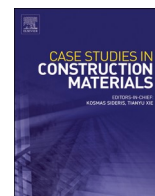




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Case study

Characterization of damages in buildings after floods in Vega Baja County (Spain) in 2019. The case study of Almoradí municipality

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ARTICLE INFO

Keywords:

Building flood exposure
Building flood resistance
Building flood vulnerability
Empirical data set
Flood damage
Flood damage model
Flood depth

ABSTRACT

September 2019 saw the most catastrophic floods on the southeast coast of Spain since 1879, leaving fatalities, thousands of people evacuated, and nearly €500 million in compensation. The aim of this work is to characterize the flood exposure, resistance, hazard, and damage in the buildings affected by that event to create an empirical data set as a tool for improving and validating damage models and their transferability to the Valencian Region. For this purpose, we developed and applied a case study methodology in Almoradí, one of the most severely damaged municipalities in Vega Baja County, after the 2019 events. The proposed methodology starts with on-site surveys to collect data, identifying three archetypes based on exposure and resistance features. Then, absolute and relative damage recorded were correlated with the flood depth. Finally, data were mapped using a GIS system. Results show a significant correlation between the recorded flood depth and both relative and absolute damage, which rises to diverse as varying building exposure and resistance characteristics. The methodology presented to characterize direct tangible damage from empirical data may be transferred to any region whose buildings have been affected by floods. However, for damage estimation purposes, the results may be used only in regions with comparable expected flood depths, building exposure and resistance features.

1. Introduction

Having an estimated annual average of 10 severe events [11], flooding is the natural hazard that has caused both the highest number of fatalities, 582 from 1971 to 2019 [13,21] and the greatest economic losses in Spain, with more than 7336 million euros in the same period [13]. Furthermore, around three million Spaniards live in high flood-risk level areas [11], and only in the Valencian Region, almost 600,000 people may be affected by surface water floods [31] caused by short and local heavy rains whose water is drained by three small and steep catchment areas [16], namely Jucar, Segura, and Ebro. Specifically, Vega Baja County is within the second one and, in addition to suffering 14 major flood events from 1971 to 2019 [15], was affected by the second and third most catastrophic floods ever documented in Spain (Table 1) [13,21]. On a municipal scale, Almoradí, with the county's highest Integrated

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<https://doi.org/10.1016/j.cscm.2024.e03004>

Received 26 June 2023; Received in revised form 14 February 2024; Accepted 20 February 2024

Available online 24 February 2024

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Global Flood Risk Ratio [31], was hardly affected by these events, reporting the highest number of claims within the county.

Flood periodicity in this area is a consequence of three leading causes. First, the region's relief and the short distance between the mountains and the Mediterranean coastline create prone climate conditions that lead to short and heavy local precipitations [16,52]. Second, the influence of global warming increases the number of heavy daily precipitations [16] and a trend to a higher number of shorter and heavier events [5]. Third, the small Segura basin area (20.23 km²) has limited detention capacity, producing fast runoff from rainfall, often leading to flooding along the Segura River and its tributaries. That is caused mainly by anthropic actions which made some parts of the Segura River course narrow considerably, such as in Orihuela, Rojasles and between Almoradí and Algorfa [5], along with quick sprawling settlements, which caused a significant reduction of Segura Orchard area [4,78], increasing, even more, the river flood hazard.

Thus, floods in Vega Baja County and Almoradí are inevitable, but their affection in buildings depends mainly on flood risk management and the buildings' resilience. The first is regulated by a legislative framework led by the Sendai Framework for Disaster Risk Reduction [91] and the European Flood Directive 2007/60/EC, published in 2007, which requires all member states to integrate flood risk management into urban planning, developing hazard and risk maps and management plans to reduce flood risk. Consequently, Spain transposed this European directive into the Royal Decree 903/2010: "Flood Risk Evaluation and Management" in 2010. The government of Valencian Region developed PATRICOVA (Territorial Action Plan for Flood Risk Prevention) in 2003 and reviewed it in 2015 as a preventive tool that provides urban planning strategies and measures to reduce flood risk at the regional scale, and PTECV (Special Plan against Flood Risk) in 2010 and reviewed it in 2020 to regulate flood risk management, classify all municipalities according to flood risk level, and include the main functions and content of the local action plans for flood risk management (PAMRI, by its acronym in Spanish) developed by the municipalities classified at medium and high flood risk level such as Almoradí. In order to increase buildings' flood resilience, the official national documents [11,70] provide guidelines to increase understanding about floods, their buildings' affection, and self-protection within society, as well as the latest international and national research [3,51,87,28,56] and guides with the scope of application in Valencian Region such as [33] to estimate flood vulnerability and damages.

To increase the effectiveness and efficiency of flood risk management and improve the buildings' flood performance, a realistic estimation of flood damage using trustworthy and consistent models to estimate flood losses is indispensable [2,29,49,62,64,67,69,94]. Several flood damage models are available with different approaches that mainly depend on the type of consequences considered (direct or indirect impacts, tangible or intangible costs) and the scale analyzed (macroscale, which refers to regions or countries, mesoscale to land uses or administrative units, and microscale to individual buildings) [10,20,25,41,45,6,71].

The current variety of models to estimate direct tangible flood damage can be classified according to their development approach, the type of damage value obtained, and the number and type of damage influencing factors considered in their methodologies. The two main approaches for flood damage models are empirical, which is based on detailed observed flood damage data from previous events, and synthetic "what-if" analysis, using expert-based knowledge to simulate potential floods and their consequential losses. Although the first group of models are feasible and reliable in their estimations for regions with observed flood loss database available or for similar case studies [40], they present limitations in terms of transferability due to noteworthy uncertainties in loss estimation when these are applied in either different areas and socioeconomic contexts than those for which they were built, or regions with no empirical damage dataset available for model calibration and validation for the specific study area [2,1,35,80,9,95]. Conversely, synthetic models achieve higher levels of standardization in loss prediction, resulting in better-suited models for both spatial (between different regions) and temporal (between different flood events) transferability [2,22,61]. Outcomes from models can be returned as values of loss in monetary terms (absolute damage models) [22] or as a percentage of the total damage or the degree of loss of an exposed asset (relative damage models) [27].

The final distinction among models is the number and type of evaluated variables. The most elemental models are the low-variable models [69], also called univariable or bivariable models (UVMs or BVMs). They evaluate a reduced number of input parameters as the determining variables for expected damage, i.e., mostly flood depth at the building location in addition to the building area. The most common and internationally accepted method to assess direct tangible damage using UVMs to assets is the application of depth-damage functions or curves [44,61,63,30].

In contrast to UVMs, multi-variable models (MVMs) can account for numerous hazard, exposure, and vulnerability factors and, therefore, are supposed to be more adaptable to specific features of different events and locations and produce more reliable estimates when empirical detailed records are available [2,17,35,40,67,69,76,74,80,86,93]. Consequently, they have a high predictive capability in spatial and temporal transferability despite requiring more detailed hazard, exposure, and loss descriptions [55,79,94]. Different techniques such as simple regression [60], machine learning, specifically Artificial Neural Networks (ANN), and Random Forests (RF) [46,82,84,9] and Bayesian Networks (BN) [92,93] are commonly applied in MVMs.

Table 1

The five major floods in Spain from highest to lowest compensation amounts. The event studied in this paper is highlighted in bold. [13].

	Compensation (€)	Year	Total Area Affected [15]	Regions affected		
				Segura Basin	Vega Baja County	Almoradí
1	888,035,167.00	1983	Basque Country (Euskadi)			
2	475,078,038.00	2019	Southeast Peninsula	X	X	X
3	308,285,653.00	1987	Valencian Region	X	X	X
4	241,673,882.00	1982	Valencian Region	X		
5	239,441,379.00	2012	Southeast Peninsula	X		

All these models generally use two types of damage functions to estimate expected losses, vulnerability curves which relate hazard, exposure, and vulnerability to the loss [2,27,29], and fragility curves which represent the intensity of the process and probability of loss [72,75,77,85,88]. Regardless of the model, the flood depth accounts as the primary explanatory variable for flood loss [29,35,36,39,40,48,53,56,96]; nonetheless, this variable cannot completely explain the damage data variance since other parameters related to hazard or flood intensity (e.g. flow velocity and flood duration) and vulnerability or resistance (e.g. type, quality, size and level of maintenance of buildings and presence or absence of a basement) [7,9,14,18,19,24,25,26,43,47,48,46,50,54,58,60,61,59,65,68,67,79,83,89,90] influence notably in the flood loss process.

Finally, the validation of models is essential to improve their robustness, precision in damage prediction, and spatial and temporal transferability. Both empirical and synthetic models need to be validated [2,9,22,34,35,42,55,57,66,68,67,69,72,76,74,80,81,82,93,97,98], the firsts because of their specific contextual calibration, while the complexity to simulate potential floods and expected losses in the second ones requires adjustments based on characteristics of the location to be applied. The validation methods used by most damage modelers are validation using empirical data from field surveys of previous floods, government or insurance compensation data, cross-validation by comparing predictive outcomes of the model with other validated models, and error estimation validation, using statistical error indicators (i.e., mean absolute error, mean bias error, root mean square error, and coefficient variation).

The present work and its results bring a detailed set of hazard, exposure, and vulnerability data, together with direct tangible losses of the assets affected by the flood events in September 2019 in Vega Baja del Segura County, Spain. Therefore, the objectives of this work are to portray hazard and exposure in the presented study area, plus characterize the flood vulnerability and losses reported in the surveyed buildings in order to evaluate their relationships. Finally, these empirical data will provide essential insights to validate flood damage models and carry out the corresponding adjustments, if required, to improve their robustness, damage estimation reliability, and transferability in the Valencian Region.

2. Materials and methods

2.1. Case study

2.1.1. Flood events

In September 2019, the most catastrophic flood events occurred on the southeastern coast of Spain since 1879. The most affected areas were Valencia, Alicante, Murcia, Albacete, Almería, and Malaga provinces and some parts of the Balearic Islands. A total of 6 people died, 3500 were evacuated [23], and nearly €500 million was the estimated total amount of the flood damage costs, with more than 70,000 processed cases, being the second registered major event in the history of Spain in terms of compensations [12,13]. However, the Valencian Region government valued €1500 million as the damage caused by the floods only in Vega Baja County, with 5513 buildings affected, of which 3313 were residential. The heavy precipitations from the 11th to the 13th were essential to overflowing a significant part of rivers from that region [16]. The Vega Baja reported two peaks of rainfall, 225 l/m² on the 12th and 191 l/m² on the 13th, and the highest value of accumulated rainfall was 521.6 l/m², registered in the Orihuela's rain gauge of the Segura River Hydrographic Confederation (Fig. 1) [73].

Another essential factor was the human impact on river systems [4], such as the replacement of natural and permeable Segura Orchard area by sealed surfaces, the anthropic alterations of Segura River, specifically its changes in the course of the river (Fig. 2), and impractical storm-water management systems [16]. The first two are consequences of the voracious urbanization process which the Segura River banks have been suffering [16,78] over the last three decades due to the increase of tourist activity and population in

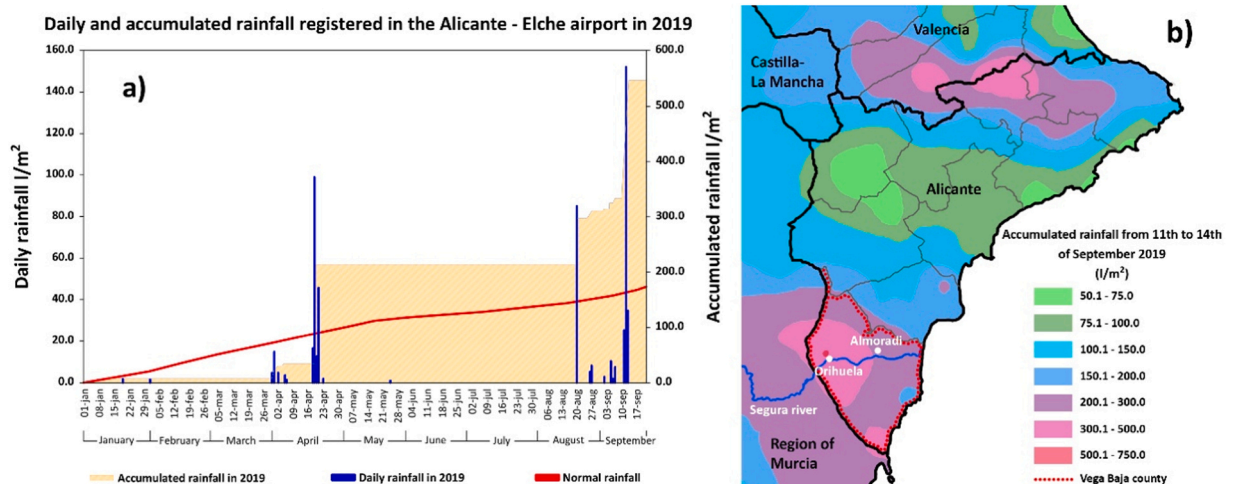


Fig. 1. a) Collected rainfall data from the Altet airport rain gauge from January to September 2019. It shows peaks of daily rainfall (blue) reached during rainfalls in September 2019, and the accumulated rainfall (yellow) increased by almost three times up to the same date. b) Accumulated rainfall from 11th to 14th of September 2019. [73].

most of the municipalities along the river. As an illustration, Orihuela increased its population by more than 50%, Almoradí by nearly 70%, and Torrevieja by more than 200% from 1991 to 2018, according to INE (National Statistics Institute) [37] (Table 2).

The last cause was the backwater-induced urban flood phenomenon [8] caused by the Mediterranean Sea level surge of almost a half meter [73], which impeded floodwater discharge from inland areas into the sea.

2.1.2. Study area

Almoradí, with an area of 42.7 km², a total population of 21,303 people, and 3893 buildings [37], is one of the two municipalities within Vega Baja County classified with the highest flood risk level along with Orihuela [31,32]. Additionally, the whole municipality was hardly impacted by the heavy precipitations in September 2019, which led to the break of two Segura River's banks within its territory and resulted in a river flood that caused the highest number of flood-stricken buildings officially claimed (877, 20% of all Almoradí's buildings) of the 25 municipalities affected in the Valencian Region, far more than other bigger cities, such as Orihuela (302), with an area of 384 km², 78,486 inhabitants and 21,731 buildings [37].

The flood risk classification established by PATRICOVA [31] evaluates risk through a six-level classification based on a hazard estimation derived from the expected flood frequency and magnitude and a vulnerability assessment that encompasses three categories: economic (which analyses land use and flood magnitude), social (potential affected people and strategic or vital facilities), and environmental (pollution to the natural environment and people). Considering this within Almoradí's municipality, the urban structure and the building density, we have differentiated four areas in Almoradí: El Saladar neighborhood (Area 1, A1), Las Heredades neighborhood (Area 2, A2), Almoradí town (Area 3, A3) and Almoradí's Orchard (Area 4, A4) (Fig. 3).

Almoradí's municipality urban form is characterized by a large Orchard extension (A4) with small consolidated settlements within, such as El Saladar (A1) and Las Heredades (A2) neighborhoods and the highest-density inner area, Almoradí town (A3). A4 has the lowest urban density of the municipality, with dispersed lots of different dimensions, while A1 and A3 are the most compact areas, with an urban layout based on regular blocks. However, A2 is a semi-dispersed area characterized by its irregular blocks. All areas show a block subdivision into lots with different dimensions depending on the location and the type of land use associated, mainly residential, industrial, and agricultural.

2.2. Methodology

The overall methodology followed in this paper comprised the following steps:

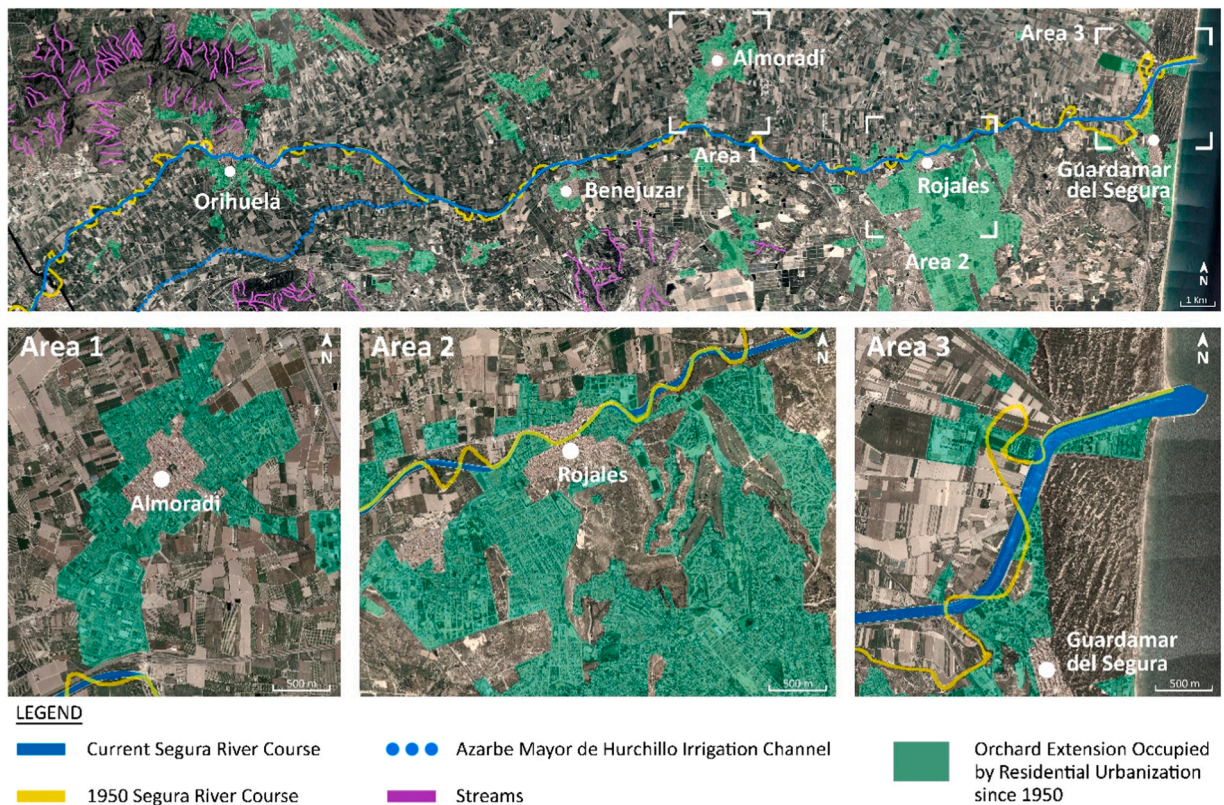


Fig. 2. Variation of Segura River course and Orchard extension from 1950 to 2020. Mapping source: 1956–1957 Serie B American Flight and 2019 PNOA (National Plan for Aerial Orthography).

Table 2
Variation of the population of some Vega Baja municipalities.

Municipalities	Population		
	1991	2020	Variation (%)
Torreveja	25 014	84 667	238.5%
Almoradí	12 509	21 208	69.5%
Orihuela	49 475	78 505	58.7%

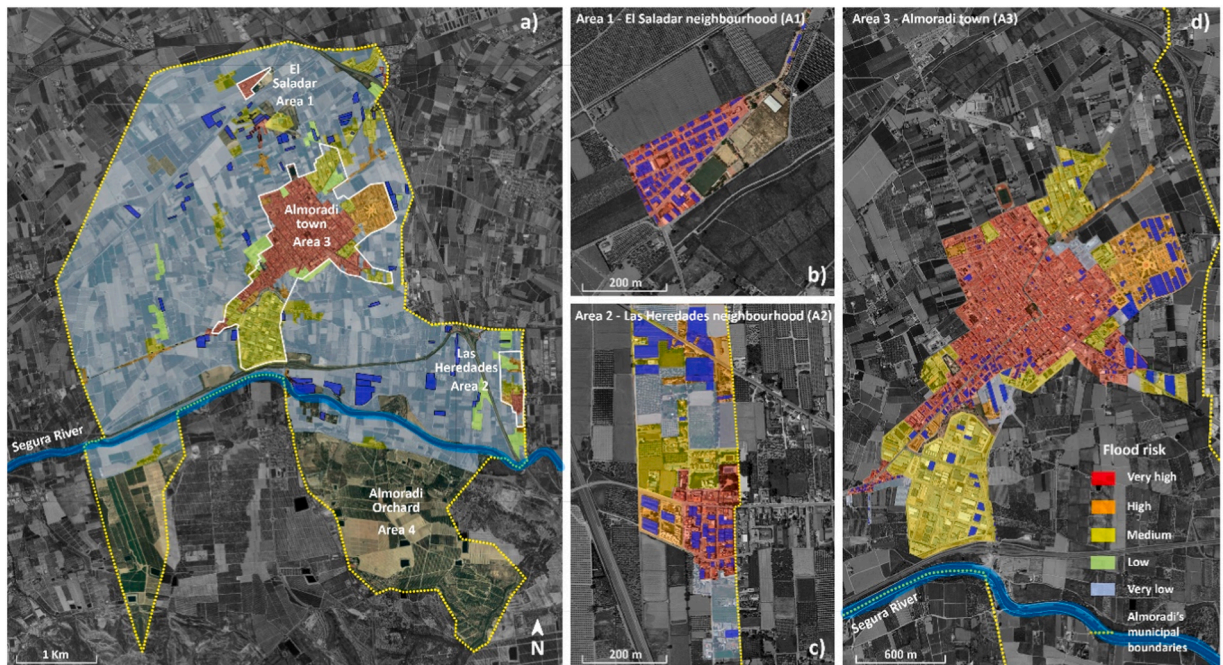


Fig. 3. Location of surveyed buildings (dark blue) and Almoradí's six levels of flood risk classification. a) Map of the whole of Almoradí's municipality, b) Area 1 (A1): El Saladar neighborhood, c) Area 2 (A2): Las Heredades neighborhood, d) Area 3 (A3): Almoradí town.

- Data collection: This process included data extraction from Spanish Cadastre and IVE datasets as well as on-site inspections in all sample buildings carried out by authorized specialists from the IVE using a datasheet provided by the same organization to gather all the required information along with supporting data such as measurements, drawings, and pictures.
- Data pre-processing and analysis: Some previous steps were needed in anticipation of analysis data. Firstly, in pursuit of the reliability and consistency of the dataset used in this research, a preliminary data completeness evaluation was done to identify files with missing or wrong information for the consequent cleaning data. Secondly, a data reorganization was completed to meet the requirements of the present study based on the authors' expert knowledge and the literature review. Then, in data analysis procedures, we identified and sorted all building types based on different parameters, in addition to a classification of all types and grades of damage recorded along with the floodwater depth registered, the accessibility condition, the maintenance level, and damage reported expressed as relative and absolute losses for all buildings in the sample.
- Correlation with variables and damage: A further analysis was carried out to identify patterns and relationships between surveyed parameters and losses registered.
- Mapping data: All collected data and results were incorporated into the Geographic Information System (GIS).
- Finally, we conclude the paper with an interpretation of the results and recommendations for future research.

However, the findings of the present study have to be seen in the light of some limitations: first, the number of buildings inspected, which depended on the number of petitioners of the building inspection services to evaluate flood damages listed in the flood damage evaluation section from PTEC [32]. Second, the incomplete information gathered in some buildings resulted from their lack of security or accessibility. Thirdly, the impossibility of gathering specific and detailed data on important hazard features such as flow velocity, flood duration, and water contamination, leaving the water depth as the only hazard-explanatory parameter. Lastly, contents and service building affections were not covered in this study.

2.3. Data description and collection

In this study, we collected a detailed and homogeneous dataset of 877 buildings affected by the floods that occurred in Almoradí's municipality in September 2019, which comprises the following micro-scale data:

- Hazard characterization, using flood depth at the building location as the only hazard variable.
- Building exposure data, including location, size, typology, and perimeter of affected buildings.
- Building resistance data, such as number of floors, presence of basements, quality and constructive characteristics of the building and its structure, level of maintenance, age...
- Reported losses in terms of type, grade, and extension of damage, as well as the percentage of the total damage (relative damage) of the asset and the replacement and reconstruction costs in monetary terms (absolute damage).

Most of the information recorded was collected from field surveys carried out by expert surveyors from the IVE (Valencia Institute of Building) as a response to the flood management protocol listed in the flood damage evaluation section from PTEC [32], which contemplates building inspection services to estimate the corresponding compensations for flood affected property owners who officially requested them.

For that purpose, a datasheet elaborated by the IVE was used to collect most of all the required information in terms of hazard, building exposure, and resistance parameters, along with type, grade, and extension of reported damage for every sample building, supported by graphic materials (drawings and pictures). The datasheet model in Fig. 18 is shown in the Appendix.

Complementary, other parameters such as building age, area, perimeter, and finishing level of construction were extracted from Spanish cadastral maps and databases. Finally, reconstruction and restoration costs per EURO/m² were obtained from the IVE database to convert relative damage percentages into absolute damage values in EURO. All microscale parameters considered in this study, their codification, a brief description, the source where they were obtained, and the year when these data were available are described in Table 3.




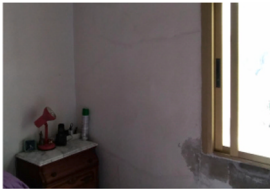



Table 3
Microscale data analyzed in the present study.

Type of variable	Data	Code	Description	Source & Year
Exposure	Area (m ²)	EA	Footprint area of the building	SEC*, 2019
	Basement	EB	Presence and number of underground floors	Field survey, 2019
	Building use	EU	Residential, mixed (residential plus others), storage, parking, commercial, office, healthcare, or others	SEC* & field survey, 2019
	Building type	ET	Apartment, detached, semi-detached or terraced building	Field survey, 2019
	Fencing (m)	EF	Presence and total length of fence walls to enclose outdoor spaces	Field survey, 2019
	Floors	EFL	Number of floors	Field survey, 2019
	Lot area (m ²)	EL	Total area of the property	SEC*, 2019
	Perimeter (m)	EP	Total length around the building enclosure	SEC*, 2019
	Place of residence	ER	Principal or secondary	Field survey, 2019
	Resistance	Building age	RA	Year when the building was built
Building quality		RQ	Low, medium, or high, according to the cadastral database	SEC* & field survey, 2019
Building structure		RBS	Type of vertical structure (load-bearing walls or structural frames) and horizontal structure (beams and joists or two-way slabs)	Field survey, 2019
Level of maintenance		RM	State of building maintenance before the event (Bad, medium, good)	Field survey, 2019
Non-structural materials		RNM	Materials used for non-structural elements in the building (roofs, non-structural walls, openings, floor and ceiling coverings)	Field survey, 2019
Hazard Damage	Structural materials	RSM	Materials used for vertical and horizontal structures	Field survey, 2019
	Flood level (cm)	HL	Flood depth in the building location	Field survey, 2019
	Accessibility	DA	Accessibility conditions assigned to the building after the event (allowed, restricted, and not allowed)	Field survey, 2019
	Preventive interventions	DP	Immediate measures determined by inspectors in field surveys to keep building safety (cordoning off, scaffolding, safety netting, and canopies, cutting off water, power or gas supply, demolishing parts or the entire building)	Field survey, 2019
	Rooms affected	DR	Number and type of rooms affected (living/dining room, kitchen, bedroom, bathroom, corridor and storage room)	Field survey, 2019
	Type, grade, and extension of damage	DD	Type of flood damage, grade (low, moderate, high), and extension of element affected (<25%, 26–50%, 51–75%, >76%)	Field survey, 2019
	Relative damage to buildings	DRD	Percentage of the entire building affected	IVE's method, 2019
	Absolute damage to buildings (EURO)	DAD	Reconstruction value of building resulting from multiplying DRD by the market value of new building construction depending on building type, quality, and location.	IVE's method and construction prices dataset, 2019

* Spanish Cadastral Electronic Site (maps and dataset).





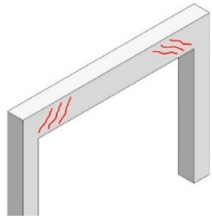
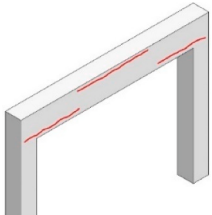
Table 4

Structural damage of the surveyed buildings: type of damage, cause, source, key parameters, and damage level.

Structural Damage		
Type of damage, cause, source, key parameters, and damage level		Illustration of damage
<p>Vertical structural system (pillars, walls, and foundations) (P)</p> <p>Dirt pulling away from foundations (P1)</p> <p><u>Cause:</u> Erosion beneath foundations</p> <p><u>Source:</u> Underground flood water</p>	<p><u>Key parameters:</u> Flow velocity</p> <p><u>Damage level:</u> High</p>	
<p>Collapse or overturning (P2)</p> <p><u>Cause:</u> Lateral pressures</p> <p><u>Source:</u> Flood water</p>	<p><u>Key parameters:</u> Flood water depth Flow velocity Large items of floating debris</p> <p><u>Damage level:</u> High</p>	
<p>Diagonal cracks (P3)</p> <p><u>Cause:</u> Lateral pressures Water accumulation on the upper slab</p> <p><u>Source:</u> Flood water</p>	<p><u>Key parameters:</u> Flood water depth Flow velocity Large items of floating debris</p> <p><u>Damage level:</u> High</p>	
<p>Horizontal cracks - Fine surface cracks (P4)</p> <p><u>Cause:</u> Lateral pressures Water accumulation on the upper slab</p> <p><u>Source:</u> Flood water</p>	<p><u>Key parameters:</u> Flood water depth Flow velocity Large items of floating debris</p> <p><u>Damage level:</u> High</p>	
<p>Horizontal cracks - Wide throughout single crack (P5)</p> <p><u>Cause:</u> Settlements caused by erosion beneath foundations or soil moisture level change</p> <p><u>Source:</u> Underground flood water</p>	<p><u>Key parameters:</u> Flow velocity Flood duration</p> <p><u>Damage level:</u> High</p>	
<p>Vertical cracks (P6)</p> <p><u>Cause:</u> Increments of gravitational loads due to water accumulation on the upper slab</p> <p><u>Source:</u> Rainfall on upper floors or roofs Flood water on lower floors</p>	<p><u>Key parameters:</u> Intensity and duration of rainfall on upper floors Floodwater depth on lower floors</p> <p><u>Damage level:</u> High</p>	
<p>Horizontal continuous damp patches - Rising from lower parts (P7)</p> <p><u>Cause:</u> Elements soak up water from flooded floors through contact surfaces</p> <p><u>Source:</u> Flood water</p>	<p><u>Key parameters:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> Low</p>	

(continued on next page)

Table 4 (continued)

Structural Damage	Type of damage, cause, source, key parameters, and damage level	Illustration of damage
Horizontal continuous damp patches - Falling from upper parts (P8)	<p><u>Cause:</u> Elements soak up water from upper flooded floors</p> <p><u>Source:</u> Rainwater on upper floors or roofs Flood water on lower floors</p> <p><u>Key parameters for upper floors:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Key parameters for lower floors:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> Low</p>	
Small single damp patches (P9)	<p><u>Cause:</u> Drainpipe leaks due to local overflows Failure of roof waterproofing</p> <p><u>Source:</u> Rainwater</p> <p><u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Damage level:</u> Moderate</p>	
Horizontal structural system (beams, slabs, and beams filling) (V) Bending or vertical deformations (V1)	<p><u>Cause:</u> Excessive load by water accumulation</p> <p><u>Source:</u> Rainwater on upper floors or roofs</p> <p><u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Source:</u> Flood water on lower floors</p> <p><u>Key parameters:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> Moderate</p>	
Collapse (V2)*	<p><u>Cause:</u> Excessive load by water accumulation</p> <p><u>Source:</u> Rainwater on upper floors or roofs</p> <p><u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Source:</u> Flood water on lower floors</p> <p><u>Key parameters:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> High</p>	
Diagonal cracks (V3)	<p><u>Cause:</u> Excessive load by water accumulation</p> <p><u>Source:</u> Rainwater on upper floors or roofs</p> <p><u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Source:</u> Uplift water pressure from completed flooded lower floors</p> <p><u>Key parameters:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> High</p>	
Longitudinal cracks (V4)	<p><u>Cause:</u> Excessive load by water accumulation</p> <p><u>Source:</u> Rainwater on upper floors or roofs</p> <p><u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Source:</u> Uplift water pressure from completed flooded lower floors</p> <p><u>Key parameters:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> High</p>	

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Table 4 (continued)




Structural Damage		Illustration of damage
Type of damage, cause, source, key parameters, and damage level		
Transversal cracks (V5)		
<u>Cause:</u> Excessive load by water accumulation	<u>Source:</u> Uplift water pressure from completed flooded lower floors	
<u>Source:</u> Rainwater on upper floors or roofs	<u>Key parameters:</u> Flood water depth Flood duration	
<u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)	<u>Damage level:</u> High	
Extensive dampness on the lower part of the element (V6)		
<u>Cause:</u> Elements soak up water from upper flooded floors	<u>Source:</u> Flood water on upper floors	
<u>Source:</u> Rainwater on upper floors or roofs	<u>Key parameters:</u> Flood water depth Flood duration	
<u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)	<u>Damage level:</u> Low	
Small single damp patches on the lower part of the element (V7)		
<u>Cause:</u> Drainpipe leaks due to local overflows Failure of roof waterproofing	<u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)	
<u>Source:</u> Rainwater	<u>Damage level:</u> Low	

Image credits: Valencia Institute of Building (IVE)

* That damage can occur due to downward water pressures when accumulated water is over the slab or upward pressures when underground flood water can exert upward pressures on the first floor or foundation slabs.

2.4. Damage assessment

2.4.1. Classification of observed damage

Flood damage in buildings was gathered in different field surveys, sorting all types of damage into six groups according to the main elements of buildings: vertical and horizontal structural systems (P and V), roofs (C), openings (H), floor and ceiling coverings (R) and non-structural walls (I). Moreover, a grade was assigned to each type of damage, sorting them into three different degrees: low, moderate, and high. The first level considered all damages that don't compromise elements' safety, durability, or release to service. Thus, any intervention in the building may be postponed for more than a year. The second grade contemplates damages that may become hazards to others building constructive elements, compromising its security or release to service. Interventions are necessary for the short to mid-term (up to one year). Damages that may be an imminent danger for either residents and other people or adjacent buildings are included in the last degree, being necessarily immediate and urgent interventions, such as evacuating occupants, closing off parts of the building, or carrying out preventative measures. The groups mentioned above were organized based on structural and non-structural damages, or in other words, damages that affect structural and non-structural elements of constructions. Structural damages are subdivided into two groups: vertical systems, specifically pillars, walls, and foundations, and horizontal systems, particularly beams, slabs, and beam fillings. Conversely, non-structural damages are sorted into four groups: roofs, openings, floor and ceiling coverings, and non-structural walls, namely facades, party walls, and partitioning. All types of damage, what can cause them, their source, the main variables that influence their grade and extension level, and pictures and sketches to illustrate them are shown in Table 4 and Table 5.








2.4.2. Relative and absolute damage evaluation

The damage evaluation method used for this study has been developed by the IVE to estimate the economic impact on buildings affected by floods in the Valencian Region [38] required by the flood damage evaluation guidelines established in PTEC [32]. In this method, two outcomes are provided: *i*) the Building Flood Loss (VUP_p) characterized by vulnerability and exposure parameters as well as the extension and grade of damage registered, expressed in relative terms on scale from 0 = no damage to 1 = complete loss, and *ii*) the Building Replacement Value (BRV), which is the result of applying the Market Value (MV) of buildings as a function of the building features to the VUP_p, expressed in monetary terms (EURO).

The VUP_p sums the primary use flood loss of the building (V_m), which can be residential (r), industrial (id), educational (e), and institutional (in), with three other additional uses that commonly complement the first, namely, commercial (V_c), garage (V_g), storage




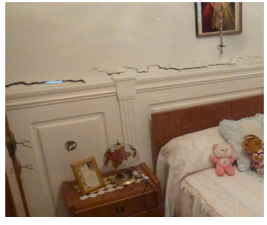



Table 5

Non-structural damage of the surveyed buildings: type of damage, cause, source, key parameters, and level.

Non-structural damage		
Type of damage, cause, source, key parameters, and damage level		Illustration of damage
Roofs (C)		
Missing or broken roof covering elements (C1)		
<u>Cause:</u> Impacts or accumulation of rainwater	<u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)	
<u>Source:</u> Rainwater	<u>Damage level:</u> Moderate	
Roof ageing (C2)		
<u>Cause:</u> Presence of water for long periods	<u>Key parameters:</u> Intensity and duration of rainfall	
<u>Source:</u> Rainwater	Frozen forms of precipitation	
	<u>Damage level:</u> Moderate	
Flooded roof (C3)		
<u>Cause:</u> Obstruction or deterioration of rainwater drainage systems	<u>Key parameters:</u> Intensity and duration of rainfall	
<u>Source:</u> Rainwater	Solid forms of precipitation (hail)	
	<u>Damage level:</u> Moderate	
Openings (H)		
Windows and door frames deterioration (H1)		
<u>Cause:</u> Presence of water for long periods	<u>Key parameters:</u> Flood water depth	
<u>Source:</u> Flood water	Flood duration	
	<u>Damage level:</u> Low	
Windows and door glass missing or breakage (H2)		
<u>Cause:</u> Impacts or accumulation of water	<u>Key parameters:</u> Flood water depth	
<u>Source:</u> Flood water	Flow velocity	
	Large items of floating debris	
	<u>Damage level:</u> Low	
Warped doors, windows and frames (H3)		
<u>Cause:</u> Lateral pressures Excessive deformation on lower slabs due to water accumulation	<u>Key parameters:</u> Flood water depth	
<u>Source:</u> Flood water	Flow velocity	
	Large items of floating debris	
	<u>Damage level:</u> Low	
Floor and ceiling coverings (R)		
Missing or broken covering (R1)		
<u>Cause:</u> Impacts or accumulation of water	<u>Key parameters for floors:</u> Flood water depth	
<u>Source:</u> Flood water for floors Rainwater for ceilings	Flow velocity	
	Large items of floating debris	
	<u>Key parameters for ceilings:</u> Intensity and duration of rainfall	
	Solid forms of precipitation (hail)	
	<u>Damage level:</u> Low	

(continued on next page)

Table 5 (continued)

Non-structural damage	Illustration of damage
Type of damage, cause, source, key parameters, and damage level	Illustration of damage
<p>Deterioration of materials (R2)</p> <p><u>Cause:</u> Presence of water for long periods</p> <p><u>Source:</u> Flood water for lower floors Rainwater for upper floors</p> <p><u>Key parameters:</u> Duration of the presence of water</p> <p><u>Damage level:</u> Low</p>	
<p>Non-structural walls (facades, party walls, and partitioning) (I)</p> <p>Collapse or overturning (I1)</p> <p><u>Cause:</u> Lateral pressures</p> <p><u>Source:</u> Flood water</p> <p><u>Key parameters:</u> Flood water depth Flow velocity Large items of floating debris</p> <p><u>Damage level:</u> High</p>	
<p>Diagonal cracks (I2)</p> <p><u>Cause:</u> Lateral pressures Water accumulation on the upper slab Settlements caused by erosion beneath foundations or soil moisture level change</p> <p><u>Source:</u> Flood water</p> <p><u>Key parameters:</u> Flood water depth Flow velocity Large items of floating debris</p> <p><u>Damage level:</u> Moderate-High</p>	
<p>Horizontal cracks (I3)</p> <p><u>Cause:</u> Lateral pressures Water accumulation on the upper slab Settlements caused by erosion beneath foundations or soil moisture level change</p> <p><u>Source:</u> Flood water</p> <p><u>Key parameters:</u> Flood water depth Flow velocity Large items of floating debris Flood duration</p> <p><u>Damage level:</u> Moderate-High</p>	
<p>Vertical cracks (I4)</p> <p><u>Cause:</u> Increments of gravitational loads due to water accumulation on the upper slab</p> <p><u>Source:</u> Rainfall on upper floors or roofs Flood water on lower floors</p> <p><u>Key parameters:</u> Intensity and duration of rainfall on upper floors or roofs Flood water depth on lower floors</p> <p><u>Damage level:</u> Moderate</p>	
<p>Horizontal continuous damp patches - Rising from lower parts (I5)</p> <p><u>Cause:</u> Elements soak up water from flooded floors through contact surfaces</p> <p><u>Source:</u> Flood water</p> <p><u>Key parameters:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> Low</p>	
<p>Horizontal continuous damp patches - Falling from upper parts (I6)</p> <p><u>Cause:</u> Elements soak up water from upper flooded floors</p> <p><u>Source:</u> Rainwater on upper floors or roofs Flood water on lower floors</p> <p><u>Key parameters for upper floors:</u> Intensity and duration of rainfall Solid forms of precipitation (hail)</p> <p><u>Key parameters for lower floors:</u> Flood water depth Flood duration</p> <p><u>Damage level:</u> Low</p>	

(continued on next page)

Table 5 (continued)




Non-structural damage		Illustration of damage
Type of damage, cause, source, key parameters, and damage level		
Small single damp patches (I7)		
<u>Cause:</u> Drainpipe leaks caused by local overflows Failure of roof waterproofing <u>Source:</u> Rainwater	<u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail) <u>Damage level:</u> Low	
Fall of specific and decorative elements (I8)		
<u>Cause:</u> Impacts or accumulation of water <u>Source:</u> Rainwater Flood water	<u>Key parameters:</u> Intensity and duration of rainfall Solid forms of precipitation (hail) Flood water depth Flow velocity Large items of floating debris <u>Damage level:</u> Low	
Covering deterioration (I9)		
<u>Cause:</u> Presence of water for long periods <u>Source:</u> Flood water	<u>Key parameters:</u> Flood water depth Flood duration <u>Damage level:</u> Low	

Image credits: Valencia Institute of Building (IVE)

(V_s) and communal areas (V_{ca}) in case of multi-residential buildings (Eq. (1)). Commercial use is not considered primary due to the considerable number of surveyed buildings with residential plus commercial uses. For clarification purposes, uses were assigned only to fully enclosed structures. Each use flood loss (V_i) represents the percentage of the building affected for the corresponding use, multiplying the total area (m^2) of the use considered ($S_{v,i}$) by the Final Replacement Coefficient by use ($RF_{V,i}$) (Eq. (2)). This coefficient is obtained by multiplying the Initial Replacement Coefficient by use ($RI_{V,i}$) by three adjustment factors, K_1 , K_2 , and K_3 , which respectively consider the studied building use, area by use, and occupation (inhabited or abandoned) (Eq. (3)). The $RI_{V,i}$ represents the percentage of the building replacement value of each use considering the contributions of every element affected in the building, as shown in (Eq. (4)), where r_j is the Initial Replacement Coefficient of each component affected as the result of multiplying the Damage Coefficient (D), which depends on the grade and extension of damage of each element, by P which is the maximum Percentage of Participation of each element in the total of replacement value and depends on the building type (Eq. (5)).

$$VUP_p = V_m + V_c + V_g + V_s + V_{ca} \quad (1)$$

$$V_i = \frac{RF_{V,i} \times S_{v,i}}{100} \quad (2)$$

$$RF_{V,i} = RI_{V,i} \times K_1 \times K_2 \times K_3 \quad (3)$$

$$RI_{V,i} = \sum_{j=1}^{16} r_j \quad (4)$$

$$r_j = D_j \times P_j \quad (5)$$

where,

i=1 Main use, namely residential, industrial, educational, or institutional

i=2 Commercial use

i=3 Garage use

i=4 Storage use

i=5 Communal areas use

j=1	Foundations	j=7	Exterior doors and windows	j=12	Electrical installation
j=2	Basement walls	j=8	Interior doors and windows	j=13	Water supply installation
j=3	Structure	j=9	Wall coverings	j=14	Water drainage/sewer installation
j=4	Roofs	j=10	Floor coverings	j=15	Gas supply installation and HVAC
j=5	Facades	j=11	Ceiling coverings	j=16	Kitchen equipment
j=6	Partitioning				

Lastly, this reconstruction value of the building (VUP_p) expressed in relative terms is multiplied by the market value of new construction (MV) as a function of building type and quality, extracted from the IVE’s costs database, to obtain the Building Replacement Value (BRV), expressed in monetary terms (EURO) (Eq. (6)).

$$BRV = VUP_p \times MV \tag{6}$$

3. Results and discussion

3.1. Exploratory data analysis

Building exposure, resistance data, flood depth at the building location, and flood damage were acquired in field surveys after the 2019 floods in the study area. Despite the fact that 877 buildings were surveyed, 99 files were considered unrepresentative for this study after pre-processing due to incomplete information in their files, leaving a final sample of 778 cases distributed in the four areas of study as follows: 151 (19.4%) in Area 1, 58 (7.6%) in Area 2, 424 (54.5%) in Area 3 and 145 (18.5%) in Area 4. The location of the surveyed buildings in the study area is mapped in Fig. 4; note that only areas 1, 2, and 3 were plotted to map all data collected, omitting area 4 to get an easier viewing and a better comprehension of the maps because of area 4 vastness with few surveyed buildings.

With the aim of identifying representative archetypes from the study area according to their flood exposure and resistance characteristics, we analyzed all the parameters considered in this work, whose results are summarized in Table 9 in the Appendix.



Fig. 4. Percentages of all surveyed buildings according to each area and their location registered in areas 1, 2, and 3. Data was collected from IVE’s database.

3.2. Building exposure data analysis

The flood exposure of sample buildings was studied based on different indicators, namely building use (EU) and type (ET), place of residence (ER), area (EA) and perimeter (EP) of the building, lot area (EL), presence and length of fencing (EF), number of floors (EFL) and presence of basement (EB).

Although all building uses were inspected within the whole municipality, results showed the vast majority of properties were residential single-family (84.45%), specifically, semi-detached (39.0%) and terraced houses (21.5%). Most of these constructions (97%) have one or two floors (around 46% and 50%, respectively) and no basement (more than 93%). Furthermore, 81% of these single-family houses are the principal household of the property's owners. Although average building areas for single-storey semi-detached and terraced houses are comparable (130.2 m² and 137.9 m²), the maximum-minimum ranges are significantly wider (306 m²-34 m² and 350 m²-46 m²), the same as for two-storey houses although with larger area records (semi-detached: 174.3 m², 594 m²-52 m²; terraced: 175.7 m², 489 m²-77 m²). Conversely, the perimeter of double-storey houses are almost identical (semi-detached: 74.8 m-23.7 m, 40 m; terraced: 62.9 m-27.2 m, 40 m), but shorter than single-storey properties (semi-detached: 87.2 m-23.8 m, 47.7 m; terraced: 100.4 m-27.1 m, 49.3 m). Lot area is the parameter with the most dispersed results with significant differences between maximum, minimum, and average values in single-storey houses (semi-detached: 7324 m²-34 m², 322.4 m²; terraced: 3519 m²-52 m², 485.7 m²) and in two-storey buildings (semi-detached: 3867 m²-31 m², 204.7 m²; terraced: 12223 m²-41 m², 599.8 m²). Finally, the vast majority of semi-detached and terraced houses are not fenced (86.5% and 74.3%, respectively).

In a more detailed analysis of the four areas considered, we highlighted all data significantly distant from the municipality results and those especially helpful in the exposure characterization of the surveyed buildings. The average values of the building and lot areas and perimeter and fencing lengths of the most predominant building types in each area are provided in Table 6. It is important to underline the significant differences between the maximum, minimum, and average values of the mentioned parameters, which, although not mentioned in this section, are shown in Table 9 in the Appendix.

Like in the municipality, the most preponderant building use in all areas is residential, specifically single-family houses (more than 80%). However, in area 1, not only does this parameter reach its peak (92%), but also the building types semi-detached (62.1%) and terraced (27.9%) houses, which mainly are the principal place of residence (more than 75%). Most of them are double-storey (62% and 74.4%) and single-storey (38% and 23.1%) constructions with no basement (more than 97%) and no fencing (more than 85%).

Area 2 displays the higher percentage of semi-detached properties (58.3%) along with the lower of terraced (18.8%); also, these buildings are prevalingly one-level (60.7% and 88.9%) and two-level (39.3% and 11.1%) households. More than 85% and 77% of the semi-detached and terraced buildings have no basements and are principal residences. Non-fenced properties are widespread in this area (around 90%).

Area 3 outcomes are similar to the municipality's, mainly due to its extensive building sample (54.5% of all surveyed buildings). In this area, semi-detached houses are the commonest single-family property type (46.7%), followed by terraced houses (26.2%). However, the percentage of principal residences is lower in the first group (78.4%) than in the second (92.3%). Single and double-storey properties share similar ratios (around 46%). Furthermore, most single-family homes do not have a basement (approximately 90%). Lastly, this area has the highest percentage of terraced houses fenced (34.1%), with results of semi-detached comparable to the municipality (13.6%).

Area 4 records reveal a study area with different flood exposure characteristics. In this case, the single-family building type more predominant is detached houses (55.7%), splitting the rest with semi-detached (21.3%) and terraced houses (23%). The vast majority of detached houses are single-storey properties (80.9%), followed by the other two (more than 60% both). Regarding the place of

Table 6
Exposure results of the most representative single-family properties by area and municipality.

	Area (EA) - m ²		Lot area (EL) - m ²		Perimeter (EP) - m		Fencing (EF) - m	
	1 Storey	2 Storeys	1 Storey	2 Storeys	1 Storey	2 Storeys	1 Storey	2 Storeys
Area 1 (A1)								
Semi-detached	120.2	154.9	287.3	136.9	45.1	38.2	121.0*	16.8
Terraced	131.8	153.6	132.3	102.8	48.2	37.4	-	16.6*
Area 2 (A2)								
Semi-detached	187.2	227.7	633.6	184.1	58.6	46.7	12.1*	-
Terraced	145.5	180.0	172.3	180.0	49.2	43.8	27.0*	-
Area 3 (A3)								
Semi-detached	121.2	184.1	213.1	260.8	45.7	40.5	26.7*	29.6
Terraced	137.3	185.0	575.5	1012.8	49.5	41.1	92.9*	61.9
Area 4 (A4)								
Detached	199.8	210.9	3993.1	3771.2	59.9	45.6	293.5	168.4*
Semi-detached	132.9	145.1	583.5	167.2	51.2	39.5	10.9*	-
Terraced	138.9	200.1	587.4	182.7	49.3	42.6	106.7*	34.7*
Municipality								
Semi-detached	130.2	174.3	322.4	204.7	47.7	40.0	25.6	23.7
Terraced	137.9	175.7	485.7	599.8	49.3	40.0	91.8	54.3
Detached	205.6	210.9	3440.2	2848.6	61.5	44.0	257.0	149.5

residence, the first type has the lowest ratio of principal residences (50%); meanwhile, the other two have similar results to other areas (around 75%). Almost all houses in this area (more than 94%) have no basement. As a final parameter, detached houses are the building type more commonly fenced (42.7%); conversely, semi-detached and terraced-houses results are lower but still comparable with municipality data (19.2% and 25%).

3.3. Building resistance data analysis

After characterizing the most common flood exposure features of the sample buildings, in this section, we study the flood resistance or vulnerability of these constructions considering parameters such as building age (RA) and quality (RQ), level of maintenance (RM), type of structure (RBS), and structural (RSM) and non-structural materials (RNM) of the inspected buildings. Some considerations are used to evaluate these parameters: first, the building age of the surveyed buildings is sorted into three periods based on the historical evolution of construction in the Valencian region, especially in terms of materials and technologies: up to 1960, 1961–1994, and from 1995 to the present. Second, we considered the level of maintenance of a building as its state of conservation before the event, and we sorted it into three levels: good, minor, or no maintenance work is required; medium, some maintenance works are necessary to improve the building flood response with no building failure risk; and bad, maintenance works are essential for the integrity and flood response of the building. Last and because of the first consideration, the study of constructive characteristics of the buildings (RBS, RSM, and RNM) is based on the building age.

The majority of single-family residences in the municipality were built before 1960 (50.7%) and after 1995 (almost 30%), mostly with high (50.8%) and medium (30.9%) construction qualities and with a good level of maintenance (78.5%). Almost all buildings' foundations (95.6%) are shallow, mainly wall, isolated, combined, and strap footings. However, the vertical structure changes with the building age, so the newer the building is, the lower the percentage of load-bearing walls (55.9% \leq 1960, 26.4% 1961–1994, and 12.0% \geq 1995) and higher of structural frame systems (33.9%, 60.0%, 82.6%). More than 98% of the load-bearing walls use different masonry systems depending on the materials used; the most common are random rubble, rammed earth, brick masonry for buildings built up to 1960, concrete block masonries for newer buildings (Fig. 5), and reinforced concrete (more than 95% of buildings) for structural frames.

The horizontal structures of almost all constructions analyzed are one-way floors (more than 96%), with two predominant types. On the one hand, for older buildings mainly built before 1960 and some between 1961 and 1994, timber beams or trusses and joists with round (trunks) or rectangular (sawn timber) cross sections using two different lightweight solutions, masonry vaults and timber deck, commonly with poor-quality materials. On the other hand, reinforced concrete elements with ceramic or concrete vaults and a 2–5 cm thick concrete compression layer using materials of medium to excellent quality for newer constructions (\geq 1961) (Fig. 6).

With reference to the materials used in non-structural elements of the buildings considered, three types of roofs were identified: inaccessible sloped roofs with ceramic shingles and a reed and plaster deck called in Spanish "cañizo", accessible flat roofs using ceramic tiles and their combination in different parts of the same building (Fig. 6). Although the first one is the most prevailing in all age periods, a noticeable gradual drop from old to new constructions with exclusively sloped roofs is noticeable (from 73.6% to 56%).

The most common covering for facades is exterior cement plaster or stucco and its combination with other materials (around 80%), which are mainly applied on the base of the exterior layer of the wall, such as stone, ceramic cladding, and concrete. Wood, aluminum, and their combination are the most popular materials for exterior doors and windows, although their application tendencies are opposite; the presence of wood frameworks is significant for older buildings (57.5% for \leq 1960 and 43.9% for 1961–1994), but very unusual for newer buildings (17.4%); on the other hand, aluminum grows from 59.7% for \leq 1960 to 89.5% for \geq 1995.

The largest number of buildings use brick partitioning to subdivide interior spaces, mainly with plaster plus paint (more than 95% for all periods) and tiling (around 70%) as covering solutions. Interior doors and windows are essentially made of wood (between 97.5% and 92%).

Lastly, ceramic tiles are the most popular flooring material in all single-family building ages (more than 93%), along with plaster ceilings that are recurrently widespread (more than 62%), plus more than 20% of cases combined with ceiling tiles.

Resistance results by area show area 4 with a considerable proportion of oldest single-family houses (60.7%) as well as a very low fraction of modern constructions (19.7%), and the highest part of low-quality buildings (32%) and the bottommost fraction of high-



Fig. 5. a) Rubble masonry fabric, b) Brick masonry fabric, c) Concrete block masonry fabric (Image credits: Valencia Institute of Building, IVE).



Fig. 6. a) Timber roof truss with "cañizo", b) Slab made of reinforced concrete frames with ceramic vaults, c) Sloping roof with ceramic shingles, d) Flat roof with ceramic tiles (Image credits: Valencia Institute of Building, IVE).

quality (35.3%). Furthermore, the building maintenance condition is the worst recorded, with the highest bad-maintenance ratio (16.4%) and the minimum with good level (67.2%).

Area 1 shows comparable results to area 4, with the highest part of the oldest properties (67.1%) and the lowest of the newest constructions (12.9%). However, this area has better construction quality and maintenance level results, with 50% of high-quality constructions, 80.7% with optimal maintenance conditions, and only 15.7% of low-quality and 7.1% badly maintained buildings.

Conversely, area 3 presents the lowest percentage of properties built before 1960 (40.4%), the highest built after 1995 (37.8%), with the maximum concentration of high-quality buildings (56.5%) and well maintained (81.6%), together with the smallest proportion of low-quality (14.1%) and poorly maintained (6.6%) buildings.

Finally, area 2 poses similar data with the municipality regarding building age (52.1%, 25%, and 22.9%), quality (52.1%, 27.1%, and 20.8%), and only well-maintained properties (79.2%) since poorly-maintained fraction is half (4.2%).

This detailed analysis shows no remarkable differences with the municipality findings in terms of structural and non-structural materials and the building's structure. However, area 4 has a remarkably higher percentage of load-bearing walls for all periods (70.3%, 58.3%, and 54.2%).

3.4. Archetype characterization according to exposure and resistance parameters

In this section, we propose three different archetypes based on the most common exposure and resistance parameters previously analyzed for the whole municipality and the proposed four study areas. Subsequently, we will analyze the damage recorded on them to identify patterns and relationships between these parameters and the observed damage. These archetypes and all data are shown in Table 9 of the Appendix.

We want to highlight the considerable flood vulnerability and risk level of the single-storey with inaccessible sloped roofs versions of the archetypes presented due to the lack of safe places within the building in case of high flood levels.

3.5. Hazard data analysis

Flood hazard characterization of the study area is imperative to correlate observed damage with building exposure and resistance characteristics. The present study uses the flood depth at the building location as the only explicative flood variable due to the impossibility of collecting other hazard parameter data such as flow velocity, flood duration, and water contamination. However, flood depth is the most used flood parameter to describe flood magnitude and to estimate building vulnerability and damage [28,51,56,87].

The floodwater depth registered was sorted in a four-range classification, ≤ 15 cm, 16–45 cm, 46–79 cm, and ≥ 80 cm, which is based on the values indicated in PATRICOVA [31], empirical data from this and other historical flood events in this region, and the local experience. According to the municipality data collected, there are no substantial differences in range occurrences, so around 60% of water depths are comprehended in the two most recurrent ranges (32.7% for 46–79 cm and 29.7% for 16–45 cm) and almost the 40% remaining in the other two (18.0% for ≤ 15 cm and 19.6% for ≥ 80 cm). This distribution is nearly the same for semi-detached and terraced single-family houses, with slight differences in detached properties, which present more recurrent higher flood levels (26.1%). Single-family properties show an average flood level of 51.4 cm with no substantial differences in comparison to semi-detached (47.3 cm), terraced (52.3 cm), and detached (61.7 cm) houses. They all reported 0 cm as the minimum water depth and the maximum between 200 and 250 cm.

Regarding areas, each one shows noteworthy differences in distributions of flood depths registered in single-family houses

compared to the municipality, which is even more evident when results are sorted by building types (Fig. 9). Notwithstanding, no distinguished differences were recorded between single- and double-storey versions of any of these building types.

In terms of absolute values, maximum and minimum water depths in areas are comparable to the municipality, along with the single-family average flood level, which goes from 42.6 cm to 68.4 cm. Greater average variations appear when comparing building type values between areas and the municipality (Fig. 8). Minimum, maximum, and average depth water values for the proposed archetypes are shown in Table 9 in the Appendix.

3.6. Observed damage records

During the field survey, inspectors not only recorded the type, extension, and grade of damage, but they also determined the requirement of immediate preventive measures, reported the number and type of rooms affected, and assigned the accessibility condition to buildings through three levels: allowed, restricted, and not allowed, depending on if the building is safe, poses a threat to the residents, or exists a high risk of partial or total collapse. The buildings allowed accessibility condition is comparable for semi-detached houses in all areas and municipality (around 80%). Despite terraced houses sharing this ratio, areas 2 and 4 present the lowest fractions (44.4% and 64.3%). In terms of detached properties, the concentration of safe buildings is lower in area 4 (66.2%) than in the municipality (77.3%).

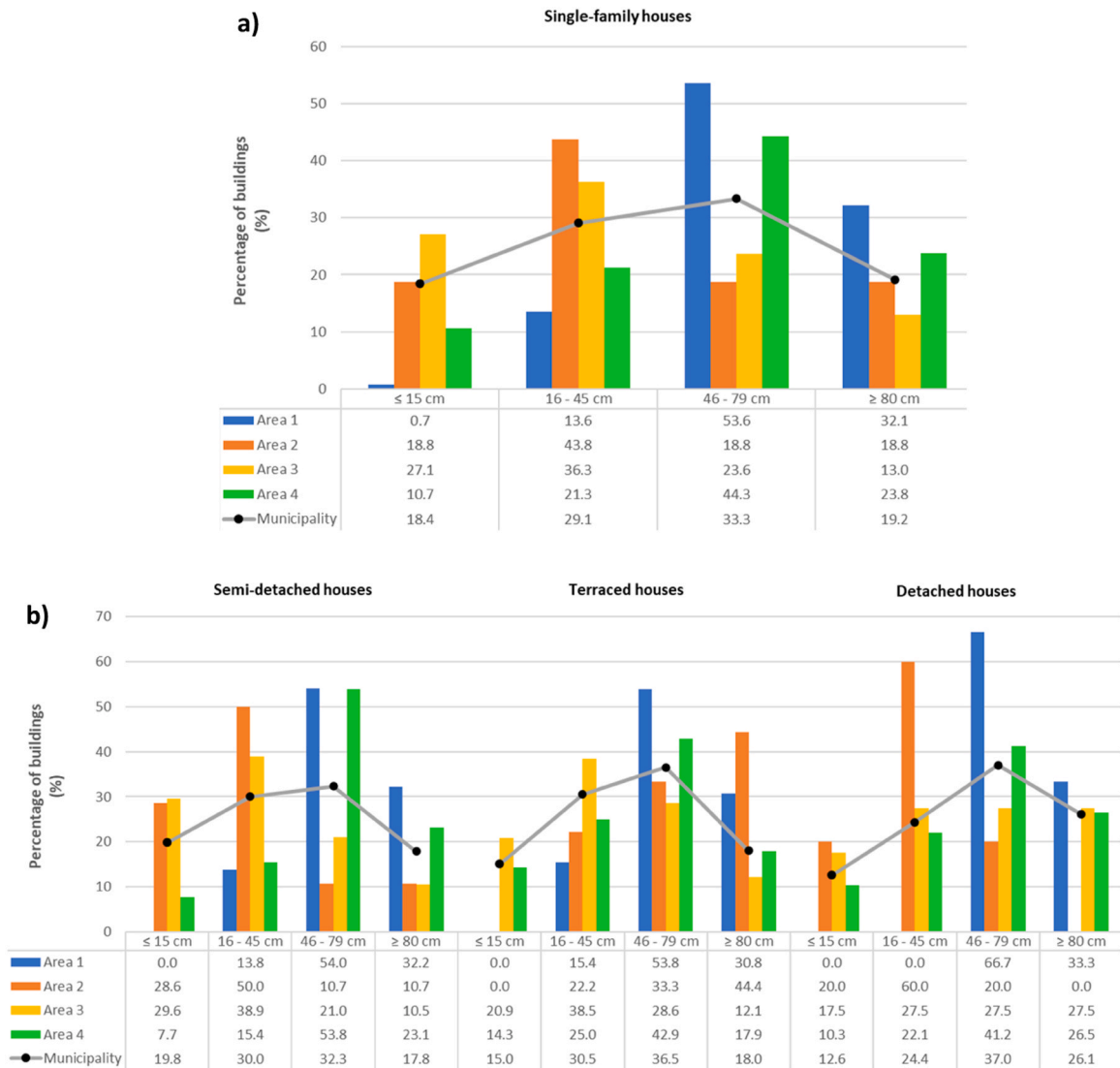


Fig. 7. a) Distribution of flood water depth registered in the residential single-family buildings of the municipality and areas 1, 2, 3 and 4. b) Distribution of flood water depth registered in the most common building types surveyed (semi-detached, terraced and detached houses respectively) of the municipality and areas 1, 2, 3 and 4. Data was collected from IVE’s database.

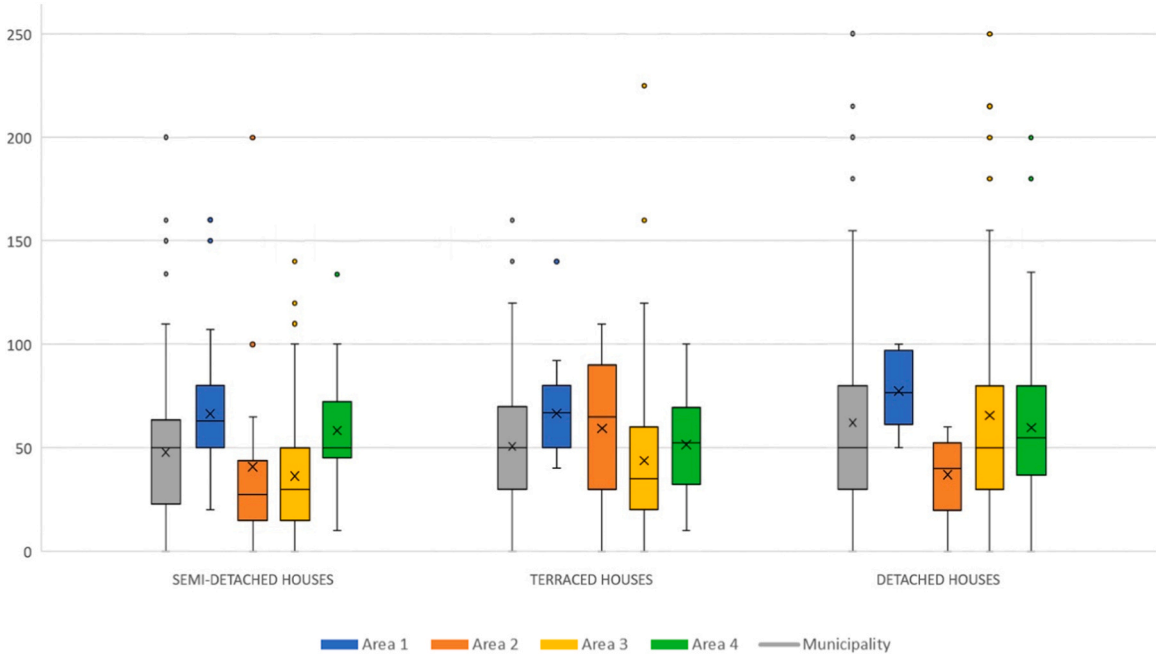


Fig. 8. Data distribution of flood water depth registered in the surveyed semi-detached, terraced and detached houses for the municipality and areas 1, 2, 3 and 4. Data was collected from IVE’s database.

Almost none of the surveyed single-family residences needed preventive measures (around 90%); however, terraced houses required the highest proportion of cordoning off (more than 14% in the municipality and around 25% in areas 2 and 4) and demolishing parts or the entire construction (more than 14%, 33.3% and 25%, respectively).

The rooms of sample buildings were sorted into six groups: living/dining, kitchen, bathroom, bedroom, corridor, and storage. The majority of all single-family properties in the municipality and the four areas (around 70%) resulted in widespread damage, reporting more than half of the rooms damaged, and in approximately 40% of the cases, the whole building was affected. The most recurrent rooms registered were living/dining rooms and kitchens in circa 75% of inspected semi-detached and terraced houses and 66% of attached residences.

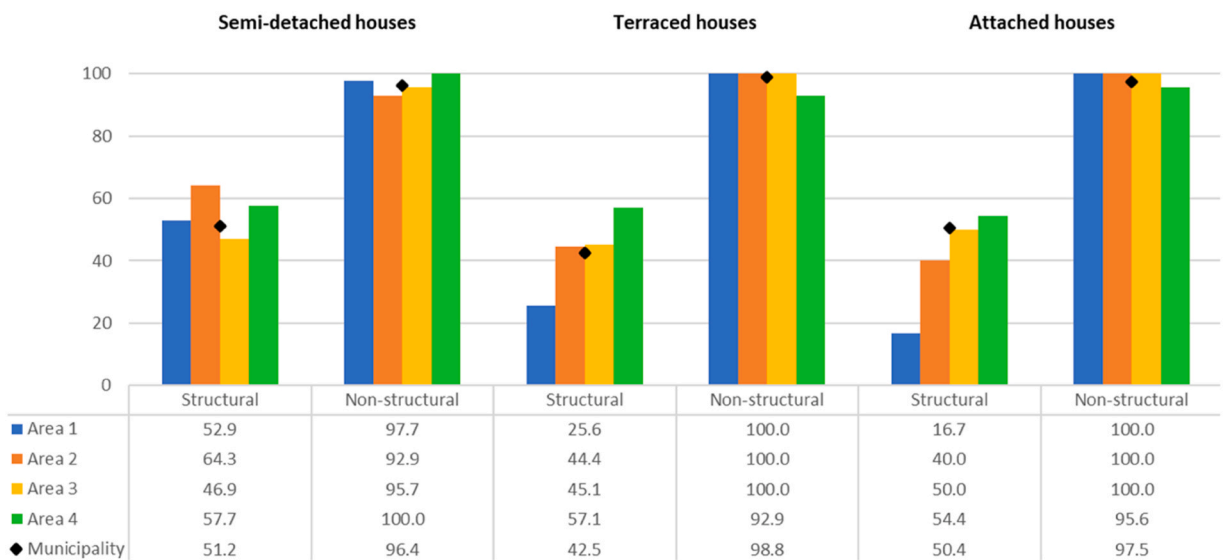


Fig. 9. Distribution of residential single-family buildings affected by structural and non-structural damages in the municipality and areas 1, 2, 3 and 4.

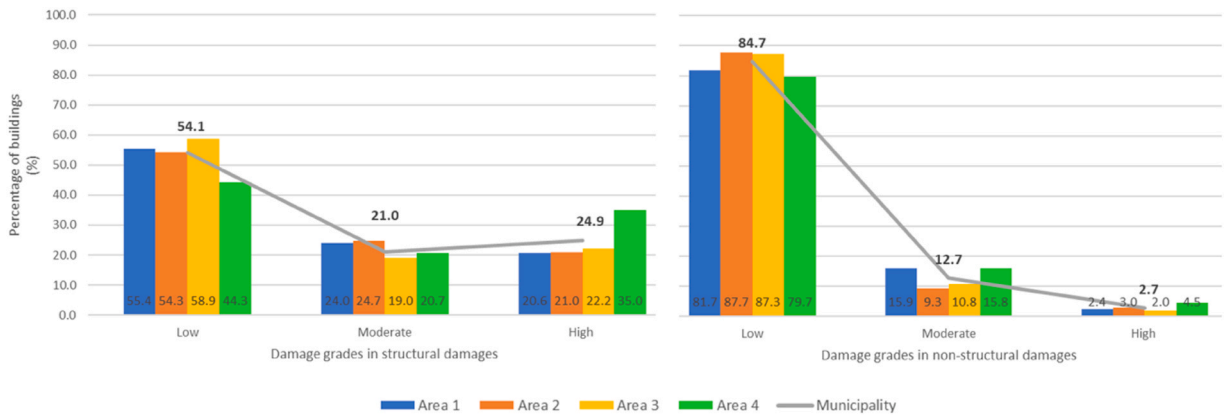


Fig. 10. Grade damage of the structural and non-structural damages registered in single-family residences for the whole municipality and the four areas.

3.6.1. Qualitative damage assessment

A three-step classification of types and grades was done to identify and characterize flood damage in the analyzed sample. Firstly, all data are sorted into two general groups (structural and non-structural damages); secondly, the corresponding subgroups (vertical and horizontal structural systems, and roofs, openings, coverings, and non-structural walls, respectively); lastly, under the specific 33 types of flood damages. Additionally, results are organized according to the whole municipality of Almoradí, the four study areas delimited, and based on the three archetypes previously explained.

Almost all single-family residence types were affected by at least one non-structural damage in the municipality (more than 96%), with no significant differences in areas (less than 4%). On the other hand, around half of them suffered some structural affection, except for the ratio of terraced houses, which falls to 42.5% for the municipality. Although area results for semi-detached houses are close to the municipality, area 2 registered the highest structural damage incidence (64.3%). Conversely, terraced houses from areas 1 and 4 present the maximum difference (more than 15%) compared to the municipal data. Finally, area 4 detached houses, the only ones considered in archetype 3, present data comparable to the average. (Fig. 9).

By analyzing the grade of these damages, in all single-family types of residence, low-grade damages are the most common in both cases (84.7% and 54.1%, respectively), although with an appreciable difference of more than 30% caused by the higher occurrence of moderate and high-grade damages in structural affections. Comparing areas, A4 presents the highest number of high-grade and moderate structural damages (35% and 20.7%) and high-grade (4.5%) non-structural damages (Fig. 10).

Non-structural walls (I) with 88.3%, floor and ceiling coverings (R) with nearly 75%, and openings (H) with more than 70% were the parts of buildings more widely damaged for all single-family residences; conversely, vertical structural systems (P) and roofs (C) with less than 25% were the most unusual building components affected (Fig. 11).

The most common structural damage types in each group are P7 - Horizontal continuous damp patches rising from lower parts and V6 - Extensive dampness on the lower part of the element, but with a significant difference in occurrence, so the first one affects less than 15% of the surveyed buildings and the other more than 45%. Nevertheless, in most cases, the grade of these damages is low (76.8% in P7 and 95.5% in V6). On the other hand, high-grade damages are widespread in damage types with the lowest incidences; for instance, collapse (P2 and V2) and diagonal cracks (P3 and V3) in vertical and horizontal structural elements affected less than 3% of properties, but more than three-quarters of these damages are high-grade (Fig. 12). As can be observed in Fig. 13, the most prevalent non-structural types of damage are I5 - Horizontal continuous damp patches rising from lower parts in non-structural walls, with 79.3% of cases documented, R2 - Deterioration of floor and ceiling coverings (65.2%) and H1 - Deterioration of windows and doors frames (63.8%). However, the most dangerous damages are C1 - Missing or broken roof coverings, with nearly 90% of cases classified as moderate and high-grade, I4 - Vertical cracks in non-structural walls (more than 75%), and C3 - Flooded roofs (practically 70%).

Finally, buildings affected by rain-related damages were nearly a third of surveyed buildings (32.8%), almost all by flood-related damages (93.8%) and by the combination of both (89.5%). Rain-related damages with the greatest occurrence were I7 - Small single damp patches in non-structural walls and C2 - Roof aging (13%); the flood-related damages were I5 - Horizontal continuous damp patches rising from lower parts in non-structural walls (79.3%) and H1 - Deterioration of windows and doors frames (63.8%), and the combination of both were R2 - Deterioration of floor and ceiling coverings (65.2%) and V6 - Extensive dampness on the lower part of

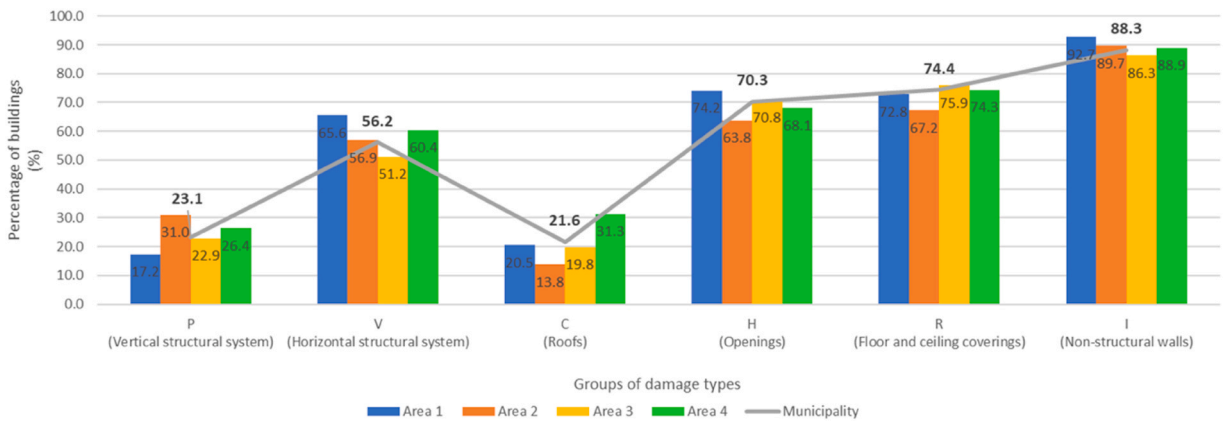


Fig. 11. Percentage of single-family properties affected by groups of damage types in the whole municipality and the four areas.

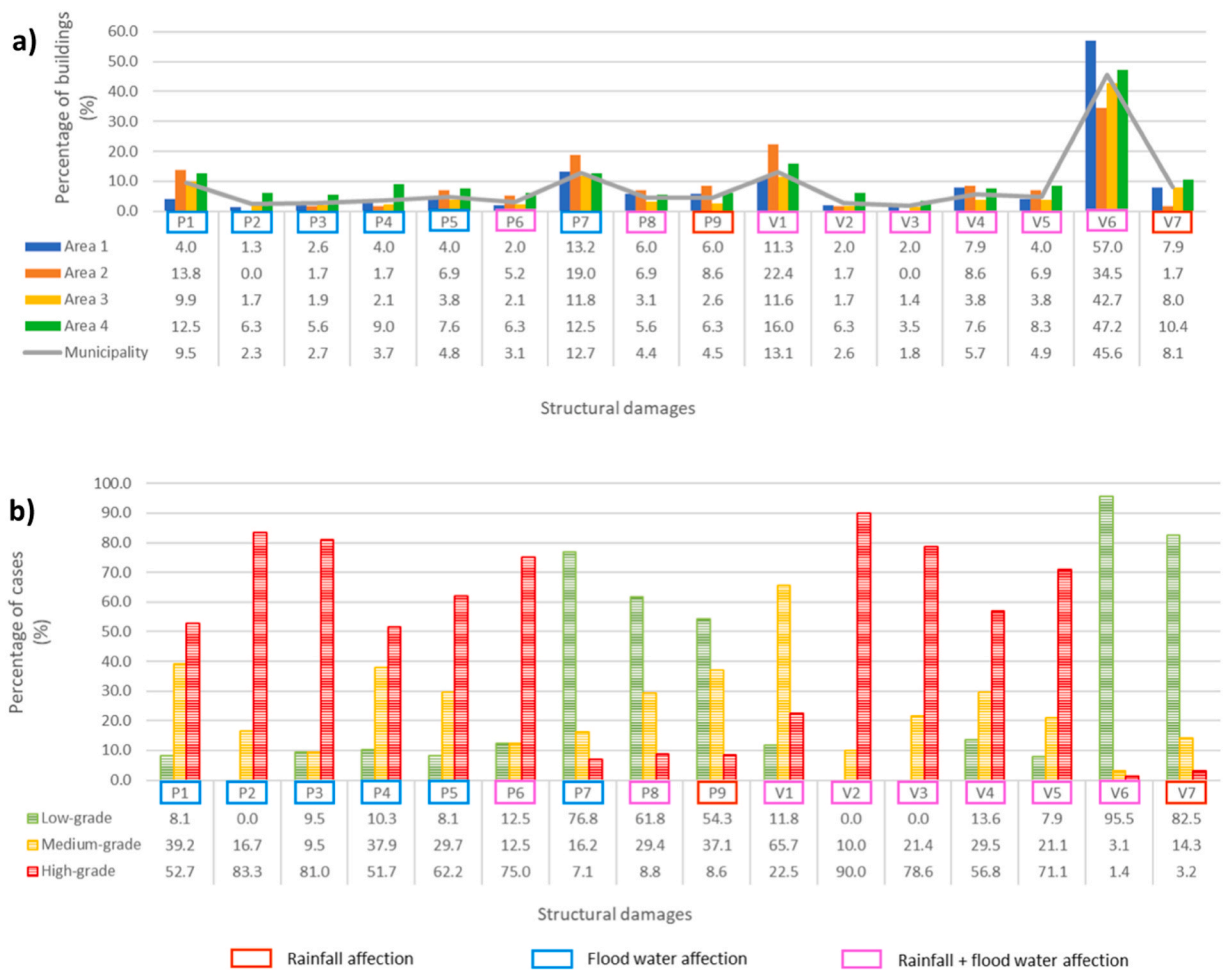


Fig. 12. a) Percentage of single-family properties affected by each type of structural damage, b) Percentage of low, medium, and high-grade damages by each type of structural damage.

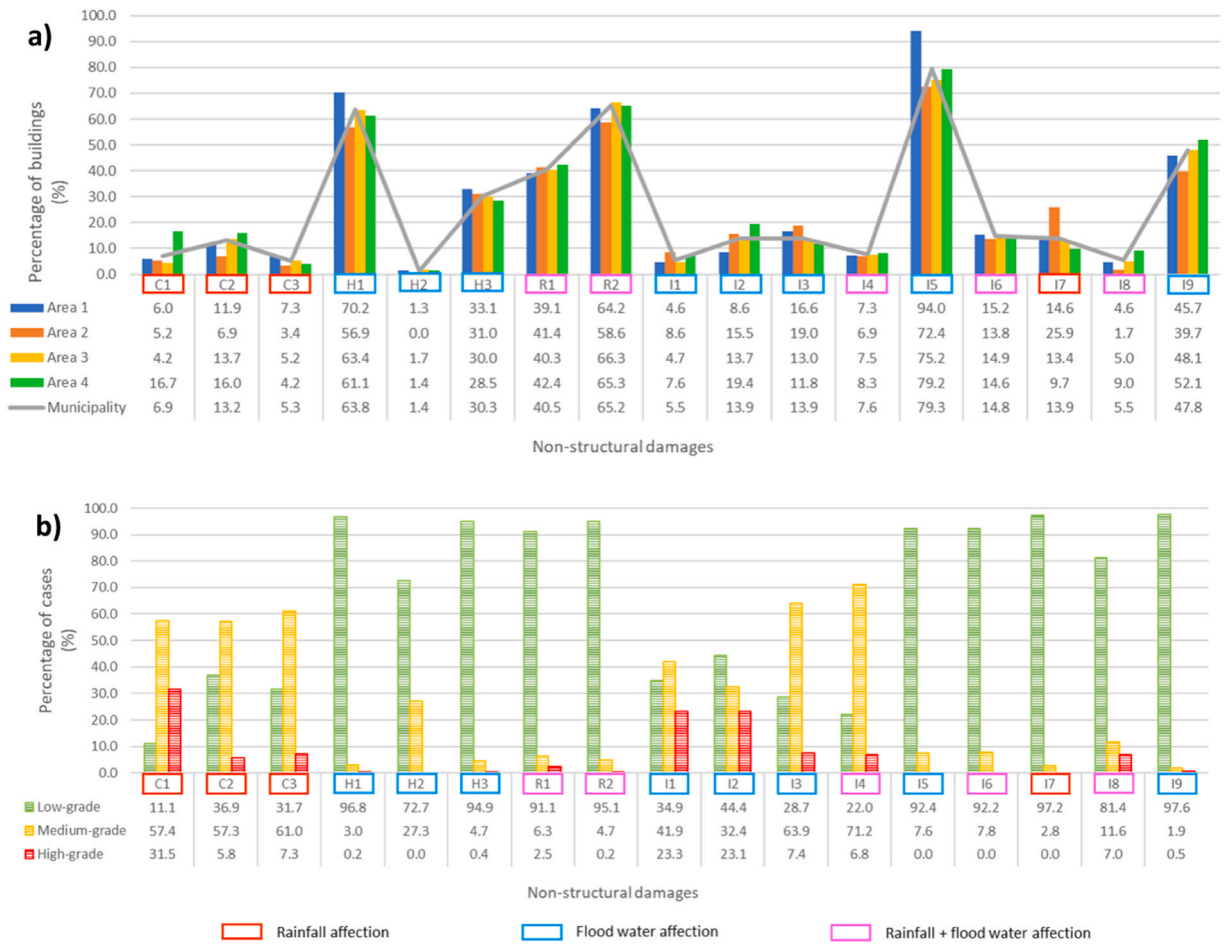


Fig. 13. a) Percentage of single-family properties affected by each type of non-structural damage, b) Percentage of low, medium, and high-grade damages by each type of structural damage.

the element (45.6%).

3.6.2. Quantitative damage assessment

Flood damage was quantitatively assessed in relative (as a percentage of the entire building) and absolute terms (as a monetary value). Both of them were calculated following the method described in the previous damage assessment section.

Scatter plots in Fig. 14 better show the density of estimated damage in relation to the water depth recorded for the three archetypes evaluated and their combination. Although certain variability in water depth and relative damage is appreciable, most results fall in 0–1.0 m and 0–0.25% ranges. In addition, Box plots in Fig. 15 and Table 7 show the distribution and the maximum, minimum, and average values of relative damage, respectively, for the same property types. Note that average relative damage is related to water depth, so the higher the flood depth, the higher DRD average ratio. However, detached houses show a slightly different distribution in comparison to semi-detached, terraced, and single-family properties whose average DRD values for ≥ 80 cm are around 1.6–2.0 higher than for ≤ 15 cm, along with a moderate growth trend up to 46–79 cm (around 0.02 per flood depth range), after which it increases considerably for the highest depths (0.05–0.07). In contrast, detached houses show the highest DRD values for deeper flood levels and the highest difference compared to lower levels (more than three times higher), and remarkable growths up to 16–45 cm (1.6–2.5 times more accentuated than the rest of building types) and up to 46–79 cm (3.6–5.3). This is a consequence of the different flood exposure and resistance features of Area 4 detached houses, which mainly are single-storey properties (80.9%) built before 1960 (67.1%) with the lowest ratio of modern constructions (19.7%), the highest percentage of low-quality (32%) and poorly maintained (16.4%) buildings, and the lowest of high-quality (35.3%) and well maintained (67.2%).

Absolute damage to buildings or building replacement value shows similar pattern results as relative damage, concentrating most of the results in 0–20,000 EUROS and the same flood depth (0–1.0 m) for all building types and areas considered, as shown in the scatter plots in Fig. 16, and the box plots in Fig. 17. Likewise, Table 8 frames the correlation between water depth and the absolute losses. However, it also highlights, along with DRD, the non-linear relation between water depth and cost of replacement, reaching remarkable increments for higher flood depths (≥ 80 cm), except for detached houses, which follow the same trend as in DRD values,

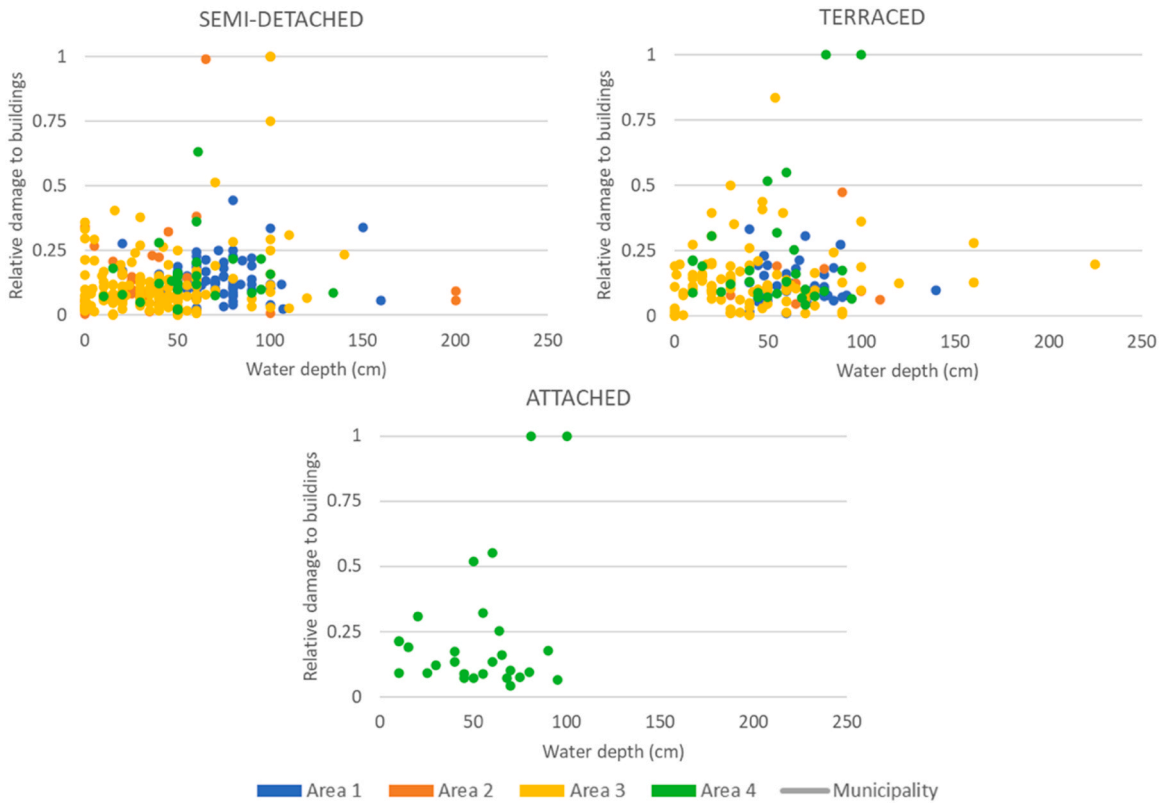


Fig. 14. Scatter plot of relative damage (y-axis) in relation to observed water depth (x-axis) for the three archetypes analyzed (semi-detached, terraced, and attached houses) by areas.

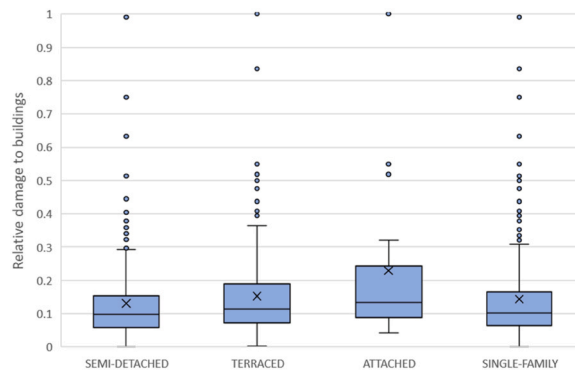


Fig. 15. Data distribution for relative damage of the three archetypes studied and their combination (single-family).

due to the different exposure and resistant building features already explained, which are around five times more than the previous ranges average values. No significant differences between replacement values of the different building types for higher ranges were found (around 12%). All these data are detailed in Table 9 of the Appendix. Note from this table that two storeys versions of archetypes registered lower relative and absolute damage values compared to single-storey.

Table 7
Summary of maximum, minimum, and average relative damage values according to the flood depth ranges of the building types considered in the archetypes of study.

	Relative damage to buildings (DRD)		
	Max	Min	Average
Semi-detached	1.000	0.000	0.131
≤ 15 cm	0.3591	0.000	0.097
16–45 cm	0.4045	0.014	0.114
46–79 cm	0.991	0.000	0.129
≥ 80 cm	1.000	0.006	0.200
Terraced	1.000	0.003	0.153
≤ 15 cm	0.273	0.003	0.124
16–45 cm	0.499	0.005	0.139
46–79 cm	0.836	0.012	0.152
≥ 80 cm	1.000	0.009	0.198
Detached	0.930	0.000	0.161
≤ 15 cm	0.258	0.000	0.079
16–45 cm	0.375	0.000	0.116
46–79 cm	0.525	0.002	0.185
≥ 80 cm	0.93	0.000	0.244
Single-family	1.000	0.000	0.141
≤ 15 cm	0.359	0.000	0.101
16–45 cm	0.687	0.000	0.124
46–79 cm	0.991	0.000	0.143
≥ 80 cm	1.000	0.000	0.197

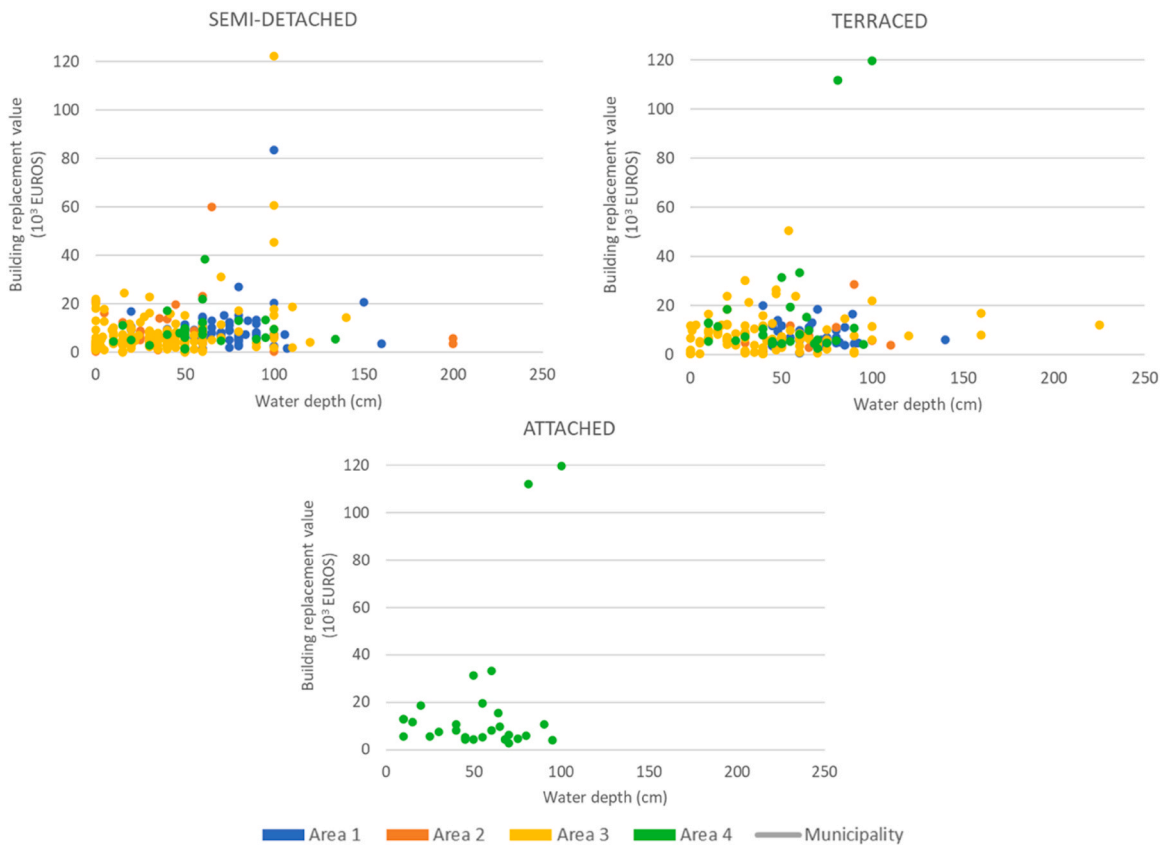


Fig. 16. Scatter plot of absolute damage in thousands of EUROS (y-axis) in relation to observed water depth (x-axis) for the three archetypes analyzed (semi-detached, terraced, and attached houses) by areas.

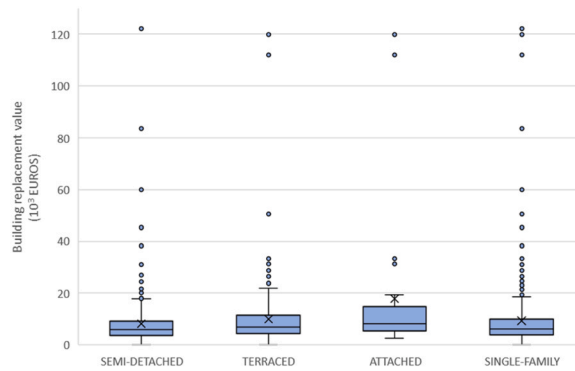


Fig. 17. Data distribution for absolute damage in thousands of EUROS of the three archetypes studied and their combination (single-family).

Table 8

Summary of maximum, minimum, and average absolute damage values according to the flood depth ranges of the building types considered in the archetypes of study.

	Absolute damage to buildings (DAD)		
	Max	Min	Average
Semi-detached	122,210.0	0.0	8186.6
≤ 15 cm	21,725.6	0.0	5838.8
16–45 cm	24,472.3	828.9	6875.2
46–79 cm	59,925.3	0.0	7797.0
≥ 80 cm	122,210.0	344.9	13,673.9
Terraced	119,790.0	163.4	9914.1
≤ 15 cm	16,486.3	163.4	7509.6
16–45 cm	30,195.6	296.5	8402.7
46–79 cm	50,559.9	720.0	9169.8
≥ 80 cm	119,790.0	544.5	15,445.7
Detached	56,265.0	0.0	9755.4
≤ 15 cm	15,603.0	0.0	4776.9
16–45 cm	22,693.6	0.0	7033.7
46–79 cm	31,768.6	102.9	11,184.3
≥ 80 cm	56,265.0	0.0	14,761.7
Single-family	122,210.0	0.0	8883.3
≤ 15 cm	21,725.6	0.0	6083.9
16–45 cm	41,563.5	0.0	7508.5
46–79 cm	59,925.3	0.0	8644.0
≥ 80 cm	122,210.0	0.0	13,618.4

4. Conclusions and recommendations

Reliable and feasible flood damage models are essential tools to support flood risk reduction strategies and plans based on risk mitigation and adaptation. These tools should be able to estimate potential damage according to hazard and asset features. The present study provides a detailed characterization of the exposure and resistance assets features, flood hazard, and the subsequent, direct tangible losses of the buildings affected by the floods in Vega Baja del Segura County, specifically in Almoradí, in September 2019. Such an empirical data set provides meaningful insights to validate and adjust these models, improving their prediction accuracy and transferability to the Valencian Region.

On this basis, we proposed three archetypes based on the sample buildings' most common exposure and resistance features, assigning the flood depth and damage parameters registered. Then, we analyzed the existing relationships between all these parameters. The result of this research leads us to draw the following concluding remarks.

Micro-scale exposure and resistance analysis of past flood events is imperative to generate exhaustive and operative data sets to improve damage prediction precision in flood damage models.

The analysis showed a strong correlation between flood depth and the recorded relative and absolute damage. Therefore, flood depth measuring accuracy during field surveys is essential to generate a reliable data set. However, this sole variable is not enough to accurately estimate flood losses since different building exposure and resistance features lead to different correlation types between flood depth and the documented direct tangible losses. Moreover, the proposed methodology could be extended to incorporate more hazard variables besides flood depth, such as flow velocity and flood duration, to provide a more suited set of data to multivariable models for more accurate loss predictions.

The methodology to characterize direct tangible damage after a flood event presented herein, the data sheet employed, data collected, and the results derived from the current research can be transferred to other regions with comparable expected flood depths, as well as building exposure and resistance features similar those characterized in the archetypes delineated in this study.

In our view, building flood performance should be improved following a collection of preventive measures based on the water depth considered, such as using low permeable materials and constructive solutions in the base of buildings (up to 0.3 m), main floor designs that facilitate water passage and draining for water depths higher than 0.6 m, all supported by designing accessible spaces and easily clean and repair materials.

Finally, as a general recommendation, we support a call to create a uniform and specific protocol that improves the efficiency of flood damage collection, analysis, geo-referenced data, and report production to improve flood risk management in the emergency stage. Furthermore, we agree with an updated data set of exposure, resistance, and damage records from past events at the micro-scale.

As prospective avenues for further investigation, this empirical data set may constitute a significant contribution towards the development of a vulnerability index based on building features to assess the physical vulnerability of the building stock of areas with a lack of or no empirical data available.

CRedit authorship contribution statement

Begoña Serrano Lanzarote: Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Ricardo Moya Barbera:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis, Data curation. **Ivan Cabrera-Fausto:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Data curation. **Teresa Escrig:** Writing – original draft, Validation, Supervision, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

Acknowledgements

We are thankful to the Valencia Institute of Building (IVE) for its support and for providing all data from the inspections conducted on all buildings affected by the floods in the Valencian Region in September 2019.

Appendix

Ive's datasheet model

This datasheet is organized into three parts: Inspection results with the accessibility condition of buildings and recommended preventative measures, building and inspector information, and damage details, where the different types of damage, their grade, and level of extension were provided. These parts are highlighted in blue, red, and yellow, respectively.

INSPECTION AND QUICK EVALUATION SHEET OF FLOOD DAMAGE BUILDING

Case number

ACCESS BUILDING:

<input type="checkbox"/> NOT ALLOWED	<input type="checkbox"/> (Red)	Building with structural damage, exists high risk of partial or total collapse.
<input type="checkbox"/> RESTRICTED	<input type="checkbox"/> (Yellow)	Building with structural or non-structural damage, but it poses a threat to the residents who only can access to take away personal items.
<input type="checkbox"/> ALLOWED	<input type="checkbox"/> (Green)	Building with minor non-structural damage. It is safe and there is no hazard.

PREVENTATIVE MEASURES:

Cordoning off	<input type="checkbox"/>	In certain parts	<input type="text"/>
	<input type="checkbox"/>	In the whole building	<input type="text"/>
Bracing	<input type="checkbox"/>	In certain parts	<input type="text"/>
	<input type="checkbox"/>	In the whole building	<input type="text"/>
Demolishing	<input type="checkbox"/>	In certain parts	<input type="text"/>
	<input type="checkbox"/>	In the whole building	<input type="text"/>
Scaffoldings or catch fans	<input type="checkbox"/>	In certain parts	<input type="text"/>
	<input type="checkbox"/>	In the whole building	<input type="text"/>
Shutting off	<input type="checkbox"/>	In certain parts	<input type="text"/>
	<input type="checkbox"/>	In the whole building	<input type="text"/>
Clearing existing rubble	<input type="checkbox"/>	In certain parts	<input type="text"/>
	<input type="checkbox"/>	In the whole building	<input type="text"/>

It is required an evaluation by a specialist of: Structures Gas supply Electricity supply

NUMBER OF AFFECTED ROOMS: Flood water depth = cm

Living room	Kitchen	Bedroom	Bathroom	Corridor	Storeroom		
<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>

Including photographs of each affected room and type of damage

OBSERVATIONS:

BUILDING INFORMATION:

Address	<input type="text"/>	Number	<input type="text"/>	CADASTRAL REFERENCE	<input type="text"/>
Municipality	<input type="text"/>	Zip code	<input type="text"/>	UTM COORDINATES	<input type="text"/>
USE	TYPE				
Residential (Number of residences) <input type="text"/>	<input type="checkbox"/> Offices	<input type="checkbox"/> Educational	<input type="checkbox"/> Detached house	<input type="checkbox"/> Terraced housing	
Others: <input type="text"/>	<input type="checkbox"/> Commercial	<input type="checkbox"/> Hospital	<input type="checkbox"/> Semi-detached house		
NUMBER OF STOREYS	Below ground level <input type="text"/>	Above ground level <input type="text"/>			

INSPECTOR:

Surname	<input type="text"/>	Phone number	<input type="text"/>	Signature
Name	<input type="text"/>	E-mail	<input type="text"/>	
Profession	<input type="text"/>	Inspection time	<input type="text"/>	
		Date	<input type="text"/>	

Fig. 18. Data sheet used in the field surveys.



INSPECTION AND QUICK EVALUATION SHEET OF FLOOD DAMAGE BUILDING

Case number

BUILDING DAMAGE: Mark the detected damage code

ELEMENTS AND EVIDENCES	DAMAGE CODE	LOCATION AND DESCRIPTION	GRADE OF RISK			EXTENT LEVEL			
			Low	Moderate	High	<25%	25-50%	50-75%	>75%
Pillars, walls and foundations									
Dirty pulling away from foundations	P1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Collapse or overturning	P2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Diagonal cracks	P3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Horizontal cracks	P4 P5		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vertical cracks	P6		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Damp patches	P7 P8 P9 P10 P11 P12		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Beams, slabs and beams filling									
Bending or vertical deformations	V1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Collapse or overturning	V2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Diagonal cracks	V3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Longitudinal cracks	V4		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Transversal cracks	V5 V6		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Damp patches	V7 V8 V9 V10		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Roofs									
Missing or broken roof covering elements	C1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Roof ageing	C2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Flooded roof	C3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Openings									
Window and door frames deterioration	H1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Window and door glass missing or breakage	H2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Warped doors, windows and frames	H3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Floor and ceiling coverings									
Missing or broken covering	R1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Deterioration of materials	R2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Facades, party walls and partitioning									
Collapse or overturning	I1		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Diagonal cracks	I2		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Horizontal cracks	I3		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Vertical cracks	I4		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Horizontal continuous damp patches	I5 I6		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Small single damp patches	I7		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fall of specific and decorative elements	I8		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Covering deterioration	I9		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
LEVELS OF DAMAGE GRADE:									
High:	Detected damage may be an imminent danger for either residents and other people or adjacent buildings because of a partial or total collapse of building or falling of constructive elements. Immediate and urgent interventions are necessary such as evacuation of occupants, closing off some building zones, use of bracing, scaffoldings, catch fans...								
Moderate:	Detected damage can affect other building constructive elements, compromising its security or release to service. Interventions are necessary in the short to mid-term (up to one year).								
Low:	Detected damage don't compromise the safety, durability or release to service of building or its constructive elements.								

Fig. 18. (continued).

Table 9
Summary of exposure, resistance, hazard, and damage results for the proposed archetypes

	ARCHETYPE 1						ARCHETYPE 2						ARCHETYPE 3			
	M	A1	A2	A3	A4		M	A1	A2	A3		A4	M	A4		
EXPOSURE																
EU	Residential						Residential						Residential			
ET	Semi-detached						Terraced house						Detached			
ER	Principal						Principal						Principal			
EB	No						No						No			
EF	No						No						No			
EFL	1	2	2	1	1	2	1	2	2	1	1	2	1	1		
EA (m ²)	130.2	174.3	154.9	187.2	121.2	184.1	132.9	137.9	175.7	153.6	145.5	137.3	185.0	138.9	205.6	199.8
EP (m)	47.7	40.0	38.2	58.6	45.7	40.5	51.2	49.3	40.0	37.4	49.2	49.5	41.1	49.3	91.8	59.9
EL (m ²)	322.4	204.7	136.9	633.6	213.1	260.8	583.5	485.7	599.8	102.8	172.3	575.5	1012.8	587.4	3440.2	3993.1
RESISTANCE																
RA	<1960						<1960						<1960	>1995 & <1960	<1960	
RQ	High & Medium			High	Medium & High	Low	Medium & High			Low & Medium	Medium	<1960	High	High & Low	Low	
RM	Good						Good						Good			
RBS	Shallow footings						Shallow footings						Shallow footings			
Foundation	W/F						W						W/F			
Vertical	W/F	W/F	W	W	W/F	W	W	W	W	W	W	W	W	W	W	
RSM**	Masonry for Load-bearing walls (W) and concrete for structural frame systems (F)															
RNM	Sloped inaccessible with ceramic shingles															
Roofs	Only with exterior cement plaster or combined with stone, ceramic cladding, or concrete															
Façade covering	Wood and aluminum for older buildings (<1960), and aluminum for newer (>1995)															
Exterior openings	Brick partitioning with plaster, paint, or tiling															
Partitioning	Wood															
Interior openings	Ceramic tiles															
Floor covering	Plaster ceiling and combination with ceiling tiles															
Ceiling covering																
HAZARD																
HL (cm)																
Maximum	140	200	160	65	140	140	100	100	225	140	100	100	225	100	215	200
Minimum	0	0	20	0	0	0	10	0	0	40	0	0	0	10	0	0
Average	45.2	49.7	68.3	23.7	40.2	32.1	54.6	42.9	59.4	69.8	53.1	35.3	51.7	49.6	64.2	62.8
DAMAGE																
DD – Type (%)																
P - Vertical structure	P7	P7 16.1%	P7 21.4%	P1 & P7	P7	P1	P6	P1	P1	P1	P1	P1	P7	P6		
	15.8%			13.6%	23.1%	13.2%	2.6%	22.2%	13.2%	28.6%	9.2%	10.3%				
H - Horizontal structure	V1	V6 21.8%	V1 32.1%	V1	V1	V1	V1	V1	V1 & V6	V1	V1	V1				
	17.5%			14.8%	23.1%	13.2%	7.7%	22.2%	13.2%	17.9%	16.0%	19.1%				
C - Roofs	C2	C2	C2	C2	C2	C2	C1	C1	C2	C1 & C2	C1	C1				
	15.2%	12.6%	10.7%	15.4%	26.9%	13.8%	7.7%	11.1%	19.8%	10.7%	15.1%	22.1%				

(continued on next page)

Table 9 (continued)

	ARCHETYPE 1					ARCHETYPE 2					ARCHETYPE 3					
	M	A1	A2	A3	A4	M	A1	A2	A3	A4	M	A4				
H - Openings	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1	H1				
	66.7%	78.2%	60.7%	62.3%	61.5%	73.1%	84.6%	55.6%	73.6%	60.7%	63.0%	61.8%				
R - Floor & ceiling coverings	R2	R2	R2	R2	R2	R2	R2	R2	R2	R2	R2	R2				
	64.0%	67.8%	53.6%	63.0%	69.2%	62.9%	66.7%	66.7%	68.1%	39.3%	71.4%	69.1%				
I - Non-structural walls	I5	I5	I5	I5	I5	I5	I5 & I9	I9	I5	I5	I5	I5				
	68.3%	85.1%	57.1%	60.5%	73.1%	58.7%	66.7%	33.3%	59.3%	57.1%	67.2%	63.2%				
DRD																
Maximum	1.000	0.513	0.445	0.991	1.000	0.513	0.633	1.000	0.836	0.307	0.475	0.499	0.836	1.000	0.930	0.930
Minimum	0.000	0.004	0.006	0.014	0.000	0.004	0.021	0.004	0.003	0.050	0.047	0.004	0.003	0.043	0.000	0.000
Average	0.153	0.115	0.132	0.196	0.146	0.102	0.168	0.186	0.129	0.120	0.166	0.168	0.125	0.257	0.182	0.192
DAD (x10³ EURO)																
Maximum	122.2	31.0	26.9	59.9	122.2	31.1	38.3	119.8	50.6	18.6	28.8	30.2	50.6	119.8	56.3	56.3
Minimum	0	0.2	0.3	0.8	0.0	0.3	1.3	0.2	0.2	3.0	2.8	0.2	0.2	2.6	0.0	0.0
Average	9.8	6.9	8.0	11.9	9.6	6.2	10.2	12.7	7.8	7.2	10.0	10.2	7.5	21.7	11.0	11.6

** Materials used in horizontal structures are not considered because, in most cases, they were hidden by the existing ceiling coverings.

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