S1 Data survey

The survey for the Northern Italy case was carried out with the help of common real estate websites (immobiliare.it and idealista.it). Due to the great degree of uncertainty surrounding the completeness and quality of the data provided on these platforms, in most of the cases, only partial information could be extracted, either due to the lack of data or out of respect for privacy. In some cases, geometrical features were not coherent either. Since the postings on the websites were for single families, the entire data survey is based on individual housing units. To ascertain the authenticity and the quality of the data, only the ones that could be precisely located and had sufficient information about both the structural properties and the house contents were considered. Specifically, to be fit for the selection, the house would need to have at least the interior details of the house, main geometrical attributes, syncing architectural plans and profiles and a sufficient number of images taken from various angles to cover most of the spaces across all the rooms within the household. Due to these highly selective criteria, out of about 500 houses studied, only 60 houses were deemed fit for the analysis. Out of those 60 houses, 54 were further identified in Google Earth through the Street View feature, and several secondary measurement techniques were adopted to validate the website data. Table 1 shows the details of the information collected from the survey. The details of the surveyed houses, along with both raw and processed data, are provided in Supplement 2. In order to maintain confidentiality, the specific coordinates of the house locations have not been shared though.

Table S1. Information collected in the virtual survey.

VARIABLE	DESCRIPTION
Region	indicates the region in Italy
Location	indicates the tentative location of the building
Zone	indicates the **latitude & longitude of the house**
Easting	
Northing	
Typology	indicates the building typology: **D: Detached, A: Attached & Semi-Detached AP: Apartment**
Setting	indicates if the house is inside or outside of city area; **Urban or Rural**
Year of Const.	indicates the year of construction as specified in the real estate website
Condition	indicates the condition of the place as specified in the real estate website
Heating	indicates the presence and the type of heating system
Heating Dist.	indicates if the heating distribution is **Independent or Centralized**
Basement	indicates the presence of a basement/cellar (**YES or NO)**
Height	indicates the height of the room; **default value assigned as in INSYDE**
Finishing Level	indicates the finishing level of the house **(High, Medium, or Low)**
Footprint Area	indicates the footprint area of the house
Surface Area	indicates the total built area of the house
External Surface	indicates the ext. surface of the structure; **P: Plastered, M: Masonry**
Bedroom	indicates the no. of bedrooms
Bed Size	indicates the size of the bed as **L: Double Bed and S: Single Bed**
Living Room	indicates the number of living rooms
Kitchen	indicates the number of kitchens
Kitchen & Living	indicates if the Kitchen and Living rooms are combined **(YES or NO)**
W/C	indicates the number of washrooms
Sofa	indicates the no. of sofa sets
Sofa Shape	indicates the shape of the sofa as **L-shaped & l-shaped**
Single Sofa	indicates the number of single sofas
Dining Table	indicates the number of dining tables with the number of chairs
TV	indicates the number of TV sets
TV-Base Height	indicates the base height of the TV **with respect to the floor level**

VARIABLE	DESCRIPTION
PC	indicates the number of PC monitors
PC-Base Height	indicates the base height of the PC **with respect to the floor level**
Bed Wardrobe	indicates the number of **L: Large** wardrobes present in bedrooms
Decorative Wardrobe	indicates the **L: Large & S: Small** wardrobes present in the living room
Small Wardrobe	indicates other additional **S: Small** wardrobes in the household
Kitchen Setup	indicates the number of upper and lower cabinets including the stove
Microwave	indicates the number of microwave ovens
Oven	indicates the number of ovens
Washing Machine	indicates the number of washing machines
Refrigerator	indicates the number of refrigerators
Dishwasher	indicates the number of dishwashers

S2 Modelling assumptions

S2.1 Content distribution within the house

The content distribution within the house is governed by its typology. In case of apartments, all the housing units have been considered as single floored (based on data survey). Hence, all the contents are assumed to be present within the single floor. However, for detached and semi-detached housing units, the contents can span across either one or two floors. For single floored units, the distribution is similar to that of the apartments. In the survey, it was observed that for double floored units the ground floor typically consists of the living and dining room, kitchen and bathroom. Hence, in the model, all the sofas, decorative wardrobes, kitchen and dining setups, one TV, and the rest of the electrical appliances are assumed to be within the ground floor. The upper floor is instead generally used for bed room purpose, with inclusion of additional toilets in some. Hence, additional one TV, beds and both large and small wardrobes are assumed to be in that specific floor.

S2.2 Building use

While the model has been developed specifically for the residential buildings, the use of the ground floor may vary (e.g., garage, storage or common areas), especially in case of apartment buildings, while the ground floor in detached and semi-detached houses, irrespective of the housing units, are typically used for the residential purpose. To account for this variation, the GroundUse variable (GU) has been introduced into the model (GU=1: Residential use; GU=2: Other use).

Due to the complexity in quantifying the type and monetary value of contents in GU=2, a lump sum is assumed in the model, which randomly samples a value between 300 and 1,000 euro for each housing unit present in the building.

S2.3 Damage driving factors

The calculation of the number of damage items is achieved by identifying the main driving factors for damage induction for each type of content and defining the corresponding damage mechanism.

In INSYDE-content, a probabilistic approach based on the use of fragility functions is adopted for describing the damage mechanisms. The model assumes a binary damage state: an undamaged state (ds_0) or a fully damaged state (ds_1). For each content type, fragility functions express the probability of reaching a fully damaged state, based on the event intensity measure(s) (IM). To combine this probability with the actual occurrence of a damage state for the individual exposed elements, a random value P_i is sampled from a uniform distribution between 0 and 1 and compared to the damage probability derived from the fragility function for the corresponding content type. P_i accounts for the survival probability of each item and the random nature of the implemented process serves to capture the inherent uncertainty in the damage mechanisms, reflecting the intrinsic variability in content vulnerability to the same event intensity. Consequently, if P_i falls below the damage probability calculated from the fragility function, it is considered fully damaged (ds_1), otherwise, it remains undamaged (ds_0).

The formulation of fragility functions is based on expert knowledge, practical experience, as well as available technical and scientific documentation.

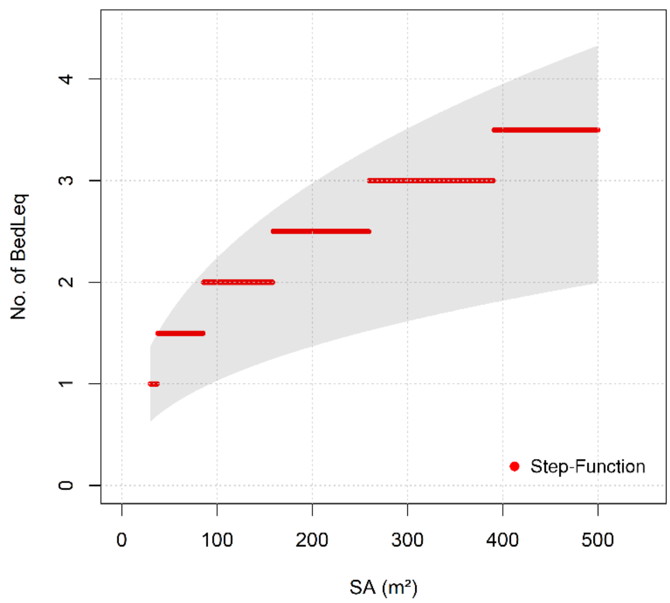
The inundation depth and duration are considered as the primary damage driving factors, while sediment and pollution are considered secondary factors, as follows:

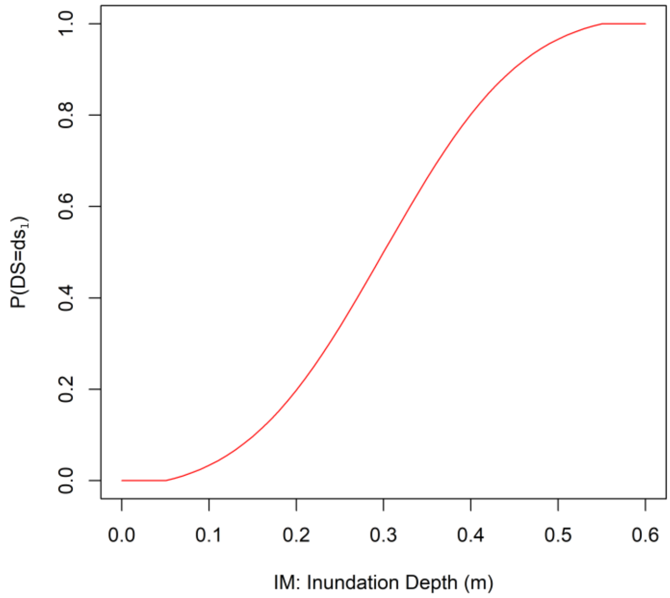
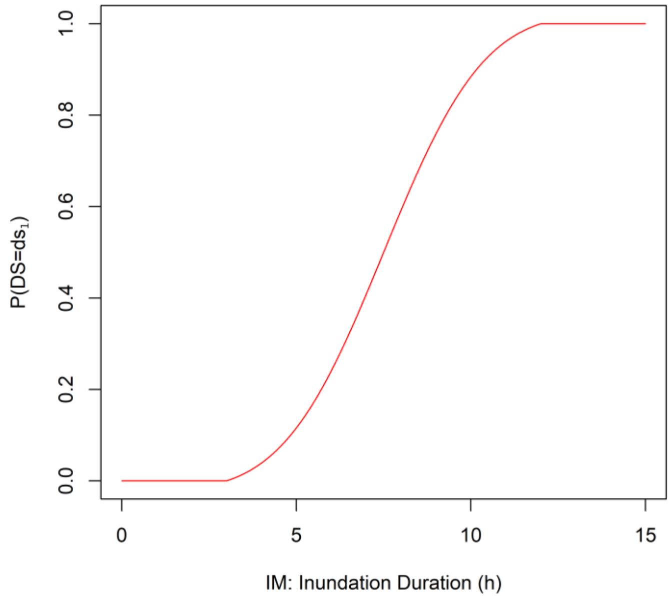
- *Inundation depth*: it is the main driving factor for the damage induction for all the components;
- *Inundation duration*: it is a major driving factor for the damage induction for certain components;
- *Presence of sediments*: the presence of sediments may amplify the probability of damage to the contents as compared to the clean water. In the model, it is assumed that sediments are always present (s = 1) and contributes additional 10% damage to the damage probability resulting from either inundation depth or inundation duration only.
- *Presence of contaminants:* The presence of pollutants in flooded water may amplify the probability of damage to the contents, potentially rendering it unusable even after drying (e.g., due to the inability to clean it properly or irreversible damage to its surface coating). In cases where information is missing, the model randomly samples between q = 1 (pollutant present) and q = 0 (no pollutant) with equal probability, then applies 20% of the sampled value as an increment to the damage probability coming from either inundation depth or inundation duration only.

Therefore, the probability of damage to an item is influenced by both the primary and secondary factors. Specifically, the damage induced by the primary factors is adjusted by a scaling factor that accounts for the secondary factors. This scaling factor is determined by the values of sediment (s) and pollution (q), where the damage is increased by a factor that is the greater of either $(1+s\cdot 0.1)$ or $(1+q\cdot 0.2)$.

S2.3 Assumptions and fragility functions for the content items

S2.3.1 BEDS

Exposure assessment	
Assumption	1 Double Bed = 2 Single Beds = 1 BedLeq
Quantitative formulation	Based on a regression function derived from the survey $BedLeq = 0.27663 \cdot SA^{0.40914}$ converted into a stepped function, as represented in the figure (showing also the uncertainty band associated to the empirical data) 

Damage mechanisms	
Damage driving factors	Inundation depth, inundation duration, sediment and pollution
Fragility functions for primary factors (truncated normal distributions)	Fragility function related to inundation depth in each floor  Fragility function related to inundation duration 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds span from the floor level to the average height of the mattress base in the beds (from literature and market study). The inundation duration thresholds have been assigned based on literature review and practical considerations.

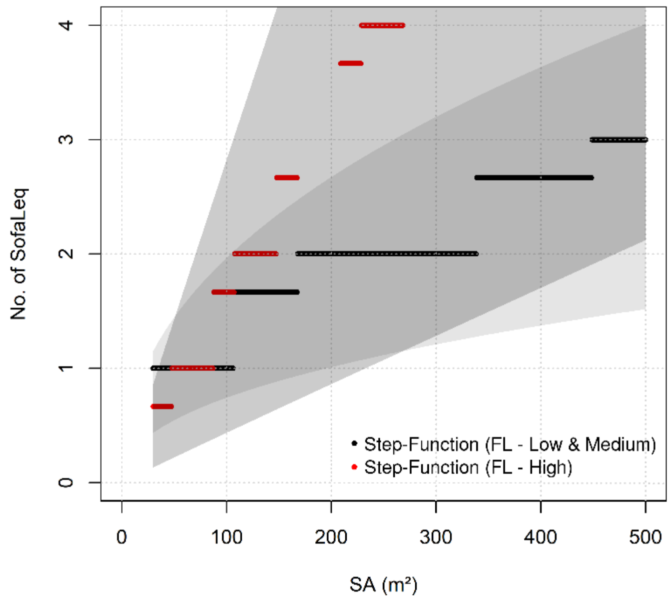
S2.3.2 SOFAS

Exposure assessment	
Assumption	1 Large Sofa = 3 Single Sofa = 1 SofaLeq
Quantitative formulation	Based on a regression function derived from the survey $\boldsymbol{SofaLeq = 0.1926 \cdot SA^{0.4434}}$ *(FL - Low & Medium)*

<table>
<tr><td></td><td>

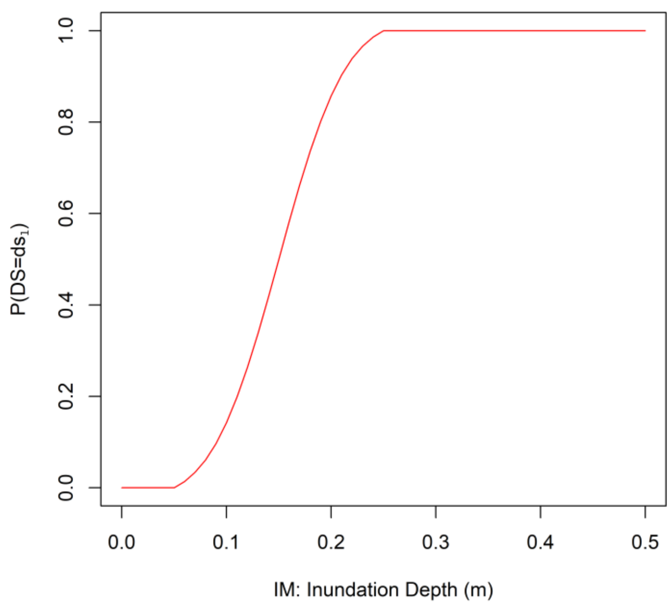
$SofaLeq = 0.01815 \cdot SA^{0.98228}$ *(FL - High)*

converted into a stepped function, as represented in the figure (showing also the uncertainty band associated to the empirical data)



</td></tr>
<tr><td colspan="2">Damage mechanisms</td></tr>
<tr><td>Damage driving factors</td><td>Inundation depth, inundation duration, sediment and pollution</td></tr>
<tr><td>Fragility functions for primary factors
(truncated normal distributions)</td><td>

Fragility function related to inundation depth in each floor



</td></tr>
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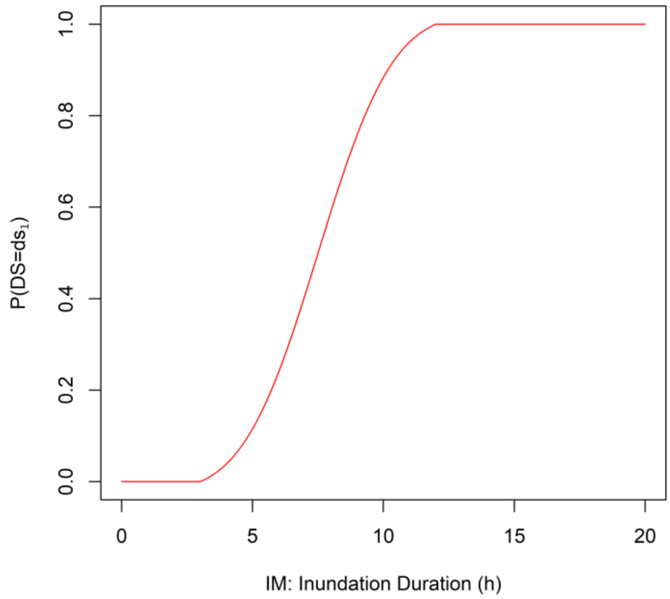
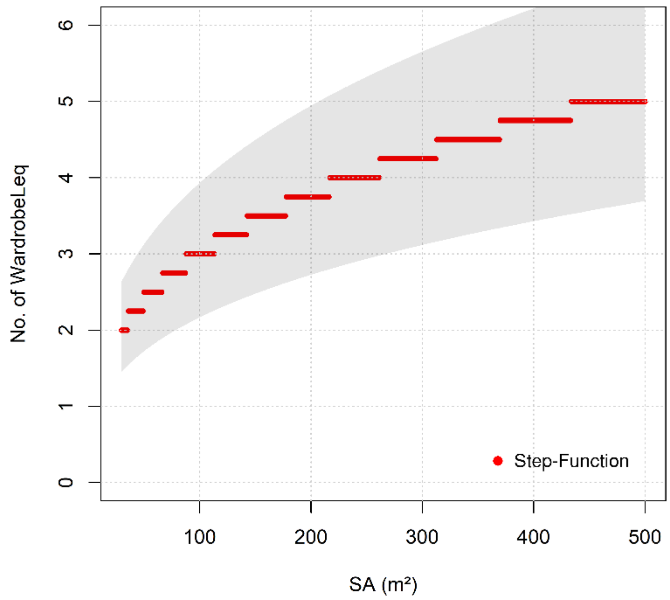
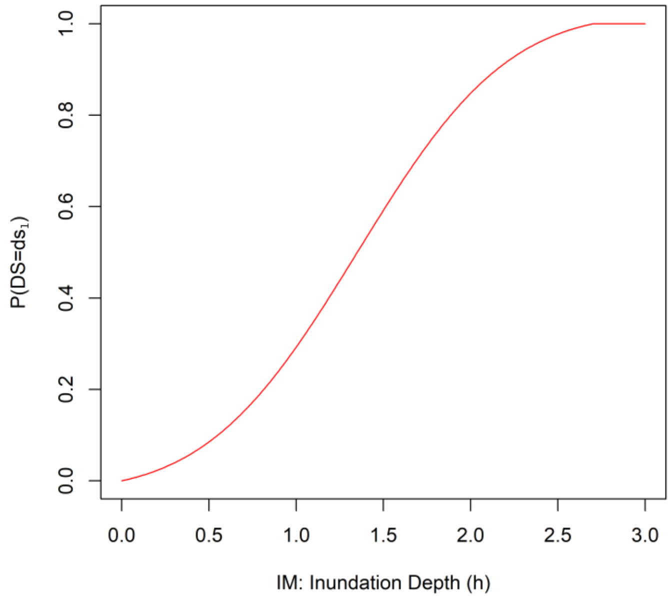
	Fragility function related to inundation duration 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds span from the floor level to the average height of the lower cushion base of the sofa (from literature and market study). The inundation duration thresholds have been assigned based on literature reviews and practical considerations.

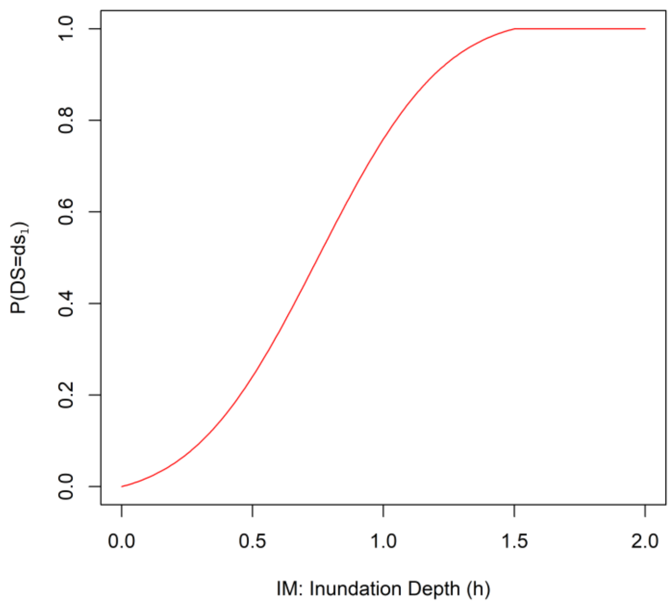
S2.3.3 WARDROBES

Exposure assessment	
Assumption	1 Large Bedroom Wardrobe = 1 Large Decorative Wardrobe = 4 Small Wardrobe = 1 WardrobeLeq
Quantitative formulation	Based on a regression function derived from the survey $\boldsymbol{WardrobeLeq = 0.7175 \cdot SA^{0.3309}}$ converted into a stepped function, as represented in the figure (showing also the uncertainty band associated to the empirical data) 

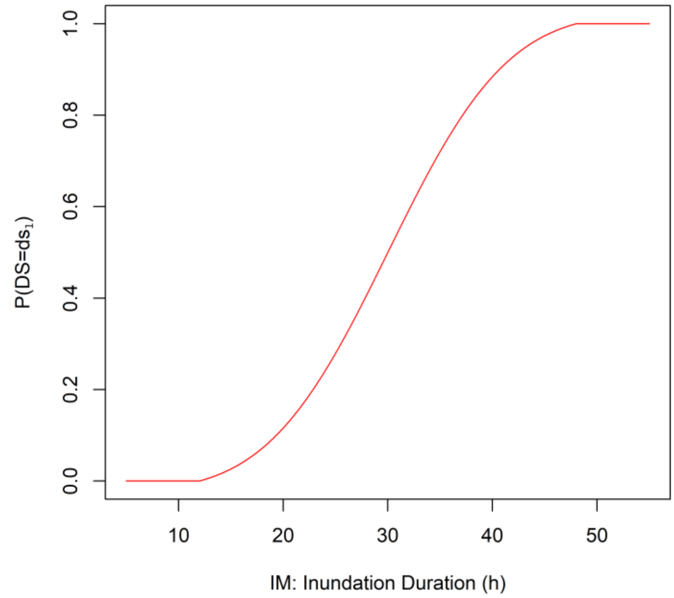
<table>
<tr><th colspan="2">Damage mechanisms</th></tr>
<tr><td>Damage driving factors</td><td>Inundation depth, inundation duration, sediment and pollution</td></tr>
<tr><td>Fragility functions for primary factors
(truncated normal distributions)</td><td>Fragility function related to inundation depth in each floor for large wardrobes



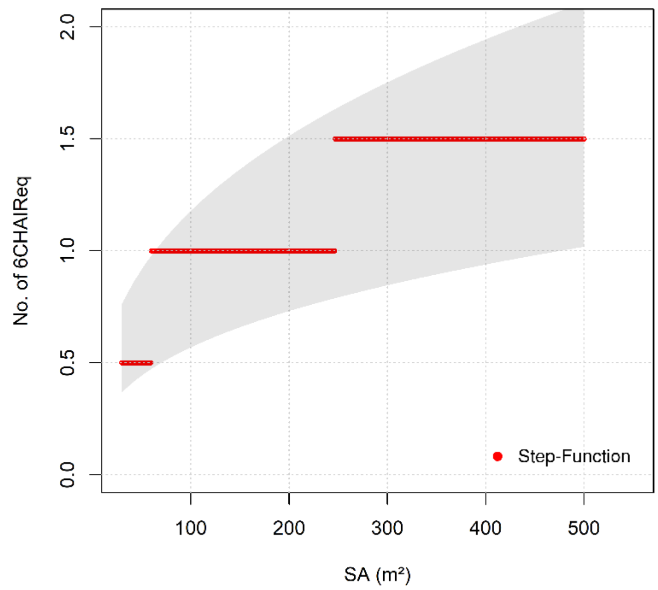
Fragility function related to inundation depth in each floor for small wardrobes

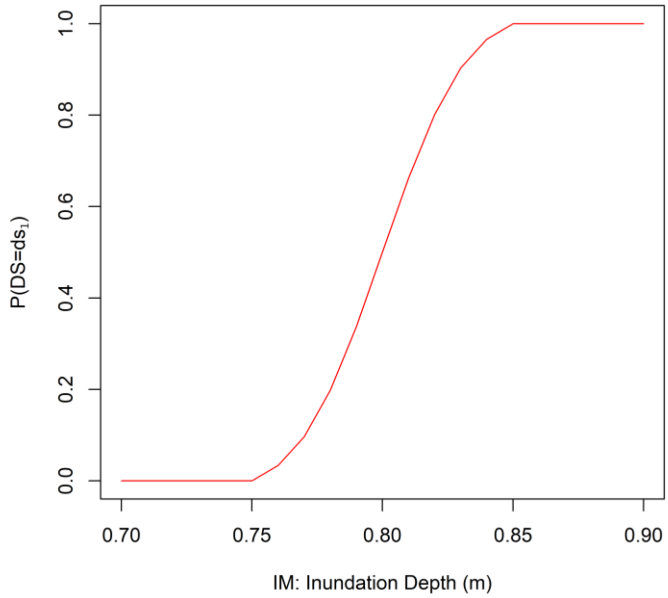


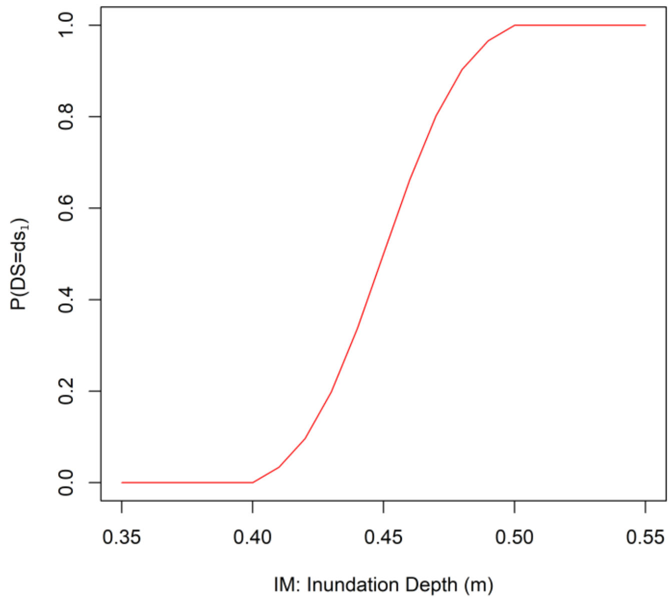
</td></tr>
</table>

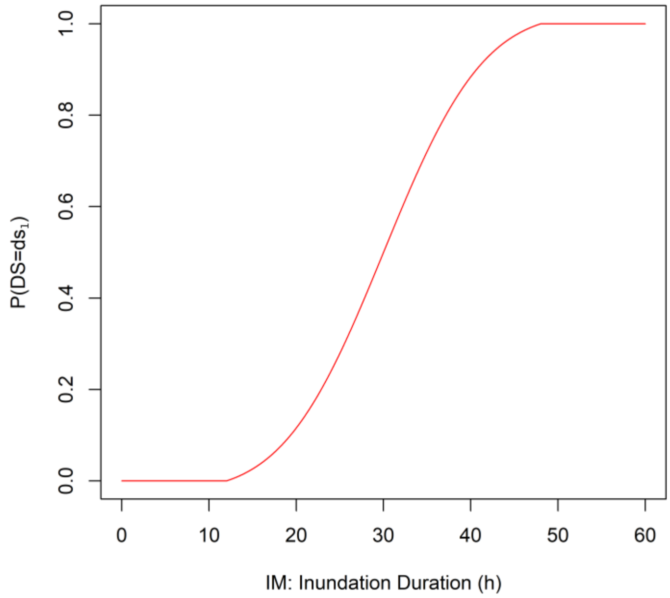
	Fragility function related to inundation duration for large and small wardrobes 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds span from the floor level to the average height of both large and small wardrobes (from literature and market study). The same fragility functions with depth as driving factors are also adopted for the contents within the wardrobes. The commonly found items in large and small wardrobes are clothes, shoes, electrical items and other personal items. The inundation duration thresholds have been assigned based on literature reviews and practical considerations.

S2.3.4 DINING SETUP

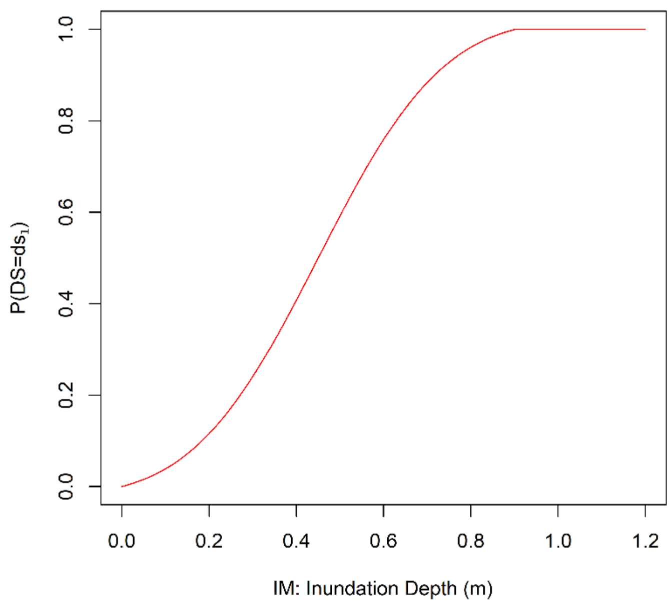
Exposure assessment	
Assumption	A table with 6 standard chairs = 6CHAIReq
Quantitative formulation	Based on a regression function derived from the survey $\boldsymbol{6CHAIReq = 0.1788 \cdot SA^{0.3615}}$ converted into a stepped function, as represented in the figure (showing also the uncertainty band associated to the empirical data) 

<table>
<tr><th colspan="2">Damage mechanisms</th></tr>
<tr><td>Damage driving factors</td><td>Inundation depth, inundation duration, sediment and pollution</td></tr>
<tr><td>Fragility functions for primary factors
(truncated normal distributions)</td><td>Fragility function related to inundation depth in each floor for dining table


Fragility function related to inundation depth in each floor for chairs

</td></tr>
</table>

<table>
<tr><td></td><td>Fragility function related to inundation duration for dining setup (both table and chairs)

</td></tr>
<tr><td>Explanation for the considered thresholds in the fragility functions</td><td>The inundation depth thresholds for chairs and table span between the average height of the seat and the base of the table top, respectively (from literature and market study). The inundation duration thresholds have been assigned based on literature reviews and practical considerations.</td></tr>
</table>

S2.3.5 KITCHEN SETUP

<table>
<tr><td colspan="2">Exposure assessment</td></tr>
<tr><td>Assumption</td><td>Kitchen setup indicates the combination of lower and upper cabinets</td></tr>
<tr><td>Quantitative formulation</td><td>Each housing unit has 1 kitchen setup</td></tr>
<tr><td colspan="2">Damage mechanisms</td></tr>
<tr><td>Damage driving factors</td><td>Inundation depth, inundation duration, sediment and pollution</td></tr>
<tr><td>Fragility functions for primary factors
(truncated normal distributions)</td><td>Fragility function related to inundation depth in each floor for lower cabinets

</td></tr>
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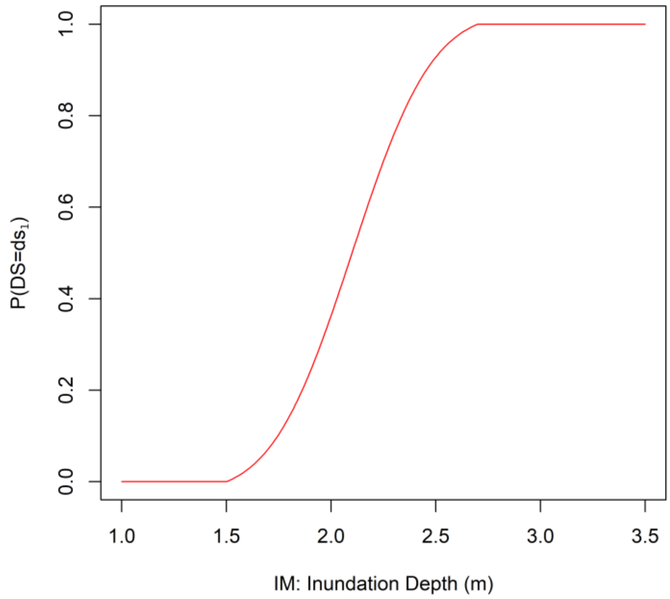
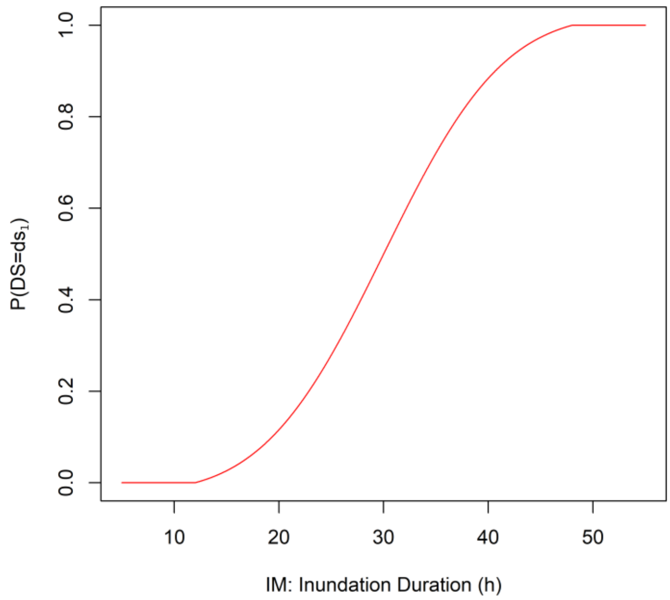
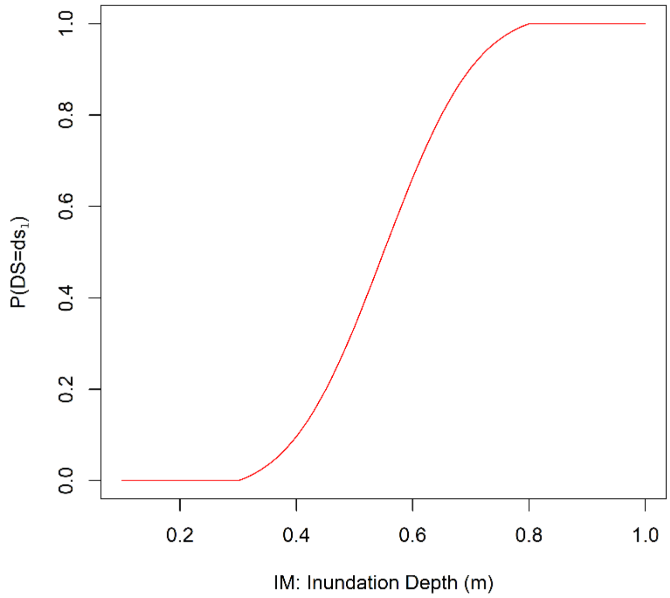
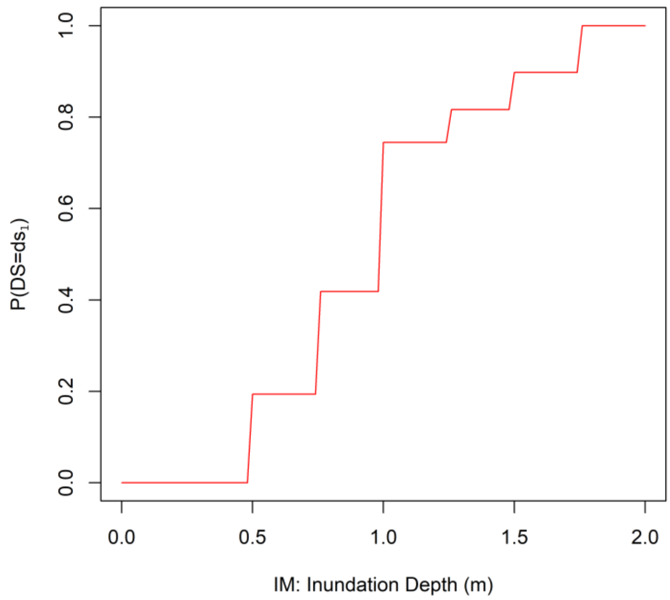
	Fragility function related to inundation depth in each floor for upper cabinets  Fragility function related to inundation duration for lower and upper cabinets 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for both cabinets span across their average placement heights (from literature and market study). The inundation duration thresholds have been assigned based on literature reviews and practical considerations.

S2.3.6 WASHING MACHINE

Exposure assessment	
Quantitative formulation	Each housing unit has 1 washing machine (based on the survey & ISTAT data)

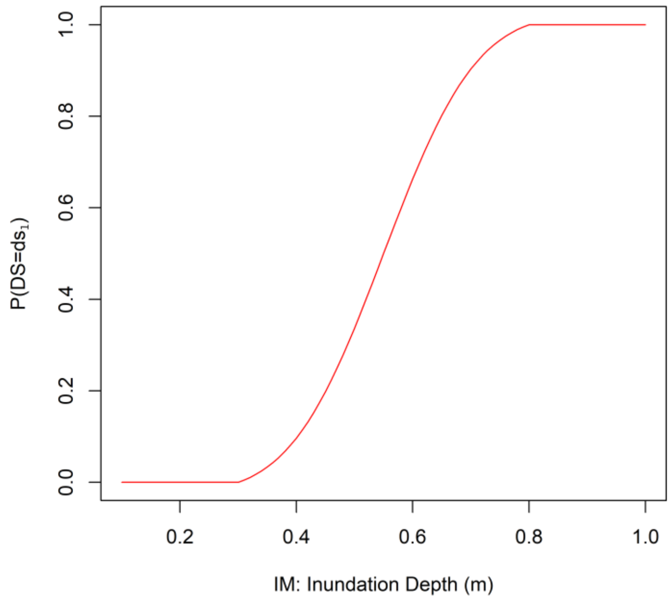
Damage mechanisms	
Damage driving factors	Inundation depth only
Fragility functions for primary factors (truncated normal distribution)	Fragility function related to inundation depth in each floor 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for the washing machine is based on the average position of the main motor component in it.

S2.3.7 TVs

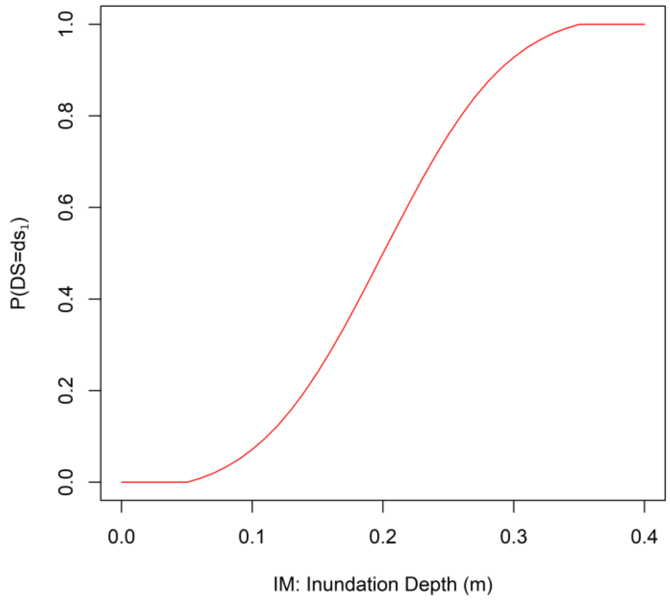
Exposure assessment	
Assumption	1 TV = 1 PC = 1 TVeq
Quantitative formulation	Each housing unit has 2 TVeq (based on the survey & ISTAT data)
Damage mechanisms	
Damage driving factors	Inundation depth only
Fragility functions for primary factors (empirical CDF based on base heights of TVs from survey data)	Fragility function related to inundation depth in each floor 

Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for the TV is based on the empirical CDF of the estimated based heights of the TVs collected during the data survey phase.

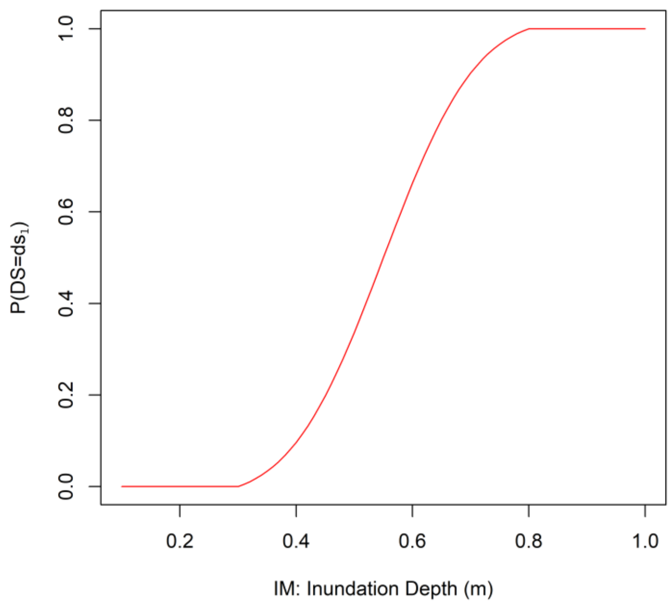
S2.3.8 OVEN

Exposure assessment	
Quantitative formulation	Each housing unit has 1 oven (based on the surveyed data)
Damage mechanisms	
Damage driving factors	Inundation depth only
Fragility functions for primary factors (truncated normal distribution)	Fragility function related to inundation depth in each floor 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for the oven is based on the average position of the bake and broil elements in it (from market study).

S2.3.9 REFRIGERATOR

Exposure assessment	
Quantitative formulation	Each housing unit has 1 Refrigerator (based on the surveyed data)
Damage mechanisms	
Damage driving factors	Inundation depth only
Fragility functions for primary factors (truncated normal distribution)	Fragility function related to inundation depth in each floor 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for the refrigerator are based on the average position of the compressor component in it (from market study)

S2.3.10 DISHWASHER

Exposure assessment	
Assumption	It is only present in housing units with high finishing level
Quantitative formulation	Each housing unit has 1 dishwasher (based on the surveyed data).
Damage mechanisms	
Damage driving factors	Inundation depth only
Fragility functions for primary factors (truncated normal distribution)	Fragility function related to inundation depth in each floor 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for the dishwasher are based on the average position of the circulation pump/motor component in it (from market study).

S2.3.11 MICROWAVE OVEN

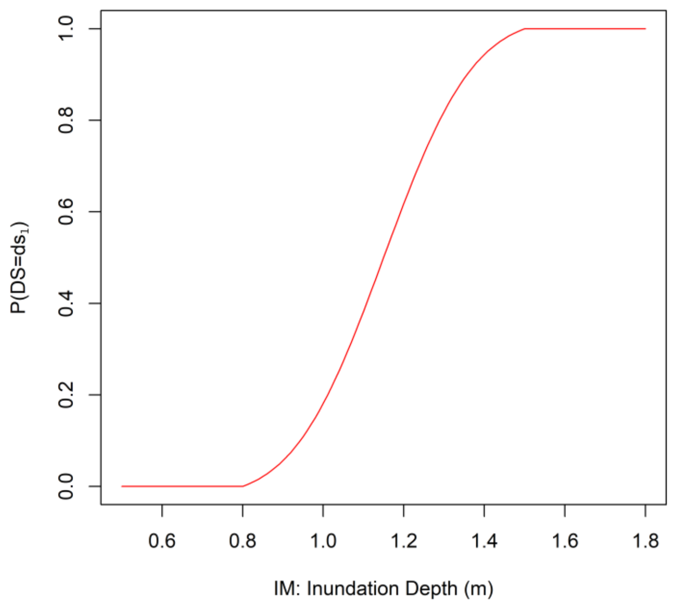
Exposure assessment	
Assumption	It is only present in housing units with high finishing level
Quantitative formulation	Each housing unit has 1 microwave oven (based on the surveyed data).
Damage mechanisms	
Damage driving factors	Inundation depth only
Fragility functions for primary factors (truncated normal distribution)	Fragility function related to inundation depth in each floor 
Explanation for the considered thresholds in the fragility functions	The inundation depth thresholds for the microwave oven are based on the average position of the magnetron component in it (from market study).

Table S2. Reference unit prices for the Northern Italy case (year 2023).

House content components	Unit price (Euro)
Single bed	762
Double bed	1270
3-seater sofa	1778
2-seater sofa	1270
Single sofa	762
Decorative wardrobe (frame)	2540
Large wardrobe (frame)	2032
Small wardrobe (frame)	1016
Large wardrobe (content)	1532.1
Small wardrobe (content)	567.11
Toilet cabinet	676.91
Dining table	762
Dining chairs (x6)	914.4
Kitchen setup	4953
TV	614.4
Refrigerator	609.6
Oven	508
Washing machine	508
Dishwasher	508
Microwave oven	200

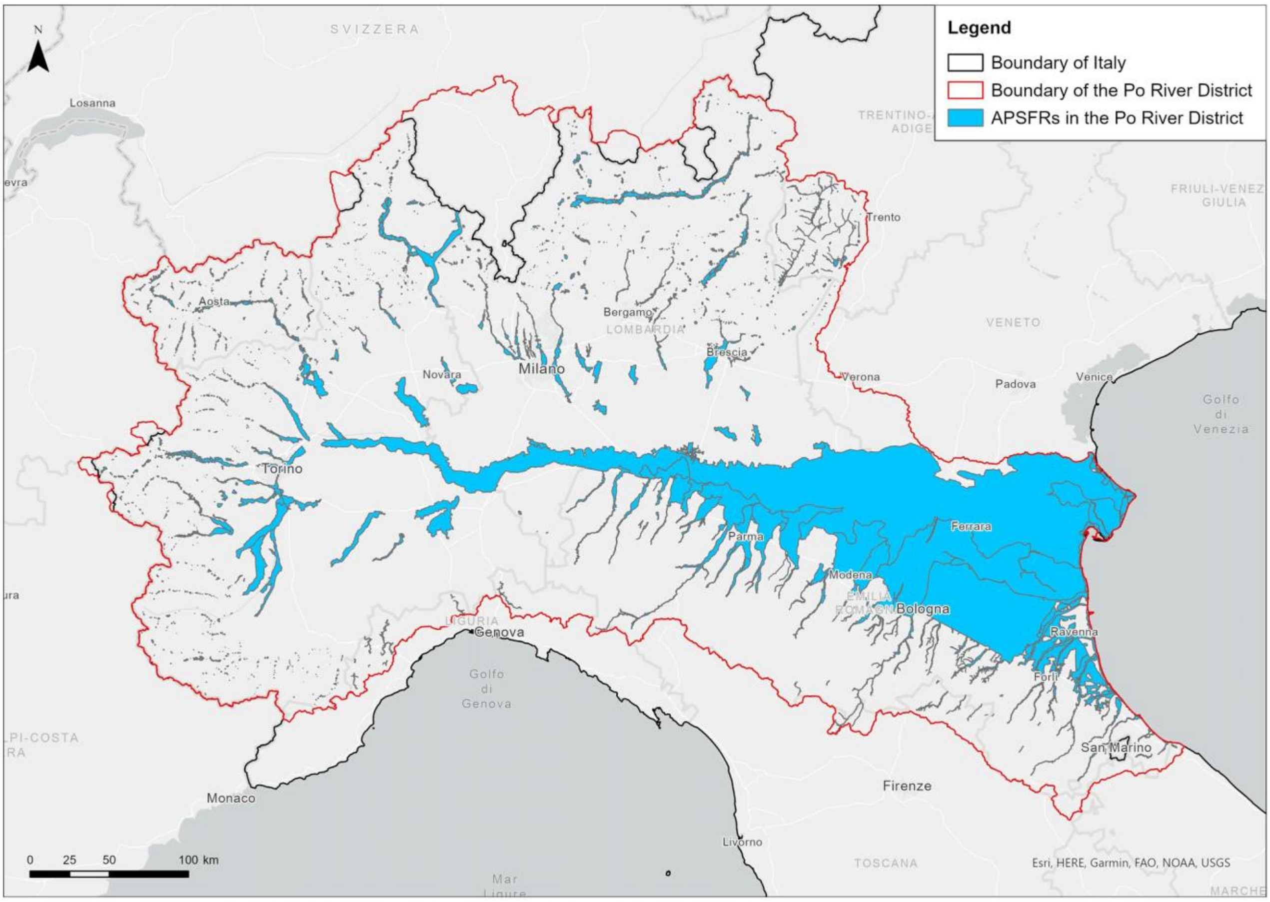


Figure S1. Overview of the Po River District, with indication of Areas of Potentially Significant Flood Risk (APSFRs).

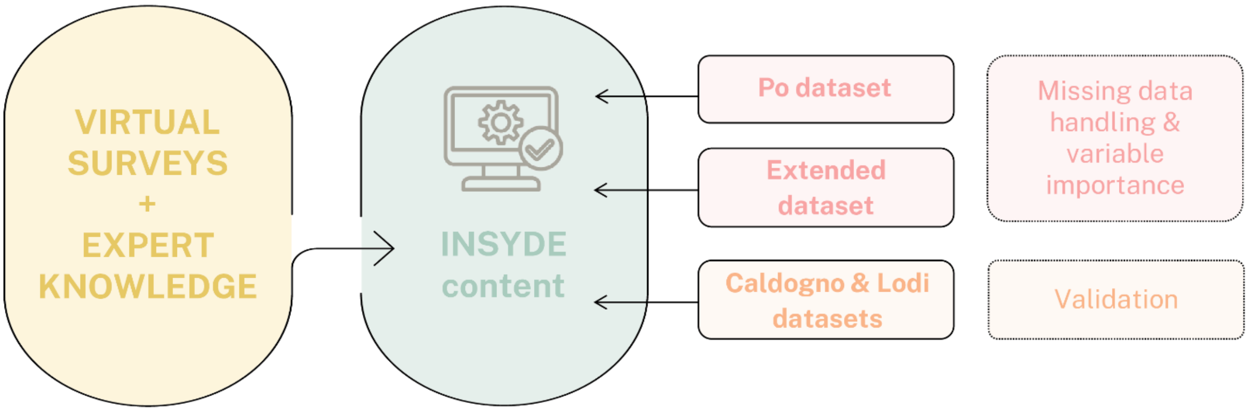


Figure S2. Synthetic overview of the methodological process for model development and assessment, with involved datasets.

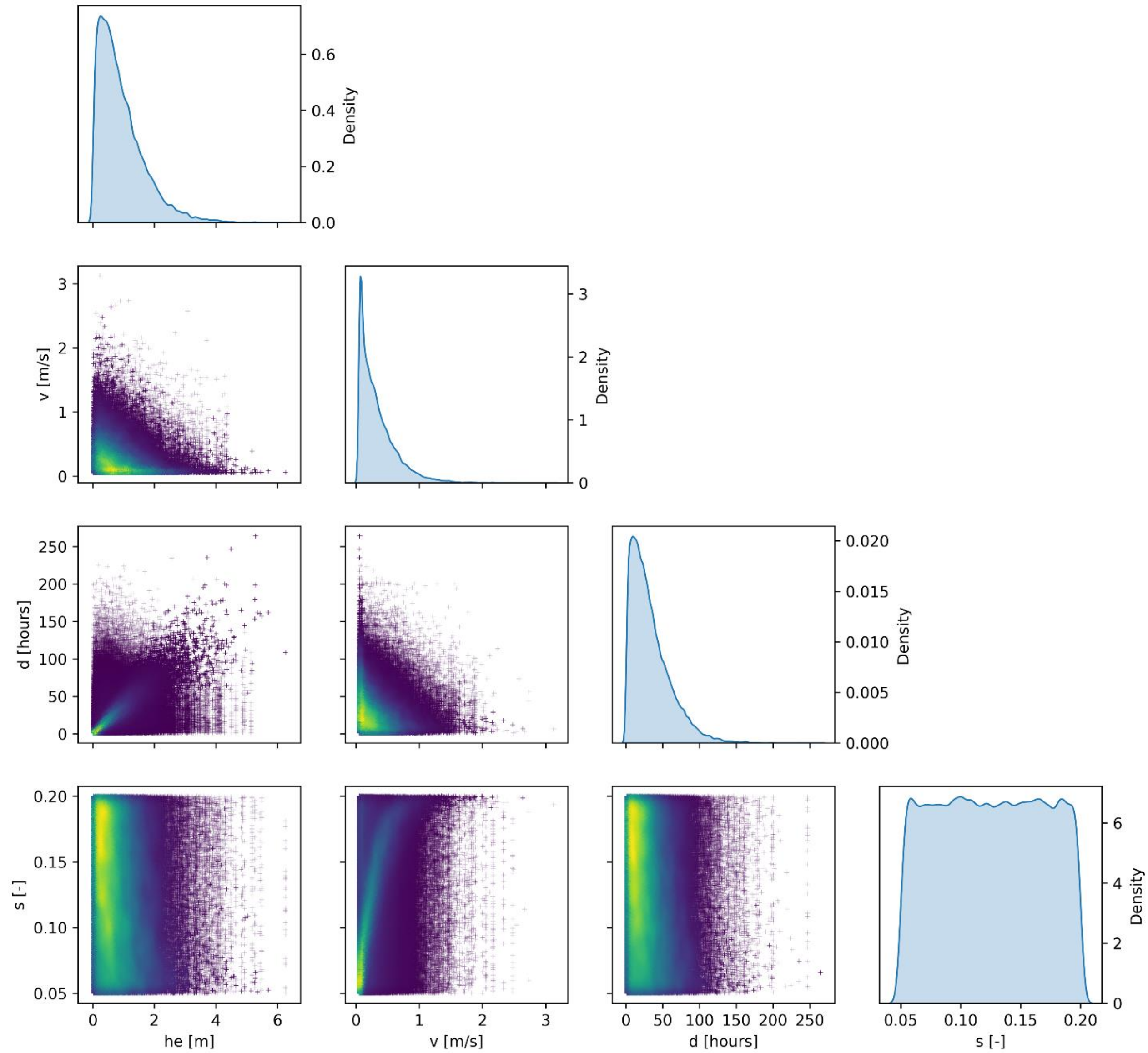


Figure S3. Pairwise relationships assumed for the generation of the Po River District synthetic dataset in Di Bacco et al. (2024)[1]: hazard variables (water depth (he), flow velocity (v), inundation duration (d) and sediment load (s)).

[1] Di Bacco, M., Molinari, D. & Scorzini, A.R. (2024). The value of multi-source data for improved flood damage modelling with explicit input data uncertainty treatment: INSYDE 2.0. Natural Hazards and Earth System Sciences, 24(5), 1681-1696. doi: 10.5194/nhess-24-1681-2024.

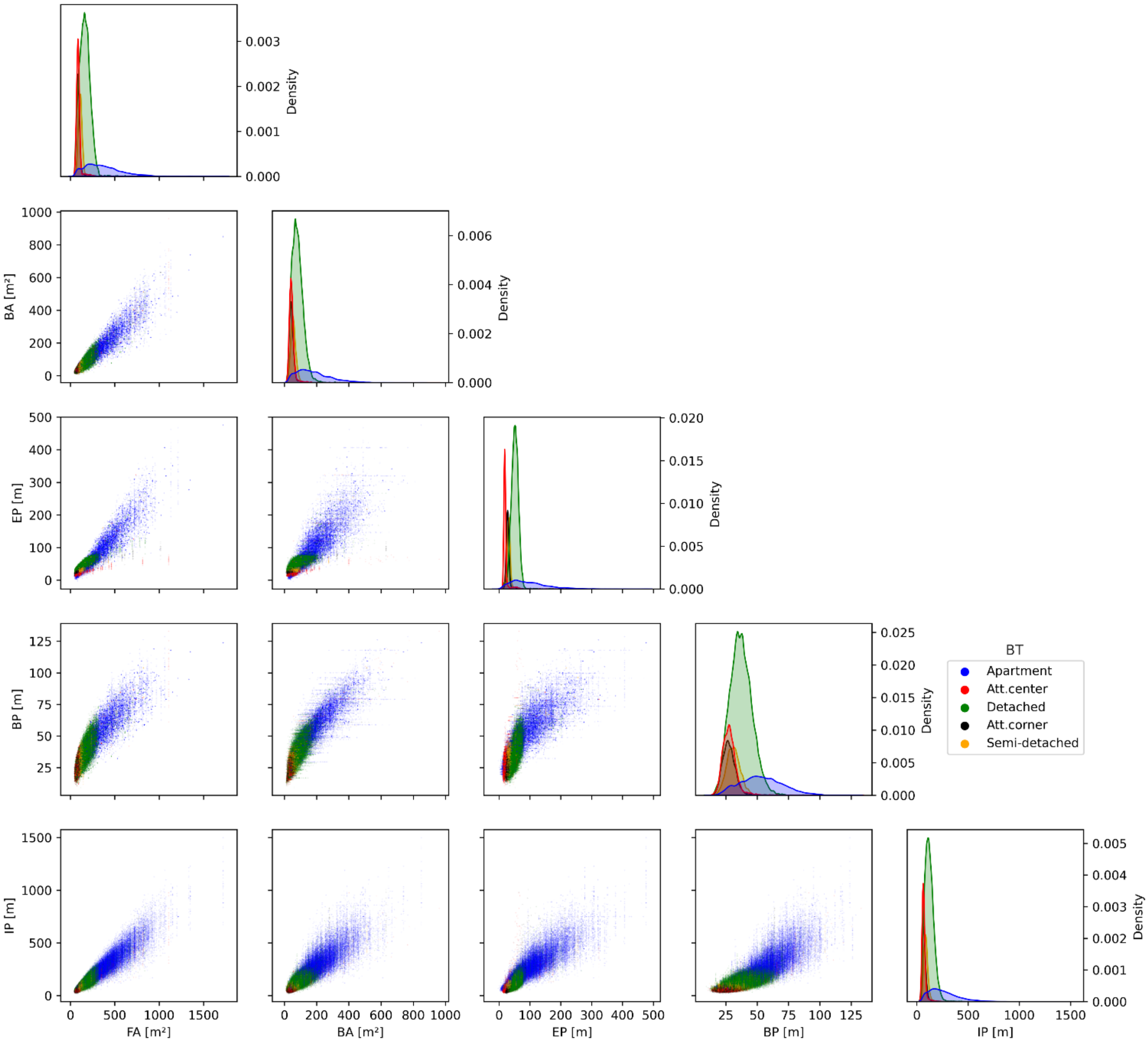


Figure S4. Pairwise relationships assumed for the generation of the Po River District synthetic dataset: extensive building variables (footprint (FA) and basement (BA) area; external (EP), internal (IP) and basement perimeter (BP)).

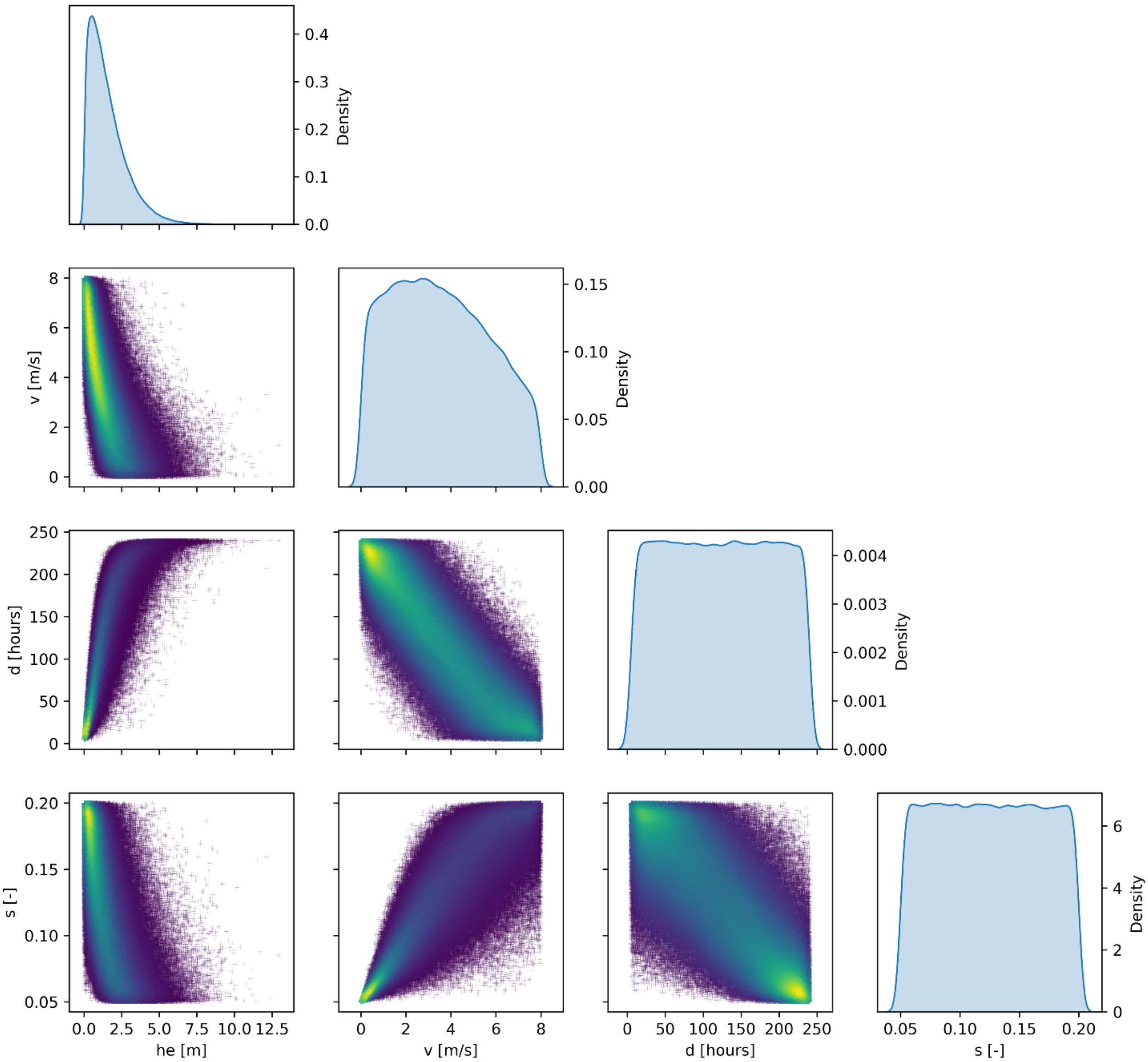


Figure S5. Pairwise relationships assumed for the generation of the extended synthetic dataset in Di Bacco et al. (2024): hazard variables (water depth (he), flow velocity (v), inundation duration (d) and sediment load (s)).

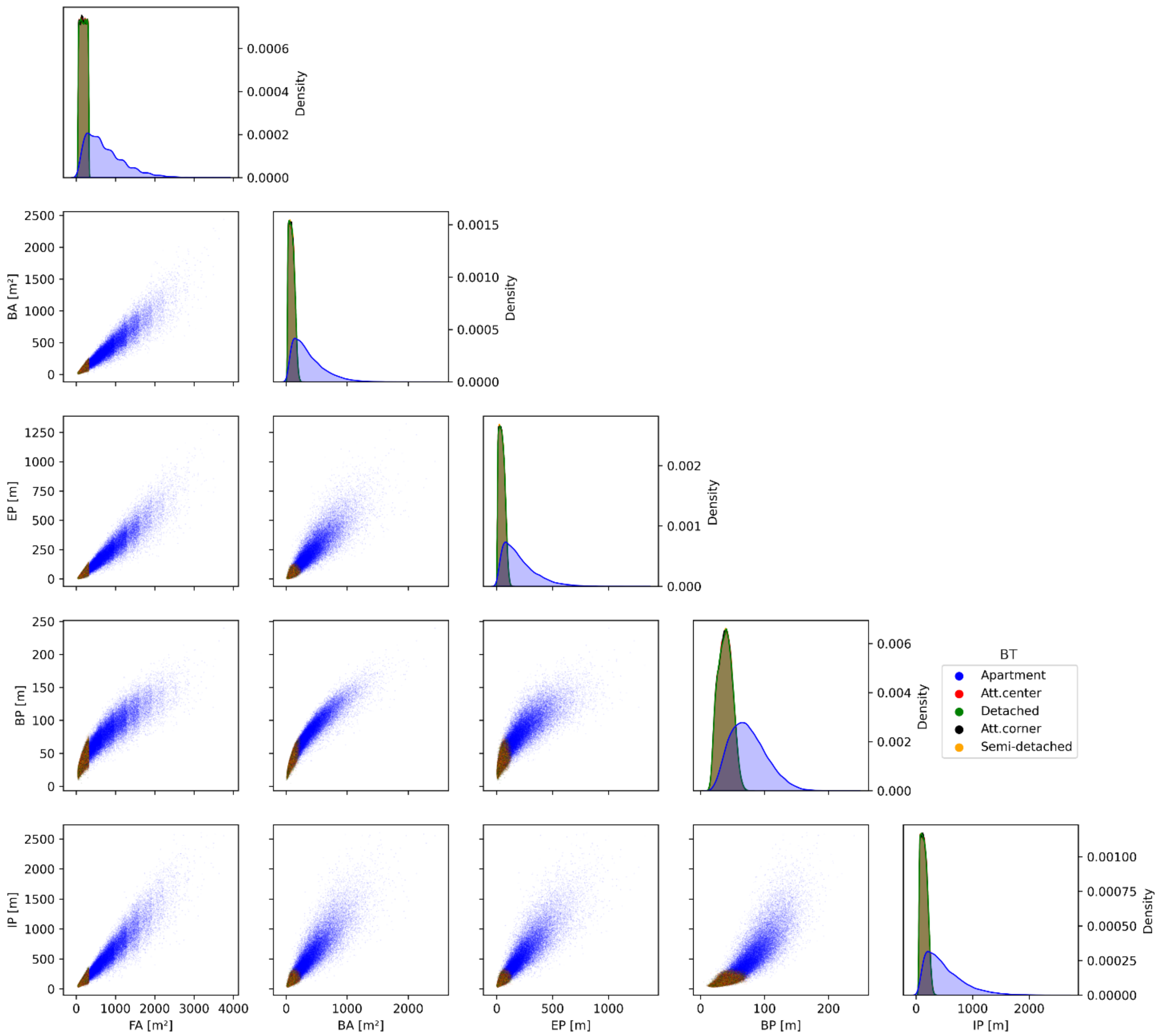


Figure S6. Pairwise relationships assumed for the generation of the extended synthetic dataset in Di Bacco et al. (2024): extensive building variables (footprint (FA) and basement (BA) area; external (EP), internal (IP) and basement perimeter (BP)). Uniform distributions are instead assumed for the other categorial variables in the extended dataset.

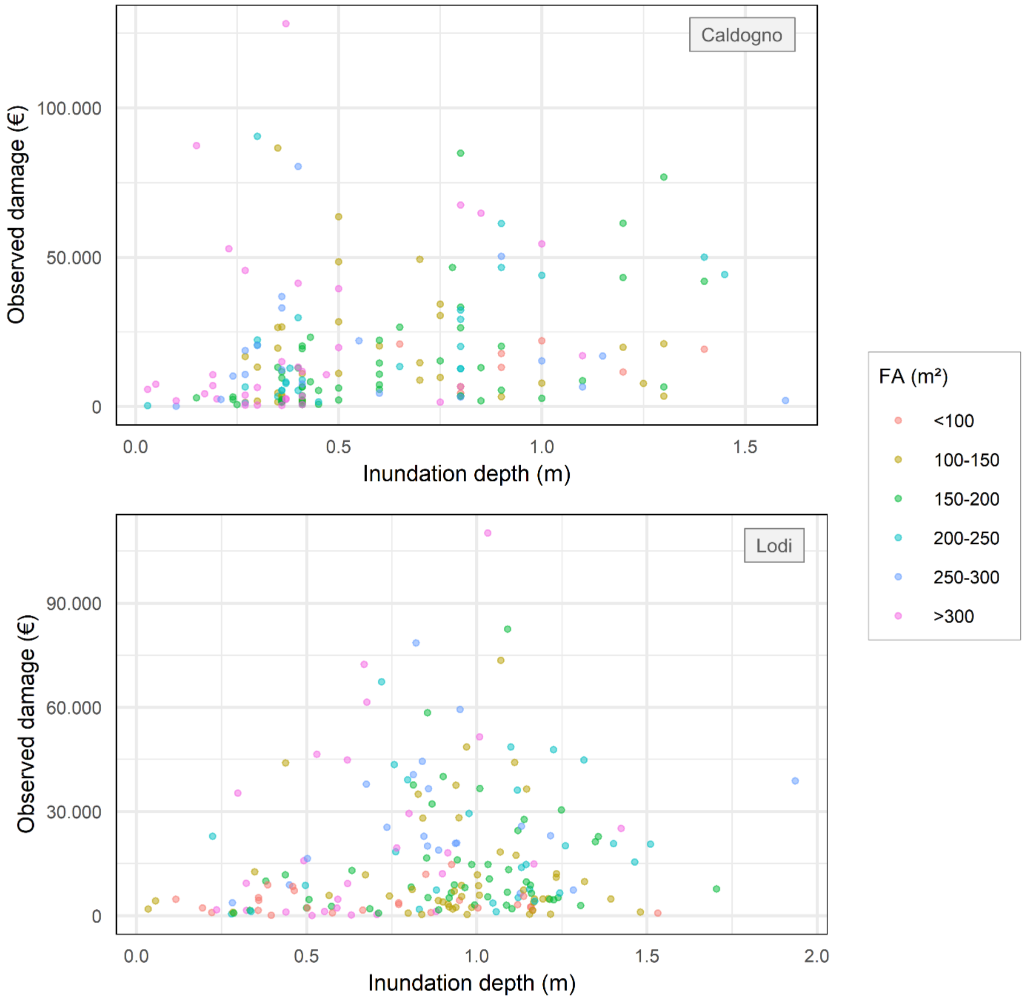


Figure S7. Relationship between observed content losses and inundation depth for individual buildings in Caldogno and Lodi case studies.