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THE ARCHITECTURAL STRUCTURE IN THE FACE OF CLIMATE-RELATE CATASTROPHE: A CLASSIFICATORY APPROACH

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ABSTRACT

Nowadays, given the geopolitical and climatic emergency context in which we find ourselves, various catastrophes of different kinds, including natural ones such as floods, volcanic eruptions or earthquakes, and human ones such as armed conflicts, nuclear accidents or most fires, whose impact often results in human and economic losses, have highlighted the need to rethink architectural structures in order to ensure that they are as resilient as possible.

The key to achieving this and aim of this manuscript, is to firstly identify the intrinsic objective parameters of the most statistically probable catastrophes that we can currently suffer, in order to characterize and classify them from different points of view based on their future consequences on building structures, since only in this way will we be able to conceive and materialize them with the capacity to withstand not only usual loads, but also to present the best possible behaviour in the face of accidental situations caused by potential new adverse episodes.

KEYWORDS

Architecture; resilience; structure; climate; catastrophe.

1. INTRODUCTION

In 2015, the United Nations (UN) approved the 2030 Agenda for Sustainable Development with the aim of building a better world and improving the lives of all its inhabitants. This Agenda contains seventeen Sustainable Development Goals (SDGs), among which we highlight for this paper Goal 11, which calls for making cities more inclusive, safe, resilient and sustainable, and Goal 13, which refers to taking urgent action to fight climate change and its effects.

In relation to this last goal, we see more and more scientific evidence and publications every day that defend and provide objective data on the current process of global warming. Human influence on the climate system is obvious. The warming of the climate system is unequivocal and anthropogenic emissions of greenhouse gases are the highest in history (fig. 1). The atmosphere and ocean have warmed, snow and ice volumes have decreased and sea levels have risen *(IPCC 2014)*.

Since the 1980s, the earth's surface temperatures have been rising, a process that seems to be continuing today, and whose consequences in the form of extreme atmospheric episodes can affect both economic activities and urban life itself (Olcina Cantos J. 2019). This phenomenon and its consequences for our lives and our planet do not go unnoticed by the vast majority of people,

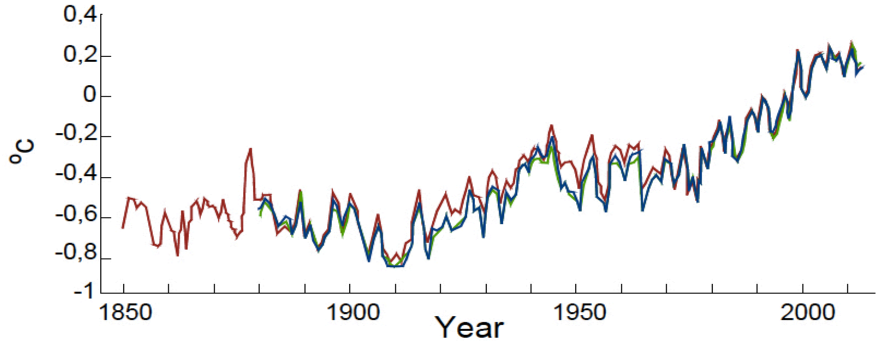

Figure 1. Global average anomaly of surface (red), land (green) and ocean (blue) temperatures combined. Source: (IPCC 2014)

as is shown in some of the risk reports that have been published.

One of these reports is The Global Risk Report (World Economic Forum 2022), for which a survey was conducted in which respondents were shown a list of 37 risks to be ranked, according to their criteria, in order of importance in terms of global damage over the next 10 years. Among the top 10, 50% are related to the environment, as opposed to only 10% for technological or economic risks, for example.

This demonstrates the worrying reality in which we find ourselves and which, at least, is not going unnoticed among the population.

In 2021, as shown in the Emergency Events Database (EM-DAT 2021) created by the Centre for Research on the Epidemiology of Disasters - CRED, 432 disastrous events related to natural hazards were recorded worldwide and 149 others considered to be of a technological nature such as industrial or transport accidents. All of them unfortunately involved more than 10,000 deaths, affected more than 100 million people and caused more than 200 billion euros in economic losses. Globally, while the number of deaths and the number of people affected were below their 20-year averages, 2021 was marked by an increase in the number of disastrous events and large economic losses. Moreover, due to the effects and consequences of climate change, the observed trend is for the number of events to continue to increase.

Part of these losses, both economic and human, could be avoided or minimised if we ensure that the buildings we design are themselves as resilient as possible. For a building to be resilient to disastrous events, the materials and construction systems that we employ need to be resilient, which is why research into the use of optimal types of structures that ensure the sustainability of buildings in unexpectedly adverse conditions is considered essential (Cortés Cely O. 2015).

It is therefore necessary, in order to research or discuss the consequences of any phenomenon, to have a clear idea of what that phenomenon is, and therefore to identify beforehand the intrinsic objective parameters that characterise different types of catastrophes.

Several authors have already shown interest in the different intrinsic risks of the main phenomena to which population concentrations, and therefore our buildings, are subjected. An example of this is the statement by Jorge Enrique Vargas González (2002) when he talks about the risk of disaster due to landslides, which, according to him, depends on the mass of earth that can occasionally detach, which, depending on the lack of protection or the relative mobility between the building structure and the soil particles, can lead to different types of thrusts and the sliding of structural elements. This creates an overall framework determined by three key factors: economic, social and environmental. While the economic factor is the one most emphasised today in our immediate environment due to the lack of liquidity resulting from several consecutive crises such as the real estate crisis and the health crisis due to the Covid19 pandemic, it is the social factor that must be addressed in order to save lives.

All of the above should not be understood without taking into account the problem of sustainability in all areas, and of course, in the subject that concerns us: the current world of construction and the design of the structures of our buildings. Linked to the above-mentioned Goal 11, the structures used often do not conform to objective resilient parameters from the point of view of economic, social and environmental sustainability. Furthermore, the overexploitation of resources and the limitation of unlimited access to them makes it essential to analyse and rethink the way we build. In many cases, oversized structures are still being used and in others, they are too fragile to withstand other natural phenomena or subsequent replicas of the initial ones. All of this, given sufficient empirical data and being aware that the climate crisis has accelerated various natural catastrophes and can lead to or accentuate others of human origin, such as, for example, the energy crisis in which Europe is immersed due to the Russian invasion of Ukraine.

2. RESEARCH OBJECTIVES

The aim of this article is to develop a bibliographic search on which catastrophes are considered most relevant from a scientific point of view by specialists in terms of potential damage to architectural structures, to analyse them briefly and to classify them based on different criteria.

3. METHODOLOGY AND LIMITS OF THE RESEARCH

During the course of this research, different scientific internet platforms were consulted, depending on the type of information to be studied and shown. On the basis of the documentation found and the bibliographical consultations made on the different types, each of the selected catastrophes was analysed with a critical eye in order to classify them from different points of view.

4. RISK, VULNERABILITY, DISASTER AND CATASTROPHE

It is important to distinguish between these four closely related concepts, which in many cases are incorrectly used as synonyms, without forgetting that giving a comprehensive definition is difficult, as each discipline or field of research gives its own assessment of the concept.

In the case at hand, we consider the best definitions to be those given by the United Nations Department of Humanitarian Affairs *(UNDHA 1992, 64, 77 & 27)*.

We understand risk as expected losses (of lives, people injured, property damaged and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability.

We will define vulnerability as the degree of loss (from 0% to 100%) resulting from a potentially damaging phenomenon.

We will consider a disaster as a serious disruption of the functioning of society, resulting in widespread human, material or environmental losses that exceed the ability of the affected society to cope using only its own resources. Disasters are often classified according to their cause (natural or human/ manmade).

Finally, for the definition of catastrophe, we will use the one given by Karlos Pérez de Armiño

(1999): extreme event, of natural or human origin, which by affecting a place at a given time can cause damage and disturbances such that it triggers a disaster process. This is the relevant concept in the present document.

Caution should be taken with the concepts "catastrophe" (in English usually hazard) and "disaster", which, although often confused in colloquial language, have different meanings. A catastrophe is an event which, in a pre-existing context of vulnerability, can act as a trigger for a disaster, i.e., a process of severe crisis and socio-economic dislocation with serious consequences at various levels (famine, misery, epidemics, exodus, etc.) (Fig.2). The severity and type of impact caused by the disaster depends, of course, on the intensity and characteristics of the catastrophe that caused it, but even more so on the degree of vulnerability to which the affected population was subjected (Pérez de Armiño K. 1999).

It follows that while catastrophes may be natural and unavoidable due to the current climate crisis, disasters are not. Disasters can and should be avoided if a strong commitment is made to help communities prepare for them, reduce their risks and become more resilient. Examples of this are the different territorial action plans on risk prevention that, on a sectoral basis, are being developed in some areas, such as in the Valencian Region in Spain.

5. CATASTROPHY TYPES AND PROBABILITY

Many definitions and classifications of catastrophes have been made over the years (Grisham 1986; IRDR 2014; Lechat 1990; Logue, Melick and Hansen 1981; Weiss and Clarkson 1986) in which we can see that the classification that is a priori most obvious is the one that is most repeated among the different authors and is the one that divides catastrophes into two groups according to their origin, natural or human.

5.1. Natural

We take as a reference the definitions given in the Integrated Research on Disaster Risk (IRDI) report (2014):

a) Biological: Hazard caused by exposure to living organisms and their toxic substances (e.g., poison, mould) or the vector-borne diseases they may transmit (e.g., malaria). Consider: disease/(epidemic), insect infestation and animal incident.
b) Geophysical: Hazard originating from solid earth. We will consider: earthquake, mass movement (dry) and volcanic activity.
c) Climatological: Hazard caused by long-term, meso to macro-scale atmospheric processes, ranging from intra-seasonal to multi-decadal climate variability. These are: drought, glacial lake outburst floods and forest fires.
d) Hydrological: Hazard caused by the occurrence, movement and distribution of fresh and salt surface and groundwater. Consider: flooding, landslides and wave action.
e) Meteorological: Hazard caused by extreme weather and atmospheric conditions of short duration, micro- to mesoscale, lasting minutes to days. We mean: convective storm, extratropical storm, extreme temperature, fog and tropical cyclone.
f) Extraterrestrial: Hazard caused by asteroids, meteoroids and comets passing close to Earth, entering Earth's atmosphere and/or colliding with Earth, and by changes in interplanetary

Figure 2. Relationship between vulnerability, disaster and catastrophe. Source (Prepared by the authors)

conditions affecting Earth's magnetosphere, ionosphere and thermosphere. We refer to impact and space weather.

5.2. Human (man-made)

a) Transportation: Any eventual occurrence which results in damage to property or persons and which is caused by a direct act or occasion of the employment or use of a mechanical, animal or human-powered vehicle.
b) Industrial catastrophes: Hazards originating from industrial conditions, hazardous procedures, infrastructure failures or human activity. They are characterised by the release of potentially harmful substances. They are known as CBRN releases: chemical, biological, radiological and nuclear.
c) Political conflicts and wars. These are those arising from a social relationship whereby two or more collectivities aspire to satisfy incompatible interests or demands, using their inequalities of power to maintain antagonistic or opposing actions, resorting, in the last resort, to violence (Calduch R. 1993). We will consider wars, terrorism, popular uproars, riots, events or actions of the Armed Forces, famine and refugees.
d) Explosion: is the simultaneous, sudden and usually violent release of heat, light and sound energy. We refer to physical and chemical.
e) Fire: uncontrolled fire occurrence that can affect or scorch something that is not intended to burn, at urban, forestry or industrial level.
f) Plastic islands: grouping of non-biodegradable waste that accumulates due to marine currents.

In the light of the above, and with the aim of summarising and classifying in a more synthetic and graphic way the different catastrophes based on the repercussions they can have on the structures of buildings, the following table has been devised (Table 1).

	NATURAL	HUMAN
AFFECT BUILDING STRUCTURES	Earthquake Mass movement (dry) Volcanic activity Glacial lake outburst Wildfire Flood Landslide Wave action Covective storm Extratropical storm Tropical cyclone Impact (sidereal bodies)	Impacts (transportation) Explosions (transportation) Wars Terrorism Popular uproar Riots Events or actions of the Armed Forces Chemical explosions Physical explosion Urban fire Wildfire Industrial fire
DOES NOT AFFECT BUILDING STRUCTURES	Disease/Epidemic Insect infectation Animal incident Drought Extreme temperature Fog Space weather	Spills (trasnportation) CBRN releases Famines Refugees Plastic islands

Table 1. A first classification of catastrophes. Source: (Prepared by the authors)

Amounts updated to 31-12-21

CAUSE	No of Files	%	Indemnities	%	Average Cost	Property Damage	Pecuniary Losses	Personal Injury
Flood	783,323	44.28%	6,897,387,229 €	55.89%	8,805 €	98.00%	1.90%	0.10%
Atypical Cyclonic Storm (TCA, for the Spanish)	728,401	41.18%	1,571,795,561 €	12.74%	2,158 €	97.30%	2.70%	0.00%
Earthquake	54,964	3.11%	622,038,013 €	5.04%	11,317 €	96.50%	3.10%	0.40%
Terrorism	22,375	1.26%	496,122,161 €	4.02%	22,173 €	77.30%	1.20%	21.50%
Popular uproar	7,082	0.40%	91,021,462 €	0.74%	12,853 €	99.70%	0.00%	0.30%
Volcanic activity	6,052	0.34%	223,070,187 €	1.81%	36,859 €	97.00%	3.00%	-
Events or actions of the Armed Forces	2,524	0.14%	5,822,825 €	0.05%	2,307 €	90.90%	2.60%	6.50%
Riot	153	0.01%	1,241,356 €	0.01%	8,113 €	100.00%	-	-
Impact of sidereal bodies	3	0.00%	110,394 €	0.00%	36,798 €	100.00%	-	-
TOTAL	**1,604,877**	**100.00%**	**9,908,609,188 €**	**100.00%**	**6,174 €**	**96.80%**	**2.00%**	**1.20%**

Table 2. Percentage distribution of claims according to cause of claim in the period 1987-2021. Source: (Prepared by the authors based on figures from Consorcio de Compensación de Seguros 2021)

As we can see that the casuistry that can affect buildings, even in a very partial and specific way, is very broad, and we could even subdivide the different types of catastrophes into more subtypes that could end up affecting them, it is necessary to carry out a study of which of the above are those that statistically generate the greatest impact on property, people and pecuniary losses. To illustrate the above, and as an example in the case of Spain, the number of cases or files opened according to the cause of the claim can be taken as a reference. To do so, we will use the database of the Insurance Consortium in Spain (Consorcio de Compensación de Seguros 2021) (Table 2).

The relevance of catastrophes will depend, to a large extent, on the geographical area considered, understood as its location on the planet and its characteristics. We will use the Valencian Region as an example in this document, which will be the focus of our interest in the following sections. To this end, from the same source as above, we can see in the percentage distribution of total compensation, that two of the three provinces in the region appear among the ten Spanish provinces with the highest values, accounting for 16.3% of the entire national territory (Table 3).

In a society like the Valencian society, where the environment has been so intensely transformed over the last few decades, there is no such thing as zero risk, and no matter how many resources are allocated, it is difficult to completely eliminate them. What is more manageable is to try to mitigate their effects until they become acceptable from an economic, social and environmental point of view.

The catastrophic effects of natural disasters considered to be of extraordinary magnitude are related, in most cases, to the improper occupation of vulnerable areas of our territory by human beings.

In addition, future scenarios regarding the evolution of the physical environment in relation to the behaviour of the earth's climate suggest, in areas such as ours, the possibility of more extreme atmospheric dynamics, which means that the territory must adapt to this new reality. On the Spanish Mediterranean coast, for example, changes can already be observed in certain climatic elements such as temperatures and rainfall (Olcina Cantos J. 2019).

Ranking Position	PROVINCE	%	Ranking Position	PROVINCE	%
1	Barcelona	12.4%	7	Málaga	5.0%
2	**València/Valencia**	**10.7%**	8	Sta. Cruz de Tenerife	3.6%
3	Bizkaia	9.9%	9	Madrid	3.6%
4	Murcia	8.2%	10	Tarragona	2.6%
5	Gipuzkoa	5.8%	11	Illes Balears	2.2%
6	**Alacant/Alicante**	**5.6%**	12	Resto	30.4%
				TOTAL	**100.0%**

Table 3. Percentage distribution of total compensation per province in the period 1971-2021. Properties. Source: (Prepared by the authors based on figures from Consorcio de Compensación de Seguros 2021)

However, climate change should be of concern not so much for the variation in the values of the main climatic elements (temperature, rainfall) as for the alteration of atmospheric dynamics and its possible tendency towards a more extreme functioning of its phenomena as a whole. The Valencian territory, due to its physiographic configuration, its climatic conditions and its spatial distribution pattern of the population, is highly susceptible to this type of risk due to extreme atmospheric phenomena.
Furthermore, the European Spatial Planning Observatory (ESPON) has identified the provinces of the Valencian Region as being among those with the greatest risks in Europe as a whole and highlights floods and droughts as the most important risks, as well as seismicity, hail storms, cold and heat waves and windstorms *(Comunitat Valenciana 2011)*.

6. CLASSIFICATION ACCORDING TO STRUCTURAL IMPACT

Before classifying the different catastrophes on the basis of their structural impact, it is necessary to be clear about several concepts that can be confused. These are loads and internal forces.
Loads are defined as the set of external forces that act on a body, or structure in our case, with the intention of displacing and/or deforming it, while internal forces are the forces with which the structure of the body responds to the previous actions in order to maintain its equilibrium.
If, for example, a load P acts on a frame, in order for it to be driven towards the supports, a series of internal forces are produced in the structure itself. A structure is, therefore, a closed set of forces. The external forces are known as loads, and are balanced by means of the internal. For a structural system to be in static equilibrium, the resultant of the sum of internal and external forces must be zero (Alonso Durá A. et al. 2005).
Internal forces in a structure will be the result of the external forces to which it is subjected and depending on its nature and projection over the cross-section local we classify them as axial force, shear force, bending moment and torque (Fig. 3).

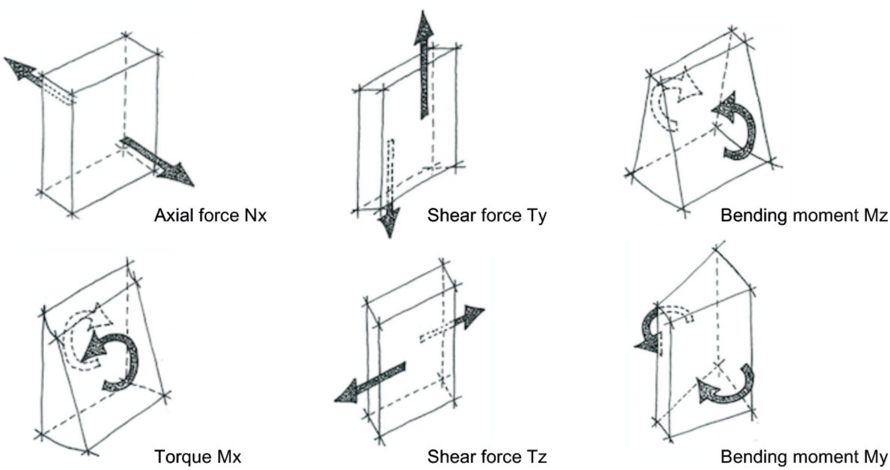

Figure 3. Internal forces. Source: (Prepared by the authors)

Knowing the nature and orientation of the loads that a catastrophe can produce on a structure and knowing the internal forces that they might induce, helps us to be able to identify the damages that our structure might suffer and, therefore, to draw up a strategy to increase its resilience.

With regard to the aforementioned catastrophes, we can establish the following classification:

a) Floods:

- Horizontal thrusts in support bases can involve an increase in bending and shear moments.
- Washing of foundation bases or softening of soil often imply potential differential setting induced and the appearing of bending moments and shear forces in hyperstatic structures, as well as uncontrolled redistribution of axial forces.

b) Earthquakes:

- Horizontal thrusts involve increased bending moments and shear forces.
- Vertical ground motion involves an increase in axial forces, and bending moments and shear moments.

c) Fires:

- Dilatations that, if restrained, might imply an increase in axial forces in elements with a hindered lengthening and frequent increases in bending and shear in the elements that limit this expansion.

d) Strong gusts of wind:

- Horizontal thrusts might imply an increase in bending and shear moments, even alteration of the axial values in the supports located in the façades in the case of slender buildings.
- Suction can lead to the failure of tensile construction elements due to stress reversal.

6. CONCLUSIONS

On the basis of the previous discussion, it can be concluded:

- There are many different types of catastrophes to which we are subject. No matter how much resources are allocated, which would be disproportionate and economically unsustainable and would introduce unaffordable budgetary imbalances, there is no such thing as zero risk.
- It is possible to try to mitigate the effects of catastrophes until they are economically, socially and environmentally acceptable. In the case of architecture, the study of these effects on the structures of our buildings is relevant.
- An appropriate risk assessment is necessary, in which a key factor is the location within the territory of the area in which to act and the identification of the most statistically probable catastrophes in that territory.
- The catastrophic effects of natural catastrophes considered to be of extraordinary magnitude are most often related to the improper occupation of vulnerable areas of our territory by human beings.
- Knowing the nature and orientation of the loads that a catastrophe can produce on a structure and knowing the stresses and their effects helps us to be able to identify the pathologies that can affect it and, therefore, to draw up a strategy to increase its resilience.

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