URBAN LAB - SYNTHESES 2025

Cost-benefit analysis of buildings' adaptation to flood risk

The Inond'Act model

MASTER GETIC

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OID
ŒUVRER POUR L'IMMOBILIER DURABLE

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PREFACES

Preface by our project supervisor at the OID, Geoffroy Gourdain

How can we adapt to a France that is significantly more exposed to stronger heats and more intense and frequent climate hazards by 2100? This is the central question posed by the Reference Trajectory for Climate Change Adaptation (TRACC), established in Fall 2024. For the real estate sector this represents a dual challenge: not only must relevant and large-scale solutions be identified and deployed to enable the adaptation of the building stock, but this must also be achieved within a limited timeframe to avoid reactive, last-minute adaptation efforts that are both costly and ineffective.

To address this challenge, the *Observatoire de l'Immobilier Durable (OID)* has, for the past four years, been developing tools to assess buildings' vulnerability to various climate-related hazards and their impacts on biodiversity — compiled on the R4RE platform. This year, in partnership with the *Urban School of Sciences Po*, we were able to further deepen this vulnerability analysis, going beyond physical consequences to translate them into economic terms.

Opening up such perspectives is essential to enable real estate stakeholders to move from awareness to action. We are therefore pleased to have supported the valuable work carried out by Chiara Andreazza, Iris Aubé, Jonathan Motte, Clémence Pautrat, and Léon Rube.

The *Inond'Act* model represents a significant step forward — not only in terms of the results it delivers, but also through the insights gained during its development. It also serves as a remarkable example of alignment between the academic goals of Sciences Po's Urban School and the more operational aims of the OID, both promoting the environmental transition of the sector. The student team successfully served as a bridge between these two worlds, as *Inond'Act* is now intended to be integrated into OID's operational tool: *BAT-Adapt*.

We extend our warm thanks to all those whose involvement made this project a success and helped bring it to life.

Preface by the project's tutor, Pauline Gleizes.

This project is the result of a collaboration between the *Observatoire de l'Immobilier Durable*, who was looking for new indicators for the cost of action and inaction when it comes to adapting buildings to climate change, and a group of five students from the GETIC master.

The students' choice of focusing on floods was particularly relevant since major floods had recently been happening in France and throughout Europe. Additionally since the birth of the Cat-Nat insurance system, a significant part of the economic costs of natural disasters in France have been identified as related to floods.

The findings show that the limits of our French natural-disaster coverage system might soon be reached, and these alarming results are essential to inform public policymakers. Beyond demonstrating that adapting buildings to climate change is beneficial, the students have found that the multi-stakeholders governance around water management and flood-risk management could be made more coherent in order to deliver more efficient crisis responses. Furthermore, they have found that insurance companies should be differently involved in this environment. These recommendations are more relevant than ever, as we experience fast-paced urbanization and climate change, thus increasing risks of floods.

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THE PARTNER

With over a hundred members and partners, the Observatoire de l'Immobilier Durable (OID) is an independent association aiming to accelerate the ecological transition of the real estate sector in France and in Europe. Their activities focus on the building scale, and are structured around three thematic pillars:

- **Mitigation**, by providing guidance to the real estate sector to engage in energy efficiency, and general mitigation strategies;
- **Environmental awareness**, by encouraging greater understanding of biodiversity, adaptation to climate related risks and water use;
- **Social change** by breaking down sociological behaviors and assisting actors in fostering greater societal acceptance of their climate-related actions.

ISSUES

A two billion euro issue

In late 2024, the disastrous floods in Valencia reminded Europe that natural catastrophes are becoming increasingly common and extreme. In particular, flooding events, which represent the greatest threat to both human life and material loss. According to the Caisse Centrale de Réassurance's (CCR) 2024 Scientific report, about half of the economic cost of natural catastrophes in France can be tied to floods since 1982. In 2023 alone, flooding damage in France was estimated to have cost more than 2 billion euros.

These last few years, the French system covering flood damage has been pushed to its limits. The CCR, the public body in charge of covering the cost of natural catastrophes, has been operating at a deficit since 2016, as particular regions of France have faced repeated catastrophic floods (see case studies section). Moreover, private insurance companies are facing significant economic stress as risk continues to worsen. This leads them to increase their premiums, and consequently individuals and municipalities are forced to terminate their unaffordable contracts.

Considering the increasing intensity and variability in weather events due to climate change, one can only expect that this cost will increase in the future. Thus, adaptation measures which reduce buildings' vulnerability to flooding events need to be deployed urgently.

Fortunately, the State has recognized, at least partially, that it needs to increase its mobilization to reduce flood risk. Experimental programs like MIRAPI (Mieux Reconstruire Après Inondation), which was first implemented on a large scale after the Nord Pas de Calais 2023-2024 floods, showcase that adaptation measures can be successfully subsidized and considerably lower risk.

Despite these limited efforts, there remains a dire need to highlight the attractiveness of adaptation measures to floods in France. Yet, very little quantitative information exists to determine the extent to which adaptation measures reduce costs at the building scale. Until then, neither households, nor public and private actors, will adapt their buildings as they lack critical information that precisely measures the economic benefits of adaptation to floods.

Our answer: a cost-benefit analysis model

Via their platform Bat-Adapt, our partner, the OID, has already developed an online tool which evaluates the level of risk that buildings in metropolitan France currently face, for example, whether a given building resides in an area prone to flooding or heat waves. While this tool remains useful to map risks for these types of events, it does not specify the cost of damage that a building would bear if struck by a natural disaster. The goal of this capstone project is thus to deepen the platform's precision on floods specifically. As such, we were tasked with building a cost-benefit analysis model focused on adaptation measures for buildings exposed to floods.

Given our objective was to measure the potential benefit of adaptation measures, and that Bat-Adapt was already fixed at the building scale, we adopted the same level of analysis to ensure compatibility between our model and the OID's. Therefore, the scope of this model is restrained to buildings. More specifically, our model, named Inond'Act, focuses solely on residential building typologies and freshwater floods, as developing an accurate model for other types of buildings and floods was deemed unfeasible in the allotted time frame. (It must be noted that the model's structure permits future ameliorations to include these additional parameters at a later date).

In short, our model seeks to measure quantifiably which adaptation strategies, if any, are the most cost effective to limit a floods' economic damage on individual residential buildings. Hence, our model calculates two costs:

- On one hand, the amount of damages buildings face when exposed to flooding events;
- On the other hand, the amount of damages buildings face post-adaptation.

Subsequently, a simple subtraction of the second mentioned cost with the first will provide the model's users with the potential economic benefit of adaptation measures for their building. In doing so, our model aims at shifting the real estate sector's practice in France, by demonstrating quantifiably whether flood adaptation measures at the building scale are economically rational.

The main challenges facing Inond'Act

Building a model able to estimate the cost of damages for residential buildings exposed to floods presents two obvious challenges:

1. Determining how different types of floods affect the internal and external structure of a building requires detailed information regarding various flood parameters
2. Determining which specific parts of a building are compromised in the event of a flood, and to what extent, requires detailed knowledge of a building's components

The approach we selected is best-fit to tackle these two challenges.

In brief, Inond'Act uses a component by component approach to estimate flooding costs on a building. The building is segmented into its different parts, and the model estimates the extent to which each part is damaged by a flood (for example, the damage to walls, floors, etc.). The final cost is then determined by summing up all these damages.

Put simply, this entails that the total cost of damage for a building after a flood is the sum of the costs of all its components, as detailed in this function:

$$D_1 = \sum_{i=1}^{n} Ci$$

Where D_1 is the total cost of damage for a building, and Ci is the individual cost of damage per component of the building. Adaptation measures reduce the flood's damage to each individual component differently. Therefore, the cost of damage after adaptation measures are implemented is the following:

$$D_2 = \sum_{i=1}^{n} Cia$$

Where D_2 is the total cost of damage for a building after adaptation measures are implemented, and Cia is the individual cost of damage per component of the building post-adaptation. Ultimately, the cost-benefit analysis can be synthesized by subtracting D_1 and D_2, which determines whether an economic gain is made after adapting the chosen building to floods. Inond'Act automatically calculates which adaptation measures are the most cost effective for the building selected by the user.

The diagram shown here summarizes all the main aspects of the Inond'Act model. On the left, users input their building characteristics, as well as the flood scenario they wish to simulate. These inputs fuel our model which first estimates the cost of damage per component of that building. Then, the same flood is tested on that building post-adaptation, and a cost benefit analysis calculates whether the cost of flooding was significantly reduced after adaptation measures were implemented.

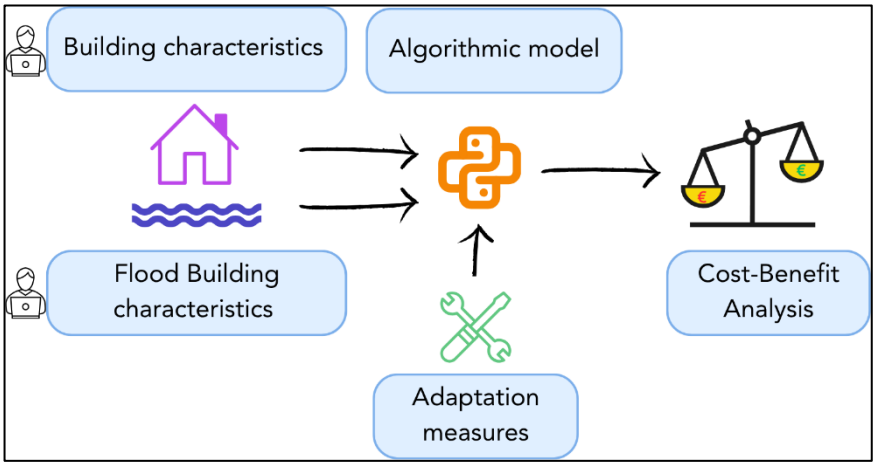

Figure 1: Inond'Act's structure summarized.

METHODOLOGY

Throughout this project, we used the following research methods:

1. **Literature review**

Regarding the literature review, we mostly focused on pre-existing research and studies which measured floods impacts on buildings in economic terms. Furthermore, we narrowed the scope to models estimating damages at a component scale. Two models in particular came to occupy a central role : INSYDE and FLOODAM. The first one, an open source model designed in Italy, offered key insights that informed the conceptual framework of Inond'Act. The second, designed for the French public services and with more restricted access, played a crucial role in the model's evaluation phase.

2. Quantitative data

In the context of our study, quantitative data were essential to fuel our model and increase its accuracy. Thus, we made use of BatiChiffrage to estimate market prices of damaged components, ProRéno to enrich structural characteristics and Fichiers Fonciers to determine a dwelling's luxury.

3. Expert testimonies

In order to best understand flood risks, and design accurate functions for our model, we conducted interviews with professionals from a wide range of backgrounds. Among them, hydrogeologists, civil engineers, flood experts as well as government representatives from agencies overseeing water resource governance (DDTM, Watershed agencies, etc.).

4. Field Work

In order to best align our model with the reality of flood damages in the field, we went on three different case studies, visiting flood affected dwellings and engaging directly with their occupants. These cases were useful to polish the Inond'Act functions and validate our initial predictions. Moreover, this fieldwork taught us about flood risk and management beyond building, for instance understanding the insurance system difference between Italy and France

FIELDS STUDIED

Nord Pas de Calais – France

The first field we studied was Nord Pas de Calais, and more specifically the municipalities of Saint-Omer, Arques and Blendecques. Nord Pas de Calais in general is a very "hydraulic" region, with a lot of rivers, and therefore floodplains throughout the territory. The floods that the region suffered in the winter 2023-2024 were among the worst ever recorded in France. On some of the Nord Pas de Calais watersheds, the river overflow records were surpassed several times in the first few days of the event. The flooding episode is supposed to have affected about half a million people.

	Nombre d'arrêtés par département
Minimum (75 – Paris)	36
1er décile	420
1er quartile	725
Médiane	1 111
Moyenne	1 220
3e quartile	1 633
9e décile	2 154
Maximum (62 – Pas-de-Calais)	3 924
Écart type	702

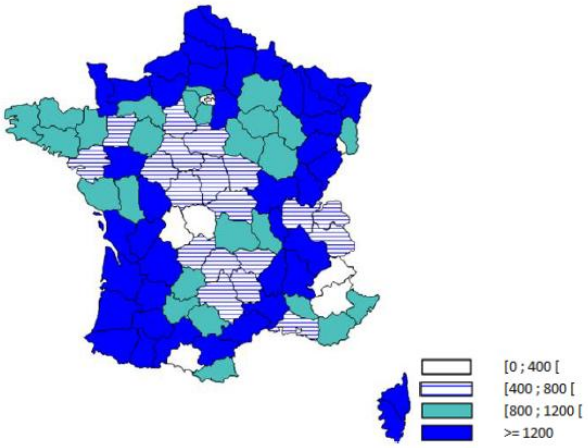

Figure 2: Geographical repartition of the number of municipalities affected by a flood from 1982 to 2023. Credit: CCR, Journal officiel.

Economically, the event impacted 315 municipalities, thousands of homes, some of which were flooded multiple times in the span of a few months. The CCR had to repay insurance companies up to 800 million euros. In total, the catastrophe cost the French state 1.8 billion euros, all expenses included. When considering a cost evaluation of floods on buildings, taking this particularly expensive episode into account for our analysis seemed especially pertinent. More specifically, we chose to focus on Saint-Omer and the surrounding municipalities, because that's where most buildings were flooded during the 2023-2024 episode.

Figure 4: Photo of a house in Arques during the 2023-2024 floods. Photo graciously provided by the owner of the house.

Figure 3: Photo of the same house in Arques, during our field visit, March 2025. Credit : Iris Aubé.

Bologna – Emilia Romagna, Italy

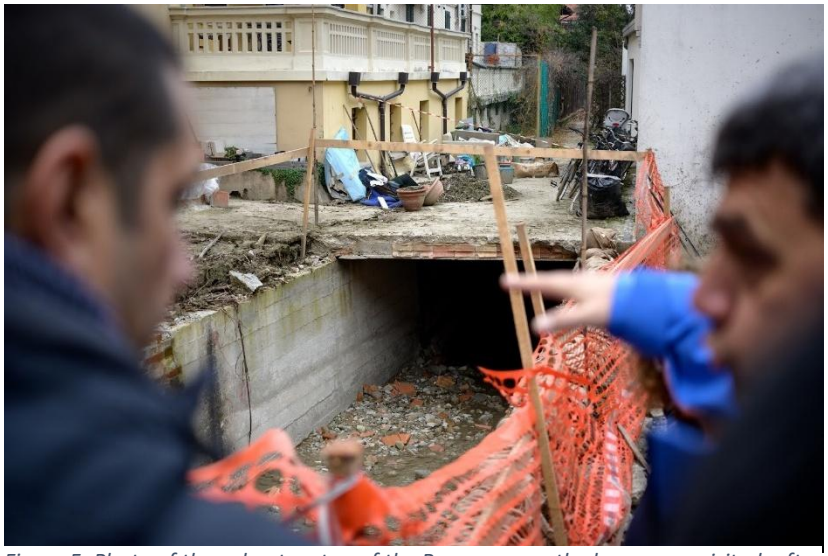

Figure 5: Photo of the culvert on top of the Ravone, near the houses we visited, after breaking during the Fall 2024 flood. Credit: Emilia Romagna region

Secondly, our partner asked us to consider a case study outside of France, in order to study the European context. We chose Bologna, in the Emilia Romagna region in Italy, for multiple reasons. Compared to France, Italy has a drastically different legislative and regulatory environment concerning natural risk protection and insurance schemes. Regarding flooding specifically, Emilia Romagna has been hit by several major floods in recent years, particularly during the deadly episode of Spring 2023, as well as during the Fall of 2024.

Within this region, the city of Bologna presented a unique case as it's traversed by canals. It was therefore noteworthy to observe how adaptation efforts were carried out in this context, both at the territorial and individual levels. At the city scale, Bologna's public institutions are currently attempting to decrease flood risks by taking measures upstream. Yet, results have been limited as flooding still occurs, damaging homes within the city's center and around its

periphery. Additionally, homeowners located near the canals are fearing the next flood, and are therefore starting to take adaptation measures at the building scale, as was clearly illustrated during our field work.

Apt – Provence, France.

Finally, we went on a third case study, mostly focused on adaptation matters, in the region of Apt (Provence, France). We chose this region because the PPRI (Plan de Prévention des Risques Inondation) for the Calavon Coulon watershed has been recently adopted, and the watershed syndicate (SIRCC) is therefore currently encouraging owners to get a vulnerability diagnosis of their assets in the context of flooding. In this case study, we therefore had the opportunity to do several vulnerability diagnoses of houses exposed to flood risks, alongside a professional consulting firm. This third field trip was instrumental to our work as it enabled us to properly integrate realistic adaptation measures into our model.

MAIN RESULTS

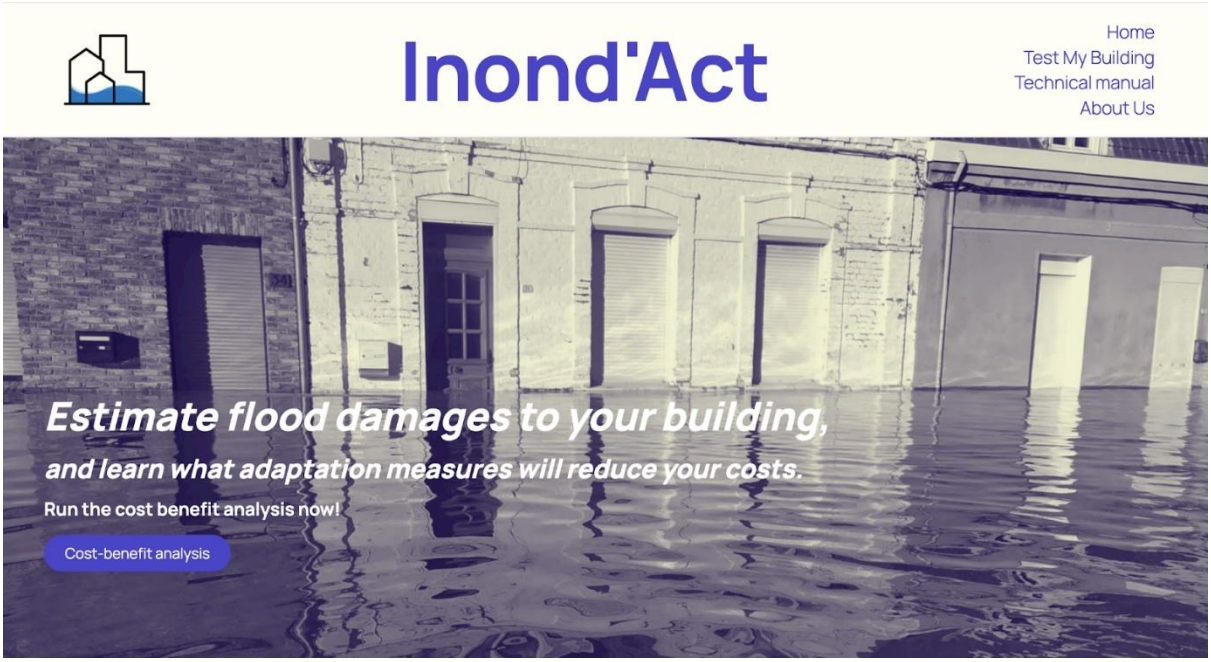

Figure 6: Screenshot from the homepage of our website, hosting our model.

The main result of our project was the official launch of the Inond'Act model, available online at Inondact.com. On this webpage, you can run the model yourself, inputting the characteristics of your building and testing its damage when exposed to different flood scenario types. Additionally, the website grants open access to the technical manual of the model. In it, you will find all of the model's functions, as well as the main hypothesis we took. Moreover, a resource page includes useful information regarding flooding, adaptation, and summaries of the case studies we conducted to realize this model.

The cost of inaction

The first overarching conclusion to draw from this project is that, based on the figures of our model, the cost of inaction is very expensive. Unsurprisingly, even light floods have the possibility to cause tens of thousands of euros of damage. As will be seen in later results, the

main flood variables which influence the total cost of flooding damage are height, duration and velocity. These findings align with the literature and the two other models mentioned earlier in this report.

Figure 7 represents the different costs for a slow overflowing in a standard individual house. We notice that main costs are changes of flooring, doors and paint, as well as plaster and cleaning costs. These costs remain high for all types of buildings and floods tested. The results of this initial analysis highlights how flood costs are unevenly distributed among a building's different components. Therefore, adaptation measures should target these very components, in order to diminish total costs as effectively as possible.

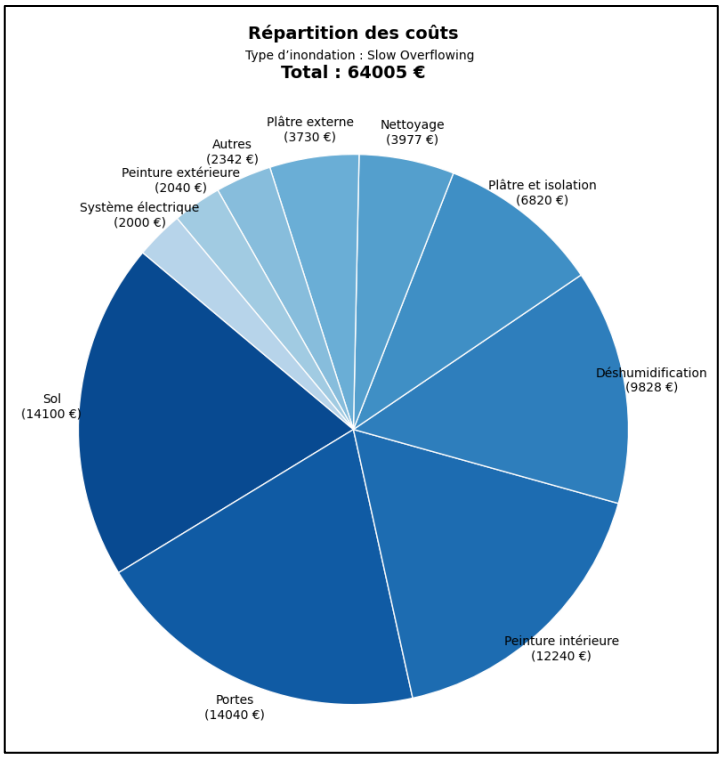

Figure 7: Cost distribution, for a standard individual house, in the case of a flood caused by a slow overflowing.

The benefit of adaptation

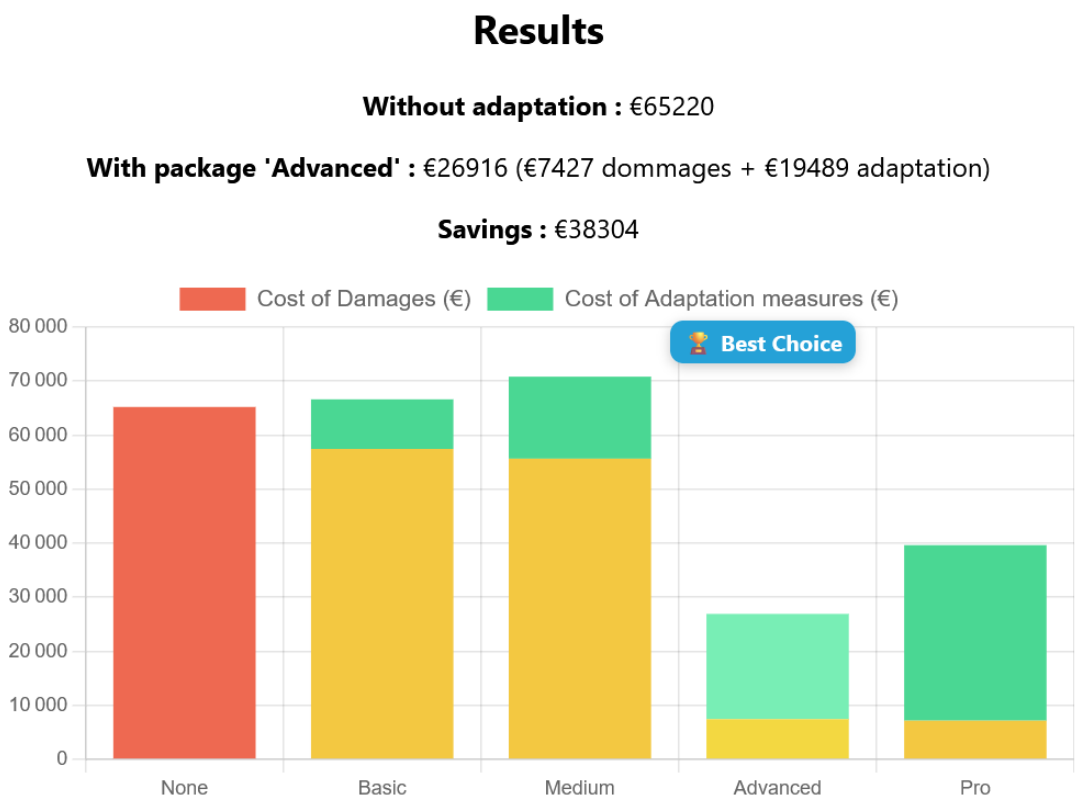

Figure 8: Results from the Inond'Act model for a standard individual house, in the case of a flood caused by a slow overflowing.

Figure 8 shows the result of the model for the same flood and building as considered in Figure 7. Inond'Act is equipped with four different adaptation packages ranging from "Basic" to "Pro". In these packages, measures such as cofferdams and non-return valves limit the penetration of water in the home. In more premium packages, other measures such as elevating electrical and heating systems are included. The results are clear in this graph. Spending about 10.000 € on adaptation measures with the "Advanced" package may seem like a lot, but in the eventuality of a flood, this cost combined with that of residual damages will be lower than any other scenario, including inaction. Of equal interest is the fact that some adaptation may be less cost-effective compared to not adapting the building at all. This can be explained by the fact that some of these measures are complementary and therefore work best together in certain buildings.

Beyond the building: wider observations on flood risk in France

The role of insurances companies

One of the central actors involved in the economic aftermath of floods is insurance companies. Paradoxically, they are the actors we had the least contact with during our capstone, and the actors from whom it was the hardest to obtain data. Many of the actors we talked with during our capstone shared their frustration with the lack of cooperation from insurance companies. Given their confidentiality agreements, they often refuse to share precise economic data with public actors, thereby presenting an additional hurdle to be overcome. This is a significant obstacle to the efficient development of knowledge and expertise regarding the economic impact of floods for many of the actors concerned, since only insurance companies, apart from the building owners themselves, possess precise data on damages. One of the few cases where we managed to get a lot of data on actual economic damages on buildings was during our case study in Bologna. In Italy, since there is little insurance coverage for natural disasters, owners and public actors pay for the reconstruction effort, as well as the adaptation measures out of pocket.

Another aspect where insurance companies are concerned is the question of insurance premiums and franchises. This is mostly something we saw in relation to the Nord Pas de Calais case study, since we went on the field one year after the flooding event. A key concern lies in declining the insurability of municipalities, with escalating premiums forcing certain at-risk cities to forgo insurance altogether. This issue is very likely to expand to other cities in France as flood risk becomes more significant. To take the example of Blendecques specifically, their premiums increased from 47.000 to 142.000€. Moreover, the franchise, which used to be 0, now stands at 500.000€. Similarly, this dynamic can be observed at the individual's scale, as insurance premiums, as well as the franchise, can increase dramatically once the 2-year waiting period for Cat Nat is over. Ultimately, both public entities such as municipalities and households have been progressively pressed to terminate their insurance contracts due to, both, rising insurance premiums and franchises.

According to actors we met on the field, about 2000 municipalities self-insure in Pas de Calais, which means that they keep part of their own funds on the side, in case they are hit by a natural catastrophe. As a result, funds which could have been directed towards municipal development are now being saved to anticipate flooding damage. This situation can be called an "insurance deadlock territory", and France's Mayors Association is currently lobbying with France Assureurs in order to put in place an insurance market at the scale of the territory and not at the scale of the municipality.

Throughout our different experiences on the field, it became clear that the "identical reconstruction" practice of insurance companies should be revised. Enshrined in the French Insurance Code, this provision limits the resilience of the real estate sector when faced with floods and is an obstacle to the adaptation of buildings.

Note: the L121-1 article of the French Insurance Code states that "the indemnity owed by the insurer to the insured cannot exceed the value of the element insured at the time of the event". Therefore, the insurance code doesn't state verbatim that the reconstruction has to be identical, but it has become common practice in the case of natural catastrophe insurance, according to testimonies we gathered during our case study.

Our field work in Apt underscored the need to involve insurance companies in the adaptation process. One of the reasons, behind owners' reticence in participating in vulnerability diagnoses of their assets, are their worries that insurance companies raise their premiums based on the results (which is exactly what happened in Nord Pas de Calais after the 2023-2024 floods).

In the context of Apt, the watershed syndicate is trying to involve local insurance companies more, since it would be beneficial for all the actors: if owners put in place adaptation measures at the building level, damage costs in the case of floods would be limited, which means insurances would have less to cover, which would justify a decrease in insurance premiums. This is also in insurance companies' interests, because they would have to pay a lower insurance premium to the CCR in order to be paid back themselves.

One of the suggestions that was made by several actors we met was the idea of putting in place a subsidy for adaptation measures prior to any flood actually happening on the territory. This would mean expanding the MIRAPI measure on a larger scale, throughout the territory. Such an approach is currently explored by the CCR and insurance companies for the clay shrinkage and swelling risk (retrait-gonflement d'argiles in French).

Outdated regulatory frameworks

One of the elements that stood out in the case of Nord Pas de Calais specifically was the issue of urbanization in overflow areas (zones d'expansion de crue in French). Throughout our field work, it became clear that urbanization was still ongoing in certain riverbeds. Moreover, there's a continued practice of artificialization, despite elders explicitly knowing that these areas are at risk of flooding. For instance, one of the last neighborhoods in Blendecques to be built in 2008, witnessed a 80% level of damage during the 2023-2024 floods, for the simple reason that some construction permits were allowed in high flood risk zones, despite the existence of a PPRI, and the local population's memory.

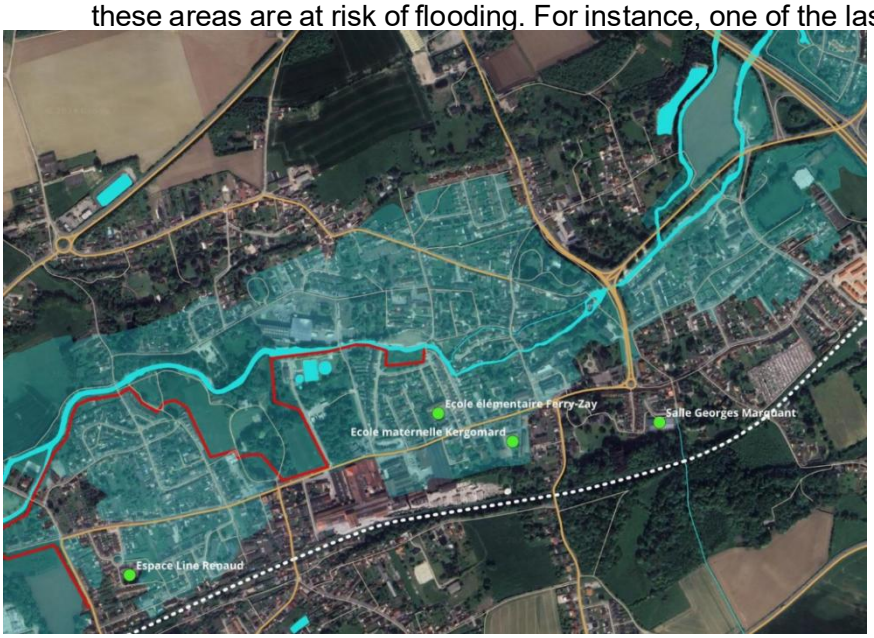

Figure 9: Extent of the water pocket on the city of Blendecques during the January 2024 flood. The red lines represent the dykes that had been put in place after a 2002 flood episode.

Credit: Blendecques Municipality.

Another main takeaway from this capstone is that France lacks holistic flood risk data. One of the main examples of this is the little consideration of the risk of flood via runoff. PPRI and hazard maps often only considered flood via river overflow (inondation par débordement de cours d'eau in French) and coastal floods (inondation par submersion marine in French). Similarly, the knowledge on underground water overflow (inondation par remontée de nappe in French) is still lacking, even though the BRGM (Bureau de Recherche Géologique et Minière) is developing a more precise cartography at the French scale of this specific hazard.

Whatsmore, we were often confronted with outdated regulations and documents. In some cases documents such as the PLU, PPRI or PCS (plan local d'urbanisme, plan de prévention du risque inondation et plan communal de sauvegarde) had not been updated in years. A more regular update of these documents would make territories more resilient when faced with a flood.

The hidden impacts of floods

Throughout our case studies, we observed firsthand how material damages only represented one of the many impacts of floods. The case study in Nord Pas de Calais was particularly striking on this matter: in Arques, the price of assets that were exposed to floods had gone down, while others were promoted as "non-affected by floods in 2023-2024", which gave these listings a competitive advantage on the real estate market.

Another non-material economic effect of the flood was the loss of income for households who had to take leave or paid vacation in order to take care of their homes. Most importantly, there are also non-economic costs that must be taken into account, such as the psychological trauma experienced by the regions' inhabitants due to this repetition of extreme floods in a short period of time.

LEARNINGS

Our recommendations can, in line with our results, be interpreted across two distinct scales. At the building scale, the importance of adaptation measures emerged clearly, validated both through our field trips and quantified through our model. The latter serves primarily to acknowledge the significant economic damages caused by floods and to estimate one's own potential exposure. Additionally, beyond merely promoting risk awareness, our model suggests operational solutions, thus encouraging proactivity among stakeholders. Furthermore, its structure also ensures replicability and scalability, making it a valuable contribution to risk research.

Our findings point to the constraints of adaptation at the building scale and emphasize the importance of territorial-scale action in addressing severe flood risks. In this regard, our work points to an enduring need for a restructuring of the French insurance system. Moreover, one of the main obstacles we encountered on the field was the multiplicity of public actors and outdated regulatory documents which had incompatible or overlapping competences, hindering both risk awareness and crisis management in the case of natural disasters.

As a professionalizing experience, this capstone taught us the importance of dialogue with a multiplicity of actors, coming from different backgrounds and acting in several expertise

fields. We had the opportunity to do more than 40 interviews, both in field specific contexts and national & regional context related ones, in order to develop our Inond'Act model. This was a great networking opportunity, but more importantly, it is the overlapping of all these testimonies which enabled us to produce the most accurate and realistic model possible.

At the same time, the technical direction of our project was, for many of us, our first exposure to modeling. It not only enabled us to build technical skills and internalize the conceptual foundations behind modeling but also, reinforced our interest in applying such tools in future professional contexts.

FIND OUT MORE

Find out more about our model:

The link to our website, where one can access and try the model we developed: https://www.inondact.com/

Our partner:

The BatAdapt platform, developed by the OID, where one can see the natural risks one's buildings is exposed to: https://r4re.resilience-for-real-estate.com/resilience/analysis This platform is where our model is meant to be integrated in the future.

Taloen, OID's resource center where you can find useful documents on building adaptation. https://www.taloen.fr/ressources

The two main models who take a similar approach to ours:

Dottori, F., Figueiredo, R., Martina, M. L. V., Molinari, D., and Scorzini, A. R.: INSYDE: a synthetic, probabilistic flood damage model based on explicit cost analysis, Nat. Hazards Earth Syst. Sci., 16, 2577–2591, https://doi.org/10.5194/nhess-16-2577-2016, 2016.

F. Grelot, C. Richert. Floodam: Modelling Flood Damage functions of buildings. Manual for floodam v1.0.0. [Research Report] irstea. 2019, pp.59. ffhal-02609309f https://hal.inrae.fr/hal-02609309v1/document

The Capstone project: an original educational tool

Thanks to this original tool, students are placed in a work situation on a real problem posed by a public, private, or associative organisation. For all the Masters of the Urban School, the structure and management are identical: the project is jointly monitored by the the Urban School and the partners, at all phases of the project, and regular methodological supervision is provided by a professional or academic tutor specialised in the issue. The Capstone projects allow the partners to take advantage of the research and training acquired within the Urban School, to benefit from the production of studies and quality work, and to have a capacity for innovation.

Capstone projects are a great tool to study, diagnose, forecast, lead a comparative analysis, even to prepare for evaluation, and more generally to deal with any problem that can enlighten the organisation concerned in a logic of "R&D ". Each project mobilises a group of first-year students from one of the Urban School's Master’s. Students work between 1.5 days and 2 days per week on dedicated time slots, for a period of 6 to 9 months (depending on the Master’s concerned). In Executive education, collective projects concern the Executive Master “Territorial governance and urban development” and mobilize professionals for a period of 4 months.