(adaptation != "Pro")

Cc4 = (Ec4 * catalogue["Pc4"])

- **Surface of damaged partitions :** Refers to costs associated with partitions across all storeys. The spatial extent of the damage is measured by multiplying the perimeter of the walls on one floor by the floor height, for all storeys affected by floodwater. It must be noted that, int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration and water height :** The partitions are destroyed when the water height exceeds 1.6m and when the flood lasts : when it exceeds 48 hours, it generates at first 50% of damage costs and when the duration equals or exceeds 72 hours, it results in the complete destruction of the partition.[27]
- **Adaptation measures :** While the Basic, Medium, and Advanced packages do not directly affect partition costs per se (remember cofferdams & nonreturn valves), the

[24] Based on interviews with several floor structure & flood damage specialists & empirics
[25] *ibid*
[26] Translation (fr) : cloison
[27] Based on CEPRI : "Tableau de synthèse" p.36-42 & INSYDE Supplément P.5

Pro adaptation package fully offsets them. This is because it includes the use of more resilient (resist) or even removable partitions (retreat). [28]

- **Unit cost of partitions :** Refers to the Ec4 partition m² cost, which is in our model set at 128 €.

List of used building characteristics :

- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Pw (Perimeter of walls, float) [m]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **d (flood duration, integer) [h]** : measures duration of the water inside the building

List of assumptions

- **0,5 [%] :** We equate the presence of partitions to half (50%) of the combined surface areas of interior walls (PW). This is inferred from the assumption that interior walls may be partitions, or that additional 'partitioning' elements could be present within the rooms.[29]

Ec5 - Suspended ceiling [m²][30]

This function estimates the costs associated with suspended ceilings, areas in the dwelling where the ceiling height is lower than in the rest of the dwelling, which are typically found in kitchens or bathrooms.

Ec5 = 0.2 * Af * [Nfu - 1 + int(Hi - (Nfu - 1)*Hf >= Hf - 0.5)] * int(Hi>0) * int(d>=12)
Cc5 = Ec5 * catalogue["Pc5"][Qc]

- **Surface of damaged suspended ceilings:** Captures the damages sustained by suspended ceiling surfaces. The function is obtained by multiplying the suspended ceiling's surface area by the number of affected floors. The latter component being measured through the Nfu function, and its add-on, measuring the water height within the last water-affected story. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impact of flood duration :** the ceiling is destroyed if the flood exceeds 12 hours[31]
- **Unit cost of suspended ceilings:** Refers to the Ec5 suspended ceiling m² cost, which in our model varies according to the component's quality, determined by Qc, resulting in : 50 € for a lower quality, 64€ for a medium and 72€ for the highest quality.

[28] Based on CEPRI : "Liste des mesures de réduction de la vulnérabilité" p.47-53
[29] Based on INSYDE, Supplement p.4
[30] Translation (fr) : faux plafond
[31] Based on empirics

List of used building characteristics :

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **d (flood duration, integer) [h]** : measures duration of the water inside the building
- **Qc (Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

List of assumptions

- **0,2 [%] :** It is assumed that only certain rooms have suspended ceilings, which correspond to 20% of the overall ceiling surface. [32]
- **- 0,5 [m] :** We consider 'suspended ceilings to be placed 0.5 m below the original ceiling level.[33]

Ec6 - Internal plaster & insulation [m²][34]

This function estimates the costs associated with the plaster layer applied to walls and insulation within a storey. Preceding the paint layer, all walls of the dwelling are considered to have this coating. Internal plaster and insulation are grouped within a single function, as they consistently appear bounded in the price data we relied on to build and validate our model.

Ec6 = Pw * (Hi + 0.2) * int(Hi>0.1) * max(int(d>=36), q, Qm) * int(adaptation != "Pro")

Cc6 = Ec6 * catalogue["Pc6"][Qc]

- **Surface of damaged plaster and insulation :** Refers to the plaster and insulation surface affected by the floodwater per storey. This cost results from the product of wall perimeter and water height, to which capillary rise is added. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impacts of flood characteristics :** internal plaster and insulation are destroyed if the flood duration exceeds 36 hours, if the water is polluted or if the maintenance quality is poor.
- **Adaptation measures :** If the adaptation measures fall under the Pro package, no costs will apply. This is due to the fact that our 'Pro Package' includes secondary construction measures designed to apply water-resistant coatings to the walls.
- **Unit cost of internal plaster & insulation :** Refers to the Ec6 internal plaster and insulation m² costs, which in our model vary according to the component's quality,

[32] Based on INSYDE,Supplement p.5
[33] *Ibid*
[34] Translation (fr) : plâtre interne

determined by Qc, setting costs at : 50€ for a lower quality, 52€ for a medium and 62€ for the highest quality.

List of used building characteristics :

- **Pw (Perimeter of walls, float) [m]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **d (flood duration, integer) [h]** : measures duration of the water inside the building[35]
- **q (water quality, boolean)** : Determines the presence of pollution in the water[36]
- **Qm (Quality of maintenance, boolean):** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.
- **Qc (Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

List of assumptions

- **0,2 [m] :** We consider that due to capillary rise the damaged area is 0.2 m above the internal water height (Hi).[37]

Ec7 - External plaster [m²][38]

Refers to costs associated with the plastered facade of the building (outer layer of the four structural walls) affected by the flood.

Ec7 = (Pf/4 + 2*Tw) * 4 * (He + 0.2) * max(int(d>=72), int(ve>=1,3), Qm)

Cc7 = Ec7 * catalogue["Pc7"]

- **Surface of damaged external plaster :** Determines the outside plastered surface area of the façade (m²). To correctly assess the facade, the width or thickness of the structural walls when defining the outer perimeter of the building. As apparent in the prior function, capillary rise as well as the control function to Nfu are reemployed in this present function.
- **Impacts of flood characteristics :** External plasters are damaged if the flood duration exceeds 72 hours, the velocity exceeds 1,3m/s or the maintenance quality is poor. [39]

[35] Based on CEPRI "Tableau de synthèse" p.38 & empirics
[36] Based on INSYDE, Supplement p.6
[37] Based on empirics & INSYDE, Supplement p.6
[38] Translation (fr) : plâtre externe
[39] Based on CEPRI "Tableau de synthèse" p.37 & INSYDE, Supplément p.5

- **Unit cost of external plaster :** Refers to the Ec7 external plaster m² cost, which is in our model set at 30 €.

List of used building characteristics :

- **Pf (Perimeter of facade, float) [m]** : calculated in geometric parameters
- **He (external Height of water, float) [m] :** height of water according to flood scenario
- **Tw (Thickness of walls, float) [cm] :** Refers to the width of the 4 structural walls, derived from the building characteristics tables.
- **d (flood duration, integer) [h]** : measures duration of the water inside the building
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **Qm (Quality of maintenance, boolean) :** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.

List of assumptions :

- **0,2 [m] :** We consider that due to capillary rise the damaged area is 0.2 m above the internal water height (Hi)[40].

Ec8 - Doors [unit]

This section captures doors related costs by differentiating: interior doors (Ec8a) within the dwelling, the entrance door (Ec8b), and its lock (Ec8c). Consistent with the pavement component, our model assumes that adaptation measures influence the various door functions similarly. Consequently, adaptation improvements are addressed towards the end of this section.

Ec8a - Interior Doors - [unit]

This function assesses costs associated with doors in the building, including those in the basement and upper storeys, but excluding the entrance door that will be assessed separately. Since water damages doors primarily through warping the door frame, we consider them to be entirely destroyed, leading us to round up our estimates.

Ec8a = round [(0,02 * Ab + (0,09 * Af * Nfu * int(Hi>0)) * max(int(d>=48), int(ve>=1.3))
]

Cc8a = Ec8a * catalogue["Pc8a"][Qc]

- **Extent of damaged doors in the basement :** Count of doors present in the basement.

[40] Based on empirics & INSYDE, Supplement p.6

- **Extent of damages to doors throughout all storeys** : Refers to the number of doors affected by the flood in the building. It must be noted that int(Hi>0) serves as a control variable for Nfu.
- **Impacts of flood characteristics :** Doors are damaged if the flood duration exceeds 48 hours or the velocity exceeds 1,3m/s[41].
- **Unit cost of internal doors :** Refers to the Ec8a internal doors unit cost, which in our model varies according to the component's quality determined by Qc. Consequently, costs are set at : 138 € for a lower quality, 182 € for a medium and 300 € for the highest quality.

List of used building characteristics :

- **Ab (Area of basement, float) [m2]** : calculated in geometric parameters
- **Af (Area of one floor, float) [m2]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **d (flood duration, integer) [h]** : measures duration of the water inside the building
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **Qc (Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

List of assumptions :

- **0,02 [unit/m²]:** Refers to the door count based on the basement's m² surface, which is derived from our previous assumption of 2,5 (perimeter of walls) and verified empirically. We assume our basement to feature 2 doors every 100m² of the basement.
- **0,09 [unit/m²]:** Refers to the door count based on the storeys surface area in m², which is derived from our previous assumption 2,5 (perimeter of walls) and confirmed empirically. We assume our basement to feature 2 doors every 100m².

Ec8b - Entrance doors - [unit]

This function assesses costs associated with the entrance doors of each flooded storey.

$$Ec8b = (1 + Sh * Ndfu) * int(Hi>0) * max(int(He>=1.2), int(ve>=1.3, Qm)$$
$$Cc8b = Ec8b * catalogue["Pc8b"][Qc]$$

- **Extent of damaged doors :** Is assessed the amount of affected entrance doors, which strongly influences the building's structural typology. In fact, collective housing (LC) will include one entry door for each dwelling, with the understanding that some floors may contain multiple dwellings. It must be noted that in the collective housing case, a supplementary door is added to the count, i.e. the one serving as the main entrance at the ground level. In contrast, individual housing will typically solely

[41] Based on CEPRI "Tableau de synthèse" p.38 & INSYDE, Supplement p.6

feature one entrance door. Similar to Nfu, int(Hi>0) serves as a control variable, this time for Nfdu.

- **Impacts of flood characteristics :** Doors are damaged if the flood height exceeds 1.2m or the velocity exceeds 1.3m/s or the maintenance quality if poor. [42]
- **Unit cost of entry doors :** Refers to the Ec8b entry doors unit cost, which in our model varies according to the component's quality, determined by Qc. Consequently, costs are set at : 1930 € for a lower quality, 3168 € for a medium and 3680 € for the highest quality.

List of used building characteristics :

- **Sh (Structure of housing, boolean) :** refers to the structure of the housing, 0 meaning individual houses and 1 collective housing.
- **Ndfu (Number of dwelling per floor underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **He (external Height of water, float) [m] :** height of water according to flood scenario
- **Qm (Quality of maintenance, boolean):** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.
- **Qc (Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

Ec8c - Lock of the entrance door - [unit]

Given locks to represent a significant cost burden and, based on our empirical research, to be often damaged independently from the rest of the door, we have developed a dedicated function.

$$\text{Ec8c} = (1 + Sh * Ndfu) * int(Hi>0) * [\ 1-int(Cc8b>0)) * int(Hi>=1.2) * int(se=="high")+int(se=="medium")\ ]$$

$$\text{Cc8c} = \text{Ec8c} * catalogue["Pc8c"][Qc]$$

- **Extent of damaged entry locks :** Is assessed the amount of affected entrance locks, which is strongly influenced by the building's structural typology. In fact, collective housing (LC) will include one entry door for each dwelling, with the understanding that some floors may contain multiple dwellings. It must be noted that in the collective housing case, a supplementary door is added to the count, i.e. the one serving as the main entrance at the ground level. In contrast, individual housing

[42] Based on empirics & INSYDE, Supplement p.5

will typically solely feature one entrance door. Similar than for Nfu, int(Hi>0) serves as a control variable, this time for Nfdu. Similar to Nfu, int(Hi>0) serves as a control variable, this time for Nfdu.

- **Impacts of flood characteristics :** Locks are damaged if entrance doors are damaged, and if the flood height exceeds 1,2m and the sediment concentration is high or medium.[43]
- **Unit cost of entry locks:** Refers to the Ec8c entry lock unit cost, which in our model varies according to the component's quality, determined by Qc. Consequently, costs are set at : 632 € for a lower quality, 763 € for a medium and 800 € for the highest quality.

List of used building characteristics :

- **Sh (Structure of housing, boolean) :** refers to the structure of the housing, 0 meaning individual houses and 1 collective housing.
- **Ndfu (Number of dwelling per floor underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **se (sediment concentration, string) [qualitative]** : describes concentration of sediment in the water.
- **Qm (Quality of maintenance) [unit]:** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.
- **Qc (Quality of the component) [unit] :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

$$Cc8 = (Cc8a + Cc8b + Cc8c) * int(adaptation !="Pro")$$

- **Associated component costs of the different pavement types :** This part regroups the costs associated to each door function (Ec8a , Ec8b, Ec8c).
- **Adaptation measures :** If the Pro package is implemented, doors will be replaced by flood proof (water repelling) doors, prohibiting any flood related damages.[44]

Ec9 - Windows [unit]

This component captures windows related costs, distinguishing between ordinary dwelling windows (Ec9a) and window bays (Ec9b). Consistent with other components regrouping several functions, we consider in our model adaptation measures to improve windows

[43] Based on empirics
[44] Based on CEPRI : "Liste des mesures de réduction de la vulnérabilité" p.47-53

vulnerability similarly. Consequently, adaptation improvements are addressed toward the end of this section.

Ec9a- Room Windows

This function evaluates the costs associated with windows. Analogous to doors, windows are considered completely destroyed when damaged; accordingly, we round up the function.

Ec9a = round [0.09 * Af * Nf * (Nfu - 1 + int((Hi - (Nfu-1)*Hf) >=1.5)) * int(Hi>0)] * max[int(d>=48), int(ve>=0.9)]

Cc9a = Ec9a * catalogue["Pc9a"][Qc]

- **Extent of damaged windows :** Refers to the number of affected windows which is obtained by multiplying the floor window count with the number of flooded storeys, with the uppermost storey being probed separately. If the water height (Hi) exceeds 1.5 meters, windows are deemed destroyed. Additionally, int(Hi>0) serves as a control variable for Nfu.
- **Impacts of flood characteristics :** Windows are damaged if the flood duration exceeds 48 hours or the velocity exceeds 0,9m/s[45].
- **Unit cost of room windows:** Refers to the Ec9a room windows unit cost, which in our model varies according to the component's quality, determined by Qc. Consequently, costs are set at : 595 € for a lower quality, 780 € for a medium and 1276 € for the highest quality.

List of used building characteristics :

- **Af (Area of one floor, float) [m2]** : calculated in geometric parameters
- **Nf (Number of floors, integer) [unit]:** Refers to the number of storeys throughout a building.
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.
- **d (flood duration, integer) [h]** : measures duration of the water inside the building
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **Qc (Quality of the component) [unit] :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

List of assumptions :

- **Double-glazed windows [qualitative]:** To streamline the model and reduce complexity, our model will assume windows to be uniformly double-glazed[46].

[45] Based on empirics & INSYDE, Supplement, p.8
[46] Based on interviews with engineers

- **Absence of windows in the basement [qualitative]:** Based on empirical studies, we will assume there to be no windows in basements.
- **0,09 [unit/m]:** Refers to the window count based on the storeys surface area in m², which is derived from our previous assumption 2,5 (perimeter of walls) and confirmed empirically. Based on the reference scenario of a 100m² dwelling, we assume it to have 9 windows.
- **1.5 [m]:** Refers to our assumed window installation height.[47]

Ec9b - Window Bays [Unit]

Through empirical research we observed window bays to be very often present in individual housing (MI).

Ec9b = int(Sh == 0) * int(Hi>0) * int(He>=1) * int(ve>=0.7) * [int(Qc=="medium") + int(Qc=="high")]

Cc9b = Ec9b * catalogue["Pc9b"][Qc]

- **Extent of damaged window bays :** Refers to the costs associated with flood affected window bays, solely attributed to individual housing. Additionally, int(Hi>0) serves as a control variable for Nfu.
- **Impacts of flood characteristics :** Window bays are damaged if the velocity exceeds 0,7 m/s, the water height exceeds 1m and the quality of construction is high or medium.[48]
- **Unit cost of window bays:** Refers to the Ec9b window bay unit cost, which in our model varies according to the component's quality determined by Qc. Consequently costs are set at : 867 € for a lower quality, 1055 € for a medium and 1447 € for the highest quality.

List of used building characteristics :

- **Sh (Structure of housing, boolean) :** refers to the structure of the housing, 0 meaning individual houses and 1 collective housing.
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **He (external Height of water, float) [m] :** height of water according to flood scenario
- **Qm (Quality of maintenance, boolean):** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.
- **Qc (Quality of the component, boolean) :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

[47] Based on INSYDE, Supplement, p.7
[48] Based on empirics & personal insights

Cc9 = (Cc9a + Cc9b) * int(adaptation !="Pro"))

- **Associated costs of the grouped window functions :** This part regroups the costs associated with each window function (Ec9a , Ec9b).
- **Adaptation measures :** If the 'Pro' package is implemented, windows are replaced flood proof windows prohibiting any window replacement costs[49].

Ec10 - Boilers

This component captures cost related to boilers, distinguishing between centralized or distributed boilers.

Ec10a - Boilers centralized[50]

This function assesses costs related to centralized boilers, where the dwellings of one's housing are supplied with hot water from pipes stemming from one central unit. We derive from it, there to only be one throughout the entire building. As it is considered fragile, the boiler is assumed to be destroyed upon direct contact with water.

Ec10a = (1-Db) * (Eb + (1-Eb) * int(Hi>=1.6)
Cc10a = Ec10a * (15300 + (user["Nf"]-1) * 2000) * user["Sh"] + 4500 * (1-user["Sh"])

- **Extent of damage to the central boiler :** After determining the boiler's typology, its location is assessed. If there is the presence of a basement the boiler is, in case of a flood automatically deemed destroyed.
- **Impacts of flood characteristics :** If there is no basement, the boiler is destroyed once the water height exceeds 1,6m.
- **Unit cost of centralized boilers :** Refers to the Ec10a centralized boiler unit cost, which varies in the model based on the building structure. For collective housing (LC), the base cost is 15 300 €, with an additional 2000 € added per floor (excluding the first). For individual housing (MI), the boiler cost is fixed at 4500 €.

List of used building characteristics :

- **Db (Boiler Distribution, boolean) :** Determines the type of boiler in the building. Inferred from the 'Building characteristics table' is attributed 0 to centralized boilers and the value of 1 to distributed boiler systems.
- **Eb (Existence of basement, boolean) :** Determines the presence of a basement in the building. Inferred from the 'Building characteristics table' the presence of a basement is associated to 1, and the absence of a basement to 0.
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Nf (Number of floors, integer) [unit]:** Refers to the number of storeys throughout a building.

[49] Based on CEPRI : "Liste des mesures de réduction de la vulnérabilité" p.47-53
[50] Translation (fr) : chaudière centralisé

- **Sh (Structure of housing, boolean) :** refers to the structure of the housing, 0 meaning individual houses and 1 collective housing.

List of assumptions :

- **Boiler in the basement [qualitative] :** We assume centralized boilers to be always located in the basement.[51]
- **1.6 [m]:** We consider the boiler's installation height at 1.6 meters (above the ground).[52]

Ec10b - Boilers distributed[53]

This function estimates costs of distributed boiler systems, where each dwelling owns an individual boiler.

$$Ec10b = Db * Ndf * [Nfu - 1 + int(Hi - (Nfu-1)*Hf >= 1.6)] * int(Hi>0)$$

$$Cc10b = Ec10b * catalogue["Pc10b"]$$

- **Extent of damage to distributed boilers :** After determining the boiler's typology, the number of boilers is calculated based on the number of dwellings. Boilers are considered destroyed if water reaches their installation height (i.e., 1.6 m). Additionally, int(Hi>0) serves as a control variable for Nfu.
- **Unit price of distributed boilers :** Refers to the Ec10b distributed boiler unit cost, which is in our model set at 4500 €.

List of used building characteristics :

- **Db (Boiler Distribution) [unit]:** Determines the type of boiler in the building. Inferred from the 'Building characteristics table' is attributed 0 to centralized boilers and the value of 1 to distributed boiler systems.
- **Ndf (Number of dwelling per floor, integer) [unit]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters

List of assumptions :

- **Every dwelling owns a distributive boiler [qualitative]:** Under a distributed boiler system, it is assumed that every dwelling is equipped with an individual boiler.

[51] Based on empirics and interviews with engineers
[52] Based on INSYDE, Supplement, p.8
[53] Translation (fr) : chaudière distribuée

- **1.6 [m]:** We consider the boiler's installation height at 1.6 meters (above the ground).[54]

Cc10 = (Cc10a + Cc10b) * int(adaptation =="None")

- **Associated costs of the grouped window functions :** This part regroups the costs associated with each boiler function (Ec10a , Ec10b).
- **Adaptation measures :** If an adaptation package is implemented, boilers are protected by cofferdams or relocated to the upper floors when present in the basement, resulting in no cost of boiler replacement in case of flood[55].

Ec11 - Internal Painting [m²]

This function measures costs associated with interior painting within the dwelling.

Ec11 = [Hf * Nfu * Pw + Af * (Nfu-1)] * int(Hi>0.1) * int(adaptation != "Pro")
Cc11 = Ec11 * catalogue["Pc11"][Qc]

- **Surface of damaged interior painting:** Wall surfaces in contact with water must be fully repainted. Ceilings of fully flooded storeys are also included. Additionally, int(Hi>0) serves as a control variable for Nfu.
- **Adaptation measures :** If the 'Pro' package is implemented, a special layer of flood proof painting is applied to walls, resulting in no internal painting related costs.
- **Unit cost of internal painting :** Refers to the Ec11 internal painting m² cost, which varies in our model according to the component's quality determined by Qc. Consequently, costs are: 15€ for a lower quality, 31€ for a medium and 36€ for the highest quality.

List of used building characteristics :

- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Pw (Perimeter of walls, float) [m]** : calculated in geometric parameters
- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Qc (Quality of the component) [unit] :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

List of assumptions :

[54] Based on INSYDE, Supplement, p.8
[55] Based on empirics

- **Internal surface painting [qualitative]:** It is assumed that wall surfaces exposed to flood water must be completely repainted, rather than only the directly affected areas typically covered by insurance.[56]
- **Absence of basement painting cost [qualitative]:** We exclude basement painting from our cost assessment.[57]

Ec12 - External Painting [m²]

This function measures costs associated with the paint layers applied on the outside facade of the building.

Ec12 = He * Pf
Cc12 = Ec12 * catalogue["Pc12"][Qc]

- **Surface of damaged facade painting :** External surfaces have to be repainted where the water touched them.
- **Unit cost of external painting :** Refers to the Ec12 external painting m² costs, which varies in our model according to the component's quality determined by Qc. Consequently, costs are set at: : 27€ for a lower quality and 51€ for a medium and higher quality.

List of used parameters :

- **He (external Height of water, float) [m] :** height of water according to flood scenario
- **Pf (Perimeter of facade, float) [m]** : calculated in geometric parameters

List of assumptions :

- **Facade surface re-painting [qualitative]:** It is assumed that only the exposed part of the facade wall surface requires repainting (in opposition to internal painting).[58]

Ec13 - Elevator [unit]

This function measures costs associated with elevator cabin repairs. Costs linked to the flooded elevator shaft are measured in the pumping function.

Ec13 = Ee * (int(Hi>=0.2) * 0.2 + int(Hi>=1.5) * 0.8)
Cc13 = Ec13 * catalogue["Pc13"][Qc]

- **Presence of elevator :** Triggers the function when an elevator is installed in the building (Ee=1).
- **Impact of flood characteristics :** Determines the percentage of damages to the cabin according to the floodwater's height within the building :
    - Below 0,20 m the elevator cabin and its electrical system remains unaffected.

[56] Based on empirics & personal insights
[57] Based on empirics
[58] Based on empirics & personal insights

    - If the water level ranges from 0.2m to just below 1.1m, repair costs are estimated at 20% of the total replacement cost of a fully compromised elevator cabin as first parts of the electrical system are reached.
    - Once the water level ranges from 1.1m to just below 1,5 m, the entire lift cabin will be considered damaged (20% + 80%)[59]
- **Unit cost of the elevator :** Refers to the Ec13 elevator unit cost, which in our model varies according to the component's quality determined by Qc. Consequently, costs are : 500 € for a lower quality, 1250 € for a medium quality and 2000 € for higher quality.

List of used building characteristics :

- **Ee (Existence of elevator) [Unit, boolean] :** Refers to the presence of an elevator in the building. Derived from our 'building characteristic' table, is attributed 0 to the absence of an elevator, and 1 to the presence of one in the building.
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Qc (Quality of the component) [unit] :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

List of assumptions :

- **Lift stationed at the ground floor [qualitative]:** We assume the lift to station at the ground floor for 'un-adapted' places, ie. places that have not yet taken any action to protect themselves from floods.[60]
- **Mechanics on top [qualitative]:** Based on empirical evidence, we assume that the electrical and mounting mechanisms are located at the top of the elevator shaft, though not universally true.[61]

Ec14 - Radiators

This section calculates costs associated with radiator repairs or replacements. We separate the radiators into two categories : electric and hydraulic ones. Electric radiators are damaged upon contact with water, while hydraulic ones, deemed more resistant, are exposed to costs related to purging or unclogging procedures.

Ec14a - Electric radiators [unit]

Ec14a = round(Er * 0.09 * Af * (Nfu - 1 + int[Hi - (Nfu-1)*Hf>= 0.2]) * int(Hi>0))

Cc14a = Ec14a * catalogue["Pc14a"] *
(1 - int(adaptation == "Pro") - int(adaptation == "Advanced"))

[59] Based on empirics and interviews with engineers
[60] *Ibid*
[61] *Ibid*

- **Extent of damaged electric radiators** *:* We assume 9 electric radiators every 100m², placed at 20cm of the ground. For every flooded storey, electric radiators are damaged if the water exceeds 0,2m thus reaching the bottom of the radiator. Additionally, int(Hi>0) serves as a control variable for Nfu.
- **Adaptation measures** : If the 'Advanced' or 'Pro' packages are implemented, electrical radiators' locations are raised, resulting in no repair nor radiator replacement costs.
- **Unit cost of electrical radiators:** Refers to the Ec14a electric radiator unit cost, which varies in our model according to the latter's age, which is inferred from the building's construction year. Consequently, costs are set at : 100 € when built prior to 1990 and 350 € for housings constructed from 1990 onwards

List of used building characteristics :

- **Er (Existence of radiators) [unit, boolean]:** Determines the type of radiator. Obtained from our 'building characteristic' table, is attributed 0 to hydraulic radiators, and 1 to electrical one's.
- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.
- **Yc (Year of construction, integer) [unit]:** Refers to the building's construction year, allowing to derive characteristics of the structural features from it.

List of assumptions :

- **0,09 [unit/m²]:** Refers to the radiator count based on the storeys surface area in m², which is derived from our previous assumption 2,5 (perimeter of walls) and confirmed empirically. Based on the reference scenario of a 100m² dwelling, we assume it to feature 9 radiators (one per window).
- **0,2 [m]:** We consider the electrical radiator's installation height at 0,2m (above the ground).[62]

Ec14b - hydraulic radiator purging [unit]

Measures the costs associated with the purging procedure of hydraulic radiators, i.e. the process of removing water that accumulated in the radiator's plumbing during the flood.

Ec14b = round [(1-Er) * 0.09 * Af * [Nfu - 1 + int(Hi - (Nfu-1)*Hf>= 0.3)] * int(Hi>0)] * [1-int(se=="no")]

Cc14b = Ec14b * catalogue["Pc14b"]

[62] Based on empirics

- **Extent of hydraulic radiator purging :** We assume the presence of 9 hydraulic radiators placed directly on the ground, with valves positioned at a height of 30 cm. Radiators must be purged when water depth in a storey exceeds 0.3 m.
- **Impact of flood characteristics :** Radiator purging is only required when the floodwater is sediment free (se==’no’). In the presence of sediments, hydraulic radiators will be more severely damaged and will trigger repair costs, which are assessed in the next function (Ec14c).
- **Unit cost for hydraulic radiator purging :** Refers to the Ec14b hydraulic radiator purging cost per procedure (unit), which is in our model set at 50 €.

List of used building characteristics :

- **Er (Existence of radiators) [unit, boolean]**: Determines the type of radiator. Obtained from our 'building characteristic' table, is attributed 0 to hydraulic radiators, and 1 to electrical one’s.
- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Hf (Height of floor, float) [m]** : Refers to the height of one storey including slab and ceiling, obtained from building characteristics table.

List of assumptions :

- **0,09 [unit/m²]:** Refers to the radiator count based on the storeys surface area in m², which is derived from our previous assumption 2,5 (perimeter of walls) and confirmed empirically. Based on the reference scenario of a 100m² dwelling, we assume it to feature 9 radiators (one per window).
- **0,3 [m]:** We consider the hydraulic radiator’s valves to be situated at 0,3m above the ground. This height marks the radiators’ vulnerability point, as it allows floodwater to enter their own heating system.[63]

Ec14c - hydraulic radiator unclogging [unit][64]

Refers to costs associated with the unclogging procedure of hydraulic radiators, i.e. the process of removing sludge that accumulated within the building’s plumbing system .

Ec14c = (1-Er) * int(se=="high") * int(Hi>=0.6)
Cc14c = Ec14c * catalogue["Pc14c"]

- **Extent of hydraulic radiator unclogging :** Unclogging is possible only for hydraulic radiators (Er=0)
- **Impact of flood characteristics :** Unclogging is needed in case of high sediment concentration and when the water height exceeds 0,6m.[65]

[63] Based on empirics
[64] Translation (fr): désembouage
[65] Based on empirics & personal insights

- **Unit cost for hydraulic radiator unclogging:** Unclogging is done at the scale of the building, and costs 10 € per m².

List of used building characteristics :

- **Er (Existence of radiators) [unit, boolean]:** Determines the type of radiator. Obtained from our 'building characteristic' table, is attributed 0 to hydraulic radiators, and 1 to electrical one's.
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **se (sediment concentration, string) [qualitative]** : describes concentration of sediment in the water.

$$Cc14 = (Cc14a + Cc14b + Cc14c) * [\ 0.5 * int(adaptation !="None") + int(adaptation =="None")\ ] * [\ 1 - int(adaptation =="Pro")\ ]$$

- **Associated costs of the grouped window functions :** This part regroups the costs associated with each radiator function (Ec14a , Ec14b, Ec14c).
- **Adaptation measures :** If any adaptation package is implemented, radiator repair costs are decreased by 50%. Moreover, the implementation of the Pro package results in no cost of radiator replacement as flood proof radiators are installed.

Ec15 - Electricity system

This function assesses the cost of electrical repairs, which are in our model broken down into: the overall electrical system (ec15a) and the alarm system (ec15b).

Ec15a- Electrical System [m²]

This function evaluates costs associated with the electrical system for the first storey.

$$Ec15a = Af * (int(Hi>=0.2) * 0.2 + int(Hi>=1.1) * 0.3 + int(Hi>=1.6) * 0.5)$$
$$Cc15a = Ec15a * catalogue["Pc15a"]$$

- **Scope of the electrical system :** Takes the surface area of one storey as a factor to determine the electrical system's size and thus costs.
- **Influenced by the water height inside the building :** Determines the varying cost levels incurred by the electrical system based on the floodwater height within the building :
    - Below 0,20 m the electrical system will be considered unaffected.
    - If the water level ranges from 0.2m onwards to just below 1.1m, repair costs are estimated at 20% of the total replacement cost of a fully compromised electrical system, as switches are reached.
    - If the water level ranges from 1.1m onwards to just below 1,5 m, repair costs are estimated at 50% of the total replacement cost of a fully compromised electrical system, due to the affected upper sockets and cables.

    - From 1,5m onwards, the entire electrical system will be considered impaired (100%), as the electric panel is reached.[66]
- **Unit cost for electrical system :** Refers to the Ec15a electric system reparation or replacement cost per m², which is in our model set at 100 €.

List of used parameters

- **Af (Area of one floor, float) [m2]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters

Ec15b - Alarm System [m²]

This function refers to video surveillance system costs, of which we consider one set per building.

Ec15b = int(Hi>=2) * Qm

Cc15b = Ec15b * catalogue["Pc15b"][Qc]

- **Impact of flood characteristics :** The alarm system is damaged when the water height exceeds 2m and at the same time poorly maintained.
- **Unit cost for the alarm system :** Refers to the Ec15b alarm system unit cost, which in our model varies according to the component's quality determined by Qc. Consequently, costs are : absent for a lower quality, set at 500 € for a medium one and 5500 € for a higher quality.

List of used building characteristics :

- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Qm (Quality of maintenance) [unit]:** This parameter indicates whether a component is well-maintained, helping to prevent cost overvaluation. Since our cost estimates rely on market prices, it allows us to adjust for components that lose value quickly over time. A component in good condition is assigned a 1, while one in poor condition is assigned a 2. This parameter is set in two ways: either directly provided by the user or inferred from the building's construction year. If built before 2005, maintenance quality is poor; if built after 2005, it is good.
- **Qc (Quality of the component) [unit] :** This parameter assigns a luxury rating to a dwelling as 'low', 'medium' and 'high', affecting the prices and resistance of components.

Assumption :

- **2 [m]:** We assume the alarm systems to be located 2m above the ground (building entrance)[67]

[66] Based on empirics & INSYDE, Supplement p.12
[67] Based on personal insights

Cc15 = (Cc15a + Cc15b) * int(adaptation =="None"))

- **Associated costs of the grouped window functions :** This part regroups the costs associated with each electrical function (Ec15a , Ec15b).
- **Adaptation measures :** If an adaptation package is implemented, electrical systems are protected by cofferdams and the switches location will be raised, resulting in no cost of electrical repair in case of flood.

Ec16 - Plumbing System [m²]

This function evaluates costs associated with the plumbing system for the first storey.

Ec16 = Af * (int(Hi>=0.15) * 0.1 + int(Hi>=0.4) * 0.2 + int(Hi>=0.9) * 0.2) * int(se=="high")* int(adaptation == "None")
Cc16 = Ec16 * catalogue["Pc16"]

- **Scope of the plumbing system :** Takes the surface area of one storey as a factor to determine the plumbing system's size and thus costs.
- **Influenced by the water height inside the building :** Determines the varying cost levels incurred by plumbing systems based on the floodwater height within the ground floor :
  - Below 0,15 m the plumbing system remains unaffected.
  - If the water level ranges from 0,15 m onwards to just below 0,4 m, repair costs are estimated at 10% of the total replacement cost of a fully compromised plumbing system, due to the affected shower.
  - Water level ranges from 0.4 m to just below 0,9 m, repair costs are estimated at 30% of the total replacement cost of a fully compromised plumbing system, due to additional affected sanitaries.
  - From 0,9 m onwards, repair costs are estimated at 50% of the total replacement cost of a fully compromised plumbing system, given the water to be reaching the sinks.[68]
- **Impacted by flood characteristics :** plumbery repairs are only required in case of a high sediment concentration.
- **Adaptation measures** : if adaptation measures are implemented, nonreturn valves are implemented, resulting in no plumbing cost in case of flood.
- **Unit cost for plumbing system :** Refers to the Ec16 plumbing system reparation cost per m², which is in our model set at 100 €.

List of used parameters

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **se (sediment concentration, string) [qualitative]** : describes concentration of sediment in the water.

[68] Based on empirics & INSYDE, Supplement p.12

Structural

Es1 - Soil consolidation [m²]

This function accounts for costs related to soil consolidation as a consequence of the water's eroding nature at the base of the facade. During the flooding event, water pressure washes away sections of the soil next to the house's foundation. Sealing these gaps and ensuring proper soil consolidation is essential to prevent later landslides.

Es1 = Af * Nfu * Hi * 0.03 * (int(Sb==1) + int(Sb==3))
Cs1 = Es1 * catalogue["Ps1"]

- **Extent of required soil consolidation :** Takes the building's (facade) perimeter and the number of flooded storeys to estimate floodwater-induced scour and resulting soil loss.
- **Varying according to the building's characteristics :** Scour only occurs to buildings disposing of a 'bricks' or 'stone' facade.
- **Unit cost for soil consolidation :** Refers to the Es1 soil construction work cost per m², which is in our model set at 100 €.

List of used parameters :

- **Af (Area of one floor, float) [m²]** : calculated in geometric parameters
- **Nfu (Number of floors underwater, integer) [unit]** : calculated in geometric parameters
- **Hi (internal Height of water, float) [m]:** calculated in geometric parameters
- **Sb (Structure of building) [unit]** : describes the material of the facade among stone, brick and concrete.

Assumption :

- **0,03 [%]:** Refers to the friction coefficient, determining the amount of soil loss. [69]

Es2 - Local repair [m²]

This function assesses costs tied to facade obstructions and repairs resulting from flood water pressure and shocks stemming from higher sediment loads. Less resistant than concrete, we only consider brick and stone walls to be vulnerable to these types of damages.

[69] Based on INSYDE, Supplement p.10, & empirics

Es2 = Sj * Pf/4 * He * 0.05 * [1+int(se=="high")+int(se=="medium")] * int(ve>=2) * max [int(Sb == 1), int(Sb == 3)]

Cs2 = Es2 * catalogue["Ps2"]

- **Affected facade surface** : Determines to what extent the four external walls (facade) will be subject to local repairs, based on shared walls with adjacent buildings multiplied by a fixed damage coefficient.
- **Impacts of flood characteristics :** Shocks pertaining to the facade occur in case of high or medium sediment loads tied with a water velocity exceeding 2m/s and only damages facades constituted of bricks or stones.
- **Unit cost pertaining to local repairs:** Refers to the Es2 local repair costs per m², which is in our model set at 50 €.

List of used building characteristics :

- **Sj (Structure juxtaposition) [unit] :** Identifies whether the house shares walls with neighboring structures. Based on the 'building characteristic' table, it assumes the house to have either all 4 external walls exposed or only 2.
- **Pf (Perimeter of facade, float) [m]** : calculated in geometric parameters
- **He (external Height of water, float) [m] :** height of water according to flood scenario
- **se (sediment concentration, string) [qualitative]** : describes concentration of sediment in the water.
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **Sb (Building structure) [unit]** Refers to the constituent material of the building's structure. Derived from our 'building characteristic' table, it assigns : 1 to brick, 2 to concrete, and 3 to stone.

Assumption :

- **0,05 [%]:** Determines the depth of scour impact on the wall[70]

Es3 - Pillar repair [m²]

This function estimates costs related to pillars, thereby only focusing on buildings featuring concrete facades. More resilient than other wall types in absorbing shocks, the energy of these impacts is directly transferred to the pillars.

Es3 = Sj * (Pf/4) * He * 0.05 * [1+int(se=="high")+int(se=="medium")] * int(ve>=2 * int(Sb == 2))

Cs3 = Es3 * catalogue["Ps3"]

- **Extent of required pillar reparations** : Determines to what extent pillars will be subject to reparations, based on the wall structure multiplied by a predetermined damage coefficient.

[70] Based on INSYDE, Supplement p.10 & empirics

- **Impacts of flood characteristics :** Shocks pertaining to the pillars occur in case of high or medium sediment loads tied with a water velocity exceeding 2m/s and only damaging facades made of concrete.
- **Unit cost pertaining to pillar repairs:** Refers to the Es3 pillar repair costs per m², which is in our model set at 300 €.

List of used building characteristics :

- **Sj (Structure juxtaposition) [unit] :** Identifies whether the house shares walls with neighboring structures. Based on the 'building characteristic' table, it assumes the house to have either all 4 external walls exposed or only 2.
- **Pf (Perimeter of facade, float) [m]** : calculated in geometric parameters
- **He (external Height of water, float) [m] :** height of water according to flood scenario
- **se (sediment concentration, string) [qualitative]** : describes concentration of sediment in the water.
- **ve (water velocity, float) [m/s]** : measures velocity of the water outside the building
- **Sb (Building structure) [unit]** Refers to the constituent material of the building's structure. Derived from our 'building characteristic' table**,** it assigns : 1 to brick, 2 to concrete, and 3 to stone.

Assumption :

- **0,05 [%]:** Determines the depth of tremor damaging the pillars [71]

[71] Based on INSYDE, Supplement p.10

COSTS

Find here under a table summarizing the costs associated with each function. Keep in mind that the costs differ according to the housing's luxuriousness rating (QC).

Costs encompass the component's replacement price (new), the associated labour, and any energy demand specific to the function.

These costs stem from a combination of BatiChiffrage (french construction work quotation software), empirics from our field works and other online sources.

Name	Code Ref	Costs			Unit
		low quality (QC)	medium quality (QC)	high quality (QC)	
I. Preliminary measures					
Pumping	Pp1	5	5	5	€/m³
Waste disposal	Pp2	200	200	200	€/m³
Cleaning	Pp3	8	8	8	€/m²
Dehumidification	Pp4	18	18	18	€/m³
II. Components					
Wood pavement	Pc1a	99	99	141	€/m²
Porcelain stoneware pavement	Pc1b	109	109	0	€/m²
Natural materials pavement	Pc1c	111	111	200	€/m²
Screed	Pc2	25	25	25	€/m²
Baseboard	Pc3	12	12	12	€/ml
Partition wall	Pc4	128	128	128	€/m²
Fake ceiling	Pc5	50	64	72	€/m²
Internal plaster and insulation	Pc6	50	52	62	€/m²
External plaster	Pc7	30	30	30	€/m²
Internal door	Pc8a	138	182	300	€/unit

Entrance door	Pc8b	1930	3168	3680	€/unit
Entrance lock door	Pc8c	632	763	800	€/unit
Window	Pc9a	595	780	1276	€/unit
Window bay	Pc9b	867	1055	1447	€/unit
Boiler centralized	Pc10a	(15300 + (user["Nf"]-1) * 2000) * user["Sh"] + 4500 * (1-user["Sh"])			€/unit
Boiler distributed	Pc10b	4500	4500	4500	€/unit
Internal painting	Pc11	15	31	36	€/m²
External painting	Pc12	27	51	51	€/m²
Elevator	Pc13	500	1250	2000	€/unit
Electric radiator	Pc14a	100 * int(user["Yc"]<1990) + 250 * int(user["Yc"]>=1990)			€/unit
Radiator purging	Pc14b	50	50	50	€/unit
Radiator mud pulled out	Pc14c	10 * user["Ai"]			€/house
Electrical system renovation	Pc15a	100	100	100	€/m²
Alarm system	Pc15b	0	500	5500	€/unit
Plumbing system renovation	Pc16	100	100	100	€/m²
III. Structural					
Soil consolidation	Ps1	300	300	300	€/m²
Local repairs	Ps2	50	50	50	€/m²
Pillar repairs	Ps3	300	300	300	€/m²

Glossary of variables used

Symbol	FLOOD CHARACTERISTICS		Unit
He	External height of water above ground surface	Float, >=0	m
ve	External velocity of water	Float, >=0	m/s
se	Sediments concentration	String, {No, Low, Medium, High}	Qualitative
d	Flood duration	Float, >=0	h
q	water quality, pollution	Boolean, {0-not polluted, 1-polluted}	

Symbol	BUILDING CHARACTERISTICS		Unit	Source
Ai	**Internal Area, m2**	Float, >0	m2	User
Nf	**Number of floors (including ground floor)**	Integer, >0		User
Yc	**Year of construction**	Integer, >0		User
Sh	**Structure housing**	Boolean, {0-individual housing, 1-collective housing}		User
Sj	**Structure Juxtaposition**	Integer, {2-adjoined, 4-separated}		User
Db	**Boiler distribution**	Boolean, {0-centralized, 1-distributed}		User
Eb	**Existence of basement**	Boolean, {0-no, 1-yes]		User
Hf	**Height of floor**	Float, >0	m	User / ProReno
Hg	**Height of ground**	Float, >0	m	User / ProReno
Hb	**Height of basement**	Float, >0	m	ProReno
Ad	**Area of one dwelling**	Float, >0	m2	User / ProReno
Sp	**Structure of ground pavement**	wood, 2-porcelain stoneware, 3-marble		User / ProReno
Tw	**Thickness of walls**	Float, >0	cm	ProReno
Yr	**Year of last major renovation**	Integer, >0		User / ProReno
Sb	**Building structure**	Integer, {1-brick, 2-concrte, 3-stone}		User / ProReno
Ee	**Existence of elevator**	Boolean, {0-no, 1-yes}		User / ProReno

Cq	**Quality of construction**	String, {low, medium, high}		User
Hcs	**Height of Crawl space**	Float, >0	m	ProReno
Er	**Existence of electrical radiators**	Boolean, {0-no, 1-yes}		ProReno
Qm	**Quality of maintenance**	Boolean, {0-low, 1-high}		User

Symbol	Geometrical parameters	Unit	Extension of damage
Hi	Internal height of water	m	max(0, He - Hg)
Af	Area of one floor	m2	Ai / Nf
Ab	Area of basement	m2	0,5 * Af * Eb
Pf	Perimeter of facade	m	4 * sqrt(Af)
Pb	Perimeter of basement	m	4 * sqrt(Ab)
Pw	Perimeter of Walls	m	2,5 * Pf
Vu	Volume flooded	m3	Hi * Af + Hb * Ab + Hcs * Af
Nfu	Number of floors underwater	unit	int(Hi/Hf) +1
Lm	Level of maintenance	0 ou 1	1 - int(Yr>=2005)
Nd	Number of dwellings	unit	round(Ai/Ad) * Sh + (1-Sh)
Ndf	Number of dwellings per floor	unit	Round (Nd/Nf + 0,5)
Ndfu	Number of dwellings per floors underwater	unit	Nfu*Ndf

Symbol	PRELIMINARY MEASURES	Unit	Extension of damage
Ep1	Pumping	m3	Ab * Hb + Ee * 8 + Hcs * Af
Ep2	Waste Disposal	m3	Vu * se * (1 + q * 0,4)
Ep3	Cleaning	m2	(2 * Ab + Hb * Pb + ((Hi + 1) * Pw + 2 * Af * Nfu - Af) * int(Hi>0)) * (1 + 0,4 * q)
Ep4	Dehumidification	m3	(Ab * Hb + Af * Hf * Nfu * int(Hi>0)) * (0,2 * int(d>=12) + 0,8 * int(d>=24) + 0,2 * int(d>=48)
	FINISHING WORK		
Ec1a	Wood / ceramic Pavement (revêtement)	*m2*	int(Sp==1) * int(d>24) * (Af * Nfu * int(Hi>0) + Ab)
Ec1b	Porcelain stoneware pavement	*m2*	int(Sp==2) * (int(YY<1990) * (0,2 + int(d>24) * 0,4)+ int(YY>1990) * int(d>48) * 0,2) * (Af * Nfu * int(Hi>0) + Ab)
Ec1c	Marble / natural pavement	*m2*	int(Sp==3) * (q * 0,2 * Af * Nfu * int(Hi>0) + Ab) * int(d>=72)
Ec2	Screed (chape)	*m2*	Af * Nfu* int(Hi>0) * (1-Lm) * int(d>=12)

Ec3	Baseboard (plinthe)	ml	Pw * Nfu * int(d>=24) * int(Hi>0)
Ec4	Partition wall (cloison)	m2	0,5 * Pw * Hf * Nfu * (int(d>=48)*0.5 + int(d>=72)*0.5) * int(Hi>1.6)
Ec5	Suspended Ceiling (faux-plafond)	m2	0,2 * Af * Ndf * (Nfu-1 + int((Hi - (Nfu-1)*Hf)>= (Hf - 0,5)) * int(Hi>0) * int(d>=12)
Ec6	Internal plaster (plâtre interne) + insulation	m2	Pw * (Hi + 1) * max(int(d>=36), q, Lm) * int(Hi>0.1)
Ec7	External plaster (plâtre externe)	m2	(Pf/4 + 2*Tw) * 4 * (He + 1) * max(int(d>=72), int(ve>=1,3), Lm)
Ec8a	Door	unit	round((0.09 * Af * Nfu * int(Hi>=0.1) + 0.02 * Ab * int(He>0)) * max(int(d>=48), int(ve>=1.3)) +0.9)
Ec8b	Entrance door	unit	max(int(He>=1,2), int(ve>=2), Lm) * (1 + Ndfu * Sh) * int(Hi>0)
Ec8c	Lock entrance door	unit	(1-int(Cc8b>0)) * int(He>=1,2) * int(se>=0,05) * (1 + Ndfu * Sh) * int(Hi>0)
Ec9a	Windows	unit	**round(0,09** * Af * Nf * (Nfu - 1 + int((Hi - (Nfu-1)*Hf) >=1,5)) * max(int(d>=48), int(ve>=0,9)) * int(Hi>0) +0.9)
Ec9b	Window bay	**unit**	(Sh == 0) * int(He>=1) * int(ve>=0.7) * int(Cq="medium"or"high")
Ec10a	Boilers centralized	unit	(1-Db) * (Eb + (1-Eb) * int(Hi>=1,6))
Ec10b	Boilers distributed	unit	Db * Ndf * (Nfu - 1 + int((Hi - (Nfu-1)*Hf) >=1,6)) * int(Hi>0)
Ec11	Internal Painting	m2	(Hf * Nfu * Pw + Af * (Nfu-1)) * int(Hi>0.1)
Ec12	External painting	m2	He * Pf
Ec13	Elevator	unit	Ee * (int(Hi>=0.2) * 0.2 + int(Hi>=1.5) * 0.8)
Ec14	*Isolant*	*m2*	*Pw * (Hi + 1) * int(d>=24) * int(Hi>0)*
Ec15a	Electrical Radiators	unit	round(Er * 0.09 * (Nfu - 1 + int(Hi - (Nfu-1)*Hf)>= 0,2) * int(Hi>0) +0.9)
Ec15b	Nonelectrical radiators purging	unit	round((1-Er) * 0.09 * (Nfu - 1 + int(Hi - (Nfu-1)*Hf)>= 0,3) * int(Hi>0) +0.9)
Ec15c	Désembouage of non electrical radiators	0 or 1	(1-Er) * int(se>0,1) * int(Hi>=0,6)
Ec16a	**Electrical system**		Af * (int(Hi>=0.2) * 0.2 + int(Hi>=1.1) * 0.3 + int(Hi>=1.6) * 0.5)
Ec17	**Plumbing system**		max(int(se>=0.1), q) * Af * (int(Hi>=0.15) * 0.1 + int(Hi>=0.4) * 0.2 + int(Hi>=0.9) * 0.2)
Ec16b	alarm system		int(Hi>=2) * Lm
	STRUCTURAL WORK		
Es1	Soil consolidation	m3	Af*Nfu*Hi*0.03 * (int(Sb==1) + int(Sb==3))
Es2	Local repair	m2	Sj * Pf/4 * He * 0,05 * (1+se) * max(int(Sb==1), int(Sb==3))
Es3	Pillar repair		Sj * (Pf/4) * He * 0,05 * (1+se) * int(Sb==2)