Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

multi-Risk sciEnce for resilienT commUnities undeR a changiNgclimate

Codice progetto MUR: **PE00000005** – CUP LEAD PARTNER: D53C22002510002

Risk-Oriented Taxonomy and Ontology of Urban Subsystems and Functional Models

DV 5.2.1

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1. Technical References

Project Acronym	RETURN
Project Title	multi-Risk sciEnce for resilienT commUnities undeR a changiNg climate
Project Coordinator	Domenico Calcaterra UNIVERSITA DEGLI STUDI DI NAPOLI FEDERICO II domcalca@unina.it
Project Duration	December 2022 – November 2025 (36 months)

Deliverable No.	DV 5.2.1
Dissemination level*	PU
Work Package	WP2 - WP Title
Task	Risk-Oriented Taxonomy and Ontology of Urban Subsystems and Functional Models
Lead beneficiary	EURAC
Contributing beneficiary/ies	UNIBO, UNINA, UNIFI, UNIGE

* PU = Public

PP = Restricted to other program participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

2. Technical References

Version	Date	Lead contributor	Description
1.0	30/11/2023	EURAC	First release

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1. Introduction

The purpose of this **document is to provide a first proposal** of conceptual ontological modeling of urban and metropolitan systems aimed at better understanding, assessing, and managing current and emerging natural, environmental, and anthropic risks. Also, we would like to propose a **framework to standardize and harmonize the description (and later assessment) of the main components of risk** related to multiple hazards and climate change in urban areas. As such, for each of the considered subsystems we reviewed existing taxonomies (i.e., structured categorizations) and where deemed necessary we proposed suitable changes and updates. Most technical descriptions and information can be found in the Appendices. We invite the RETURN scientific partners to provide us with comments and observations, but also to use as much as possible the definitions and categories described in this document in order to set a common and shared understanding upon which to build efficient multidisciplinary collaboration.

Note 1: This document is to be intended as part of an ongoing iterative process. As such it will be subject to further updates and modifications in the following phases of the project, also according to the feedback and consultations among the project partners and with the stakeholders.

Note 2: in order to foster the use of consistent and share definitions for most of the concepts relevant to the RETURN project, a preliminary version of a glossary has been collaboratively developed and is provided in Appendix B – Dictionary of Terms (Preliminary Glossary).

European Environment Agency (EEA) estimates that 72% of the European population lives in cities, towns, and suburbs[1] (more than 50% globally, with an estimated two more billion urban residents expected in the next 20 years). Cities are human-built systems composed of subsystems and integrated with other artificial and natural systems at various levels. Given the extent of human, social, economic, and technological capital the urban areas represent, it is no surprise that they emerge as a hotspot for risk as well (e.g., Dickson et al. 2012). Financial and economic crises, population flows, environment and climate phenomena, natural and anthropogenic disasters, social conflicts, and terrorism are just a few of the challenges that cities may experience. In Italy, for instance, the 2022 Regione Marche Flash floods, the 2023 Emilia Romagna floods as well and the 2016 Central Italy earthquake have once more highlighted the high combination of exposure and vulnerability of South European cities, with an increasing trend expected in the next decades as the effects of climate change will further intensify. The range of impacts of natural, environmental, and anthropic risks on cities is broad and entails both direct, physical damages to built-up structures and indirect consequences on services and the socio-economic fabric. Urban and metropolitan areas can be seen as adaptive systems characterized by complex interactions among their inhabitant and the surrounding infrastructure, explaining the increasingly common comparison with living organisms. In Figure 1, for instance, the 'urban metabolism' (waste and emissions) refers to the flows necessary to satisfy the needs of those living in cities in different environment layers (local, regional, and global environments). This metabolism, seen as human actions

[1] Available at https://www.eea.europa.eu/soer/2015/europe/urban-systems

(technology, labor, waste, and emissions) on the various natural systems (soil, water, air, etc.) and artificial systems (human-made systems), results in consequences (positive and negative).

On the other hand, society, defined as a group of people living in the same space and at the same time, following a set of implicit and explicit norms, assigns values to the urban system, considering the physical components as well as the services and the governance components.

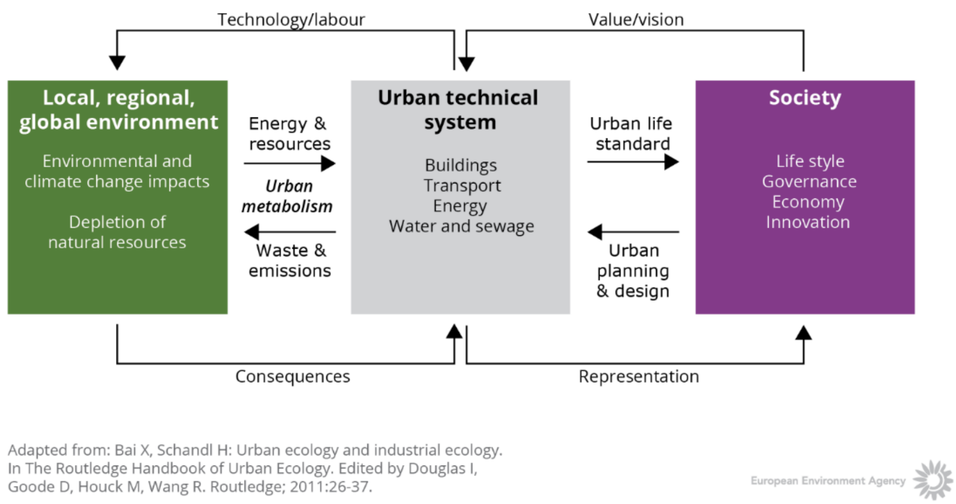

Figure 1 Urban system schema

It emerges, hence, the need for considering as key components of the urban system, alongside the population, the so-called *'grey'*, '*green'* and '*soft'* infrastructure'.

The '*gray infrastructure*' includes artificial, physical features such as roads, metros, railways, buildings, and utilities (European Commission 2012), (OECD 2022).

'*Green infrastructure*' refers instead to all components of the urban system with natural or semi-natural aspects, often to provide social, ecological, and economic benefits to the urban population such as air filtration, temperature regulation, noise reduction, flood protection, and recreational areas (European Environment Agency 2011), (European Commission 2013), (Dige et al. 2014).

'*Soft infrastructure*' includes all the services that are required to maintain the economic, health, cultural, and social standards of a population, as opposed to the hard infrastructure, which is the physical infrastructure of roads, bridges, etc. It includes both physical assets such as highly specialized buildings and equipment, as well as non-physical assets, such as communication, the body of rules and regulations governing the various systems, the financing of these systems, the systems and organizations by which professionals are trained, advance in their careers by acquiring experience, and are disciplined if required by professional associations. It includes institutions such as the financial and economic systems, the education system, the health care system, the system of government, and law enforcement, and emergency services. The explicit consideration of soft infrastructure is increasingly considered as key to improve the resilience of complex urban systems (e.g., Pagano et al. 2018).

The high concentration of people and economic activities in cities cause environmental pressures. Yet cities can be planned, designed, managed, and governed in an increasingly efficient way. The European Union (EU) has significantly impacted urban development through its cohesion and sectoral policies, including those addressing water, waste, noise, and air. The Thematic Strategy on the Urban Environment[11] and the recent 7th Environment Action Program (7th EAP) [12] advocate for integrated urban policy.

This could also apply to the principles of urban development in the EU as expressed in its 'Territorial Agenda of the European Union 2020'.[13] An intergovernmental process, coupled with the practical experiences gained through the European Regional Development Fund (ERDF), has led to clear principles of urban development. This is known as the *acquis urbain*[14].

1.1 Urban Structure (to be updated by Daniele)

In this document we approached the conceptualization of urban systems from an abstract perspective, which aims at categorizing and describing the individual subsystems of the urban area (as a complex system) and their relationships, rather than addressing the different spatial patterns to be observed over different geographical scale. This is of course a relevant characteristic which is strongly correlated to the exposure and vulnerability of urban areas to different hazards, and eventually to the related risks. There are approaches to defining elements of an urban form as organized from macro to micro scale, as, for instance, indicated in the "Creating Places for People – An Urban Design Protocol for Australian Cities" (Department of Infrastructure and Transport 2011):

- **Urban structure:** The overall framework of a region, town, or precinct, showing relationships between zones of built forms, landforms, natural environments, activities, and open spaces. It encompasses broader systems including transport and infrastructure networks.
- **Urban grain:** The balance of open space to build form and the nature and extent of subdividing an area into smaller parcels or blocks. For example, a "fine urban grain" might constitute a network of small or detailed streetscapes. It takes into consideration the hierarchy of street types, the physical linkages, movement between locations, and modes of transport.
- **Density and mix:** The intensity of development and the range of different uses (such as residential, commercial, institutional, or recreational uses).
- **Height and massing[2]:** The scale of buildings concerning height and floor area and how they relate to surrounding landforms, buildings, and streets. It also incorporates the building envelope, site coverage, and solar orientation. Height and massing create a sense of openness or enclosure and affect the amenity of streets, spaces, and other buildings.
- **Streetscape and landscape:** The design of public spaces such as streets, open spaces, and pathways, which includes landscaping, microclimate, shading, and planting.
- **Facade and interface:** The relationship of buildings to the site, street, and neighboring buildings (alignment, setbacks, boundary treatment) and the architectural expression of their facades (projections, openings, patterns, and materials).

[2] Massing in architecture refers to the perception of the general shape and form as well as size of a building.

- **Details and materials:** The appearance of objects and surfaces, the choice of materials, and their respective details, craftsmanship, textures, colors, durability, sustainability, and treatment, all impact the public and private domain. This includes structures, space, street furniture, paving, lighting, and signage, which collectively improve human comfort, safety, and enjoyment.
- **Public realm:** Much of urban design is concerned with the design and management of publicly used space and the way this is experienced and used. The public realm includes the natural and built environment used by the public on a day-to-day basis such as streets, plazas, parks, and public infrastructure. Some aspects of privately owned space such as the bulk and scale of buildings, courtyards, and entries that are traversed by the public or gardens that are visible from the public realm can also contribute to the overall result. At times, there is a blurring of public and private realms, particularly where privately owned space is publicly used.
- **Topography, landscape:** The natural environment includes the topography of landforms, water, and environment.
- **Social and economic fabric:** The nonphysical aspects of the urban form include social factors (culture, participation, health, and well-being) as well as the productive capacity and economic productivity of a community. It incorporates aspects such as demographics and life stages, social interaction, and support networks.

1.2 Relationships with Climate and Disaster Risk

In accordance with IPCC (IPCC 2022; IPCC et al. 2014) and ISO (ISO/IEC 2018; 2019), and acknowledging the different interpretation of this concept across the Disaster Risk Reduction community (see also the enclosed Glossary) we define **Risk** as "the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems". Risks can arise from the potential impacts of natural, environmental and anthropic hazards, including the impacts related to climate change and the human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social, and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems, and species.

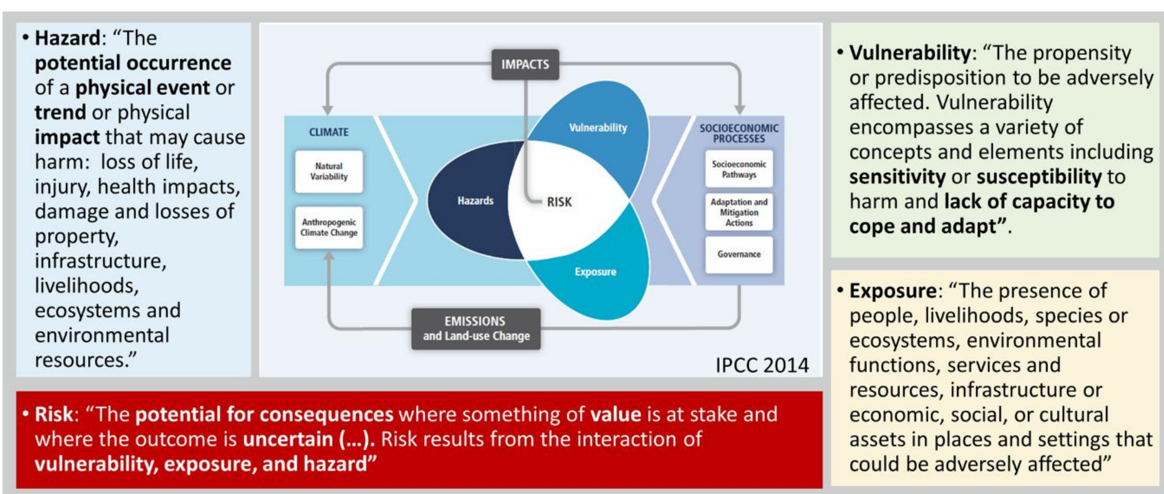

Figure 2 Definition and graphical depiction of Risk according to IPCC.

Risks result from dynamic interactions between **hazards** with the **exposure** and **vulnerability** of the affected human or ecological system to the hazards (see Figure 2). Hazards, exposure, and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socioeconomic changes and human decision-making. In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs).

Considering the definition above, urban areas are contributing to risk mostly from the exposure and vulnerability perspective. In fact, cities represent a spatially dense and extended concentration of people, built assets and infrastructure that are exposed to a variety of hazards (e.g., earthquakes, floods, heatwaves) and susceptible to incur physical damages. Moreover, being often the urban areas the core of social, cultural, and economic activities, their exposition also includes those intangible assets related to service provision, socio-cultural and economic capital. This exposure is furthermore not static but can dynamically change according to high (day and night, weekends), medium (seasons) as well as long (decadal) frequency cycles and trends.

Due to the high density of population and construction, cities are particularly sensitive to climate change (EEA 2009). On the other hand, cities as built environments and socio-ecological systems are responsible for GHG emissions that intensify climate change (TCPA 2007). Consequently, the climate-responsible approach to urban development emphasizes the need for activities to minimize negative impacts on climate and the need for cities to adapt to the consequences of climate change that cannot be avoided."

Impacts due to climate change in cities are broad and can be grouped according to three main urban components, namely grey infrastructure, green infrastructure, and human health and comfort:

- **Grey infrastructure.** Both buildings and infrastructure are at risk of increased coastal, fluvial, and pluvial floods as well as shrinking and swelling of the ground erosion. This is stimulated by sea-level rise, increased storminess, and increased winter precipitation. These impacts depend on the type of urbanization, which alters natural hydrological regimes by reducing the infiltration capacity of the ground (Handley and Carter 2006). Severe heatwaves can also strongly affect the integrity of different transport infrastructure, e.g., due to damage to bridges and airport runways and buckling of tram and railway tracks (e.g., Mulholland and Feyen 2021).
- **Green infrastructure** is important for improving the climate conditions and combating the threats induced by climate change, but it can also be affected by the change of climate. Expectations that climate change will lead to more droughts in summer mean that there will be a greater need for urban green spaces to be watered. Limited water resources may cause problems in managing and effectiveness of urban green space, and therefore various methods that allow rainwater harvesting, reuse of gray water, and making use of water in rising aquifers under cities should also be employed (Gill et al. 2007).
- **Human comfort and health** in urban areas are threatened due to rising temperatures and more intense meteo-climatic events associated with heatwaves, windstorms, landslides, and flooding. The adaptive capacities of different communities and groups vary, and vulnerable groups, such

as elderly and poor inner-city residents, will be disproportionately affected by climate change (Handley and Carter 2006). It can be expected that climate change will affect people's demand for, use of, and experience of open space (CABE 2008). Natural venting and shading, accessibility, quantity, and quality of green and blue space areas, which can moderate temperatures and enhance human comfort, are for that reason of main importance (Živković and Lalović 2011)."

Table 1 The link between policy and urban climate scales (Živković 2019).

Physical scale	Policy scale	Urban climate scale
Individual building/street (facade and roof construction materials, design and orientation)	Building regulations and building control Urban design strategy Local development framework	1–10 m Indoor climate and street canyon
Urban design (arrangement of buildings, roads, green space)	Urban design strategy Area action plan Local development framework	10–1000 m neighborhood scale, suburban variations of climate
City plan (arrangement of commercial, industrial, residential, recreational, and green space)	Subregional spatial strategy Regional spatial strategy	1–50 km city/metropolitan scale, UHI form and intensity

1.3 Modelling approaches

Different approaches can be pursued in the modeling of complex systems such as cities and metropolitan areas, as well as different interpretations of what a model should be. From the perspective of this project, a model is one of several possible representations of a specific portion of the real world driven by the scope of the model itself. In our case, the scope is to represent an urban system exposed to a variety of hazards in such a way as to capture the most relevant impacts and assess the related risks in a consistent and sustainable way. In our case, the scope is to represent an urban system exposed to a variety of hazards in such a way as to capture the most relevant impacts and assess the related risks consistently and sustainably. The model will therefore not include all possible details and features of the physical world, but only those that are relevant to fulfill its scope.

Models can be formal or informal, physical, or abstract, descriptive, or analytical. A *physical model* is a simplified material representation, usually at a reduced scale, of an object or phenomenon that is the subject of investigation. For instance, maquettes in architecture or physical models to simulate the tsunami impacts.

On the other hand, an *abstract model* is a simplified representation without the use of tangible elements. Like physical models, abstract models represent a slice of the real world using abstract languages, i.e., logic, mathematics, etc. Mathematical models are classified as analytical models, and logical models are classified as descriptive models. *Analytical models* can be further divided into dynamic and static models. *Dynamic models* describe the time-varying state of a system, its behavior, and its functionalities; conversely, *static models* do not represent the time-varying state of a system but rather describe the structure of the system or the phenomenon, which is considered less likely to change than the functions of the system.

While many models are developed to describe and represent physical systems (and as such are referred to as *descriptive models*), in some cases they can extended into *predictive models*. A predictive model, when applied to a set of input data, can identify patterns and predict what might happen. By identifying patterns in structured and unstructured data, predictive modeling improves decision-making by providing more plausible scenarios. For predictive analysis to be effective, however, it is necessary to have a significant amount of valid data - complete and without errors - and to use a predictive model that is appropriate for the type of data available, and the goals assigned.

There are two main types of predictive models: supervised and unsupervised. In the former, input and output data are entered and the model searches for relationships between the data after a training phase, which allows to identify of the level of accuracy of the mathematical function adopted. In the unsupervised model, only input data is entered and the model's function is to identify existing patterns in the analyzed data and to predict possible trends and events that may recur.

In the project RETURN, we aim at building a predictive, dynamic model of impacts and risks in urban environments, able to be operationalized in a set of real-world cases. This requires, in turn, a development path that entails a first conceptual and logical descriptive modeling of the main components, which will be further enhanced by modeling the underlying relationships and processes.

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In outlook, a further modeling phase that should be considered is related to so-called prescriptive modeling which also includes descriptive and predictive analytics and entails the application of mathematical and computational sciences to suggest decision options for how to take advantage of the results of descriptive and predictive phases.

Regarding the representation type, models are classified as graphical, iconic, or symbolic models. An *iconic model* is a match representation of some specific entity, for instance, the icon  represents a person. On the other hand, a *symbolic model* is the representation of entities of a system by mathematical or logical symbols. Finally, *graphical models* are the representation of probabilistic relationships among a set of variables. For instance, state machines are a set of nodes (states) and edges (transition actions). Other examples of graphical models are visual modeling languages, such as UML and OntoUML, which produce diagrams that use graphical notations to express the slice of reality. In Ontologies (Section 9), the diagrams were designed using OntoUML[3]. The ontological models were designed considering the perspective of risk in urban systems. For example, in the sub-ontology of population, it represented some types of non-human populations that can impact a city (e.g., For example, in the sub-ontology of population, represented some types of non-human populations that can impact a city (e.g., viruses, bacteria). In this case, it was decided to classify populations into human and non-human, artificial and natural.

[3] For further information on OntoUML and how to read and understand the notation used in the models, see Appendix C – Basic Notions on UFO and OntoUML.

2. Methodology: Towards a Risk-Oriented Conceptual Model of Urban Environments

To tame the challenges related to the intrinsic complexity of the system to be addressed, it is proposed that a perspective focusing on the potential risks is employed. A set of physical/risk storylines are therefore developed to identify, collaboratively and incrementally, the set of elements (including all physical, technological, and socio-economic components) that should be prioritized in the conceptualization and later refined or integrated with additional components. This is carried out within a three-tier procedure:

1) Initial identification of main systems/subsystems and exposed elements (including functions)
2) Development and analysis of risk storylines
3) Critical review and refinement/updating of the conceptual model.

The steps described above can be iterated multiple times, e.g., by adding further storylines addressing specific combinations of events and or cascades of impacts, hence describing different (multiple) risks.

2.1 Method Applied to Ontology Engineering

To design the ontology of urban systems driven to risks, it is planned to implement cycles of sprints with the following steps: 1) Requirement elicitation with experts of each domain; 2) Creating vocabulary with the main concepts (naming), negotiating meanings (semantic level), and establishing some foundational theories to base the design of the domain ontologies and the taxonomies. 3) building taxonomies based on the vocabulary; 4) designing the mentioned ontologies using a foundational ontology to ground on them as well as a set of theories for each sub-domain represented in the sub-ontologies; 5) validating the models (an approach bottom-up using storyline and data it will be used in the development cycles); 6) releasing and reviewing the designed artifacts. Also, it is planned to use data from real databases to build knowledge graphs in the last cycles. Finally, the launch and delivery of the artifacts produced in each cycle. With the analysis of the delivered artifacts will be possible to decide if the expected granularity has been achieved. In case of not, another cycle restarts.

The number of cycles/sprints will be determined by the expected granularity to be achieved with the project. Figure 3 shows the main steps of each cycle, including the requirement elicitation for each sub-ontology.

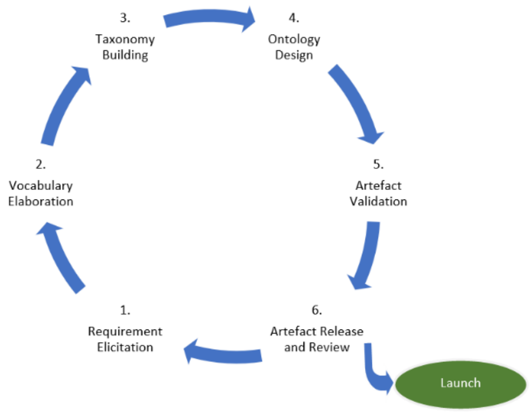

Figure 3 Ontology and taxonomies engineering phases

Step 4 – Ontology Design – is composed of the following sub-steps: 4.1) ontology-driven conceptual modeling using UFO/OntoUML; 4.2) Debugging (syntactic verification); 4.3) Operational Ontology generation using gUFO[1] to generate a turtle file[2] (Appendix C - Operational Ontology – gUFO/OWL – Sub-ontology of Population). This design cycle aims to arrive at an open-source RDF database to be filled with data as shown in Figure 4.

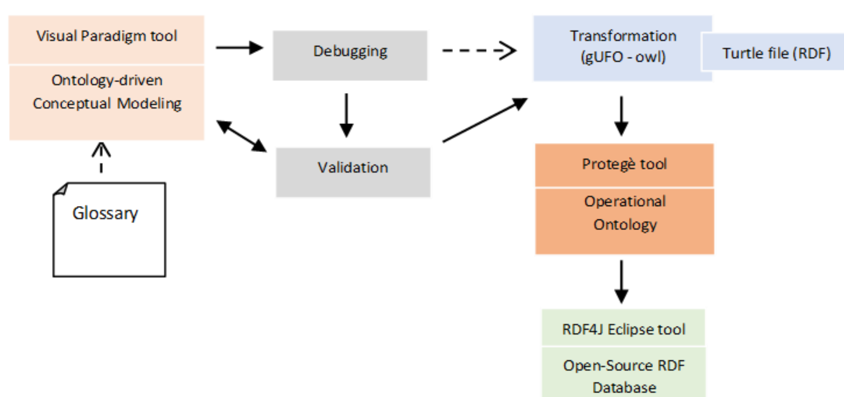

Figure 4 Development Schema - from a glossary to RDF database

3. A Conceptual Model of the Urban System

The initial urban system model is shown in Figure 5 and is approaching a set of nested, mutually exclusive, and collectively exhaustive classes. The system consists of two primary components. one concerning the human (the social component) as well as the non-human population. This represents the 'living' component of the urban system, and arguably the population is indeed the core of the urban system. The other main component is indicated generally as the 'infrastructure' to include all non-population elements to be found in an urban system. This component is further divided into hard infrastructure, which includes all physical components such as roads, metros, railways, buildings, and utilities, and soft infrastructure, which includes the set of relevant functions necessary for the ordinary and extraordinary management of the urban system, for instance, health, emergency, law enforcement, mid-term services (e.g., waste management), and long-term services including educational and recreational.

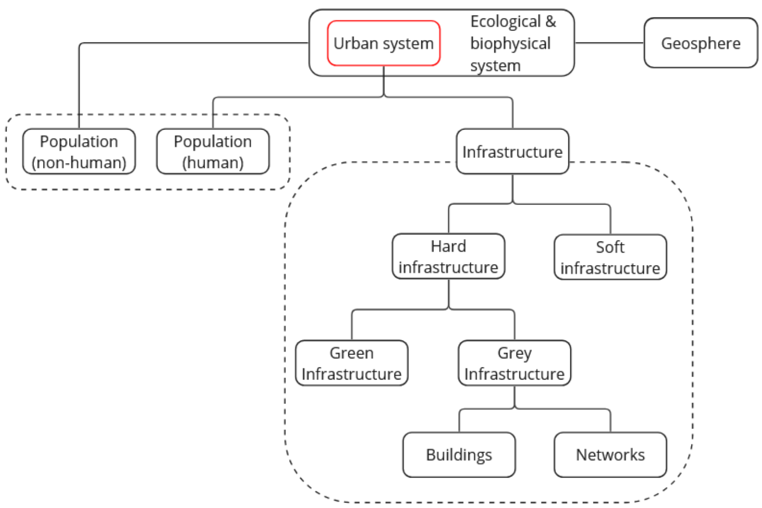

Figure 5 Conceptual model of urban system and corresponding subsystems

'*Green infrastructure*' refers to all components of the urban system with natural or semi-natural aspects, often to provide social, ecological, and economic benefits to the urban population such as air filtration, temperature regulation, noise reduction, flood protection, and recreational areas (European Environment Agency 2011), (European Commission 2013), (Dige et al. 2014).

In the next sections, these individual components will be analyzed and discussed in terms of the available taxonomies useful to describe them in the context of risk assessment.

4. Taxonomies for Urban Systems

The purpose of taxonomies is to provide a sound and systematic framework for the classification/ categorization of the individual elements and sub-systems of a complex system. Such categories allow for a more harmonized description of the overall system both at the conceptual level and in practical terms.

In the context of RETURN, the ultimate objective of all endeavors is to offer a comprehensive structure for evaluating urban and metropolitan areas' natural, environmental, and anthropic risks. The primary focus is on Italy, but with a future expansion and adoption of the proposed approach on a European level.

Within this context, is paramount to provide an operative conceptual framework within which to develop further specific approaches and tools, rather than seeking for a "perfect" solution encompassing all potential situations and the whole complexity of urban environments.

4.1 Human Population

The human population of a city can present different characteristics according to the geographical and socio-economic context of its belonging.

What profoundly influences the characteristics of those who inhabit and frequent it are the type of productive activities present, the conformation of the natural environment, and social and historical stratification. Furthermore, the taxonomy of an urban population can be understood as a set of categories that picture aggregated (e.g., number of residents, birth rate, etc.), as well as individual characteristics.

An attempt at generalization can be made if we look at the context of advanced capitalist countries, particularly European ones, where urban contexts while presenting heterogeneity in many areas, are subject to common pressures (e.g., incoming migratory flows from the global south, effects of technological innovation, ecological conversion of public services, etc.) and present recurrences in certain macro-characteristics (aging of the population, welfare restructuring, etc.). Furthermore, a generalization of the urban population can be carried out from its greater or lesser exposure and vulnerability to the effects of climatic and environmental risks.

Our proposal is to start a taxonomy of the urban population from three principles of identification, focusing on segmentations that concern individuals rather than the whole aggregate: 1) socio-demographic characteristics; 2) physical-cognitive and socio-economic characteristics; and 3) socio-cultural characteristics. We propose to start a taxonomy of the urban population from three principles of identification, focusing on segmentations that concern individuals rather than the whole aggregate: 1) socio-demographic characteristics; 2) physical-cognitive and socio-economic characteristics; and 3) socio-cultural characteristics.

An operationalization of the individual categories is in progress. Some examples are described below:

1. **Socio-demographic characteristics:** gender; long term population (resident, dweller, commuter); short term (tourist, city users; seasonal); belonging to macro age classes (0-14; 15-65; over 65); native; migrant; citizenship; marital status; property ownership; ownership of work activities.

2. **Psycho-cognitive and socio-economic characteristics**: 2.1 Physical-cognitive vulnerability: visual disability; motor; cognitive; hearing disability; 2.2. Socio-economic vulnerability: income (absolute and relative poverty threshold); occupation (permanent, temporary, unemployed, inactive); housing condition (owner, renter, evictor); beneficiary of social assistance; car ownership; resident in housing unit with no. people.

3. Socio-cultural characteristics: level of education; linguistic competence in Italian or English (native, fluent, intermediate, etc.:).

4.2 Non-Human Population

Although the concentration of humans is a defining feature, urban areas typically contain numerous opportunities for the persistence of native nonhuman species as well as the invasion or introduction of exotic species. Similarly, although a height built-over land is often used to identify areas as urban, urban land is far from impervious and often includes a range of different land use types, including gardens, grassland, wooded land, and agricultural land. There is a wide range of animal species that can live in urban communities. Animals can be kept for company as pets, others for production purposes, but animals can also be wild, including pets, or they can be synanthropic, originally wild but adapted to live in proximity to human settlements where they can find favorable conditions (Figure 6).

Companion animals primarily consist of dogs and cats, but other species like caged birds, small rodents, reptiles, and carnivores are also included. The urban pet population is rising due to improved living conditions, social diffidence, and the need for companionship and protection. Companion animals are particularly close to people with whom they continuously interact, therefore pets can be direct or indirect disease and injury vehicles, but also act as important indicators for monitoring the presence of hazardous biological and chemical pollutants.

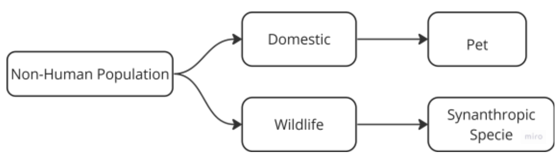

Figure 6 Taxonomy of non-human population

Animals kept in Italian urban areas for production purposes are rare. Cities seldom contribute to the production of their food, which is often subsidized; generally, they simply consume it. However, the incorporation of former peri-urban areas in cities can include farms and land plots. Urban breeders can be more common when dealing with companion animals, particularly of small sizes, such as rodents or fish.

Wild animals have found favorable habitats in urban areas due to the availability of resources and the destruction of natural habitats. As a general trend, the number of wild species that have adapted to urban living near human settlements has significantly increased, coinciding with the rise in urbanization. Some wild species have evolved to become entirely dependent on urban habitats, for example, synanthropic animals are birds such as pigeons or sparrows. Other species have a minor degree of familiarity with humans and might take different advantage of human food subsidies or refuge from predators, they might even not benefit or be harmed by the urban environment. A common thread is that they favorably use recreation parks, rivers, and other green spaces, and their presence, while it can contribute to biodiversity, such as bees, can also produce property damage and transmit diseases. In the last decades, the urban environment has also seen an increase in exotic species that can become economic and public health concerns. Synanthropy, therefore, is a behavioral disposition (intrinsic aspect) that some animals develop to survive.

4.2.1 Taxonomy proposal

Table 2 presents a proposed taxonomy for populations from the perspective of risk-oriented urban systems. From this point of view, it is important to have data and information on not only human populations but also animal and plant populations living in the urban context. Thus, the classification was initially made considering the nature of the being - human or non-human. Then, the roles that people play in urban centers, for example, residents, tourists, commuters; or the stages of life that these people are in, for example, whether they are children, young people, adults, or the elderly. It is also important to know the population of animals and plants that somehow exist in the urban context and can be risk factors, for example, wild animals that, out of a desire to survive, move closer to urban centers. In addition, the characteristics presented in Section 4.1 can be included in the models (Section 9) as attributes of an object, as roles or phases, or as dispositions they take in relationships with the human element in the urban context.

Table 2 A proposal for risk-oriented population taxonomy in urban contexts

POPULATION	**Human Population**	Resident Population	
		Non-Resident Population	Tourist population
			Commuter population
			City user population
	Non-Human Population	Pet Population	
		Wild Population	Synanthropic population
		Plant Population	
		Mobile Genetic Element Population	Virus population
		Fungus Population	Mold population
		Bacterial Population	

In addition to classifying populations, it is also important to classify the agents that exist in the urban context. A population is a collection of things that can be people, animals, plants, viruses, bacteria, etc. In Table 3 we propose a classification of these elements, calling them agents, i.e., all beings that act or do not act in an urban system. Agents can be natural or artificial. Natural agents are those not constructed by humans (e.g., people, animals, plants, viruses, bacteria, or any form of biological life), while artificial agents are human constructs, such as, autonomous systems, institutions, etc.

Table 3 A proposal for risk-oriented agent taxonomy in urban contexts

AGENT	**Natural Agent**	Person	Resident Person	
			Non-Resident Person	Tourist
				Commuter
				City user
		Non-Human Being	Pet	
			Wild	
			Plant	
			Mobile Genetic Element	Virus
			Fungus	Mold
			Bacteria	
	Artificial Agent	Institutional Agent		

4.3 Geosphere

The geosphere is the collection of physical and geological elements that contribute to the shaping of the Earth's surface. In the urban environment the geosphere represents the foundation background where the population and infrastructure develop so that the geosphere elements influence them, but in turn population and infrastructure can also modify the geosphere. For example, urban development and even risk mitigation often involve excavation which interact and often modify the underlying geology. For this reason, urban development requires an understanding of the local geology, such as soil stability, groundwater conditions, and subsurface characteristics.

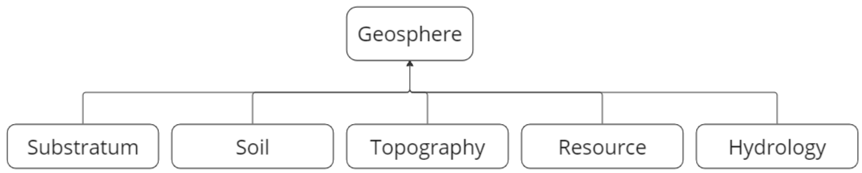

Figure 7 Basic notions of the geosphere

Individual elements (Figure 7) that contribute to the geosphere framework are:

- Geologic substratum: The geologic substratum, such as bedrock or sediments are usually covered by layers of urban infrastructure and buildings, even though they can still outcrop both naturally and through excavation – for example, tunnel escarpments. Urban development requires a thorough understanding of the geotechnical properties of the underground, including its stability, load-bearing capacity, groundwater conditions, and suitability for construction. This knowledge is crucial for construction projects, foundation design, and infrastructure development in urban areas.
- Soil: The soil forms the uppermost layer of the Earth's crust. Its thickness can vary from a few millimeters to several meters depending on the geological, climate, topographic, and biological characteristics of the area. Soil commonly lies at the interface between the solid Earth and the atmosphere. While soils are usually a natural, complex, and dynamic mixture of mineral particles, organic matter, water, air, and living organisms, in urban areas they have distinctive composition and characteristics due to human activities, such as the addition of concrete, asphalt, construction debris, and pollutants. Urban soil may have higher levels of contaminants and altered physical properties.
- Topography: Elevation, slope, and landforms, such as mountains, valleys, plains, rivers, lakes, and coastlines, encompass both natural and urban areas. In urban areas, topography can also result from construction and excavation while the landforms can also include the presence of man-made features like roads, buildings, artificial canals, and infrastructure. Human activities can modify natural landforms, but in some instances, they can still exist or be preserved in parks, green spaces, or protected areas within the city.
- Hydrology: The urban environment has an altered hydrological system due to the extensive paving and engineered, which affects the water cycle, including surface runoff, infiltration, and groundwater recharge.

Additionally, urban areas may have had or still have valuable resources that can be economically exploited. Apart from urban mining, which involves extracting materials from built environments, such as recycled metals or construction materials, some urban areas may still contain geological resources that are exploited or utilized, such as quarries for construction materials or groundwater resources for drinking water. Lately, due to technological improvements linked to sustainability, urban areas are seeking to exploit geothermal energy and solar systems for heating and cooling systems and for power production. This involves harnessing the natural heat stored in the substratum using geothermal wells or ground-source heat pumps, or using urban surfaces, preferentially well-exposed natural or man-made slopes.

In the building process of the Geosphere taxonomy, we made an effort to catch the variability of the geological system (and related thematic areas) while simplifying the variety of processes that contribute to shaping the geological environment in urban settings. The aim of the proposed taxonomy is not to provide extreme details of every single component of the geosphere but rather suggest a simplified and therefore usable characterization of the system. The proposed approach considered the four above-mentioned thematic areas, following a top-bottom rationale: starting from the outer "sphere" we propose a taxonomy for hydrological processes, shaping the Earth's surface (but interacting also with the subsurface sphere). Hydrology interacts with the "topography", contributing to the shaping of landforms and the "soil" sphere. Finally, the geologic substratum lies in the subsurface and represents the hard base for urban settlements. These four thematic spheres, not only interact but influence or are conversely influenced by the urban system. A proper, yet simplified, taxonomy, therefore, allows to catch and describe possible interactions. A proper, yet simplified, taxonomy, therefore, allows us to catch and describe possible interactions.

To build a coherent taxonomy, we have been inspired by what has already been proposed in the literature. Nonetheless, for the specific purposes of the task (i.e., building risk-oriented taxonomies), a simplification was required, and several "ramifications" were not considered. Such simplification is required to maintain the focus of the geosphere taxonomy on the "risk" factor. Therefore, several distinctions that may be considered e.g., in the "subsurface" taxonomy were avoided, as not functional to the risk evaluation.

In detail, we simplified the hydrology taxonomy (Table 4) from the work by McMillan (2022). The mentioned taxonomy focused on the description of the hydrological processes shaping Earth's surface and subsurface. The Author group hydrological processes into three main classes (i.e., "surface", "subsurface" and "channel" processes) to then declare second-order hydrological processes. Further specifications provided by the Author were not considered in our taxonomy for the above-mentioned reasons.

Table 4 Hydrological processes taxonomy (modified from McMillan, 2022)[4].

Hydrology	Surface	Evapotranspiration	Evaporation
			Transpiration
		Interception	Interception
			Streamflow
			Throughfall
		Snow	Canopy snow interception

[4] 4th rank ramification (in grey) from McMillan (2022) is reported for completeness, but for the sake of "usability" in the frame of a risk-oriented taxonomy, we decided not to use it.

			Canopy snow unloading
			Infiltration into snow
			Snow storage
			Snowpack aging
			Snow drifting
			Snowmelt
			Refreezing
			Sublimation
		Glacier	Glacier storage
			Glacier melt
		Frozen ground	Permafrost storage
			Inter hummock channel flow
			Seasonal soil freeze/thaw
			Infiltration into frozen ground
		Overland Flow	Saturation excess flow
			IE flow
			Rill flow
		Infiltration	Infiltration
			Soil surface processes
		Surface water	Detention storage
			Depression storage
			Lake storage
	Subsurface	Soils	Soil water storage
			Vertical matrix flow
			Vertical macropore flow
			Lateral unsaturated flow
			Mixing
			Hydraulic redistribution
			Vertical drainage to groundwater
			Vapor diffusion
		Subsurface stormflow	Organic layer interflow
			Lateral matrix interflow
			Lateral macropore flow

			Variable source area – subsurface stormflow
			Topographic convergence
		Groundwater	Groundwater loss
			Return flow
			Groundwater storage
			Infiltration into bedrock
			Displacement of groundwater
		Stream Groundwater	Connectivity
			Losing stream
			Gaining steam
	Channel	Channel interception	
		Channel extension	
		Channel storage	Bank storage
			Riparian aquifer storage
		Channel flow	Perennial flow
			Ephemeral flow
			Intermittent streamflow
			Quick flow
			Diurnal cycles in streamflow
		Hyporheic flow	
		Attenuation	

Topography taxonomy (Table 5) was modified from the work by Varanka (2009). The author provides a classification of landforms that can be used for describing what in the frame of the TS1 lexicon, is what is usually referred to as "morphology". In addition to this taxonomy (originally meant to catch the variability of landforms associated necessary to build topographic maps) were necessary to correctly catch the variability of specific processes shaping the topography, that may bear intrinsic risk factors. An example of an addition made to the original taxonomy is represented by the "tectonic" taxonomic group. This category, originally not considered by Varanka (2009) is necessary to describe important morpho-tectonic features that for their nature, are associated with fault, e.g., "horst" and "graben". These morpho-tectonic structures generated by fault activity are key features to recognize when characterizing an urban environment: by generating tectonic depressions in fact, they often host urban settlements that are therefore exposed to seismic (and associated) risks. A classic example of this setting is represented by the Firenze-Prato-Pistoia cities, hosted in a semi graben tectonic context. A classic example of this setting is represented by the Firenze-Prato-Pistoia cities, hosted in a semi- graben tectonic context. The presence of potentially active faults bounding the tectonic depression increases the associated seismic risk. A final remark on topography taxonomy is to be made in agreement with what was proposed by Varanka (2009): "Some geologic features are included in this taxonomy because topographic features may correlate with or correspond to them. Either as corresponding units or as generative forces for particular topography, geologic features are characterized on the Earth's surface in a way that is consistent with the criteria of this taxonomy to describe features that are cognitively easy to identify."

Table 5 Topography taxonomy (modified from Varanka 2009)[5].

Topography*	Glacial	U-valley
		Moraine
		Cirque
		Suspended valley
		Horn
	Fluvial	plain
		floodplain
		V-valley
		bench
		channel
		Delta
		fan
		Fumarole
		Terrace
		Isthmus
		Bar
		Oxbow
	Volcanic	Cone
		Volcano
		Lava flow
		Crater
		Scoria cone
		Tunnel
		Shield volcano
		Stratovolcano
		Caldera
	Coastal & Marine	Coast
		Cliff
		Island
		Pinnacle
		Peninsula
		Dune

[5] In the context of TS1 lexicon, topographic landforms are what is usually referred to as "morphology".

		Beach
		Shore
	Tectonic	Graben
		Semi-graben
		Horst
		Basin
		Scarp
	Relief	Mount
		Mountain range
		Ridge
		Hill
		Plateau
		Peneplain
		Gorge
		Divide
		Elevation

The construction of soil taxonomy (Table 6) cannot overlook a preliminary crucial disambiguation: the term soil can be intended with at least two different meanings. A first definition of soils can consider paedogenesis processes, that transform the inert regolith (sensu Neuendorf, 2005) into a mixture of organic and inorganic particles potentially supporting life. Nonetheless, the engineering concept of soils does not deal with the intensity of paedogenesis and rather characterizes soils as a function of grain composition, granulometry, and mechanical property. Nonetheless, the engineering concept of soils does not deal with the intensity of paedogenesis and rather characterizes soils as a function of grain composition, granulometry, and mechanical properties. This corresponds to the Unified Soil Classification Systems (referring to ASTM Standards D2487 and D2488). In the context of risk assessment, we believe that such classification better constrains soil variability to the aim of the taxonomic process. For this reason, we adopted the USCS taxonomy. Nonetheless, the paedogenesis concept of soils is still included in the USCS classification under the taxonomic group "highly organic soils".

Table 6 Soil taxonomy. NB. soils according to USCS correspond to the engineering concept, which does not dealing with the type and intensity of paedogenesis – which is the Italian common meaning when dealing with soils. soils according to USCS correspond to the engineering concept, which does not deal with the type and intensity of paedogenesis – which is the Italian common meaning when dealing with soils. In Italian common use, the USCS soils would.

Soils (USCS)*	Coarse-grained soils (>50% is larger than No. 200 sieve size)	Gravels	Clean Gravels (<5% of fines)	Well-graded gravels, gravel-sand mixtures, little or no fines
				Poorly graded gravels, gravel-sand mixtures, little or no fines
			Gravels with fines (>12% of fines)	Silty Gravels, gravel-sand, silty mixtures
				Clayey gravels,

				gravel-sand-clay mixtures
		Sands	Clean Sands (<5% of fines)	Well-graded sands, gravelly sands, little or no fines
				Poorly-graded sands, gravelly sands, little or no fines
			Sands with fines (>12% of fines)	Silty sands, sand-silt mixtures
				Clayey sands, sand-clay mixtures
	Fine-Grained soils (>50% is smaller than No. 200 sieve size)	Silts and Clays - liquid limit < 50%	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with sight plasticity	
			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
			Organic silts and organic silty clays of low plasticity	
		Silts and Clays - liquid limit > 50%	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	
			Inorganic clays of high plasticity, fat clays	
			Organic clays of medium to high plasticity	
		Highly organic soils	Peat and other highly organic soils	

What lies beneath soils can be defined as a substratum (Neuendorf, 200; Table 7), and therefore corresponds to the subsurface portion of the Geosphere. The taxonomy of the substratum is aimed to describe the variability of rocks and terrain types, which may be relevant to the geological and engineering characterization finalized to risk assessment. The taxonomy of the substratum is aimed to describe the variability of rocks and terrain types, which may be relevant to the geological and engineering characterization finalized for risk assessment. We, therefore, distinguish “terrains” (corresponding to the above-mentioned definition) and “rocks”. Besides these, “discontinuities” can describe and include risk-relevant categories such as “breaks”, that comprehend fault. With this latter group we include all those brittle discontinuities that may be capable of increasing risk associated with the movement of rock and terrain materials, therefore faults, slide surface, etc. With this latter group, we include all those brittle discontinuities that may be capable of increasing risk associated with the movement of rock and terrain materials, therefore faults, slide surface, etc. Substrate taxonomy is based on and simplified from BGS (British Geological Survey) Rock classification system (British Geological Survey, 2020). Substrate taxonomy is based on and simplified from the BGS (British Geological Survey) Rock classification system (British Geological Survey, 2020).

Table 7 Substratum taxonomy (modified from British Geological Survey, 2020) This refers to the "soil" as defined in the table above.*

Substratum	Terrains*	(Seem Terrains taxonomy)	
	Rocks	Sedimentary	Classic
			Organic
			Chemical
		Igneous	Coarse-grained crystalline
			Fine-grained crystalline
		Metamorphic	Foliated
			Non-foliated
	Discontinuity	Interfaces	Primary interfaces
			Secondary interfaces
		Breaks	Chemical-solution breaks
			Deformation breaks

Finally, inextricably linked with the geosphere, are resources (USGS, 1980; Neuendorf, 2005). To provide a usable simplified classification, we grouped geosphere-related resources into three main groups (Table 8): "water", "materials" and "Energy". With these three simple categories, we provide a synthetic picture of possible resources impacting urban settlements. Among explicit meanings of some definitions (e.g., water resources, energy resources), further explanation is required for what we here call "materials". In this class, we aim to group all those geological materials not related to the energetic concept. As an example, with the term "construction" we include all those geological materials necessary to the building and maintenance of urban settlements, that may be exposed to multi-risk.

Table 8 Resources (sensu USGS, 1980 and Neuendorf, 2005) taxonomy.

Resources	water	Drinking water
		Agriculture
		Industry
	material	Construction
		Mineral and elements
		CO2
		Ornamental stones
	Energy	wind
		solar
		geothermal
		hydroelectric
		combustibles
		tidal
		osmotic

4.3 Infrastructure

As reported by IPCC Report – 6th Assessment[6] (IPCC 2022), in all urban areas and cities, the risk to people and assets from climate change-related hazards has grown. Most of the world's population - 4.2 billion people - currently lives in urban areas. Urbanization processes create vulnerabilities and exposures that, when combined with climate change hazards, lead to urban risks and impacts. In unplanned and informal settlements in low- and middle-income countries, the risks and impacts are more significant.

4.4.1 Hard Infrastructure

It is the built environment, the physical connections between places that store of move people, materials, information, and energy. These "fixed" things include roads, railroads, pipes, buildings, cables, and the networks composed of these constructions. Moreover, encompasses the green infrastructure, which is a category of ecological-oriented designed structures, i.e., a combination of grey and green infrastructures; and the Blue Infrastructure defined as the blue areas, a mix of natural resources (rivers, sea, beaches, etc.) and human-designed elements.

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[6] Dodman, D., B. Hayward, M. Pelling, V. Castan Broto, W. Chow, E. Chu, R. Dawson, L. Khirfan, T. McPhearson, A. Prakash, Y. Zheng, and G. Ziervogel, 2022: Cities, Settlements and Key Infrastructure. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 907-1040, doi:10.1017/9781009325844.008. Available at Chapter 6: Cities, settlements and key infrastructure | Climate Change 2022: Impacts, Adaptation and Vulnerability (ipcc.ch)

4.4.4.1 Grey Infrastructure

Grey infrastructure refers to all tangible/physical elements that are (mostly) of anthropic origin (that is, artificial), engineered assets that provide one or multiple services required by society. This is in turn preliminary subdivided into buildings (and public spaces) and networks.

Buildings

Taxonomies of built-up structures in Europe: Classification of Products by Activity CPA 2.1

Buildings (residential and non-residential as well as other types of construction) are commonly considered as roofed and walled structures built for permanent use. They are officially classified in Europe based on the "Statistical classification of products by activity", known as the CPA, that is the classification of products (goods as well as services) at the level of the European Union (EU). These classifications are designed to categorize products that have common characteristics. The related taxonomy is available. According to the CPA taxonomy, buildings are primarily classified based on their occupancy class, specifically into 'residential' and 'non-residential', with various sub-categories available for each. This classification does not cover the specific classes of technological units of the buildings as well as the specific sub-systems that compose them. Moreover, it does not provide the useful information to perform a proper multi-hazard evaluation. For these reasons, other faceted taxonomies seem to be more proper to reach the expected goals of the ongoing study.

A well-known taxonomy, namely GED4ALL, can be considered a good reference when vulnerability analyses on buildings are considered. The GED4ALL taxonomy has been developed by GFDRR under the UK-DFID Challenge Fund. This open exposure database schema is meant for multi-hazard risk analysis. GED4ALL can be populated with building-level data from OpenStreetMap (OSM) following the guidance from the Humanitarian OSM Team, which collects contributions from the community on how OSM tags can be best aligned with the GED4ALL taxonomy. The building taxonomy is based on GEM open quake taxonomy, with the extension to multi-hazard and some simplifications. The taxonomy string is built as a sequence of attributes separated by slash:

```
MATERIAL/HEIGHT/DATE/OCCUPANCY/SHAPE/…
```

Missing attributes can be skipped from the string, e.g., 2-floor detached residential dwelling, reinforced concrete structure: *CR/H:2/RES1.* The GED4ALL taxonomy is an expanded version of the original GEM Building Taxonomy V2.0 and includes a few attributes to consider multiple hazards other than seismic. It is structured on 14 attributes, that are organized into several levels growing in detail and generally involved in the definition of the response of buildings to various hazards. Modifications compared to previous GEM V2.0 were the addition of an attribute related to ground floor hydrodynamics (linked to the flood hazard) an attribute to fire protection (linked to fire hazard) and the implementation of the attribute related to the external wall to consider the role of shadings and windows (Silva et al. 2022). The GED4ALL Building Taxonomy is shown in Figure 8.

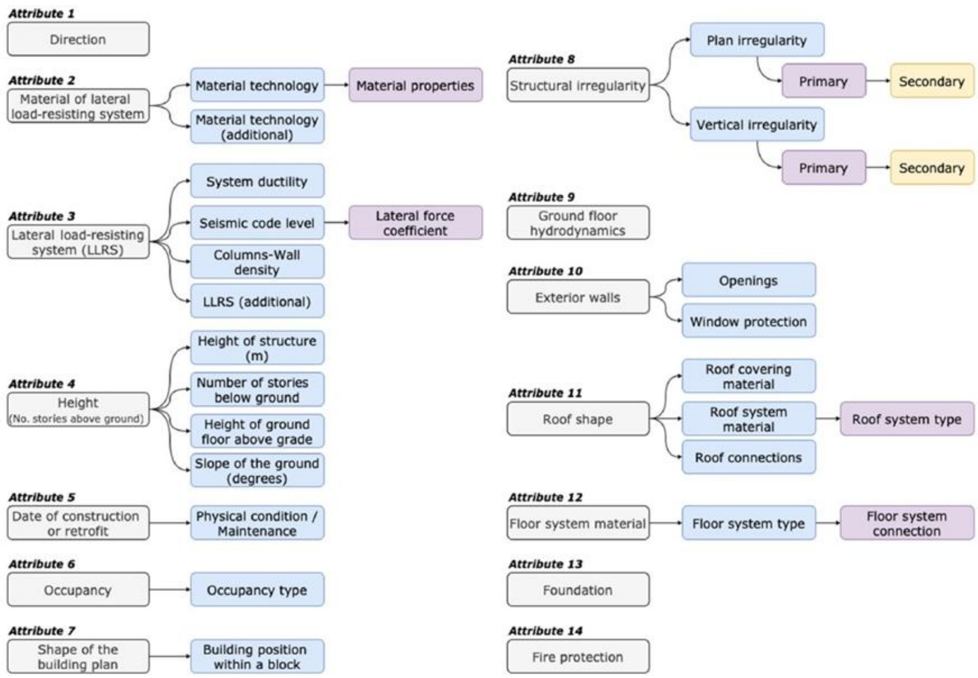


Figure 8 GED4ALL Building Taxonomy attributes and levels of detail.

To comply with the goals of the Return project, a new taxonomy for buildings have been developed (Return taxonomy for buildings), using the GED4ALL taxonomy as a reference and a basis. The proposed taxonomy has been developed to accomplish the following goals:

- Provide a comprehensive description of the building from a multi-hazard perspective, including additional characteristics useful to perform assessments and make decisions for hazards other than seismic (e.g., fire, flood, heavy rains, heatwaves, etc.).
- Harmonize the taxonomy on buildings with the contents of Italian regulations and standards[7]
- Consider the role of the entire set of technical components of the building envelope.

Compared to GED4ALL, the Return Taxonomy provides:

i) the collection of attributes into “attribute groups” to facilitate the consultation of the taxonomy.

ii) a new order and a new organization of the attributes.

iii) the addition of further attributes to the original list.

iv) some slight modifications to existing attributes. The Return Taxonomy can be considered a reliable starting taxonomy for allowing a harmonized description of sub-systems composing a building, aiming to contemplate the action of multiple hazards on the entire building. The list of the attributes structuring the Return Taxonomy for buildings is shown in Figure 9.

The "Attribute groups” in which attributes have been collected are the following:

[7] Italian UNI Norm 8290 – 1:1981 Edilizia residenziale. Sistema tecnologico. Classificazione e terminologia (Tran. Housing buildings. Technological System. Classification and Terminology).

a) Occupancy
b) Building Features
c) Vertical Structural System
d) Building Configuration and Regularity
e) Building Horizontal Diaphragms
f) Hydrological aspects
g) Foundation and Soil Conditions
h) Fire Building Performance
j) Building Envelope
k) Building Exterior Technical Elements

The new attributes that have been added are: Att. 4 Average Plan Surface; Att. 6 Gravity Load System that provides information on the structural system resisting to vertical loads; Att. 8 Internal Partition Walls that provides information on the characteristics and connection efficiency of partition walls to the vertical structure; Att. 13 Ceiling that considers also the role of ceilings (as suspended or false ceilings) and its connection efficiency to the horizontal structure; Att. 17 Soil class concerning the soil class of the foundation soil; Att. 18 Topography of the area; Att. 22 Cornice Construction technique; Att. 23 Balcony Construction Technique; Att. 24 Household Drain system material. The three last attributes are related to the characteristics of exterior technical elements.

The main modifications of existing attributes are collected into two main categories: (i) reorganization of attributes and (ii) modification of existing ones.

(i) Reorganization of attributes

The main reorganizations are related to Att. 7 Lateral Load System that now includes the information concerning the main direction of the building and the materials of the lateral load system; Att. 9 Position, Att. 10 Plan Regularity, Att. 11 Elevation Regularity, and Att. 21 Openings/windows that, compared to GED4ALL, stand out as proper attributes.

(ii) Modification of existing attributes

The main modifications of existing attributes are Att. 1 Occupancy which includes information on the present and original function of the building, the number of occupants, and the cultural heritage value of the building; Att. 2 Age of Construction which provides information concerning the construction period, the age of retrofit interventions, the state of maintenance of the building and the presence of pre-existing damage; Att. 5 Material of Structural Systems that gives details on the material of the vertical structure; Att. 14 Roof Shape that includes information on the presence and position of thermal/acoustic insulations and the presence of standing-out elements and the related slenderness; Att. 19 Fire Safety that is structured more extensively; Att. 20 Exterior Walls that includes the presence and position of thermal/acoustic insulations, the presence of decorations and/or moldings, and the role of finishings. Starting from such a holistic framework, the interoperability of the proposed taxonomy, easily tailorable at varying the building features and hazards, ensures to easily handle of information, allowing to assess of the multi-hazard impacts on urban systems as well. For more details on the attributes at the Return Taxonomy, see Appendix F – Taxonomy Return for Buildings.

Figure 9 Return Building Taxonomy: Attributes Groups, attributes, and sub-attributes.

Networks

In this document, the term *network* has been used, following (Rodrigue 2020), who refers to a network as the framework of routes within a system of locations referred to as nodes. A route is a single link (or arc) between two nodes that are part of a larger network, which may refer to tangible routes such as roads and railways, or less tangible routes such as air and sea corridors.

In Figure 10, the description of the network component is provided, subdivided into transportation networks (transportation of goods and people) and utility networks (water, sewage, power, communication), including the most critical lifelines for sustaining the urban metabolism.

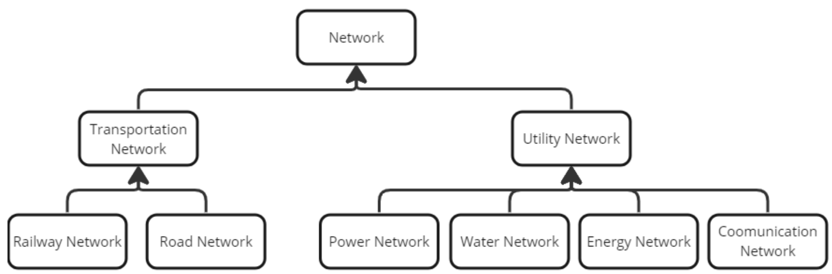


Figure 10 Taxonomy of networks

Transportation networks

According to (Rodrigue 2020), transportation networks are a framework of routes connecting locations. The structure of any region corresponds to networks of economic and social interactions. These networks are, for instance, a composition of roads or railways. There are several classifications of transportation networks. For example, they are classified according to their structure (e.g., centralized, decentralized, or distributed) or their economic finality (e.g., least cost to use, least cost to build, or hybrid).

In terms of risk, a transport network can be evaluated (its value from one perspective) by the degree of importance it has within an urban system. Thus, the impact of a disaster, causing damage and loss, both material and immaterial, is analyzed when assessing the risk of a hazard occurring. In addition, the vulnerability of transportation networks and their exposure to natural and human hazards must be considered.

Utility Networks

As Marvin and Graham (Marvin and Graham 1993) pointed out, utility networks, including water, waste, electricity, gas, and telecommunications systems, are essential to the economic, social, and environmental performance of modern society. These networks serve as the basic infrastructure that allows modern cities to function.

4.4.4.2 Green Infrastructure

Beginning in the 1990s, additional services and functions provided by nature were identified by scholars within cities. For example, natural systems are uniquely suited to provide carbon sequestration to slow the rate of climate change, mitigate harsh microclimates, cleanse the air and water, produce food, and provide habitat in support of biodiversity and food production. Due to its multiple benefits, green infrastructure is nowadays recognized as an important component of sustainable urban communities. In particular, green infrastructure is recognized to maintain ecosystem services and to promote urban livability in the following ways:

- Regulation of Water Quality and Quantity: By retaining rainfall from small storms, green infrastructure reduces stormwater discharges. Lower discharge volumes translate into reduced combined sewer overflows and lower pollutant loads. Green infrastructure also treats stormwater that is not retained. Green infrastructure can mitigate flood risk by slowing and reducing stormwater discharges.
- Regulation of Air Quality: vegetation can reduce air pollution in several ways, including the additional capture and deposition of pollutants on its surface.
- Increase in Climate Resiliency: vegetation has multiple benefits on urban resilience to climate change and in particular against climate extremes; 1) it can improve thermal comfort, by reducing the urban heat island effect; 2) it can help replenish groundwater reserves, relieving stress on local water supplies and reducing the need to import potable water; 3) it helps to manage flooding with infiltration-based practices, floodplain management, and open space preservation to complement other measures to lower flood risk; 4) it lowers building energy demands by reducing indoor temperatures and shading building surfaces; 5) it contributes to reducing energy consumption managing water by reducing rainwater flows into sewer systems. Green infrastructure can reduce pumping and treatment demands for municipalities; 6) It helps to protect coastal areas with living shorelines, buffers, wetlands, and dunes to help reduce coastal erosion and storm impacts.
- Improvement of Habitat: Vegetation in the urban environment provides habitat for birds, mammals, amphibians, reptiles, and insects.

In recognition of the importance of natural systems in cities in support of these services and functions, the term *green infrastructure* was developed, and its essential role in cities promoted since the mid-1990s (Seiwert and Rößler 2020). There are many definitions of green infrastructure (e.g., Marco Tullio and Boyle 2003; Wright 2011; Ying et al. 2022) but we can start from the operative description of green infrastructure as the collection of urban biological and natural subsystems and solutions that are not entirely of entropic origin. Green infrastructure includes:

- Urban forests, including parks, reserves, and vegetation in private areas and including habitats and ecosystems
- Natural and constructed wetlands, rivers, lakes
- Street trees
- Bio-retention areas, including rain gardens and bioswales, and
- Living roofs (green roofs)

We note that the green infrastructure might also include infrastructure which are intrinsically more sustainable (e.g., bike lanes) but this entails a different interpretation of the word "green". It is also important to note that an increasing number of green-gray infrastructure (e.g., a permeable pavement) is being implemented, and there might be a continuum of examples between gray and green extremes, but for a preliminary classification, we think this discussion can be postponed.

For green infrastructure, different typologies have been derived, in general, starting from easily available (often open) data. For instance, most classifications are derived from satellite-based data, and therefore most often lack information on the use of the different types of green infrastructure, as well as on their precise boundaries. On the other hand, ground-based mapping provides accurate boundaries but lacks details on essential features such as structural components, for example, the extent of trees or sealed surfaces in a pocket park. As such, the typologies combining elements of land use as well as land cover are the most useful since both are necessary to determine the combination of ecological and social functions that GI provides and their impacts on the well-being of urban residents.

A recent paper (Xiuli Wang et al. 2020) has classified green infrastructure starting from the way it is integrated into buildings, including horizontal, vertical, exterior, and interior spaces Figure 11. Each of these has specific advantages and disadvantages. Horizontal greenery includes green roofs and elevated forests, while vertical greenery systems include green façades, green walls, green terraces, and vertical forests.

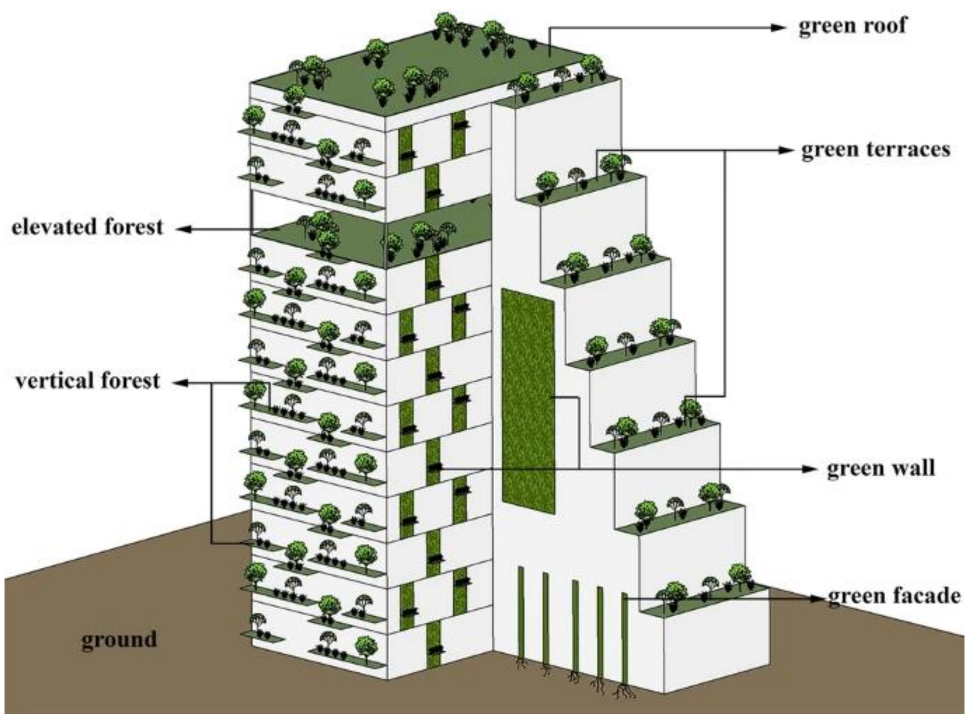


Figure 11 Classification of green infrastructure (from Wang et al., 2020)

Another proposed classification adopts a climatological approach based on its climatic function and structure (Koc, Osmond, and Peters 2016) (Figure 12). This approach requires the logical division of GI features into vegetation layers, ground surfaces, and building structures that are disaggregated into classes and sub-classes. These are combined in a double-entry matrix to generate different typologies commonly recognized as (a) tree canopy, (b) green open spaces, (c) green roofs, and (d) vertical greenery systems. (Bartesaghi Koc, Osmond, and Peters 2017) evidenced that a ternary approach in terms of the functional (purpose, use, services), structural (morphology) and configurational (spatial arrangements) attributes of GI should be applied for a more comprehensive classification, sufficiently generic to be used across research disciplines, but also specific enough to be implemented for specific scopes, scenarios, and settings. Indeed, the review of relevant literature has evidenced the lack of a common terminology and that a universal typology for all scenarios is impractical.

However, for urban planning purposes and as reported above, it is important to stress that one of the strengths of green infrastructure and more in general of Nature-Based Solutions, is that they are multi-functional and provide multiple simultaneous benefits to different hazards. The same trees that remove air pollutants also provide cooling and shade on hot days, can enhance interception, and increase infiltration into the ground thereby reducing overland water flow, providing shelter and food for insects and birds, and supporting the health and wellbeing of city residents.

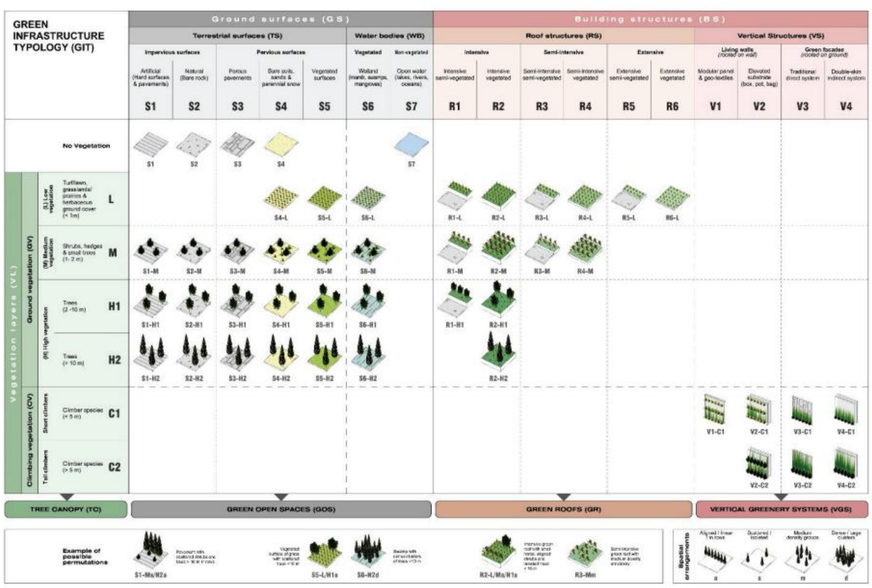


Figure 12 Proposed green-infrastructure typology based on a double-entry matrix from (Koc, Osmond, and Peters 2016)

Recently, (Morpurgo, Remme, and Van Bodegom 2023) emphasized that the absence of a unified classification for green infrastructure impedes the elucidation of synthesis and consolidated relationships among ecosystem services (ES) and biodiversity (Figure 13). To address this gap, they introduced CUGIC, the maiden classification system that accommodates research on future multifunctional ecosystem services-biodiversity, grounded on the past decade's literature and concentrated on the amalgam of ecosystem services and biodiversity.

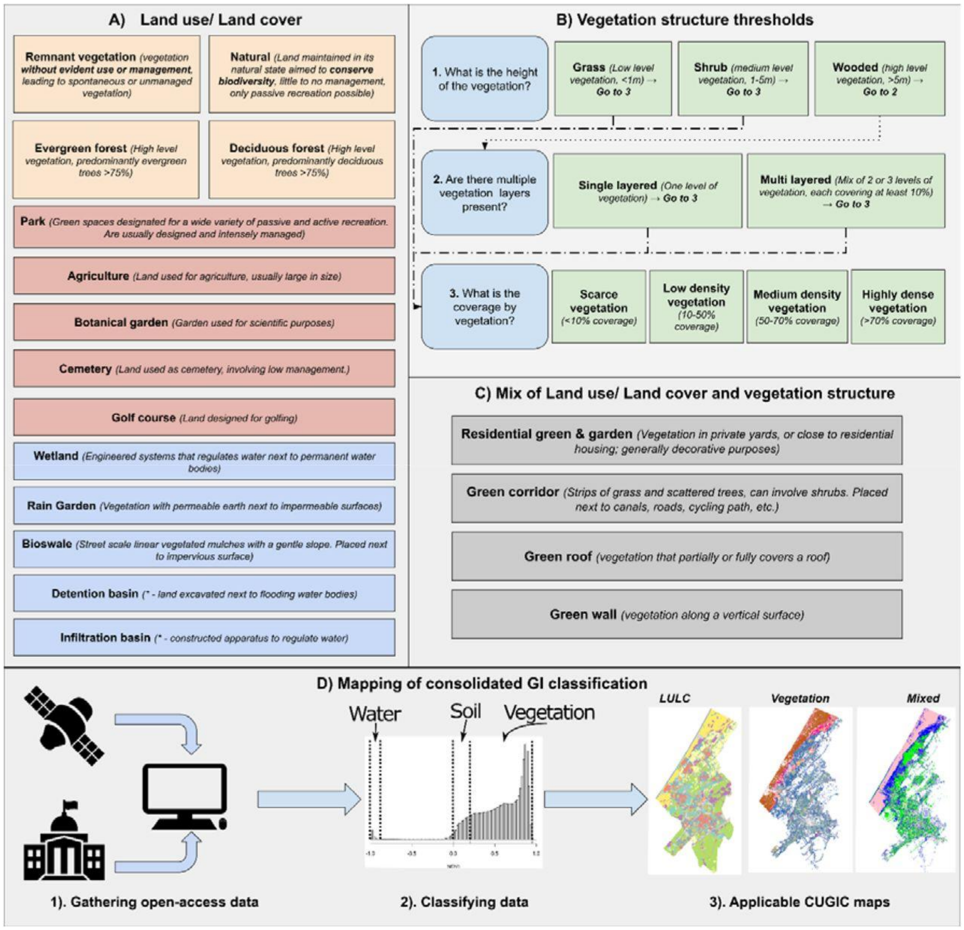


Figure 13 The Consolidated Urban Green Infrastructure Classification (CUGIC) proposed by (Morpurgo, Remme, and Van Bodegom 2023)

Another classification for green infrastructure in urban areas is proposed by the European Union. This typology[8] is based on various sources including (Vaňo, Stahl Olafsson, and Mederly 2021), (Xing, Jones, and Donnison 2017), Ecologic Institute Guidelines[9], and (Ndubisi, DeMeo, and Ditto 1995). It provides a valuable framework for understanding the different types of green infrastructure in urban settings.

- Building greens
- Urban green areas connected to grey infrastructure
- Parks and (semi)natural urban green areas, including urban forests
- Allotments and community gardens
- Agricultural land
- Green areas for water management

[8] Available at https://biodiversity.europa.eu/green-infrastructure/typology-of-gi

[9] Available at https://www.ecologic.eu/11382

(Jones et al. 2022) proposed a typology based on green infrastructure features, with the idea of matching individual features with their ecological and social functions to provide a matrix of green infrastructure and ecosystem services. The proposed typology (Table 9) has nine main categories, further divided into 47 sub-categories.

Table 9 Components and descriptions of the main and sub-classes of the typology (Jones et al. 2022)

Object type (& description)	Object category	Description/Assumptions
Gardens *(Mainly private space linked to dwellings)*	Balcony	A few plant pots, mostly flowers
	Private Garden	Mostly grass, some paving, a few trees
	Shared common garden area	Mixed grass, paving, and flower beds assume few trees
Parks *(Mainly public space, but some access restrictions may apply)*	Pocket Park	Small (up to 0.4 ha); Mix of paving, grass, a few trees
	Park	Larger than 0.4 ha; More grass than trees, may contain water features, some sealed surfaces, and infrastructure
	Botanical garden	More trees than a park
	Heritage garden	Similar to the park, often a formal layout, more flowers
	Nursery garden	Growing area for young plants; Few mature trees
Amenity areas *(Areas designed primarily for specific amenity uses)*	Sports field	Assume grass, not artificial surface
	School yard	Mostly paved
	Playground	A mix of paving, grass
	Golf course	Mostly grass, a few trees, and occasional water features
	Shared open space (e.g., square)	Mostly paved
Other public space *(Areas designed primarily for specific uses (not leisure); some access restrictions may apply)*	Cemetery	Mix of grass, trees, and paved surfaces
	Allotment/other growing space	Mostly low-growing crops, soil disturbed frequently
	City farm	Mostly low-growing crops, soil disturbed frequently

	Adopted public space	Mostly 'tubs' or 'planters' with flowers or small shrubs, in public space
Linear features/routes *(Linked to routeways, geographical features, and boundaries)*	Street tree	Usually low to medium-height trees, can be large trees
	Cycle track (as part of blue/green corridor)	Usually bare surface, with grass verge
	Footpath (as part of blue/green corridor)	Usually bare surface, with grass verge
	Road verge	Usually, grass
	Railway corridor	Land alongside railway infrastructure, often shrubs or trees
	Riparian woodland	Usually mature or mixed-age trees
	Hedge	Usually formed of maintained shrubs, 1-2 m tall
Constructed GI on infrastructure *(Constructed green and blue space, added to infrastructure)*	Green roof (extensive)	Usually formed of Sedum & other drought-tolerant species, some grasses
	Green wall	Contains low stature or hanging species, often maintained by complex watering infrastructure
	Roof garden (intensive)	A mix of decking, paving, and plants
	Pergola (with plants)	Structure covered with climbing plants
Hybrid GI for water *(Infrastructure designed to incorporate some GI components)*	Permeable paving	Limited permeability, not usually vegetated
	Permeable parking/roadway	Reasonable permeability, typically block paving or plastic pavers with grass
	Attenuation pond	Basin with mostly grass and reeds, some trees, with managed drainage for storm events
	Flood control channel	usually constructed with earth/stone banks or concrete, some contain natural features
	Rain garden	Small, constructed drainage areas, situated near houses and roads, are designed to intercept runoff. These

		areas are frequently adorned with native shrubs, perennials, and flowers.
	Bioswale	Often large, long structures, usually with grass or low vegetation, near roads/parking to retain or slow drainage water
Water bodies *(Blue space features)*	Wetland	Natural or constructed wetland, with reeds/tall vegetation
	River/stream	Small to large river/stream, often highly modified channel
	Canal	Artificial channel, vertical sides, controlled flow (usually slow)
	Pond	Small waterbody <1 ha
	Lake	Larger waterbody >1 ha
	Reservoir	Artificially created large waterbody, water level usually controlled
	Estuary/tidal river	Tidally influenced, brackish or freshwater, may include saltmarsh
	Sea (incl. coast)	Sea and coast, including beaches
Other non-sealed urban areas (*Other un-sealed features without specified use, often on private land*)	Woodland (other)	Any woodland not defined in specific features above
	Grass (other)	Any grassland not defined in specific features above
	Shrubland (other)	Any shrubland not defined in specific features above
	Arable agriculture	Any arable land (pastures come under Grass (other); orchards come under Woodland (other))
	Sparsely vegetated land	Mostly bare earth, but some plants

Typology combines aspects of land use and land cover. Thus, the components include discrete features such as gardens and parks which are typically managed as whole units but incorporate a range of land cover classes (trees, grass, water bodies, etc.), as well as land cover types such as woodland or grassland occurring in other urban spaces, both public and private.

Further, (Jones et al. 2022) created a matrix of potential delivery of a set of key ecosystem services in urban areas against all GI components in the typology (Figure 14). The ecosystem services provided span a range of provisioning services (food provision), regulating services (maintenance of carbon stocks, mitigation of poor air quality, noise, heat, water quality, flooding), and cultural services linked to the delivery of physical and mental wellbeing (providing opportunities for physical health, social interaction, restoring capacities), as well as the potential to support biodiversity.

Brief description	Object type	Object category	Food provision	Air pollution removal	Noise mitigation	Heat mitigation	Water quality mitigation	Water flow management	Maintaining carbon stocks	Supporting physical activity	Supporting social interactions	Restoring capacities - stress reduction and cognitive restoration	Supporting biodiversity
Mainly private space linked to dwellings	Gardens	Balcony	Low	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Low	High	Low
		Private garden	Medium	Low	Low	Medium	Medium	Medium	Low	Very high	Medium	Very high	High
		Shared common garden area	Medium	Low	Low	Medium	Medium	Medium	Low	Medium	High	Medium	Low
Mainly public space, but some access restrictions may apply	Parks	Pocket park	Low	Low	Low	Low	High	Medium	Low	Medium	Very high	High	Medium
		Park	Low	High	High	High	High	Medium	High	Very high	Very high	Very high	High
		Botanical garden	Low	High	Very high	Very high	High	Medium	High	Medium	High	Very high	Very high
		Heritage garden	Medium	Medium	High	High	High	Medium	Medium	Medium	High	Very high	High
		Nursery garden	Medium	Medium	Low	Low	High	Medium	Medium	Low	Medium	Medium	Low
Areas designed primarily for specific amenity uses	Amenity areas	Sports field	Negligible	Low	Low	Low	Low	Low	Low	Very high	High	Medium	Negligible
		School yard	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Very high	Very high	Medium	Negligible
		Playground	Negligible	Negligible	Negligible	Negligible	Low	Low	Negligible	Very high	Very high	Medium	Negligible
		Golf course	Negligible	Medium	Low	Low	Negligible	Medium	Low	Medium	High	High	Medium
		Shared open space (e.g. square)	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Negligible	Medium	Very high	Low	Negligible
Areas designed primarily for specific uses (not leisure); some access restrictions may	Other public space	Cemetery	Negligible	Medium	Medium	Medium	Medium	Medium	High	Low	Low	Very high	High
		Allotment/other growing space	Very high	Medium	Low	Low	Negligible	Medium	Negligible	High	High	Very high	High
		City farm	Very high	Medium	Low	Low	Negligible	Medium	Negligible	Medium	Medium	High	Medium
		Adopted public space	Low	Medium	Low	Low	Low	Low	Negligible	Negligible	Low	Medium	Low
Linked to routeways, geographical features and boundaries	Linear features/routes	Street tree	Low	High	Low	High	Low	Low	Medium	Negligible	Low	High	Medium
		Cycle track (as green/blue corridor)	Low	Low	Low	Low	Low	Low	Low	Very high	Medium	High	Low
		Footpath (as green/blue corridor)	Low	Low	Low	Low	Low	Low	Low	Very high	Very high	High	Low
		Road verge	Low	Low	Low	Low	Medium	Medium	Low	Negligible	Negligible	Low	Low
		Railway corridor	Negligible	Very high	Very high	Very high	Low	Medium	High	Negligible	Negligible	Low	Very high
		Riparian woodland	Low	Very high	Very high	Very high	Very high	High	Very high	High	High	Very high	Very high
		Hedge	Low	Medium	Low	Low	High	High	Medium	Negligible	Negligible	Medium	Medium
Constructed green and blue space, added to infrastructure	Constructed GI on infrastructure	Green roof	Negligible	Low	Negligible	Low	Low	High	Low	Negligible	Negligible	Low	Low
		Green wall	Negligible	Medium	Medium	Low	Negligible	Low	Low	Negligible	Negligible	Medium	Low
		Roof garden	Medium	Medium	Low	Medium	Low	Low	Medium	Low	High	Very high	Medium
		Pergola (with vegetation)	Negligible	Medium	Low	High	Low	Low	Medium	Negligible	Low	High	Low
Infrastructure designed to incorporate some GBS components	Hybrid GI (for water)	Permeable paving	Negligible	Negligible	Negligible	Negligible	High	High	Negligible	Low	Negligible	Negligible	Negligible
		Permeable parking/roadway	Negligible	Negligible	Negligible	Negligible	High	High	Low	Negligible	Negligible	Negligible	Negligible
		Attenuation pond	Negligible	Low	Low	Low	Very high	Very high	Medium	Negligible	Low	Medium	High
		Flood control channel	Negligible	Low	Negligible	Low	Low	Very high	Low	Negligible	Low	Negligible	Medium
		Rain garden	Low	Medium	Negligible	Low	High	High	Medium	Negligible	Negligible	High	Medium
		Bioswale	Negligible	Medium	Low	Low	Medium	Very high	Medium	Negligible	Negligible	Low	Medium
Bluespace features	Waterbodies	Wetland	Negligible	Medium	Low	Medium	Very high	Very high	Medium	Low	Medium	Very high	High
		River/stream	Low	Low	High	High	Medium	High	Low	Medium	High	Very high	High
		Canal	Low	Low	Low	Medium	Low	Medium	Low	Medium	High	Very high	Low
		Pond	Negligible	Low	Low	Low	Low	High	Medium	Low	High	Very high	High
		Lake	Medium	Low	Medium	High	High	High	Medium	High	High	Very high	Very high
		Reservoir	Low	Low	Medium	High	High	Very high	Medium	High	High	Very high	Medium
		Estuary/tidal river	High	Low	High	High	High	N/A	Medium	Medium	High	Very high	Very high
		Sea (incl. coast)	High	Low	High	Very high	High	N/A	Very high	Very high	Very high	Very high	Very high
Other un-sealed features without specified use, often on private land	Other non-sealed urban areas	Woodland (other)	Low	Very high	Very high	Very high	High	High	Very high	High	High	Very high	Very high
		Grass (other)	Low	Low	Low	Low	Medium	Medium	Low	Very high	High	Medium	Medium
		Shrubland (other)	Low	Medium	Low	Low	High	High	Medium	Medium	Medium	High	High
		Arable agriculture	Very high	Medium	Low	Low	Negligible	Low	Negligible	Low	Negligible	Low	Low
		Sparsely vegetated land	Negligible	Negligible	Low	Negligible	Low	Low	Negligible	Medium	Medium	Medium	Low

Figure 14 Assessment matrix of GI types and ecosystem services delivered (Jones et al. 2022)

4.4.2 Soft Infrastructure

The definition of soft infrastructure is one coined by (C. Turner and Johnson 2017), based on Niskanen's definition of soft infrastructure (Niskanen 1991). In this context, soft infrastructure, as shown in Figure 15, "*constitutes the enabling institutions for the territorial infrastructure system that facilitate both the interworking of the individual and the mutually supporting components through defining the body of rules and regulations that govern their operation and interaction*".

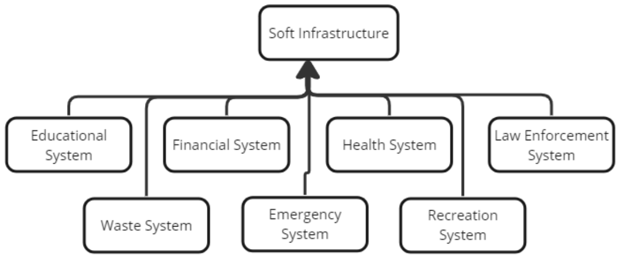


Figure 15 Soft Infrastructure concept

4.5 Taxonomy Proposal

Based on the classifications presented in the previous sections, a preliminary taxonomy was designed (Table 10). A description of each term can be found in the technical specifications Section 9.6 Technical specifications, subsection 2.

Table 10 A proposal for infrastructure taxonomy

INFRASTRUCTURE	HARD INFRASTRUCTURE	**GREY Infrastructure**	**Urban Element** *Basic Component*	Energy cable, fiber, generator	
				Water duct, pipe, tube	
				Communication tower, cable,	
				Sewage pipe, tube, tank, digester	
				Road, street	
				Rail, train	
				Bridge	
				Grey Building[10] *Homogeneous Conglomerate*	Residential Building
					Educational Building
					Health Building
					Assembly Building
					Business Building
					Mercantile building
					Industrial Building
					Storage Building
					Hazardous Building
			Urban Network *A network is a group or system of interconnected people or things. Heterogeneous Conglomerate*	Transportation network	
				Water Supply network	
				Telecommunication network	
				Energy network	
				Sewage network	
		GREEN[11] **infrastructure**	**Green Buildings**	Balcony green	
				Green ground	
				Green vertical structure	
				Green roof	
				Green pavement	

[10] Based on the GEM Building Taxonomy v2.0, attribute 6 (occupancy) + NBC 2005.

[11] Based on the typology developed by the Ecologic Institute, European Commission (see Cvejić et al. 2015, Xing et al, 2017; Ecologic Institute, 2011, Ndubisi et al., 1995) and Typology of green infrastructure (europa.eu)

				Green Noise barriers	
				Rain barrel	
				Perforated pipe	
				Permeable pavement	
			Green-Grey Area *Urban green areas connected to grey infrastructure*	Ecological corridor	
				School ground	
				Green street	
				Railroad bank	
				Green playground/school ground	
				Green parking	
				Riverbank greens	
			Urban and Peri-urban Agricultural Land	Agri sites	
				Allotment	
				Community allotment	
				Grassland	
				Arable land	
			Urban Green Area	Park	
				Green sports area	
				Urban garden	
				Urban forest	
			Natural or Semi-Natural Green Area	Wastelands	
				Bare soil	
				Shoreline	
				Dune system	
				..	
		BLUE	**Blue Area** (without human infrastructure)	Water bodies	
				Wetlands	
				Sea	
			Blue-Green Area *Urban blue areas connected to green infrastructure*	Swales	
				Filter strips	
	SOFT	**SERVICES**	Health System		
			Education System		
			Emergency System		
			Law System		
			Recreational System		
			Mobility System		

5. Urban Systems as Living Entities: An Introduction to Macro-Metabolic Processes

Cities consume about 80% of energy resources and are responsible for more than 70% of greenhouse gas emissions, despite occupying less than 3% of the Earth's surface (UN-Habitat, 2020). By 2050, the number of people living in urban areas will be three billion higher than today, rising from 45% to 70% of the world's population, according to UN socio-demographic projections (UN, 2022).

The concept of Urban Metabolism (UM) has been coined in an interdisciplinary field such as urban ecology. It aims to measure the processes of extraction, transformation, and consumption of matter and energy that take place in cities, to make them more sustainable (Corrie and Musando, 2010). The organicist metaphor of metabolism associates the city with a living being or ecosystem (Kennedy et al., 2011), whose metabolism requires inputs in the form of socio-technical and socio-environmental flows (Trane, 2020) and produces outputs in the form of reproducing the vital functions of the urban organism and generating externalities such as waste.

The UM therefore depends on several conditions: as for living beings, the species (metropolis or small town), the habitat (developed or developing country), the relationships between the organism and other species (city embedded in attractive networks or isolated) and its adaptive capacity (resilience) condition the quantity and quality of the flows (of matter, energy, information, people).

Some research (Kenneth et al., 2013; Shahrokni et al., 2015) has set out to describe and organize a typology of flows. Trane (2020) has summarized them in a diagram, which, however, reduces them mainly to those of matter and energy. The levels of observation would be three, related to the "origin" of the flows: local, regional, and global. The sectors concerned, considering all three levels, would be six: infrastructure and transport, built environment, human environment, plant environment and soil, production, and management. The content of the flows would vary by sector and level: from fuel consumed for public and private transport to food and water for consumption and industry to more ecosystem processes such as the photosynthetic activity of trees and the uptake of pollutants by soil. Finally, it identifies the units of measurement with which to analyze the impact of individual flows (liters, kg, meters, etc.).

The first limitation of this framework concerns the difficulty of finding the data it proposes to measure. This is a common problem in UM literature. Attempts to measure UM in several cities (Lanau et al.2021), including London (Best Foot Forward, 2002), Vienna (Hendriks et al.2011), Paris (Barles, 2009), have been confronted with the absence of disaggregated data, and sometimes with the very lack of datasets on the various indicators. This has led research to focus on institutional aspects, such as policies, market regulation models, and governance styles, which intervene to make metabolic processes sustainable. The reference is to good practices in the management of local public services (Romano et al.2021), including municipal solid waste, integrated water service, and mobility.

A second limitation refers to the lack of diversification of the outputs of urban metabolism. Part of the energy, food, and water that 'feeds' the city is used to generate added value, employment, services, and everything that makes an urban environment liveable. Another, however, is not retained and constitutes a significant flow of matter and energy that in the first circuit of use is not utilized (Figure 16).

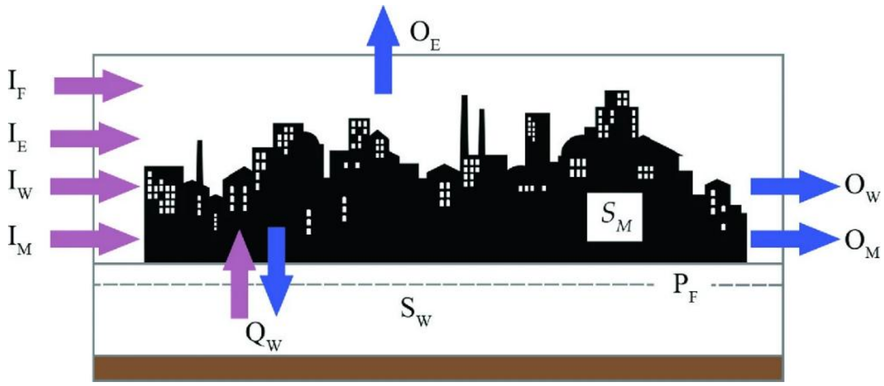


Figure 16 Sketch of UM processes accounting for inputs (I), outputs (O), internal flows (Q), storage (S), and production (P) of water (W), energy (E), material (M), and food (F) (tratto da Derrible et al.2021)

The reference is to GHG emissions, the production of urban and construction waste, and the dispersion of water and energy. The sustainability of a city's UM is played out on the ability of its social actors to know how to transform it from linear to circular (Derrible et al.2021), organizing socio-technical and socio-ecological apparatuses capable of recognizing and avoiding waste, incentivizing maintenance, and providing for reuse.

A third limitation of the framework is that it does not define, except to a preliminary extent, which processes enable the transformation of inputs into outputs, and does not identify the impact of the institutional contexts of different cities on the modeling of these processes. This stage of the UM is less explored in the literature. A preliminary method for tracing it may be to 'chase' the inputs and to observe which activities enable their transformation into outputs.

If one considers, for example, food, this arrives in the city in the form of 'raw material', for example, milk, fruit, vegetables, or meat and fish sold in markets, or 'semi-processed' and 'processed', in the case of products that are packaged or have undergone initial processing outside the city. The activities that are carried out in the urban context with food are very different, although interdependent: (i) logistics, to sort resources at the various distribution points; (ii) sale, with huge differences depending on the context of purchase (from the local market to the large hypermarket); (iii) processing, in the case where one of the processes of food processing takes place in the city, either in the case of food industries or of simpler preparation and supply by shopkeepers, as is the case with catering; (iv) consumption, from domestic to public consumption; (v) recovery and storage, with activities ranging from organic waste collection to food banks, to water purification.

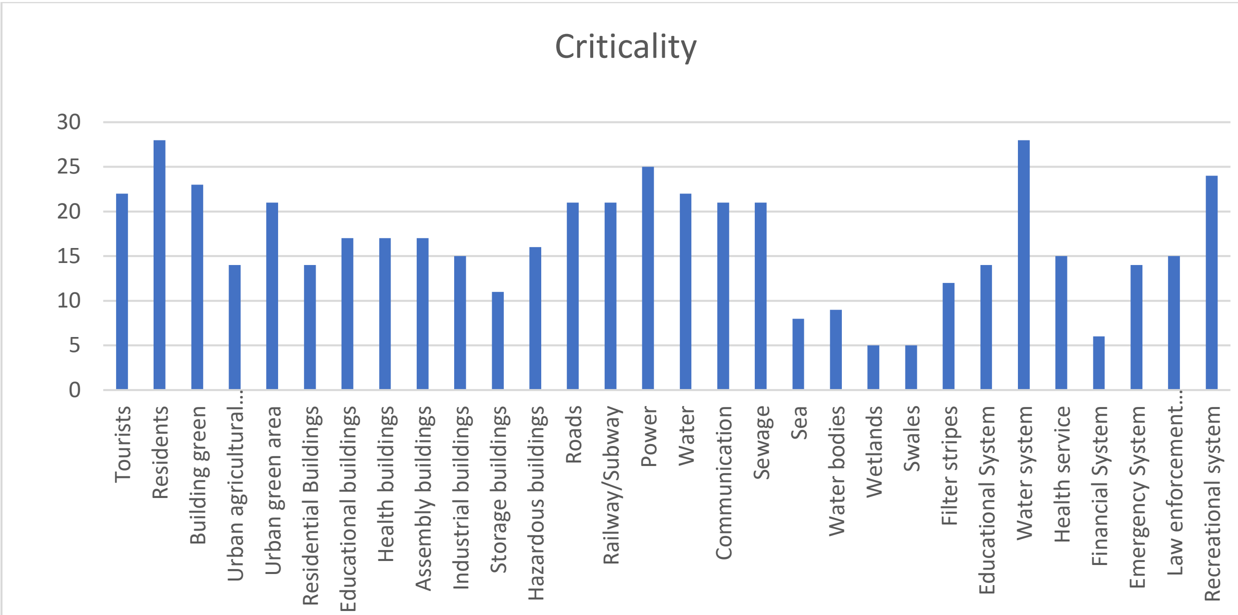
6. Relationships and Interdependencies among Urban Systems

This preliminary conceptual model can be further complemented by additional considerations on the dependencies among the different base components, as depicted in Table 11.

Table 11 Relationships and interdependencies among urban systems

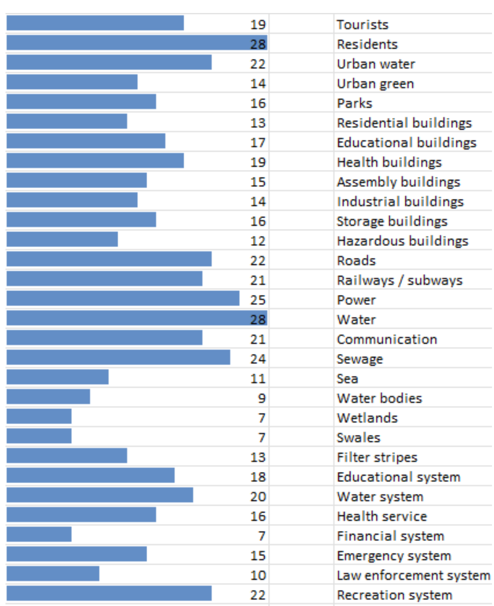
Dependencies ("row X" depends on "column Y")						Tourists	Residents	Building green	Urban agricultural land	Urban green area	Residential Buildings	Educational buildings	Health buildings	Assembly buildings	Industrial buildings	Storage buildings	Hazardous buildings	Roads	Railway/Subway	Power	Water	Communication	Sewage	Sea	Water bodies	Wetlands	Swales	Filter stripes	Educational System	Water system	Health service	Financial System	Emergency System	Law enforcement system	Recreational system
Population	Non-resident				Tourists			x	x	x			x	x				x	x	x	x	x	x	x	x					x	x	x	x	x	x
	Resident				Residents			x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Infrastructure	Hard infrastructure	Green infrastructure			Building green	x	x			x	x	x	x	x				x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
					Urban agricultural land		x			x	x	x								x	x		x		x	x	x	x	x	x					x
					Urban green area	x	x	x			x	x	x	x						x	x				x	x	x	x	x	x					x
		Gray infrastructure	Buildings		Residential buildings		x	x	x	x			x					x	x	x	x	x	x							x					x
					Educational buildings	x	x	x	x	x				x				x	x	x	x	x	x					x	x	x	x				x
					Health buildings	x	x	x		x	x	x		x				x	x	x	x	x	x						x	x	x	x	x		x
					Assembly buildings	x	x	x		x		x						x	x	x	x	x	x					x	x	x					x
					Industrial buildings		x	x	x							x	x	x	x	x	x	x	x					x		x		x			
					Storage buildings		x	x	x						x		x	x	x	x	x	x	x	x	x			x		x				x	
					Hazardous buildings		x		x						x	x		x	x	x	x	x	x							x				x	
			Networks	Transportation	Roads	x	x	x	x	x	x	x	x	x	x	x	x		x	x		x	x					x	x	x			x	x	x
					Railways/subways	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x							x	x	x		x	x	x
				Utilities	Power	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x				x	x	x		x	x	x
					Water	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x
					Communication	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x									x		x	x	x	x	x
					Sewage	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			x				x	x	x	x		x	x	x
		Blue Infrastructure	Blue Area		Sea	x	x								x		x	x	x	x	x		x							x					x
					Water bodies	x	x			x			x		x		x						x							x					x
					Wetlands	x	x			x					x		x													x					x
			Blue-green area		Swales	x	x			x					x		x													x					x
					Filter stripes	x	x	x		x	x	x	x		x	x	x						x							x					x
	Soft infrastructure				Educational system		x	x	x	x		x	x	x				x	x	x	x	x	x							x	x		x	x	x
					Water system	x	x	x		x	x	x	x	x	x	x	x			x	x	x	x					x			x		x	x	x
					Health service	x	x	x				x	x	x				x	x	x	x	x	x							x			x	x	x
					Financial system	x	x	x												x		x								x	x				
					Emergency system	x	x	x					x	x			x	x	x	x	x	x								x	x			x	x
					Law enforcement system	x	x	x										x	x	x	x	x								x			x		
					Recreational system	x	x	x	x	x	x	x		x				x	x	x	x	x	x	x	x				x	x	x	x	x	x	
						22	28	23	14	21	14	17	17	17	15	11	16	21	21	25	22	21	21	8	9	5	5	12	14	28	15	6	14	15	24

Where assessment of dependency is expert-based and binary (dependent or not dependent). Despite this simple assessment, from this preliminary dependency table, several additional considerations can be made, for instance in terms of the apparent criticality of each element, as displayed in Graph 1.



Graph 1 Criticality of infrastructure elements

This analysis shows that, unsurprisingly, power, water communication, and sewage represent the potentially most critical elements of the urban system, followed by transportation network, emergency, and law enforcement systems. Counting the dependencies on the other axis of the table provides in turn a picture of the overall dependency of the elements considered, as shown in Graph 2.



Graph 2 Overall Dependency of the elements

From this perspective, the most dependent elements are (in order of number of dependencies) the resident population, the recreational system, and the tourists. The level of dependency also contributes to defining the potential vulnerability concerning natural and environmental hazards. Of course, this representation involves a high degree of simplification (for instance not acknowledging the fact that the resident population is also key for the good functioning of most of the critical services).

These preliminary considerations already highlight the high degree of interconnectedness of the basic elements of the urban system and the need for a more systematic description.

7. Other Risk-oriented Taxonomies

7.1 Hazards

This lack of a coherent and standardized view of hazards hampers disaster risk reduction in several ways: it compromises effective reporting by countries on aspects such as mortality, morbidity, economic loss, damage to basic infrastructure and disruption of basic services; it is a barrier to implementing a comprehensive and inclusive approach to the development of national and local disaster risk reduction strategies and related financing and regulatory frameworks; and it affects the capacity to develop and use multi-hazard early warning systems effectively and forecast events in the future. In May 2019, the UN Office for Disaster Risk Reduction (UNDRR) and the International Science Council (ISC) jointly established a technical working group to identify the full scope of hazards relevant to the Sendai Framework as a basis for countries to review and strengthen their risk reduction policies and operational risk management practices. The technical working group used an iterative process of developing and reviewing the hazards listed through extensive consultation with over 500 technical experts from relevant science groups, UN organizations, the private sector and other partners (UNDRR-ISC 2020). The hazard list comprises 302 hazards grouped according to eight clusters:

- meteorological and hydrological hazards,
- extraterrestrial hazards, geohazards,
- environmental hazards,
- chemical hazards,
- biological hazards,
- technological hazards,
- societal hazards.

This hazard list is considered the most useful at the present time, although it is not a definitive list and would need regular review and updating. Hazard definitions are sourced from the highest possible authority (such as the UN agency responsible for providing guidance on the hazard), reflect scientific consensus on the issues addressed, and are of broad international relevance. The list of hazards is reported in Appendix E – Taxonomy of Hazards (UNSDR), while a complete description of the considered hazards is provided in (UNDRR-ISC 2021).

7.1.1 Climate-related hazards

The classification of hazards considered in the section above and proposed by UNSDR-ISC also encompasses phenomena that are strongly influenced by climate and as such can be related to climate change. However, a more direct consideration of climate change is advisable to better consider the related impacts and risks associated with it. An review and description of climatic hazards (also referred to as climatic impact drivers) has been carried out in 2020 by the European Environmental Agency (Crespi et al. 2020), and provides a very useful starting point for a further harmonization and standardization of hazards within a broader framework where also the assumption of stationarity on the underlying physical processes is explicitly taken in account.

7.1.2 Multi-hazard relationships

Hazards often can be observed in combinations and can also interact with each other. To provide a consistent reference to address their combination, we refer to the work of (Tilloy et al. 2019), which has considered several contributions from the recent multi-hazard literature. Five main interrelation types are proposed:

I. **Independence (I)**: Coincidence between hazards can occur. It implies a spatial and temporal overlapping of the impact of two hazards without any dependence or triggering relationship. It is equivalent to the independent relationship in Liu et al. (2016) and (Van Westen and Woldai 2012) and the spatial-temporal coincidence in Gill and Malamud (2014). An example is the 2010, Pacaya volcanic eruption and tropical storm Agatha which hit the Pacific coastline of Guatemala almost simultaneously, leading to exacerbated damages due to ash blocking the drainage system of rainfall triggering lahars (Gill and Malamud, 2014). We also include in this category cases where two hazards impact the same area, independently, at different times (e.g., a cyclone occurring a few weeks after an earthquake).

II. **Triggering** (Cascading, **T**): Implies a primary and a secondary hazard. As explained by Gill and Malamud (2014), any natural hazard might trigger zero, one or more secondary natural hazards (Tarvainen et al., 2006; De Pippo et al., 2008; Kappes et al., 2012a, Kappes et al., 2012b; Marzocchi et al., 2012). The secondary natural hazard might be identical or different from the primary hazard. As an example, an earthquake might trigger landslides, which can trigger a flood, resulting in a hazard cascade (Catane et al., 2012).

III. **Change conditions (C)**: This relates to one hazard altering the disposition of a second hazard by changing environmental conditions. This phenomenon has been discussed in previous papers (Kappes et al., 2010; Catane et al., 2012). One of the reasons is its variable temporal scale, for example, a wildfire might denude an area of vegetation and harden the soil thus amplifying the strength of floods through increasing overground flow and resulting in a debris flow (Cannon et al., 2008). A wildfire can have a non-negligible influence on soil infiltration up to one year after its occurrence (Shakesby and Doerr, 2006). For example, in Las Conchas in New Mexico in 2011, a wildfire charred >150,000 acres leading to an increased flood one month later (FEMA, 2012). There is a similar issue with river flooding amplified by landslides (Costa and Schuster, 1988).

IV. **Compound hazard** (association, **A**): In this interrelation, different hazards are the result of the same "primary event", or large-scale processes (Mazas and Hamm, 2017) which are not necessarily hazards. In this case, there is not a primary and a secondary hazard as the different hazards occur simultaneously. As an example, the co-occurrence of river flooding and sea surge could be the result of the same large-scale process (tropical cyclone, mid-latitude cyclone) (Bevacqua et al., 2017; Dowdy and Catto, 2017). The two hazards are considered as dependent and form a multi-hazard event called compound flooding (Klerk et al., 2015; van den Hurk et al., 2015; Wahl et al., 2015; Moftakhari et al., 2017). Depending on the scale we focus on this dependence can be almost instantaneous or lagged. Therefore, Klerk et al. (2015) found a statistical dependence between extreme discharge on the Rhine River and extreme sea level at its outlet into the North Sea, but with a 6-day lag time. This can be explained by the size of the Rhine catchment. Moreover, 6-day some other dependencies are spatially and temporally closer, such as the dependency between lightning activity and hail occurrence (Lang and Rutledge, 2002; Carey et al., 2003).

V. **Mutual exclusion** (negative dependence, **E**): Two natural hazards can also exhibit negative dependence or be mutually exclusive. There is limited literature because a negative dependence on two hazards does not lead to an increased impact, which is the case for positive dependence. There are many examples of hazards that show negative dependence, often hydrometeorological (e.g., heavy rain and fire). However, such negative dependence is often on a particular spatial and/or temporal scale. For example, within a tropical cyclone, both extreme wind and lightning are likely to occur, but Molinari et al. (1999) show that the extremes of these two hazards occur in different parts of the cyclone. On the scale of the whole cyclone, those two hazards are positively dependent, but on a narrower scale, they appear to not occur extremely together.

7.2 Vulnerability

Vulnerability has been recognized as a critical component of risk since now decades, and depending on multiple dimensions, has been diversely interpreted from different communities of practice (UNDRO 1980; IPCC 2022; Cardona et al. 2012; De Leon 2006; Khalid et al. 2021; Barros and et. al. 2014). Considering the most recent sources within a perspective of harmonization between Disaster Risk Reduction and Climate Change Adaptation, we define vulnerability as "*the propensity (of exposed elements) of being adversely affected by a natural hazard in multiple dimensions: environmental, physical, technical, social, cultural, economic, institutional, or policy-related factors. This condition is strongly tied with and derives from multiple short- and long-term socio-ecological processes defined as underlying risk drivers*" (i.e., inter-relations between social actors and socio-economic processes with the environmental components). As underlined in the EU Commission's risk assessment guideline, certain characteristics and circumstances of a community, system, or asset could make it more susceptible to the damaging effects of a hazard (UNISDR 2009). This definition of vulnerability does not separate the causes/process that have led to a condition of vulnerability from its observable and measurable components. These specific components result from context-dependent processes identified as underlying risk drivers that hinder the capacity to cope with risk. For instance, the ability of a building to withstand earthquake impacts is influenced by its physical characteristics, such as the height of the building and its age as well as its location or the vicinity to other buildings, but its physical vulnerability can be also related to the quality of building practices and the level of corruption in the country they are located in (Bilham 2009). Figures from recent disasters highlighted the influence that socioeconomic and cultural factors have on the impacts of hazardous events. Almost 50% of people who died in Louisiana because of Hurricane Katrina in 2008 were people older than 75 years (Brunkard, Namulanda, and Ratard 2008) and the average age of deaths recorded after the wildfires in 2017 and 2018 in California was over 70 (Hamideh, Sen, and Fischer 2022), (Los Angeles Times, 2017, 2018 - www.latimes.com). Hence, older age, which is related to issues of mobility, health, and communication, may increase the susceptibility of people to disasters. The study conducted by (Ritchie and Rosado 2022) underlines that populations in low-income countries are more vulnerable to the effects of natural disasters. When low-frequency, high-impact events occur in countries with low SDI (socio-demographic index), an index representing health, social conditions, and economic development for a country, a dramatically high number of deaths is recorded, whereas highly developed countries seem to be much more resilient to disaster events and therefore the number of deaths results consistently low. This means that the degree of people's vulnerability is directly impacted by socioeconomic inequality, poverty, population growth, lack of awareness and infrastructure, and weak institutions (Blaikie 1994); (B. L. Turner et al. 2003), (Khalid et al. 2021).

Considering the multi-dimensional nature of vulnerability and the most common definitions of vulnerability provided in the literature, (De Leon 2006; Birkmann et al. 2013; IPCC 2022; Zebisch et al. 2023), the following types of vulnerability could be defined:

- **Physical vulnerability**: the propensity of the built environment (e.g., buildings and infrastructure) built-up areas, infrastructure, and open spaces to suffer the physical impact of hazardous events (Douglas 2007; Birkmann et al. 2013).

- **Social vulnerability**: The social dimension refers to the propensity for human well-being to suffer harm due to disruptions to individual and collective social systems (Birkmann et al., 2013). This dimension addresses how the attributes of individuals and groups make them vulnerable in a particular context (e.g., gender, ethnicity, age, etc.), as well as how social relations across scales shape vulnerability (Singh, Eghdami, and Singh 2014).

- **Economic vulnerability**: the propensity of economic assets and processes to be harmed by exogenous shocks (Cardona et al. 2012), such as the potential impacts of natural and man-made hazards (i.e., business interruption, secondary effects such as increased poverty and job loss).

- **Environmental vulnerability**: potential natural resource depletion and resource degradation (destruction of forest, farmland, or crops, lower yields) following a hazardous event (United Nations Environment Programme 2011).

- **Institutional vulnerability**: The institutional dimension relates to the attributes of institutions and governance systems that influence the predisposition of a system, communities, or individuals to withstand, cope and recover from being adversely affected by the impact of a natural hazard (Papathoma-Köhle et al., 2021). This dimension is connected to the decision-making power across society and the ability of institutions/governments to implement policies related to disaster risk and climate change adaptation on the ground.

Also, susceptibilities, fragilities, weaknesses, deficiencies, or lack of capacities that favor adverse effects on the exposed elements may change over time. During the past decades (1960–2020), the world's population experienced major transformations in population size, development patterns, economic conditions, and social characteristics (Cutter and Finch 2008), (Zhou et al. 2014). These social, economic, and built-environment changes altered the temporal trends of social and economic vulnerability. Likewise, physical and environmental vulnerability could increase in time because of unplanned and informal modifications, the lack of maintenance, and environmental-induced deterioration (Cremen, Galasso, and McCloskey 2022). Therefore, vulnerability can be considered dynamic. Vulnerability models, however, are often static, in the sense that they do not consider such time-dependent or damage-dependent variation of vulnerability. Therefore, a further classification of vulnerability, referring to modeling characteristics, is between static and dynamic vulnerability.

Changes in vulnerability may also be due to consecutive or compound disasters and societal shocks, such as the effects of an earlier hazard on the vulnerability at the time of a second hazard (Zaghi et al. 2016), (De Ruiter and Van Loon 2022). When two hazards interact, the vulnerability of the exposed elements may be altered by the first one, and, in turn, their capacity to respond to the second hazard may dramatically change. For instance, the accumulation of damage in structures pre-damaged by a seismic main shock may change their physical vulnerability when threatened by aftershocks (Polese et al. 2013), (Iervolino, Giorgio, and Chiccarelli 2015), (Iervolino, Giorgio, and Polidoro 2015), (Gentile and Galasso 2021). Also, people's vulnerability can be further exacerbated when two hazards occur close in time. In November 2020, during the COVID-19 pandemic, the super typhoon Goni hit the Philippines. The ongoing pandemic impacted people's ability to cope with the impacts of the typhoon, which in turn triggered floods and landslides. The typhoon caused homelessness and loss of access to basic amenities; COVID numbers surged owing to overcrowding in evacuation centers and the limited ability to observe social distancing regulations (Gonzalo Ladera and Tiemroth 2021), (Rocha et al. 2022).

Therefore, when describing vulnerability, it should be specified if it refers to:

- Single-hazard vulnerability: the propensity of exposed elements to suffer adverse effects when impacted by a specific hazard, avoiding potential vulnerability interactions.
- Multiple-hazard vulnerability: the propensity of exposed elements to suffer adverse effects when impacted by two or more hazards, involving the potential exacerbation of vulnerability when hazards occur close in time.

7.2.1 Physical Vulnerability

- Physical vulnerability describes the susceptibility of the built environment, including homes, roads, bridges, hospitals, schools, and government buildings, to be negatively affected by hazards. It is usually expressed in terms of damages attained by such structures during a hazardous event (represented by its location, magnitude, and frequency) or costs associated with their reconstruction processes. Propension to damage of facility contents can be considered a part of physical vulnerability as well. Physical vulnerability depends significantly on the materials used for the constructions and on the design level. Typically, physical characteristics of elements at risk that affect their physical vulnerability are directly linked to a particular hazard. For example, the degree to which a building withstands an earthquake is

directly linked to the building material and construction technique used. However, a great level of resistance related to earthquakes depending on previously mentioned factors does not automatically imply that the ability to resist a flood event is similarly high as flood vulnerability also depends on other construction factors (e.g., the presence of a basement floor).
Examples of physical vulnerability include:

- Unprotected buildings and infrastructure
- Lack of irrigation infrastructure
- Lack of road infrastructure
- Poor sewage system
- Insufficient maintenance of plants/pipelines

7.2.2 Social Vulnerability

The social dimension can be disaggregated into two sub-dimensions: individual and collective. The individual sub-dimension refers to the predisposition of individuals to physical, physiological, and mental harm. This includes their abilities to cope/anticipate/adapt to these situations (e.g., based on their education, experience, etc.). The predisposition of individuals is linked to characteristics such as age, disabilities, level of education, experience, etc. (Olaya Calderon and Romagnoli 2024).

On the other hand, the collective sub-dimension refers to how the disruption of social systems can adversely affect human well-being. Therefore, the way individuals interact within a community, their social cohesion, and their social networks can all play a role in shaping vulnerability. For instance, social relations within a group can lead to marginalization, making groups more vulnerable than others. Furthermore, this subdimension also covers how access to social services such as education and healthcare can affect vulnerability and how the disruption of these services can further exacerbate it (Oliver-Smith 1999; Barros and et. al. 2014; Adger 2003; Singh, Eghdami, and Singh 2014), (Olaya Calderon and Romagnoli 2024).

The differential susceptibility of people to suffer negative consequences of natural hazards mostly depends on demographic, socio-economic, educational, health and well-being factors.

Age and gender: Children and elderly people living alone are the age groups that may be more vulnerable than others to natural hazards impacts, as they are dependent on others and require protection, financial support, transportation, medical care, and assistance with ordinary daily activities (Staffogia et al., 2006; Rosenkoetter, et al., 2007; Gosling et al., 2009; Ardalan & Mazaheri, 2010). Hence, children less than 5 and people 65 years and older might have many problems in emergency and recovery phases and require special attention by disaster response planners and operational officers. Minority groups such as migrant or ethnic community may be characterized by high social vulnerability as well, due to language and communication problems that make them unable to understand event-related information (e.g., real-time evacuation information during emergencies) (Peacock, et al., 1997; Carnelli & Frigerio, 2016). Such groups may also have more difficulties in finding employment and housing, developing distrust of authorities (Enarson and Morrow, 2000; Donner and Rodriguez, 2008). Discriminatory atmosphere to women, especially in developing countries, causes a limited access to resources and information for female population, limitations that may affect their physical and mental health during and after disasters (Sohrabizadeh, et al., 2014). For example, in the Indian Ocean tsunami of 2004, the women were made more vulnerable than man by societal norms which did not encourage survival training for girls (e.g., to swim or climb trees) and which placed the majority of the burden of child and elder care with women. Thus, escape was made more difficult for women carrying children and responsible for others (Doocy et al., 2007).

Socio-economic condition: People in poor socioeconomic conditions (high unemployment and greater poverty) show high vulnerability and low adaptive capacity to natural hazards (Nurse and Sem, 2001; Cutter, et al., 2000; (Wisner and et. al. 2003), Carnelli & Frigerio, 2016). Impoverished people are more likely to live in hazard-exposed areas and are less able to invest in risk-reducing measures. The rapid and unplanned urban growth increased in the number and extent of informal settlements often located on marginal land within cities or on the periphery because of the lack of alternative locations. Because of their location, suburbs are often exposed to hydrometeorological-related hazards such as landslides (Nathan, 2008) and floods (Colten, 2006; Aragon-Durand, 2007). Also, the lack of access to insurance and social protection means that people in poverty are often forced to use their already limited assets to buffer disaster losses, which drives them into further poverty.

Education: Lower education may constrain the ability to understand warning information and access to recovery information (Cutter et al., 2003). As a matter of fact, education can directly influence risk perception, skills and knowledge and indirectly reduce poverty, improve health, and promote access to information and resources. Highly educated individuals and societies are reported to have better preparedness and response to the disasters, suffered lower negative impacts, and can recover faster (Muttarak and Lutz., 2014).

Health and well-being: Individuals who may need additional response assistance including children, senior citizens, pregnant women, those with mobility and cognitive constraints and those have chronic medical disorders or pharmacological dependency can be considered more likely to be vulnerable to natural hazards. They are at increased risk of injuries and deaths whatever the hazard type. For some extreme weather events such as heat waves, socially isolated elderly people with pre-existing medical conditions are vulnerable to hazard-related health effects. Also, the risk of mental health problems pre- and post-event is also higher in poorer households and communities (Werritty et al., 2007). Health conditions is linked to the institutional dimension, as health service provision (e.g., environmental health and public health issues, infrastructure, and conditions; Street et al., 2005) may be impacted by extreme events as well (e.g., failures in hospital/health center building structures; inability to access health services because of storms and floods). Other examples of social vulnerability according to the individual/households and collective/community perspective include:

- Individual/Household
  - Limited skills and formal education
  - People with preexisting health conditions
  - Employment status (formal /informal) (type of employment)
- Collective/ Community
  - Marginalized groups of individuals
  - Limited social networks
  - Limited access to healthcare services

- Limited access to educational services

The social vulnerability can also encompass a **cultural dimension**, that is, the predisposition to damage intangible values, including meanings placed on artefacts, customs, habitual practices and natural or urban landscapes (Birkmann et al. 2013). This aspect also encompasses how values and beliefs shape the priorities and actions related to disaster risk reduction and climate change adaptation (IFRC, 2014; Krüger et al., 2015). Examples of cultural vulnerability include:

- Disregard of local knowledge
- Lack of engagement with local or indigenous communities
- Mismatch of traditions and modern DRR-related technologies and policies.

7.2.3 Economic Vulnerability

Economic vulnerability can be defined as the susceptibility of an economic system (including public and private sectors), to potential damage and loss (Rose, 2004; Mechler et al., 2010) and refers to the inability of affected individuals, communities, businesses, and governments to absorb or cushion the damage (Rose, 2004). Economic vulnerability influences post-event duration of indirect follow-on effects on the economic system, such as business interruption costs to firms, income losses of households unable to get to work or the deterioration of the fiscal stance post-disasters as less taxes are collected and significant public relief and reconstruction expenditure is required (Cardona et al., 2012).

Economic vulnerability mostly depends on country's ability to access domestic and foreign savings for financing post-disaster relief and reconstruction needs to quickly recover and avoid substantial adverse ripple effects (Mechler et al., 2006; Marulanda et al., 2008a; Cardona, 2009; Cummins and Mahul, 2009). To absorb the financial burdens of disasters, economic agents may rely on market-based insurance. Households as economic agents often use informal mechanisms relying on family and relatives abroad or outside a disaster area; governments may simply rely on their tax base or international assistance.

7.2.4 Environmental Vulnerability

The environmental vulnerability deal with the damage and the degradation of ecosystems and the loss of ecosystem services due to the impacts of natural hazards. Environmental vulnerability can also be represented by the loss of access to vital resources (e.g., water resources) in the case of a hazardous event occurring, generating indirect effects on communities (e.g., increases the risk of crop failure). An ecosystem is a functional unit consisting of all the living organisms (plants, animals, and microbes) in a given area, as well as the non-living physical and chemical factors of their environment, linked together through nutrient cycling and energy flow. Ecosystem services can be defined as the benefits people derive from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. Thus, the degradation of ecosystem services and functions can directly impact human well-being.

Environmental degradation may affect frequency and intensity of extreme climate events. Deforestation and desertification have demonstrable effects on local rainfall patterns and are complicit with the occurrence of drought. Also, ecological conditions affect natural barriers that can moderate the impacts of a disaster and protect communities providing natural defenses against hazards. For instance, wetland ecosystems function as natural sponges that trap and slowly release surface water, rain, snowmelt, groundwater and floodwaters. Dunes and reefs create physical barriers between communities and coastal hazards.

7.2.5 Institutional Vulnerability

The institutional vulnerability represents the lack of institutional capacity to deal with the consequences of natural hazards (Papathoma-Köhle et al., 2021). It is not referred to the vulnerability of the institution but to their role in dealing with risk management, e.g., in the response phase, i.e., how inadequate response, communication and coordination of the responsible organizations affect negative consequences of hazards. Institutional vulnerability can be defined as 'the combination of the weaknesses embedded in institutions (purposedly or non-purposedly built for disaster management) that reduce the capacity to resist/withstand/cope or recover from the impact of a hazardous event' (Papathoma-Köhle and Thaler, 2018). The capacity of institutions to manage the disaster is also influenced by the conditions of great uncertainty they face in every stage (Zaccaria, 2023).

The role of institutions is crucial in each phase of the disaster risk management cycle, including mitigation (land use planning regulations, risk transfer mechanisms), preparedness (accountability, public and local communities' inclusion, early warning systems), response (accountability, priorities, treatment of vulnerable groups, involvement of local communities) and rehabilitation (resources and allocation, insurance, compensation). Institution may refer to formal rules (such as legal instruments, regulations, government, guidance, policies, and plans), to informal institution (i.e., rules such as customs, traditions and unwritten laws that determine human behavior), and to organization including public administration, and governmental organizations such as ministries as well as funding agencies and research institutes. Thus, institutional vulnerability may be influenced by the socio-cultural status of a community including the use of local knowledge and practices, the level of community participation, the risk perception and public awareness which is connected to socio-economic and cultural characteristics. Traditional behaviors tied to local (and wider) tradition and cultural practices can increase vulnerability – for example, unequal gender norms that put women and girls at greater risk, or traditional uses of the environment that have not adapted (or cannot adapt) to changed environmental circumstances. Religion may also influence positions on environment and climate change policy because of the religious explanations of nature and the role of religion and faith in the context of disaster (e.g., Kintisch, 2006; Hulme, 2009).

The response to natural hazards is strongly related to the level of democracy and the political stability of the country. According to the World Bank & United Nations (2010), less democratic countries suffer more deaths from natural or man-made hazards, not only due to public awareness but also to the credibility of politicians to commit to the citizens. Political stability also guarantees a proper functioning of institutions in natural hazard emergencies. The lack of transparency and corruption contributes to social and ecological imbalance and therefore to the vulnerability of industry, commerce, construction, health and agriculture (Lewis 2011). Corruption also may lead to the lack of implementation of land use and building regulation; accordingly, settlements could be more exposed to natural hazards and buildings could be characterized by bad quality and low performances against them, that may lead to more disaster related deaths. Thus, the availability of building regulations and code is essential, but their implementation should be guaranteed as well. Environmental legislation (e.g., legislation related to deforestation, air pollution, land degradation, etc.) also influences the exposure and vulnerability of communities and natural resources. We suggest two main pillars necessary to address the institutional dimension (proposed by Papathimas-Köhle et al., 2021), the political and legislative-regulatory. The political pillar refers to the government's effectiveness, i.e., the quality of providing public and civil services, policy formulation quality, and political stability. The legislative-regulatory pillar relates to the legislation concerning civil protection, disaster risk reduction and climate change adaptation strategies, the disaster risk transfer and retention policy, environmental legislation, and the legal framework and policy strategies contributing to reducing risk, such as land use planning (Olaya Calderon and Romagnoli 2024).

Examples of institutional vulnerability include:

- Week land tenure and access rights for women
- Inadequate climate information service
- Poor social protection
- Lack of disaster preparedness
- Lack of coordination between national and local levels of government

8. Risk Storylines

We define a storyline as a physically self-consistent unfolding of past events, or of plausible future events or pathways (Shepherd et al. 2018; March, Sproull, and Tamuz 1991). The use of past events is very useful since they represent individual examples of the realization of processes and their consequences, therefore shedding light on the dependencies and vulnerabilities of the affected systems. However, this might also conceal possible alternative realizations which are especially useful to understand and model the impact of relatively rare events with potentially severe consequences (Woo and Johnson 2023). It is therefore important to consider potential scenarios, realistic enough to provide a plausible story or to integrate/enhance an already existing one. The integration of near misses, for instance, can be regarded as a promising way to extend a storyline toward a plausible alternative future which can be seen as a pragmatic way to address risk.

To better explore the connection between relevant risks and the specific elements and functions of urban and metropolitan systems, several risk storylines have been discussed in a workshop and are provided in

Appendix A – Risk Storylines. Each storyline focuses on a given urban context and on a specific combination of hazards (possibly compounded) and cascaded impacts.

Each storyline is also described conceptually and visually through the use of impact chains (e.g., Zebisch et al. 2022). An example is provided in the following Figure 17.

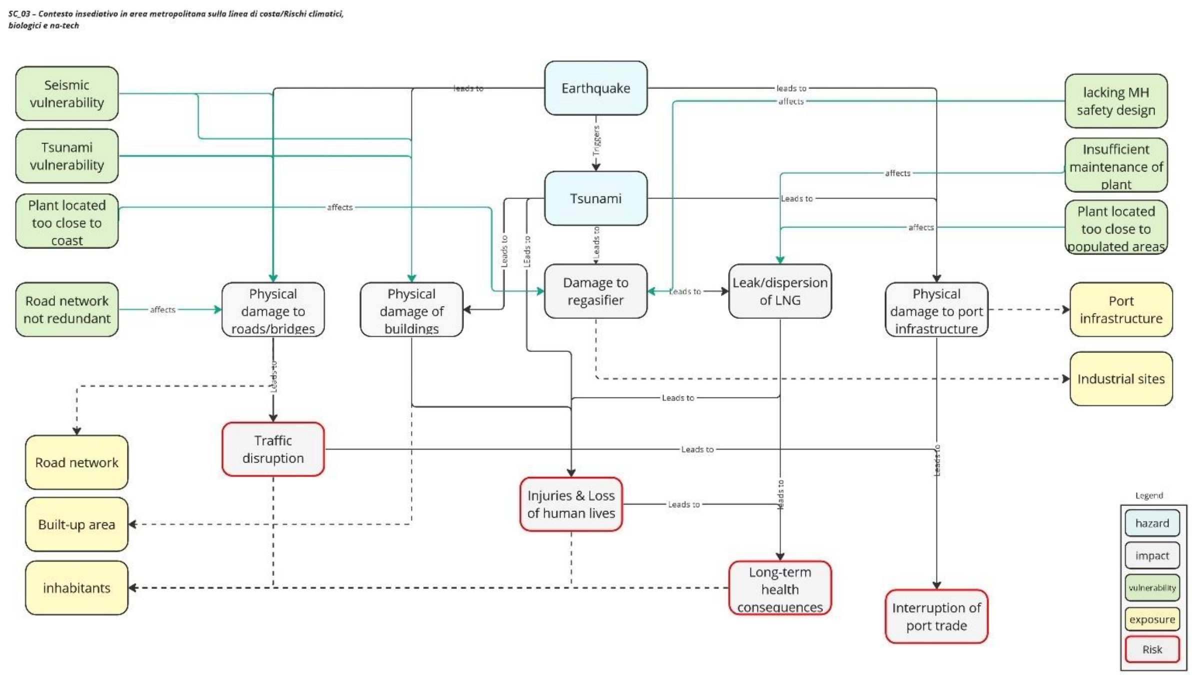


Figure 17 Example of storyline

9. Ontologies

An ontology is a formal and explicit specification of a shared conceptualization[12]. The result of ontology-driven conceptual modeling is an artifact of taxonomies (concepts organized hierarchically into categories), relations (or associations between concepts), and axioms (rules, constraints) that represent an ontological commitment to a particular domain.

9.1 Ontology Engineering

9.1.1 Purpose and Intended Uses

- The main purpose of the ontologies, taxonomies, and controlled vocabulary is to provide a shared common understanding of what are risk-driven urban systems among people, software, and databases.
- To contribute to the state of the art with a formal specification of what risk-driven urban systems are.
- Prepare the basis to design inference frameworks in the context of risk-driven urban systems with the following goals: understanding, monitoring, assessment, prevention, prediction, and mitigation.

Users: government authorities, decision-makers, industry, researchers, and third sector.

Stakeholders and experts: civil authorities, engineers, sociologists, geologists, physicists, mathematicians, and statisticians.

9.1.2 Requirements

A preliminary set of requirements (Table 12 and Table 13) related to the in-progress ontologies was identified in this first sprint. *Functional Requirement* defines a function to be available in the product being built. On the other hand, *Non-Functional Requirement* defines criteria or capabilities for the artifact. A preliminary identification of the main ontologies was conducted, followed by a search for potentially reusable existing ontologies (Table 14).

Table 12 Functional Requisites

ID	Description	Depends on
RF01	The models should provide a controlled vocabulary of the domain. This vocabulary might be available using some graphical software	RF03
RF02	The built taxonomies should be displayed using graphic softwares (e.g., miro) and standards (e.g., SKOS)	
RF03	The ontologies built should be available in some graphical environment	

[12] Guarino, Nicola, Daniel Oberle, and Steffen Staab. "What is an ontology?". *Handbook on ontologies* (2009): 1-17.

RF04	An open-source repository or site should be designed to store the technical documentation, models, and vocabulary, including vpp files, ttl files, readme.txt	RF01, RF02, RF03

Table 13 Non-Functional Requisites

ID	Description	Type
RNF01	The ontology must consider the UFO categories to ground on concepts and relationships	Consistency
RNF02	The ontological building process must follow the adapted approach SABiO (Systematic Approach for Building Ontologies)	Quality
RNF03	The IPCC definition of risk will be used as the definition of risks in the Risk-driven Ontology of Urban Systems	Precondition
RNF04	For the eliciting phase, storylines must be used	Precondition
RNF05	A bottom-up approach must be used to build models from storylines	Precondition
RNF06	The validation phase should be conducted using storylines, Alloy, and data	Quality
RNF07	The ontology to be built should consider UFO-S to specialize services in the context of urban systems	Consistency

Table 14 List of ontologies

Ontology	Abbreviation	Description
Unified Foundational Ontology (UFO)	UFO-A UFO-B UFO-C UFO-S	The domain ontologies are based on UFO. UFO-A, an ontology of endurants, UFO-B, an ontology of perdurants, and UFO-C, an ontology of social reality. The ontological language used is OntoUML, which is built on UFO theory. UFO-S is a core ontology for services, which will be used for specialized Soft Infrastructure.
Ontology of Population	OntoPop	This ontology aims to represent populations within the context of an urban system. To achieve objectivity, subkinds of populations such as human and non-human populations need to be identified.
Ontology of Infrastructure	OntoInfra	This ontology represents the infrastructure of an urban system. In this ontology is relevant to explicit concrete elements and the networks in which they are present. In addition, the soft infrastructure is the set of public and private services available in an urban system for the population.
Ontology of Geosphere	OntoGeo	This model represents the mineral, non-living portion of the Earth that supports all living organisms. It comprises the atmosphere, hydrosphere, and peripheral lithosphere within which an urban system

		is situated.
Ontology of Urban Systems	OntoUrbanSys	In this ontology, urban systems are designed as deliberately developed social systems with institutional structures, processes, and functions.
Ontology of Risk-driven Urban Systems	OntoRisk	Risk is presented in the context of urban systems through the interrelated concepts of vulnerability, exposure, and hazard, employing theories of relational risk, uncertainty, and probability.

By analyzing the project's expected results, the first expected result (*"better understanding of environmental, natural, and anthropic risks, as well as their interrelation with the effects of climate change."*) is correlated to the building of a domain ontology for urban systems oriented to risk.

Initially, five ontologies were identified from the initial conceptual models as depicted in Figure 18. Then, they were connected in a modular view (Figure 19).

1. Ontology of population (humans and non-humans)
2. Ontology of infrastructure (hard infrastructure and soft infrastructure)
3. Ontology of geosphere
4. Ontology of Risk-driven Urban Systems (environment risks, natural risks, anthropic risks)
5. Ontology of urban systems and subsystems

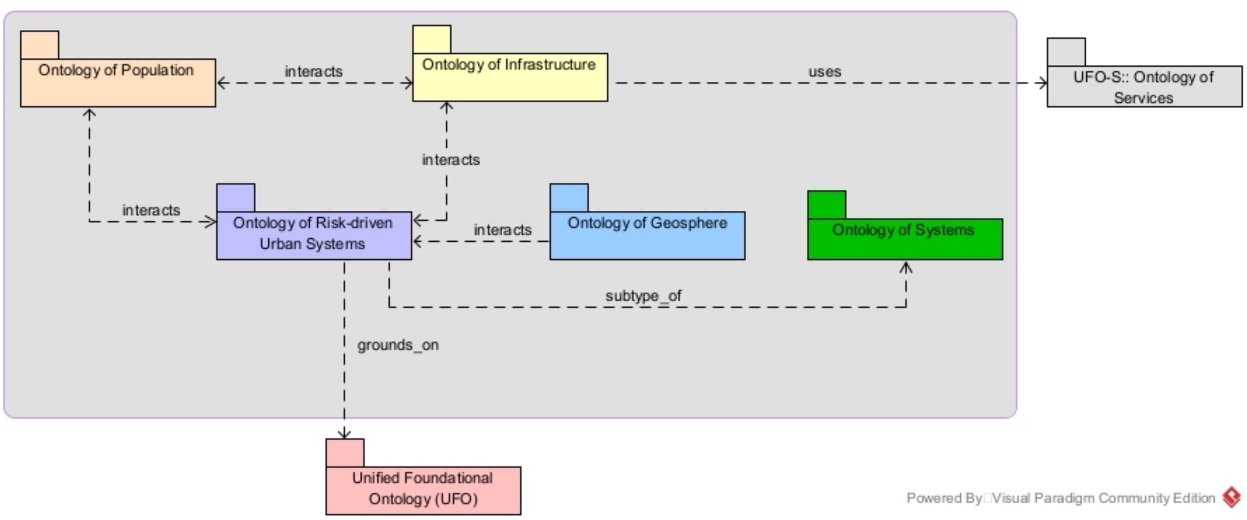


Figure 18 Overview of ontologies (Ontology Modularization)

9.1.3 Scenarios

Four fundamental risk-oriented urban system scenarios have been identified: 1) Hazards and Risks scenario; 2) scenario of occurrence of natural events; 3) predictive scenario of natural events; 4) impact mitigation scenario; and 5) liability scenario.

Scenario of Hazards and Risks

This scenario considers the elements of an urban system that may be affected by natural events. The affected elements are considered as *objects at risk* for which values and goals can be identified. Therefore, the Prevention Scenario can be analyzed from both a risk and hazard perspective. For example, a seismic zone is a hazard zone, but a person who builds a house in this area exposes himself to risk.

There is a correlation between the hazard of certain natural events and the exposure of the objects at risk (people or things) and their vulnerability. Risk is given not only by the probability of the event occurring, but also by the measure of uncertainty arising from the randomness of outcomes that cannot be expressed in terms of specific probabilities.

In a preventive risk scenario, it is necessary to identify the relationships between the object at risk and the risky object (called the driver), between the hazard and the exposure, between the hazard and the vulnerability, as well as the types of impacts (damages and losses) if the hazardous event occurs.

Scenario of Occurrence of Natural Events

In this scenario, the aim is to represent the concepts, relationships, and properties extracted from real cases of natural events that occurred. The storyline technique describes a relevant sample of earthquakes, landslides, floods, etc. The result is a model that will be contrasted with a second model built from the other scenarios so that an ontological model that is as complete and consistent as possible is found. The resulting model will serve to build a repository of data about events that have already occurred.

Predictive Scenario

This scenario identifies the elements that can be deduced or inferred from the Prevention and Occurrence Scenarios. The objective is to verify which systems, subsystems, and elements of these may suffer some impact if one or more events occur (isolated or concatenated). For example, in the case of an earthquake hazard, the chain of negative social and economic consequences or the prediction of deaths among the population in a seismic zone can be deduced.

In addition, the indication of areas with a higher level of vulnerability or exposure to a natural event. For example, areas built without anti-seismic technologies or with a higher historical value of buildings.

Impact Mitigation Scenario

In this scenario, the relevance falls on the actions that can be taken before and after natural events. For example, in the case of earthquakes, mitigation measures are the enforcement of seismic codes, land-use zoning, identifying hazards that have not been identified before, building safer structures, providing education on earthquake safety, stabilizing hitherto unstable ground, and so on.

Scenario of Liability

In this scenario, it is important to identify the agents responsible for preventing, mitigating, and executing protocols during natural events.

9.1.4 Competency Questions

A preliminary set of competency questions (CQs) was identified from the set of functional requisites (Table 15).

Table 15 List of preliminary competency questions

ID	Competency Questions	Ontology
CQ1	What are the main subsystems of the urban system? What does it need to represent? What is contingent?	Urban Systems and Subsystems
CQ2	Which components/subsystems include non-artificial components?	Urban Systems and Subsystems
CQ3	How many kinds of residential buildings are there that have a green infrastructure?	Infrastructure
CQ4	What are the components of the soft infrastructure?	Infrastructure
CQ5	What kind of agents are involved in an urban system?	Population and Agents
CQ6	Which roles are played by these agents identified?	Population and Agents
CQ7	What are the relevant properties of these roles?	Population and Agents
CQ8	What are the relevant phases of an agent or a population in the urban context?	Population and Agents
CQ9	What are the scenarios in which an urban system infrastructure is present when considering the risks, exposure, vulnerabilities, impacts, and hazards of natural events?	Infrastructure, Risks
CQ10	What kinds of relationships does an agent or population maintain with the infrastructure of an urban system?	Population and Agents and Infrastructure
CQ11	What kind of hazards to natural events exist in an urban system?	Risks
CQ12	What kind of risks to natural events exist for an urban system?	Risks
CQ13	What kind of vulnerabilities and exposures does an urban system bear in the face of natural events?	Risks
CQ14	What are the main components of gray infrastructure?	Infrastructure
CQ15	What is the relationship between the railway network and the soft infrastructure? Or in general, network infrastructure and soft infrastructure?	Infrastructure

CQ16	What subsystems are considered in the hard infrastructure?	Infrastructure
CQ17	Is there a relationship between the green-blue infrastructure and the non-human population?	Infrastructure and Population and Agents
CQ18	Which living beings are considered in the urban system?	Population and Agents
CQ19	What systems and subsystems depend on the communication infrastructure?	Urban Systems, Infrastructure, Population, Agents, Risks
CQ20	What materials flow through the road network?	Population, Agents, Infrastructure, Risks
CQ21	What components is the soft infrastructure "health system" depending on?	Urban Systems, Population, Infrastructure
CQ22	What subsystem has the most dependencies? And the least?	
CQ23	What subsystem related to population is dependent on water?	Infrastructure, Population, Urban Systems

9.2 Modular View of Ontologies

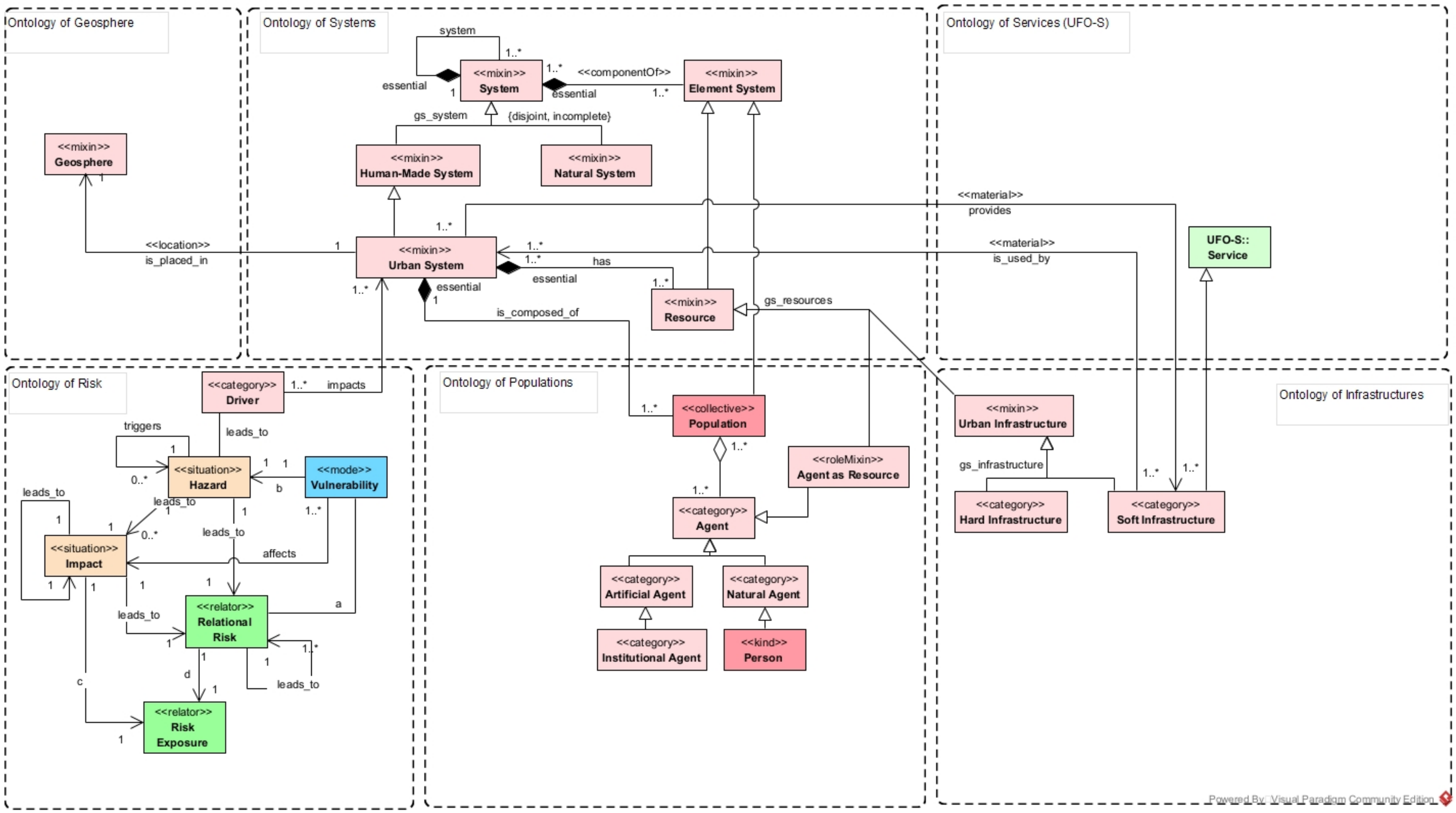


Figure 19 Modular view of ontologies

9.3 Ontology of Systems

An *Urban System* (Figure 19) is a kind of human-made system composed of one or more systems. A *system*, in turn, is essentially composed of one or more elements. An *element* is an essential part of one or more systems. In terms of ontological nature, a system is categorized as 1) made by humans (artificial systems) and 2) a natural system, which is a set of elements that arise naturally, without human construction. Both types of systems are coupled, that is, human systems interact with natural systems and vice versa in multi-levels and aspects.

There are several kinds of human-made systems (e.g., urban systems, economic systems, judicial systems) and natural systems. An urban system is a human-made system placed in a specific space and exists at a specific time. It is composed of *essential parts*, which are *Resource* and *Population*. A *Resource* is an essential part of one or more urban systems, for instance, a river can be a resource for different countries, and different cities*. The resource* is subcategorized as *Urban Infrastructure* and *Agent as a Resource.*

Urban systems using *Institutional Agents* (public and private agents) provide infrastructure services, such as health services, and educational services, to a sort of population.

Another essential part of an urban system is *Population.* It is composed of *Agents, Natural Agents,* and *Artificial Agents*. Agents can play a resource role in an urban context (*e.g.,* agents as residents, agents as tourists, epidemic agents, infectious agents, etc.*).* A constraint is set in terms of population. A population is an essential part of only one urban system.

9.4 Core Ontology of Services (UFO-S)

UFO-S is a core ontology that specializes in concepts from Unified Foundational Ontology (UFO) by providing a service conceptualization independent of a particular application domain (Nardi et al. 2013). UFO-S ontology will be reused to specialize in *Soft Infrastructure* (Figure 19). The benefit of reusing existing ontologies is, among other things, the achievement of ontological consistency. Thus, it will not be necessary to redefine the terms *service provider*, *service consumer*, or *service,* among others. In Figure 19, *Urban System* uses *Soft Infrastructure* (i.e., transportation services, mobility services, water distribution services, energy services, telecommunication services, health services, educational services, governmental services, judicial services, etc.)

9.5 Ontology of Population

The literature presents some proposals for population ontologies. Many of these ontologies were built based on theories from the biological sciences, for instance, the Population and Community Ontology (PCO)[13], which is an ontology of groups of interacting organisms, such as populations and communities. It is grounded in Basic Formal Ontology (BFO)[14] and designed to be compatible with other Open Biological and Biomedical Ontologies (OBO)[15], such as Gene Ontology (GO), Phenotype, and Trait Ontology (PATO).

In the context of this project, a *Population* is a collection of *Agents* of the same taxonomic class, counted or sampled at a given location or area. A population is categorized as `<<collective>>`, i.e., is a construct that represents rigid concepts and provides an identity principle for its instances under the UFO/OntoUML rules. The meaning of *population* is not the same definition assumed in the OBO library[3] because we have included in the model the definition of *Artificial Agent*. Figure 20 shows the ontology of the population from the RETURN project's perspective.

A population (Figure 20) is categorized into 1) Human Being Population, 2) Non-Human Being Population, and 3) Artificial Population. Human Being Population is categorized as 1.1) Resident Population and 1.2) Non-Resident Population. On the other hand, Non-Human Being Population is categorized as: 2.1) Pet Population, 2.2) Wild Animal Population, 2.3) Plant Population, 2.4) Mobile Genetic Element Population (MGE), 2.5) Fungus Population, and 2.6) Bacteria Population.

Figure 21 shows a partial representation of types of *Human Being Population*. *Human Being Population* is a *subkind* of a collective of human beings, who are residents or not in a city. In turn, *Resident Population* is a collection of people who are residents of a city. *Resident Person* is categorized as a `<<role>>` because *being a resident* is an accidental property of *a Human Being*, i.e., a kind can have its property of *being a resident* changed without losing its identity as a human being (essential property). Roles are played in the context of relationships. In this case, this role is played in a legal relationship (there will be rights, duties, permissions, prohibitions, liberties, powers, and subjections assigned to a resident person). In addition, Figure 21 presents the categories of *Agents:* 1) *Artificial Agents;* and 2) *Natural Agents.* Natural Agent is subcategorized as *Person, Pet, Wild Animal, Plant, Mobile Genetic Element (MGE), Fungus, and Bacteria.* A *Person* plays different roles *Residential Person, Non-Residential Person,* or *Tourist.* Also, he/she passes through distinct phases of life: *Child, Teenager,* and *Adult.* Also, *Person phases* are classified as *alive* and *deceased*. Additionally, there is a set of artificial agents which encompasses institutional agents (social agents), autonomous systems, and so on.

The ontology of the population was verified using Visual Paradigm software + OntoUML Plugin and it is free of syntactic errors. A file in Turtle was generated and exported by Protégè Editor to generate the operational ontology. The models still need to be validated, which can be done through storylines and the application of Alloy.

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[13] Available at https://bioportal.bioontology.org/ontologies/PCO
[14] Available at https://basic-formal-ontology.org/
[15] Available at https://obofoundry.org/

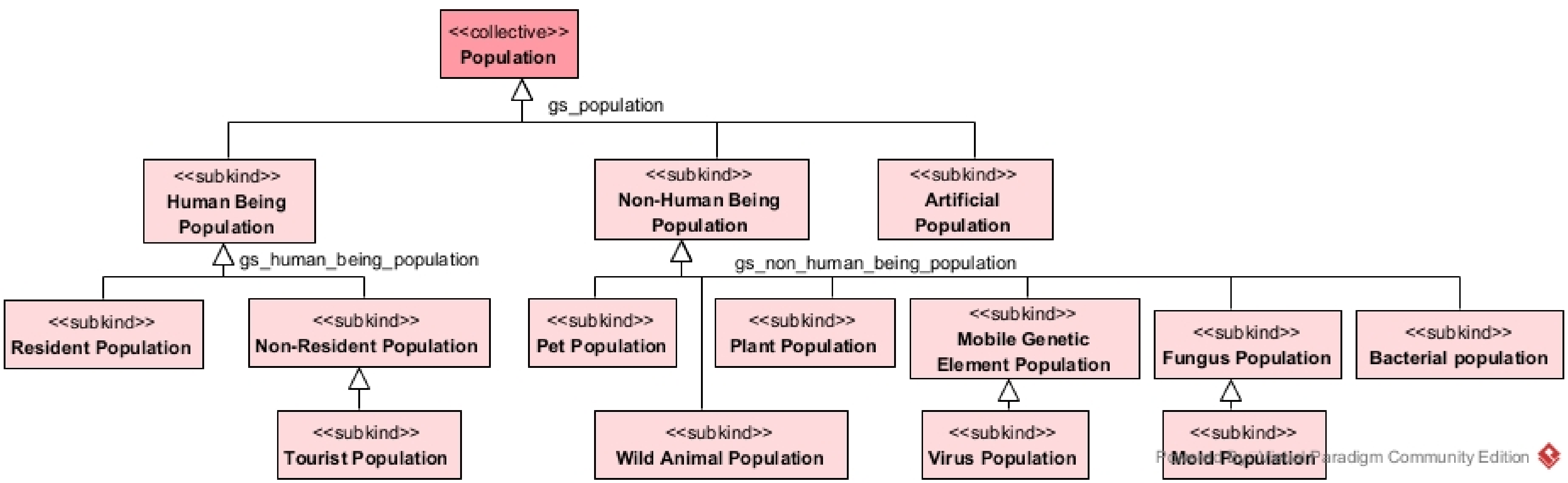

Figure 20 Ontology of Populations in an urban context

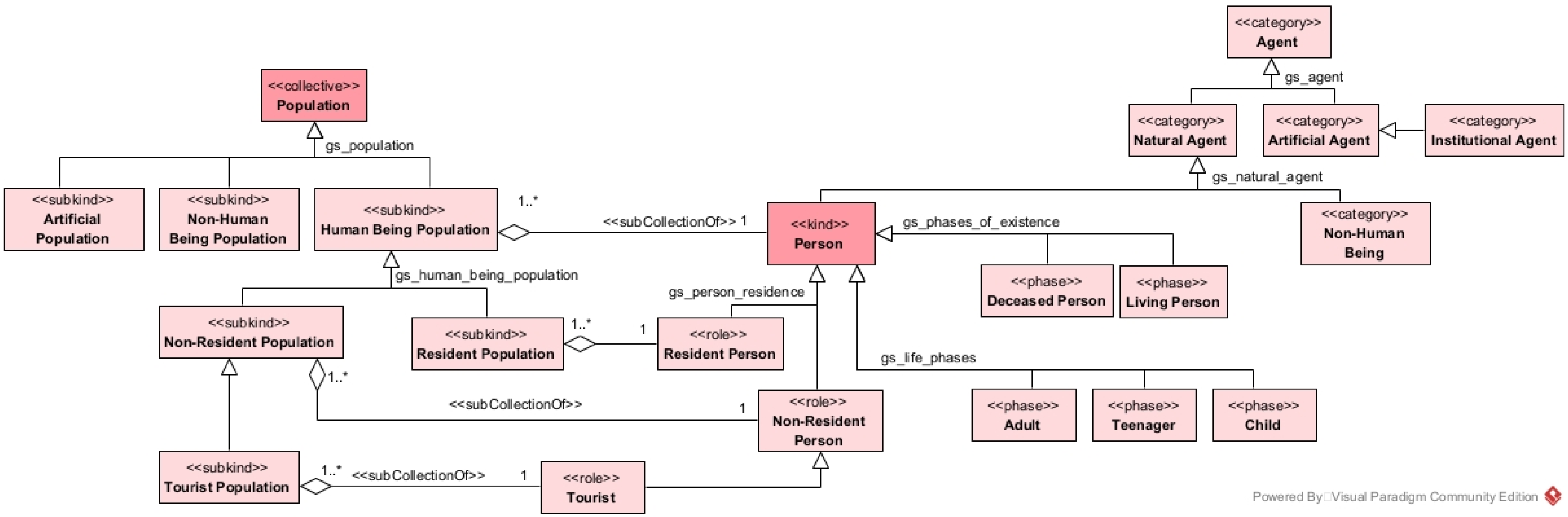

Figure 21 Sub-ontology of human beings in the context of urban systems

9.6 Ontology of Urban Infrastructure

Modeling infrastructure has been proposed in several works in the literature, some works focusing on the perspective of infrastructure as roads, pipes, and grounds, and some works focusing on the perspective of infrastructure as a service, such as communication, water, and energy. For instance, the Assessing the Underworld Ontology (ATU) (Du et al. 2023) is a top-level ontology that inherits some generic concepts from SWEET ontology[16] (DiGiuseppe, Pouchard, and Noy 2014): *substance, property, process, human activity, phenomena, and representation*. Additionally, it introduces the concept of *Method* to classify methods, tools, and techniques used in human activities. ATU is developed in OWL 2 and proposes a model of infrastructure, which is defined as "the basic physical and organizational structures and facilities that a country, a city or an organization needs and uses in order to work effectively". The city infrastructure model proposed in ATU is based on properties and processes of a group of five sub-models (Environment, Ground, Road, Buried Asset, and Human Activity). The concept of Substance is specialized in Infrastructure Asset, which, in turn, is specialized in Road, Utility (e.g., pipe, cable), and Ground (e.g., rock, soil). For each sub-model, an ontology is built with axioms, properties, and relationships. Also, there is an approach to analyzing the interdependence between ontologies. Table 16 shows the ATU sub-ontologies according to the number of classes and axioms.

Table 16 ATU Ontology - Classes and Axioms (Du et al. 2023)

	Classes	**Axioms**
Ground Ontology	110	3,337
Road Ontology	110	4,545
Water Pipe Ontology	66	894
Human Activity Ontology	55	140
Method Ontology	78	269
Investigation Ontology	45	183
Phenomena Ontology	178	382
ATU Ontology	**620**	**10,117**

On the other hand, there are in the literature infrastructure ontologies modeled from the service perspective, i.e., energy ontologies, transport ontologies, water ontologies. For instance, in the context

[16] The Semantic Web for Earth and Environmental Terminology (SWEET) is a mature foundational ontology with over 6000 concepts organized in 200 ontologies represented in OWL. Top-level concepts include Representation (math, space, science, time, data), Realm (Ocean, Land Surface, Terrestrial Hydrosphere, Atmosphere, etc.), Phenomena (macro-scale ecological and physical), Processes (micro-scale physical, biological, chemical, and mathematical), Human Activities (Decision, Commerce, Jurisdiction, Environmental, Research). Originally developed by NASA Jet Propulsion Labs under Rob Raskin, SWEET is now officially under the governance of the ESIP foundation. Available at: https://terminologies.gfbio.org/terminology/SWEET

of SEMANCO project[17], an urban energy ontology was designed in OWL 2 to support decision-making process about how to reduce CO2 emissions in cities. From the eliciting phase, it was used the techniques of use cases in which actors, data, and services are represented for different scenarios. This ontology is composed of terms and attributes that describe regions, cities, neighborhoods, and buildings; energy consumption and CO2 emission indicators, as well as climate and socio- economic factors that influence energy consumption. This ontology has a higher potential for reusability since it uses existing energy information standards for its terms and properties, such as: ISO/IEC CD 13273 Energy efficiency regulation and renewable energy sources; ISO 15927-1, for Hygrothermal performance of buildings. Calculation and presentation of climatic data; ISO/DTR 16344 Common terms, the definitions and symbols for the overall energy performance rating and certification of buildings; ISO 13790 (new 52016-1-2017), just to cite a few of standards.

Continuing from the Infrastructure as a service perspective, in particular water ontologies, there are some ontological models designed driven to risks, e.g., the Flood Disaster Support Ontology (FDSO)[18], an ontological data model to support urban flood disaster response. In this ontology, the terms *NaturalDisaster, WaterSpace, RiskManagement* among others are defined with their properties. The ontology is designed using OWL. On the other hand, there are some ontologies designed with the scope to assist the automatized decision-making process by identifying and mitigating failures in the water distribution network (Lin, Sedigh, and Hurson 2012) or for river water quality monitoring and data observation processing (Xiaolei Wang et al. 2020).

The ontological model (Figure 22) proposed in this first sprint considered the term *Infrastructure* categorized into two major branches: the *Hard Infrastructure* branch and the *Soft Infrastructure* branch. Hard infrastructure is a physical infrastructure and includes buildings, bridges, roads, and public open spaces, as well as the networks[19] formed by these elements (e.g., transportation networks are composed of railroads, highways, etc.; energy distribution networks include cables, thermoelectric plants, etc.; water distribution networks include pipes, ducts, reservoirs, etc.; sewage networks include pipes, ducts, sewage treatment centers, etc.; recycling networks include recycling plants, recyclable waste depots, recyclable waste drums, etc.; telecommunication networks are composed of optical fiber cables, signal towers, etc.).

In turn, *Soft Infrastructure* is related to the organizational, institutional, or service nature. It refers to public and private systems that provide certain utilities within the city such as local government, healthcare services, or educational services. In the ontological model proposed here, a difference is made between the (physical) distribution networks of basic infrastructure (water, sewage, energy,

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[17] The Semantic Tools for Carbon Reduction in Urban Planning (SEMANCO) Energy Model is a formal ontology – specified using Web Ontology Language 2 (OWL 2) – comprising concepts captured from diverse sources including standards, use cases and activity descriptions and data sources related to the domains of urban planning and energy management. Available at: http://semanco-project.eu/ontology.htm

[18] Available at https://www.isibang.ac.in/ns/fdso/index.html

[19] The network qualification (urban network) was done to avoid semantic confusion with other types of networks, for example, the computer network of a company.

waste, telecommunications, transportation, mobility) and the services provided by public or private companies by means of the hard infrastructure.

Hard Infrastructure is categorized as *Grey Infrastructure, Green Infrastructure,* and *Blue Infrastructure.* Grey Infrastructure refers to human-engineered infrastructure without a green aspect (visual or functional). On the other hand, Green Infrastructure refers to green open spaces in the urban context (urban forest, urban gardens, etc.) with an ecological visual or functional aspect, and structures that integrate green and grey infrastructures (green roofs, green walls, perforated pipes, permeable pavement, etc.). The category *Green-Grey Infrastructure,* mentioned in (Wesener and McWilliam 2021) as an integration of green and grey infrastructures with the goal of improving grey infrastructure through the incorporation of green in some parts of the grey infrastructure, was represented by a relationship between Grey Infrastructure and Green Infrastructure. Another possibility is to represent a category Green-Grey Infrastructure to include the integration of green and grey systems.

Regarding the subcategories of Green Infrastructure, it was based on some categories of typology of green infrastructure proposed by European Commission[20]: *Building Green, Urban Agricultural Land, Urban Green Area.* The category *Blue Infrastructure* has been defined as a subcategory of *Hard Infrastructure* rather than a subcategory of *Green Infrastructure*. Similar to *Green Infrastructure*, *Blue Infrastructure* integrates blue areas and grey infrastructure, such as lakes and coastal areas.

Regarding *Grey Infrastructure*, a level for "built things" has been added called *Urban Structure*[21] or *Urban Element*, which includes buildings, bridges, roads, paths, etc.; and Urban Network, which is the set of heterogeneous structures arranged according to their application in an urban system, e.g., a transportation network. Transportation Network is a conglomerate of roads, streets, paths, railways, bridges, etc. used for the mobility or transportation of goods and people.

Since there are several types of buildings, a category called *Grey Building* was defined to those ones built with a traditional structure with walls and a roof standing more or less permanently in one place. For example, a house or factory. *Buildings* serve several societal needs – primarily as shelter, living space, privacy & security, to store materials, workspace, etc. In this model, grey building is classified by its functionality/occupancy (the use of a structure: for housing, for educational, etc.) based on Table 6 of GEM Building Taxonomy combined with the building taxonomy proposed in NBC 2005. Furthermore, *Grey Building* is classified by its structure based on GEM Building Taxonomy, following 13 attributes have been included in the GEM Building Taxonomy Version 2.0 (v2.0): 1. direction 2. material of the lateral load-resisting system 3. lateral load-resisting system 4. height 5. date of construction or retrofit 6. occupancy 7. building position within block 8. shape of the building plan 9. structural irregularity 10. exterior walls 11. roof 12. floor 13. foundation system.

[20] Available at European Commission https://biodiversity.europa.eu/green-infrastructure/typology-of-gi

[21] The term "structure" was used to refer to anything human-made of interconnected parts with a fixed location on the ground. This includes buildings, but also any element designed to support loads, with different functions, for example, roads and streets are hard, flat surfaces on the ground for vehicles, people, or animals to travel on; bridges are structures that carry a pathway or roadway over a depression or obstacle.

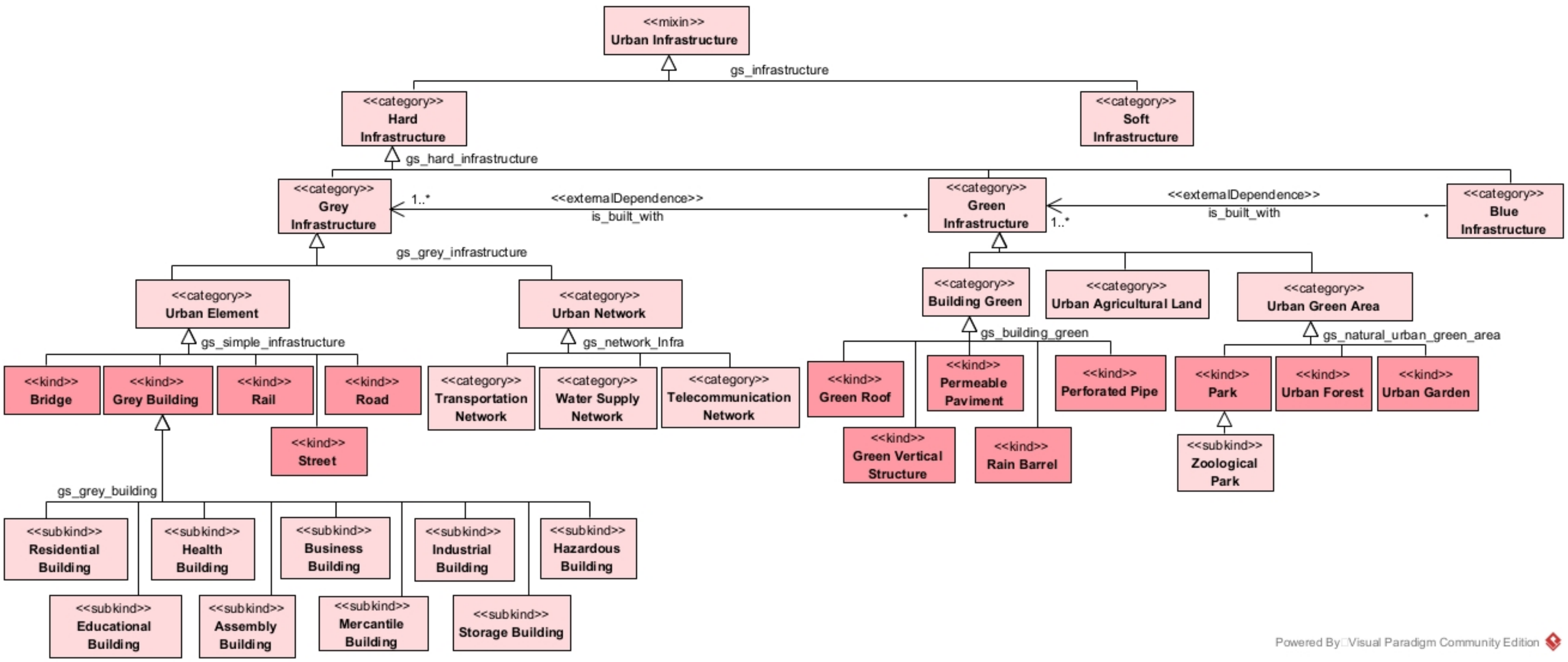

Figure 22 Ontology of Infrastructure

9.7 Ontology of Risk-oriented Urban Systems

Risk has been studied in a variety of fields for more than fifty years, contributing to the appearance of different definitions of risk. In the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[22], **risk** is defined as:

> *"The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making. In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs). Risks can arise for example from uncertainty in the implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions. See also Hazard and Impacts."*

From this definition, the following terms were extracted to categorize risk. For each of them, a meaning was negotiated, considering the vocabulary used by specialists in the field.

Terms

Adverse consequences (or negative consequences), Human and ecological systems, Values, Objectives, goals, Impacts, Human responses, Hazards, Exposure, Vulnerability, Dynamic interactions, Uncertainty, Magnitude of occurrence, Likelihood of occurrence, Time, Space, Socio-economic changes, Human decision-making, Deviation from the intended objective(s), Potential trade-offs, Side-effects, Societal objectives (e.g., Sustainable Development Goals)

In the case of urban systems, risks are assessed based on two different types of phenomena: 1) natural phenomena; and 2) man-made phenomena. Natural phenomena are events that do not have a human cause; examples include earthquakes, tsunamis, and solar storms. Conversely, human phenomena are events caused by human action. For example, pollution, urbanization, extensive monoculture, and deforestation.

[22] REISINGER, Andy, et al. The concept of risk in the IPCC Sixth Assessment Report: A summary of cross-working group discussions. *Intergovernmental Panel on Climate Change*, 2020, 15.

According to the definitions reviewed, risk is a measurement made by a risk-analyst, considering the relationship between the object at risk (e.g., human, and ecological systems), the threat to the object (i.e., the hazard), the level of exposure to that hazard, and the vulnerability of the object at risk.

A value is assigned to an object, then there is a risk evaluation that this object is exposed to. The measure of risk depends as well on the degree of uncertainty about the hazard to the object. This uncertainty can be measured in terms of uncertainty types[23] about the hazard information, pointing out: 1) Conflicting evidence, different results even when using the same model and data set (the set of threats is not fully known); 2) Lack of information, e.g., due to incomplete data (lack of adequate explicitation of the phenomena); 3) Abundance of information (complexity), the model is reductionist, generalizing the set of phenomena; and 4) vague information (ambiguity), when the language used to describe the phenomenon is vague, imprecise, for example, the ambiguity of certain concepts (e.g., risk definition) and relationships in the domain.

Furthermore, when assessing risk, the decision-maker considers the *goals* set for the *object at risk*. For instance, a water reservoir serving a city in the desert aims to prevent dehydration of the population. Hence, the decision-maker responsible for that city will assign more value to this reservoir than to a water reservoir in an uninhabited desert area. Therefore, risk is influenced by individual perceptions and object-specific objectives; it depends on how the object at risk is perceived by a specific group of people who have the power to assess it, considering the intended purposes or roles of the object. In this sense, the definition of risk presented here is grounded in Hillgartner's framework and in the relational theory of risk proposed by Boholm and Hervé[24].

[Risk object] ← (*Relationship of risk*) → [Object at risk]

Figure 23 Relational Theory of Risk framework. In (Boholm & Corvellec)

From a decision maker's perspective, objects at risk include: 1) resources used by a human or natural system (infrastructure, water, air, etc.); 2) the population (human and non-human); and 3) the geosphere.

Regarding the model of risks, the approach used was bottom-up, from storylines, texts, and schemas produced by experts to understand real cases. The storylines in Appendix A were used to design the model shown in Figure 24. In this model, there are some relations without names or cardinalities due to the lack of data from the storylines. One solution would be after designing the models to interview or send questionnaires for experts to answer. The questions/answers would serve to fill in the gaps in the models made from the storylines.

The second model oriented to risks in the urban context was designed by observing the construction of a storyline (Figure 25). Workshops were held during the project assembly in Naples with the purpose of

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[23] Zimmermann, H.-J. An application-oriented view of modeling uncertainty. *European Journal of operational research*, 2000, 122.2: 190-198.

[24] Åsa Boholm & Hervé Corvellec (2011) A relational theory of risk, Journal of Risk Research, 14:2, 175-190, DOI: 10.1080/13669877.2010.515313

building storylines with experts on natural events. In the observed group, two phenomena were analyzed: seismic phenomena and landslides occurred in an urban system. Urban system was categorized as a hazardous zone as well as hilly areas and alluvial plans. Some urban systems are situated in hazardous zones for natural events, resulting in exposure to both natural and human-made phenomena.

The driver is a factor that endangers an object of value. Risking it leads to a hazardous situation that may result in unfavorable outcomes due to different vulnerabilities and exposures. For instance, flooding poses a hazard, and urban areas constructed near riverbeds become vulnerable and expose themselves to the risk of flooding.

In this sense, there is a relationship between an urban system, which in the context of risk is called an "object at risk", and what becomes a *Hazard* for that urban system. Since a *situation* can only be classified as dangerous if the elements of *value* of the object at risk, the object at risk, the *vulnerability* and the *exposure* of that object exist at the same time, the situation can only be classified as hazardous if - a priori - the object has been valued. There is therefore a relationship of historical dependence between the value assigned to the object at risk and the hazard assigned to an event.

When a *Hazardous Situation* occurs results in a (natural) disaster. This results in a series of impacts, material and immaterial. *Impacts* are categorized as *Damage* and *Loss.* Loss refers to irreversible impacts, such as loss of land due to sea level rise or loss of freshwater resources due to desertification. Damage refers to repairable impact, such as impacts on coastlines or infrastructure related to climate change. One impact can trigger other impacts that will affect the urban center at risk.

For a hazardous situation (e.g., flooding) led by a driver (e.g., a high volume of rainfall in the same period and space), the exposure to the risk of the urban center (e.g., the existence of stilt houses near a riverbank) and at least one vulnerability (e.g., stilt houses resulting from the low income of a portion of the urban center's population) must be present in the same space-time. Population and infrastructure are used to value the urban center at risk.

Thus, one possibility for preventing natural disasters is the application of the ontological models based on the Swiss cheese theory[25]. In this context, it is necessary to analyze the place of danger (its vulnerabilities and exposure to risk), the danger situation and its characteristics, as well as the mitigation of impacts on the elements that make up the urban system (population, resources, etc.).

The models depicted in Figure 24 and Figure 25 provide an initial understanding of the risk-oriented urban systems model. However, it is essential to delineate all the roles of the objects, define their relationships, categorize them, establish the significance of the relationships detected in the storylines, and verify the models.

[25] In the book Human Error, James Reason elaborates on the theory of Swiss Cheese to argue that accidents do not result from one or more independent events. Instead, accidents occur due to several interconnected factors that culminate in failure.

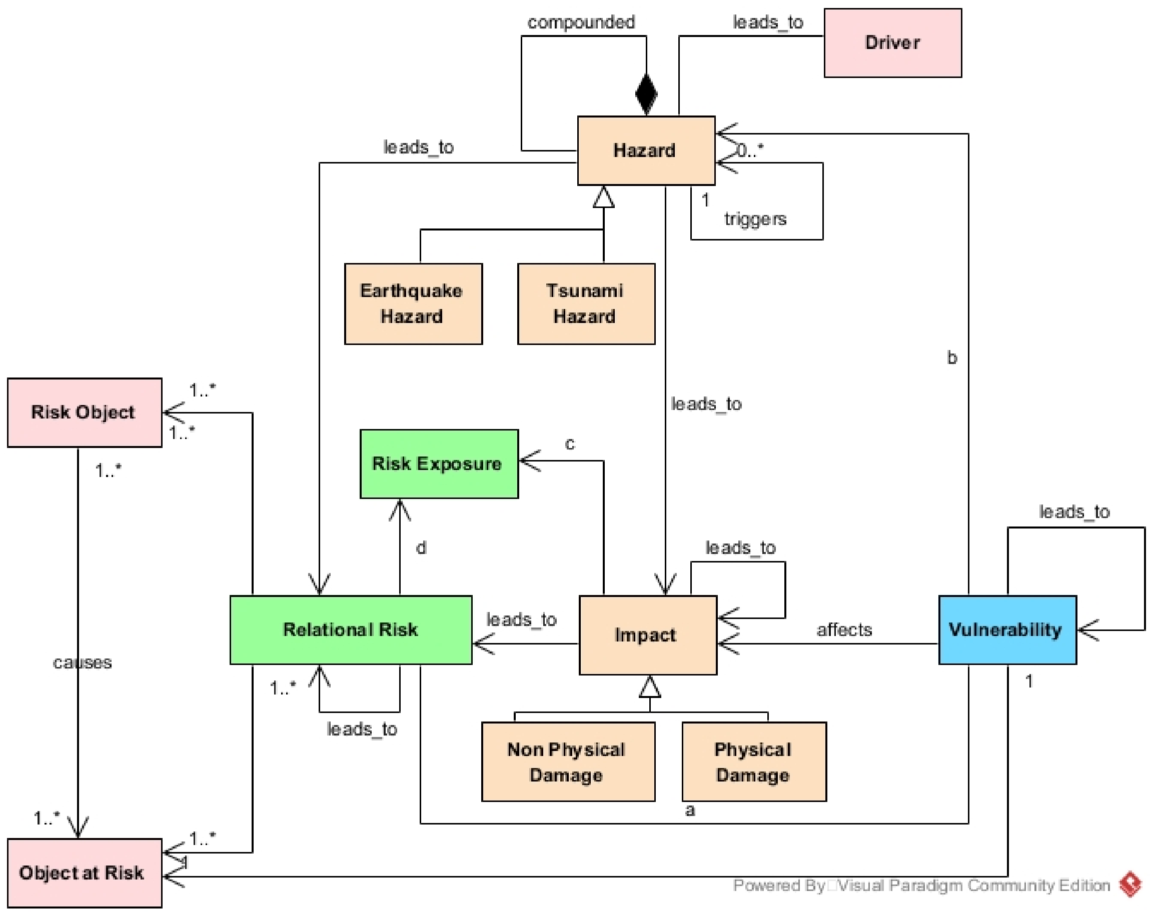

Figure 24 Model of risk-related concepts designed from storylines (Appendix A)

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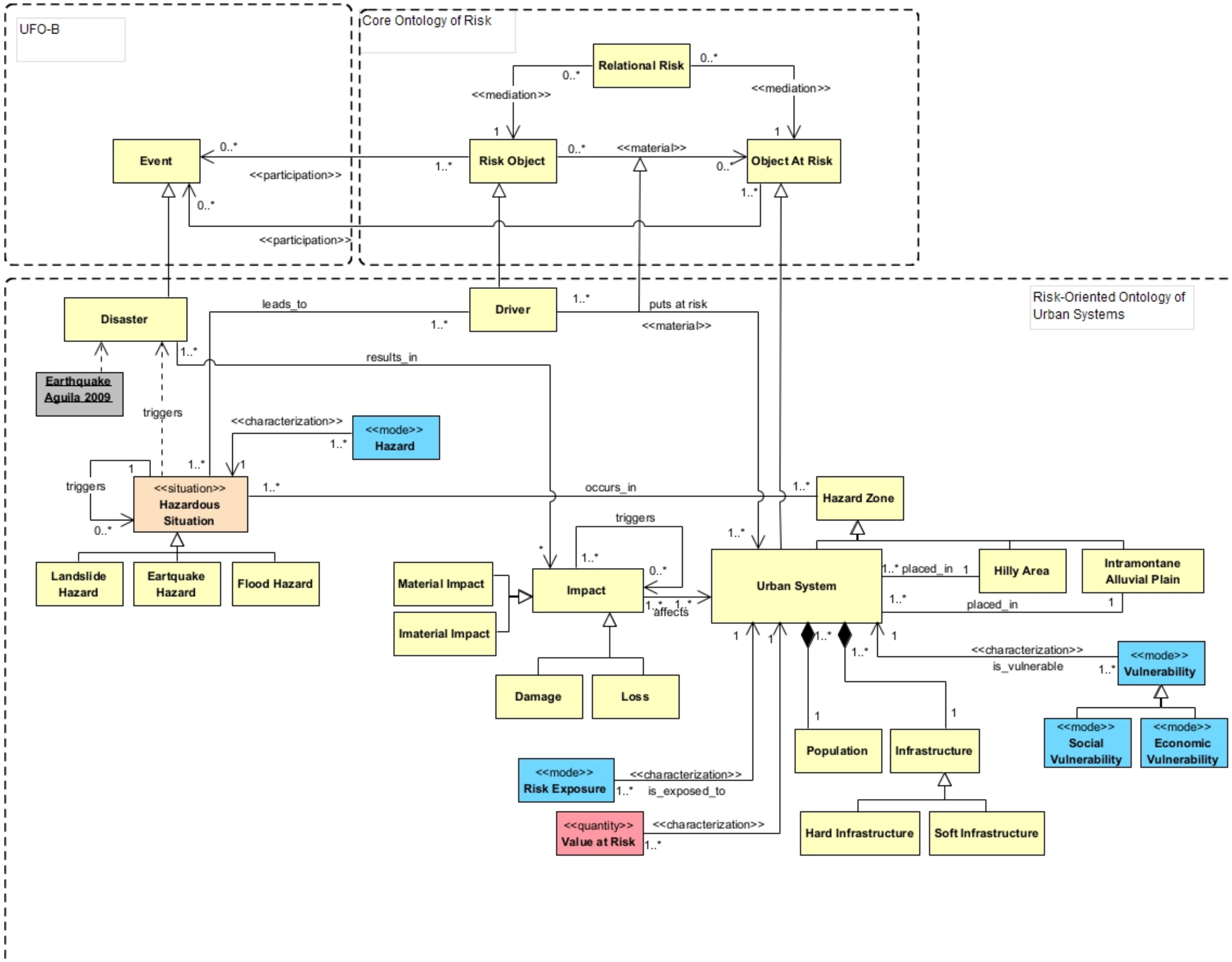
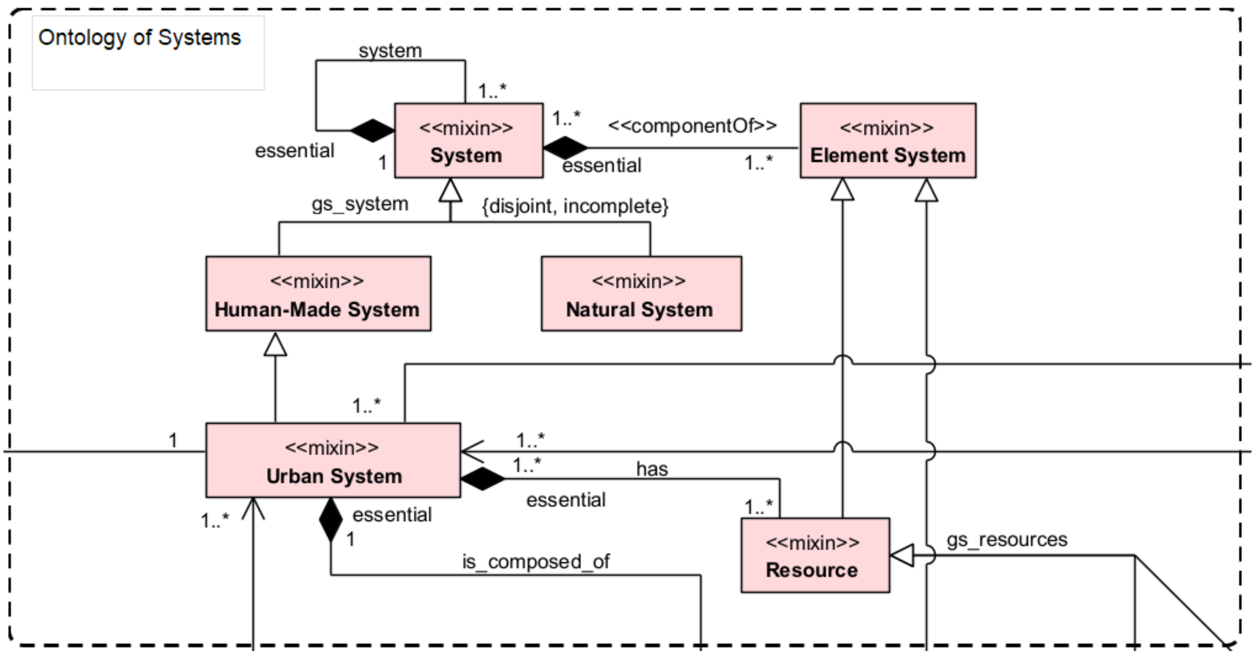


Figure 25 Ontological Model - from storylines

9.8 Technical Specifications - 1st. Sprint

1. Ontology of Systems

This ontology represents a system as a composition (or integrated set) of regularly interrelated and interdependent components created to achieve a defined objective. An urban system specializes System, and it is composed of two essential parts: population and infrastructure.



1.1 Element System

According to standard ISO/IEC 15288:2015, a *system element* is a discrete part of a system. A system element can be hardware, software, data, humans, processes, procedures (e.g., operator instructions), facilities, materials, and naturally occurring entities (e.g., water, organisms, minerals), or any combination.

2.1.1. Stereotype <<mixin>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Element System	Resource
is_composed_of	System	Element System

1.2 Natural System

A system not designed by human beings.

2.1.1. Stereotype <<mixin>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	System	Natural System

1.3 Human-Made System

A system designed by human beings.

2.1.1. Stereotype <<mixin>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Human-Made System	Urban System
specializes	System	Human-Made System
is_composed_of	System	Element System

1.4 Resource

It is everything that is used to satisfy the human needs.

2.1.1. Stereotype <<mixin>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Element System	Resource
specializes	Resource	Agent as Resource
specializes	Resource	Urban Infrastructure
is_composed_of	Urban System	Resource

1.5 System

A system is an organized collection of parts (or subsystems) that are highly integrated to accomplish an overall goal. The system has several inputs, which go through certain processes to produce outputs, which together, accomplish the overall desired goal for the system.

2.1.1. Stereotype <<mixin>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	System	Human-Made System
specializes	System	Natural System
is_composed_of	System	Element System
is_composed_of	System	System

1.6 Urban System

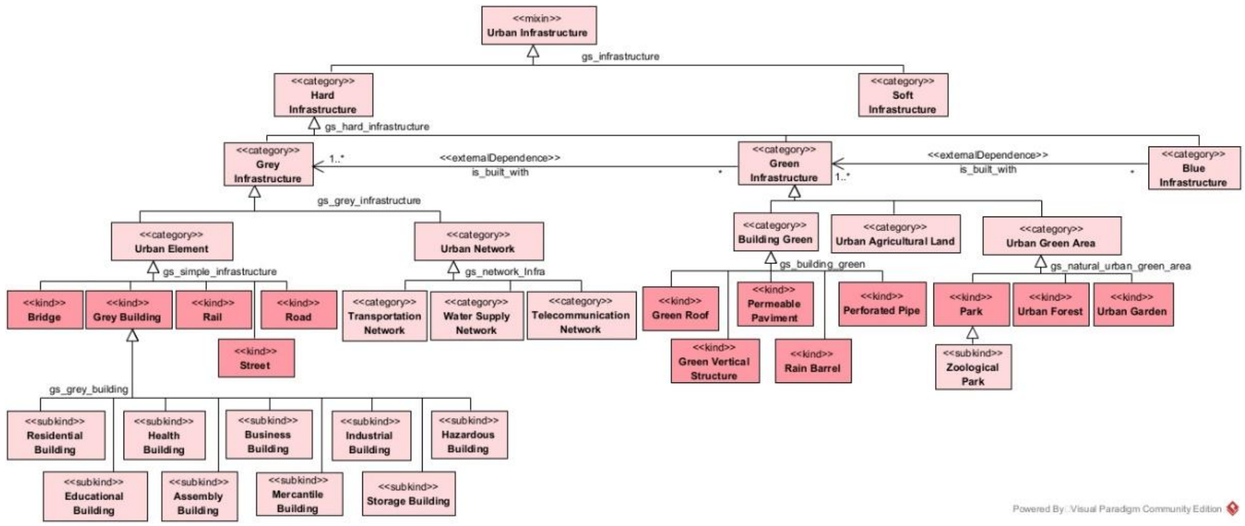
A specialization of Human-Made System, i.e., a specie of system designed by human beings. Urban system is a comprehensive collection of cities which are interdependent through economic fluctuations, diffusion and exchange of information, and flow of goods, capital, and people (Pred 1973).

2.1.1. Stereotype <<mixin>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Human-Made System	Urban System
specializes	System	Natural System
is_placed_in	Urban System	Geosphere
provides	Urban System	Soft Infrastructure
is_used_by	Soft Infrastructure	Urban System
impacts	Driver	Urban System
is_composed_of	Urban System	Resource
is_composed_of	Urban System	Population

2. Ontology of Infrastructure



2.1. Assembly Building

This type of buildings may include any building where a group of people gathers for recreation, amusement, social, religious, or purposes such as theaters, assembly halls, exhibition halls, restaurants, museums, club rooms, auditoria, etc.

2.1.1. Stereotype <<subkind>>

2.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Assembly Building

2.2. Blue Infrastructure

Blue Infrastructure integrates blue areas, such as lakes, aquifers, wetlands, floodplains, canals, and coastal areas, to the urban context.

2.2.1. Stereotype <<category>>

2.2.2. Relationships

Relationship	Generalization	Specialization
is_built_with	Blue Infrastructure	Green Infrastructure
specializes	Hard Infrastructure	Blue Infrastructure

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2.3. Bridge

2.3.1. Stereotype <<kind>>

2.3.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Element	Bridge

2.4. Building Green

Building Green or Green Construction encompasses a set of practices and principles that aim to make the design and utilization of the built environment as environmentally friendly as possible. These practices minimize the negative impact on the natural environment.

2.4.1. Stereotype <<category>>

2.4.2. Relationships

Relationship	Generalization	Specialization
specializes	Building Green	Perforated Pipe
specializes	Building Green	Permeable Pavement
specializes	Building Green	Green Vertical Structure
specializes	Building Green	Green Roof
specializes	Building Green	Rain Barrel
specializes	Green Infrastructure	Building Green

2.5. Business Building

It is any building type or part of a building that is used for business transactions, keeping records of accounts, town halls, city halls, courthouses, etc.

2.5.1. Stereotype <<subkind>>

2.5.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Business Building

2.6. Educational Building

These buildings include any building used for school, college, or daycare purposes involving assembly for instruction, education, or recreation.

2.6.1. Stereotype <<subkind>>

2.6.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Educational Building

2.7. Green Infrastructure

It is a fusion of natural resources and man-made structures (grey infrastructure) designed to work with the nature to provide social, environmental, and economic benefits to urban populations, such as air filtration, temperature regulation, noise reduction, flood control, and recreational areas.

2.7.1. Stereotype <<category>>

2.7.2. Relationships

Relationship	Generalization	Specialization
is_built_with	Green Infrastructure	Grey Infrastructure
is_built_with	Blue Infrastructure	Green Infrastructure
specializes	Green Infrastructure	Building Green
specializes	Green Infrastructure	Urban Green Area
specializes	Green Infrastructure	Urban Agricultural Land
specializes	Hard Infrastructure	Green Infrastructure

2.8. Green Roof

2.8.1. Stereotype <<kind>>

2.8.2. Relationships

Relationship	Generalization	Specialization
specializes	Building Green	Green Roof

2.9. Green Vertical Structure

2.9.1. Stereotype <<kind>>

2.9.2. Relationships

Relationship	Generalization	Specialization
specializes	Building Green	Green Vertical Structure

2.10. Grey Building

A Grey Building is one built with a traditional structure with walls and a roof standing permanently in one place. For example, a house or factory. *Buildings* serve several societal needs – primarily as shelter, living space, privacy & security, to store materials, workspace, etc. In this model, grey buildings are classified by its functionality/occupancy (the use of a structure: for housing, for educational, etc.) based on Table 6 of GEM Building Taxonomy combined with the building taxonomy proposed in NBC 2005.

In additional, Grey Building is classified by its structure based on GEM Building Taxonomy, following 13 attributes have been included in the GEM Building Taxonomy Version 2.0 (v2.0): 1. direction 2. material of the lateral load-resisting system 3. lateral load-resisting system 4. height 5. date of construction or retrofit 6. occupancy 7. building position within a block 8. shape of the building plan 9. structural irregularity 10. exterior walls 11. roof 12. floor 13. foundation system.

Source:

https://cloud-storage.globalquakemodel.org/public/wix-new-website/pdf-collections-wix/publications/GEM%20Building%20Taxonomy%20Version%202.0.pdf

https://dailycivil.com/types-of-buildings/

2.10.1. Stereotype <<kind>>

2.10.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Industrial Building
specializes	Grey Building	Residential Building
specializes	Grey Building	Educational Building
specializes	Grey Building	Health Building
specializes	Grey Building	Assembly Building
specializes	Grey Building	Business Building
specializes	Grey Building	Mercantile Building
specializes	Grey Building	Storage Building
specializes	Grey Building	Hazardous Building
specializes	Urban Element	Grey Building

2.11. Grey Infrastructure

It is a category of all tangible/physical elements that are (mostly) of atrophic origin (that is, artificial), in other words, engineered assets that provide one or multiple services required by society. This is in turn preliminary subdivided into Urban Elements (e.g., buildings, bridges, rails, roads, streets, and public spaces) and Urban Networks (a composition of these urban elements).

2.11.1. Stereotype <<category>>

2.11.2. Relationships

Relationship	Generalization	Specialization
is_built_with	Green Infrastructure	Grey Infrastructure
specializes	Grey Infrastructure	Urban Element
specializes	Grey Infrastructure	Urban Network
specializes	Hard Infrastructure	Grey Infrastructure

2.12. Hard Infrastructure

It is the built environment, the physical connections between places that move people, materials, information, and energy. These "fixed" things include roads, railroads, pipes, buildings, cables, and the networks composed of these constructions. Moreover, encompasses the green infrastructure, which is a category of ecological-oriented designed structures, i.e., a combination of grey and green infrastructures; and the Blue Infrastructure defined as the blue areas, a mix of natural resources (rivers, sea, beaches, etc) and human-designed elements.

2.12.1. Stereotype <<category>>

2.12.2. Relationships

Relationship	Generalization	Specialization
specializes	Hard Infrastructure	Green Infrastructure
specializes	Hard Infrastructure	Grey Infrastructure
specializes	Hard Infrastructure	Blue Infrastructure
specializes	Urban Infrastructure	Hard Infrastructure

2.13. Hazardous Building

These types of buildings include any building which is used for storage, handling, manufacturing, or processing of highly combustible explosive materials or products that are liable to burn extremely rapidly, which may produce poisonous fumes.

2.13.1. Stereotype <<subkind>>

2.13.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Hazardous Building

2.14. Health Building

These buildings include any building or part which is used for medical treatment etc. Such as Hospitals, nursing homes, orphanages, sanatoria, jails, prisons, mental hospitals, etc.

2.14.1. Stereotype <<subkind>>

2.14.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Health Building

2.15. Industrial Building

These types of building are mainly used for manufacturing purposes. Here products or materials of all kinds and properties are fabricated, assembled, or processed, for example, gas plants, refineries, mills, dairies, etc.

2.15.1. Stereotype <<subkind>>

2.15.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Industrial Building

2.16. Mercantile Building

These shall include buildings used for soap, markets, stores, wholesale or retail.

2.16.1. Stereotype <<subkind>>

2.16.2. Tagged Values

2.16.3. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Mercantile Building

2.17. Park

2.17.1. Stereotype <<kind>>

2.17.2. Relationships

Relationship	Generalization	Specialization
specializes	Park	Zoological Park
specializes	Natural Asset	Park
specializes	Urban Green Area	Park

2.18. Perforated Pipe

2.18.1. Stereotype <<kind>>

2.18.2. Relationships

Relationship	Generalization	Specialization
specializes	Building Green	Perforated Pipe

2.19. Permeable Pavement

2.19.1. Stereotype <<kind>>

2.19.2. Relationships

Relationship	Generalization	Specialization
specializes	Building Green	Permeable Pavement

2.20. Rail

2.20.1. Stereotype <<kind>>

2.20.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Element	Rail

2.21. Rain Barrel

2.21.1. Stereotype <<kind>>

2.21.2. Relationships

Relationship	Generalization	Specialization
specializes	Building Green	Rain Barrel

2.22. Residential Building

A building should be considered a residential building when more than half of the floor area is employed for dwelling purposes. Other buildings should be considered non-residential.

A residential building is one that is designed and accordingly built for inhabitants to measure in and call House. Inhabitants can either be a family, single, a couple, roommates or may be in a group. A residential building has basically:

- A sleeping room(bedroom)/space,

- A living room/space,

- Conveniences (as in toilet and bath),

- Cooking room/area (kitchen).

All of those functions can either be in shared rooms or spaces or have exclusive rooms per function. These types of buildings include one or two private dwellings, apartment houses (flats), bungalows, duplexes, storey houses, terrace buildings, apartment buildings, condominium buildings, hotels, dormitories, semi-detached buildings, etc.

Source: https://dailycivil.com/types-of-buildings/

2.22.1. Stereotype <<subkind>>

2.22.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Residential Building

2.23. Road

2.23.1. Stereotype <<kind>>

2.23.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Element	Road

2.24. Soft Infrastructure

It refers to everything that is needed to maintain the utilities and services in an urban system, such as the educational, health, cultural systems.

2.24.1. Stereotype <<category>>

2.24.2. Relationships

Relationship	Generalization	Specialization
is_used_by	Soft Infrastructure	Urban System
provides	Urban System	Soft Infrastructure
specializes	Urban Infrastructure	Soft Infrastructure
specializes	UFO-S:: Service	Soft Infrastructure

2.25. Storage Building

These buildings are generally used for the storage or sheltering of goods, wares, or merchandise like warehouses, cold storages, garages, stables, transit sheds, etc.

2.25.1. Stereotype <<subkind>>

2.25.2. Relationships

Relationship	Generalization	Specialization
specializes	Grey Building	Storage Building

2.26. Street

2.26.1. Stereotype <<kind>>

2.26.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Element	Street

2.27. Telecommunication Network

Telecommunication networks comprise of transmission, switching, and network management components that operate jointly to facilitate communication in urban and long-distance settings.

2.27.1. Stereotype <<category>>

2.27.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Network	Telecommunication Network

2.28. Transportation Network

Transportation Network is a conglomerate of heterogeneous urban elements, such as roads, streets, paths, railways, bridges, etc., used for the mobility or transportation of goods and people.

2.28.1. Stereotype <<category>>

2.28.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Network	Transportation Network

2.29. Urban Agricultural Land

It refers to the land within the urban development boundary designated for small-scale farming activities and growing crops for personal use or sale in surrounding markets. This encompasses vertical production, warehouse farms, community gardens, rooftop farms, hydroponics, aeroponic, and aquaponic facilities, as well as other innovative techniques.

2.29.1. Stereotype <<category>>

2.29.2. Relationships

Relationship	Generalization	Specialization
specializes	Green Infrastructure	Urban Agricultural Land

2.30. Urban Element

It is a category of constructed items encompassing buildings, bridges, roads, footpaths, streets, rails, and other related infrastructures.

2.30.1. Stereotype <<category>>

2.30.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Element	Bridge
specializes	Urban Element	Road
specializes	Urban Element	Grey Building

Relationship	Generalization	Specialization
specializes	Urban Element	Rail
specializes	Urban Element	Street
specializes	Grey Infrastructure	Urban Element

2.31. Urban Forest

2.31.1. Stereotype <<kind>>

2.31.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Green Area	Urban Forest

2.32. Urban Garden

2.32.1. Stereotype <<kind>>

2.32.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Green Area	Urban Garden

2.33. Urban Green Area

Urban green space refers to open areas reserved for parks and natural environments - encompassing plant life. The landscape of urban open spaces typically ranges from playing fields and highly maintained environments to more natural landscapes. It links ecological processes and functions and encompasses forests, roadside trees, park trees, garden trees, and nature conservation areas.

In the context of urban land-use growth and its impact on the environment, green spaces offer ecosystem services to promote human health. Green spaces such as parks, public gardens, and roadside trees are vital components of urban planning.

Available at: https://doi.org/10.3390/land10020105

2.33.1. Stereotype <<category>>

2.33.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Green Area	Park

Relationship	Generalization	Specialization
specializes	Urban Green Area	Urban Forest
specializes	Urban Green Area	Urban Garden
specializes	Green Infrastructure	Urban Green Area

2.34. Urban Infrastructure

Urban infrastructure is a mix of structures built horizontally or vertically by humans, which provide a variety of utilities and services such as housing, transportation, and leisure. The design of these structures serves to ensure accessibility and convenience to meet the needs of the urban dwellers.

2.34.1. Stereotype <<mixin>>

2.34.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Infrastructure	Hard Infrastructure
specializes	Urban Infrastructure	Soft Infrastructure
specializes	Resource	Urban Infrastructure

2.35. Urban Network

It is an ordered composition of heterogeneous urban structures, arranged according to their application in an urban system, e.g., a transportation network.

2.35.1. Stereotype <<category>>

2.35.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Network	Transportation Network
specializes	Urban Network	Water Supply Network
specializes	Urban Network	Telecommunication Network
specializes	Grey Infrastructure	Urban Network

2.36. Water Supply Network

It is a system of engineered hydrologic and hydraulic components that provide water supply for an urban system.

2.36.1. Stereotype <<category>>

2.36.2. Relationships

Relationship	Generalization	Specialization
specializes	Urban Network	Water Supply Network

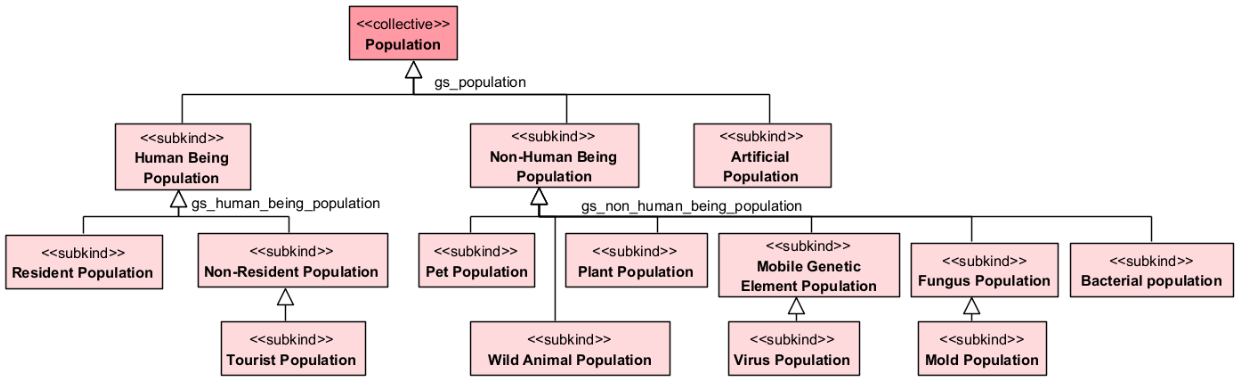
2.37. Zoological Park

2.37.1. Stereotype <<subkind>>

2.37.2. Relationships

Relationship	Generalization	Specialization
specializes	Park	Zoological Park

3. Ontology of Population



3.1. Artificial Population

Artificial Population is all populations that do not encompass natural beings (humans or not) and are designed by human beings. For instance, autonomous systems, institutional agents, intelligent artificial agents, etc.

3.1.1. Stereotype <<subkind>>

3.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Population	Artificial Population

3.2. Bacterial population

It is the collective of bacteria of a specified gender and species. A bacterial colony may expand in a geometric or exponential fashion.

3.2.1. Stereotype <<subkind>>

3.2.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Human Being Population	Bacterial population

3.3. Fungus Population

It is a collective of Fungus, which is any of about 143.000 known species of organisms of the kingdom Fungi, including yeasts, mildews, molds, and mushrooms.

3.3.1. Stereotype <<subkind>>

3.3.2. Relationships

Relationship	Generalization	Specialization
specializes	Fungus Population	Mold Population
specializes	Non-Human Being Population	Fungus Population

3.4. Human Being Population

It is a subtype of the population collective, covering the subtypes of resident, non-resident and tourist populations in a given space and a time.

3.4.1. Stereotype <<subkind>>

3.4.2. Relationships

Relationship	Generalization	Specialization
specializes	Human Being Population	Resident Population
specializes	Human Being Population	Non-Resident Population
is_collection_of	Human Being Population	Person
specializes	Animal Population	Human Being Population
specializes	Population	Human Being Population
specializes	Population	Human Being Population

3.5. Mobile Genetic Element Population

It is a collective of Mobile Genetic Element (MGE), also known as transposable element (TE).

3.5.1. Stereotype <<subkind>>

3.5.2. Relationships

Relationship	Generalization	Specialization
specializes	Mobile Genetic Element Population	Virus Population
specializes	Non-Human Being Population	Mobile Genetic Element Population

3.6. Mold Population

It is the collective of mold, a subtype of fungus that grows indoor.

3.6.1. Stereotype <<subkind>>

3.6.2. Relationships

Relationship	Generalization	Specialization
specializes	Fungus Population	Mold Population

3.7. Non-Human Being Population

Non-Human Being Population is all populations that do not encompass human beings. It is subcategorized as: 2.1) Pet Population, 2.2) Wild Animal Population, 2.3) Plant Population, 2.4) Mobile Genetic Element Population (MGE), 2.5) Fungus Population, 2.6) Protist Population, and 2.7) Bacteria Population.

There is a subtype of MGE, which is the Virus Population. Also, there is a subtype of Protist Population, which is Mold Population.

3.7.1. Stereotype <<subkind>>

3.7.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Human Being Population	Pet Population
specializes	Non-Human Being Population	Wild Animal Population
specializes	Non-Human Being Population	Plant Population
specializes	Non-Human Being Population	Mobile Genetic Element Population
specializes	Non-Human Being Population	Bacterial population
specializes	Non-Human Being Population	Fungus Population
specializes	Population	Non-Human Being Population

3.8. Non-Resident Population

It is the collective of individuals who are not registered with the Registry of the Resident Population in a given municipality in a given time. It can be a tourist or a person who is temporally living in a particular place without the duties required of the residents.

3.8.1. Stereotype <<subkind>>

3.8.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Resident Population	Tourist Population
is_collection_of	Non-Resident Population	Non-Resident Person
specializes	Human Being Population	Non-Resident Population

3.9. Pet Population

It is a collective of any domesticated or tamed animal that is kept as a companion and cared for affectionately.

3.9.1. Stereotype <<subkind>>

3.9.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Human Being Population	Pet Population

3.10. Plant Population

It is the collective of plants per unit area of land. Plant populations are characterized by their size (or density) and their structure (the number of individuals of different ages and sizes).

3.10.1. Stereotype <<subkind>>

3.10.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Human Being Population	Plant Population

3.11. Population

It is a collection of Agents of the same taxonomic class, counted or sampled at a given location or area, given a time interval.

3.11.1. Stereotype <<collective>>

3.11.2. Relationships

Relationship	Generalization	Specialization
is_composed_of	Urban System	Population
specializes	Population	Human Being Population
specializes	Population	Non-Human Being Population
specializes	Population	Human Being Population
is_collection_of	Population	Agent

3.12. Resident Population

It refers to the collective of people enlisted with the Resident Population Registry in a particular local authority area in a given time. The classification of a Resident Person as a <<role>> derives from residency being an incidental characteristic of a human being.

3.12.1. Stereotype <<subkind>>

3.12.2. Relationships

Relationship	Generalization	Specialization
is_collection_of	Resident Population	Resident Person
specializes	Human Being Population	Resident Population

3.13. Tourist Population

It is a collective of people who is traveling or visiting a place for pleasure or interesting.

3.13.1. Stereotype <<subkind>>

3.13.2. Relationships

Relationship	Generalization	Specialization
is_collection_of	Tourist Population	Tourist
specializes	Non-Resident Population	Tourist Population

3.14. Virus Population

It is a collective of a kind of virus. It is possible that viruses originated from mobile genetic elements that acquired intercellular migration capabilities. They could be descendants of formerly free-living organisms that adopted a parasite replication strategy.

3.14.1. Stereotype <<subkind>>

3.14.2. Relationships

Relationship	Generalization	Specialization
specializes	Mobile Genetic Element Population	Virus Population

3.15. Wild Animal Population

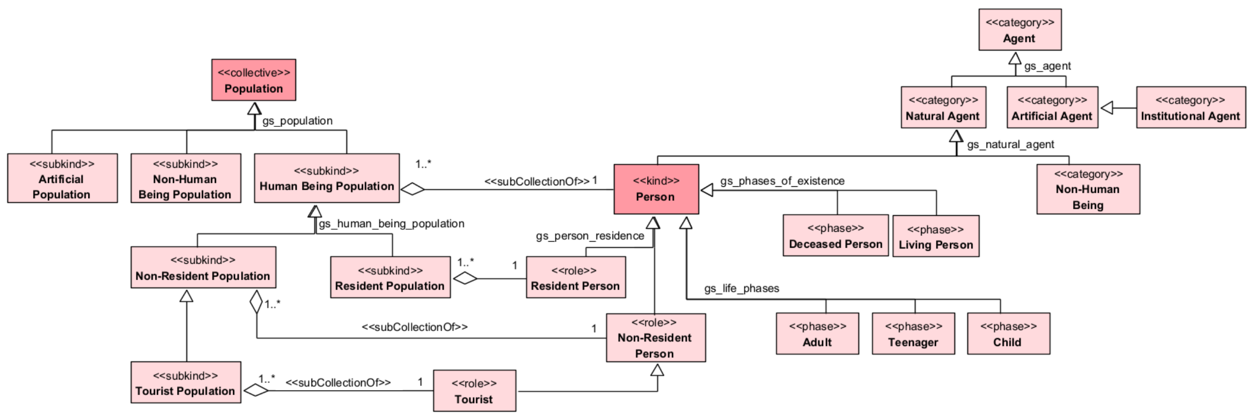
Urban wildlife animal populations consist of species that utilize human-dominated ecosystems.

3.15.1. Stereotype <<subkind>>

3.15.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Human Being Population	Wild Animal Population

4. Ontology of Human Being Population



4.1. Adult

It is a phase or stage of human development that occurs after the stage of adolescence and puberty. There are three distinct stages: early (ages 19 to 45), middle (ages 45 to 60), and late (the later years thereafter).

There is no consensus about the starting age for these three stages of adulthood. The stages used here are extracted at https://psychologydictionary.org/adulthood/

However, the Italian population statistics by age group are arranged as follows at https://www.statista.com/statistics/789270/population-in-italy-by-age-group/

4.1.1. Stereotype <<phase>>

4.1.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Adult

4.2. Agent

From UFO-C. Agents are agentive substantial individuals that are classified as physical agents (e.g., a person) or social agents (e.g., an organization, a society). Here, Agent is classified as Natural Agent (e.g., human beings, non-human beings) and Artificial Agent (e.g., institutional agents, autonomous systems).

4.2.1. Stereotype <<category>>

4.2.2. Relationships

Relationship	Generalization	Specialization
specializes	Agent	Person
specializes	Agent	Agent as Resource
specializes	Agent	Natural Agent
specializes	Agent	Artificial Agent
is_collection_of	Population	Agent

4.3. Artificial Agent

It is an artefact that was designed by human beings and can act autonomously, learn, perceive, and improve. For instance, artificial intelligent agents, autonomous systems, robots, institutional agents, and artificial organisms.

4.3.1. Stereotype <<category>>

4.3.2. Relationships

Relationship	Generalization	Specialization
specializes	Artificial Agent	Institutional Agent
specializes	Agent	Artificial Agent

4.4. Child

It is a human being between the stages of birth and puberty, or between the developmental period of infancy and puberty. It may also refer to an unborn human being.

For the UNICEF Convention, a child means every human being below the age of eighteen years unless under the law applicable to the child, the majority is attained earlier.

In the context of urban systems, the Child is a phase that a human being goes through. The following subphases are covered: Early childhood (birth to age 5), middle childhood (ages 6 to 12).

4.4.1. Stereotype <<phase>>

4.4.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Child

4.5. Deceased Person

It is the phase in which a person is no longer alive. A person cannot be alive and not alive at the same time. Therefore, it is a disjointed phase from the Alive phase.

4.5.1. Stereotype <<phase>>

4.5.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Deceased Person

4.6. Human Being Population

It is a subtype of the population collective, covering the subtypes of resident, non-resident and tourist populations in a given space and period of time.

4.6.1. Stereotype <<subkind>>

4.6.2. Relationships

Relationship	Generalization	Specialization
specializes	Human Being Population	Resident Population
specializes	Human Being Population	Non-Resident Population
is_collection_of	Human Being Population	Person
specializes	Animal Population	Human Being Population
specializes	Population	Human Being Population
specializes	Population	Human Being Population

4.7. Institutional Agent

4.7.1. Stereotype <<category>>

4.7.2. Relationships

Relationship	Generalization	Specialization
specializes	Artificial Agent	Institutional Agent

4.8. Living Person

It is a phase or stage of being alive, as opposed to being dead, during which your organs work and carry out their functions.

4.8.1. Stereotype <<phase>>

4.8.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Living Person

4.9. Natural Agent

It is every agent, human or non-human, with a natural existence, that can influence an urban system.

4.9.1. Stereotype <<category>>

4.9.2. Relationships

Relationship	Generalization	Specialization
specializes	Natural Agent	Person
specializes	Natural Agent	No-Human Being
specializes	Agent	Natural Agent

4.10. Non-Human Being

It is every non-human being with agentive capacity to influence an urban system. This category is classified as Pet, Plant, Wild Animal, Fungus, MGE, Virus, Mold, and Bacteria.

1) Pet is any domesticated or tamed animal that is kept as a companion and cared for affectionately.

2) Wild animal in an urban system is any non-domesticated animal that has adapted its lifestyle to living in the cities or in suburban neighborhoods.

3) A plant is a living and natural organism of the kind exemplified by trees, shrubs, herbs, grasses, ferns, and mosses, typically growing in a permanent site, absorbing water and inorganic substances through its roots, and synthesizing nutrients in its leaves by photosynthesis using the green pigment chlorophyll.

4) Mobile genetic element (MGE), also known as transposable element (TE), is a type of moving genetic material that can either move around within a genome or jump across different genomes.

5) Viruses may have arisen from mobile genetic elements that gained the ability to move between cells. They may be descendants of previously free-living organisms that adapted a parasitic replication strategy. Viruses can leave the cell and move to other cells and organisms; mobile genetic elements generally just move around the genome within a cell.

6) Fungus is any member of a kingdom of organisms called Fungi that lack chlorophyll, leaves, true stems, and roots, reproduce by spores, and live as saprotrophs or parasites. The group includes molds, mildews, rusts, yeasts, and mushrooms.

7) A mold is a microscopic fungus that grows and lives on plant or animal matter or on non-organic objects. Most molds are made up of filaments and reproduce through the production of spores. Spores spread by air, water, or insects. There are many thousands of species of fungi. Mold is the colloquial term used for indoor fungi. Fungal spores occur naturally outdoors easily be transferred inside well they can sit on surfaces. Mold organisms are

extremely resilient and have evolved to adapt to survive in sub-optimal conditions. Types of indoor mold differ according to geographical location.

4.10.1. Stereotype <<category>>

4.10.2. Relationships

Relationship	Generalization	Specialization
specializes	Natural Agent	No-Human Being

4.11. Non-Human Being Population

Non-Human Being Population is all populations that do not encompass human beings. It is subcategorized as: 2.1) Pet Population, 2.2) Wild Animal Population, 2.3) Plant Population, 2.4) Mobile Genetic Element Population (MGE), 2.5) Fungus Population, 2.6) Protist Population, and 2.7) Bacteria Population.

There is a subtype of MGE, which is the Virus Population. Also, there is a subtype of Protist Population, which is Mold Population.

4.11.1. Stereotype <<subkind>>

4.11.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Human Being Population	Pet Population
specializes	Non-Human Being Population	Wild Animal Population
specializes	Non-Human Being Population	Plant Population
specializes	Non-Human Being Population	Mobile Genetic Element Population
specializes	Non-Human Being Population	Bacterial population
specializes	Non-Human Being Population	Fungus Population
specializes	Population	Non-Human Being Population

4.12. Non-Resident Person

It is a role played by individuals who are not registered with the Registry of the Resident Population in a given municipality in a given time. It can be a tourist or a person who is temporally living in a particular place without the duties required of the residents.

4.12.1. Stereotype <<role>>

4.12.2. Relationships

Relationship	Generalization	Specialization

Relationship	Generalization	Specialization
specializes	Non-Resident Person	Tourist
specializes	Person	Non-Resident Person
is_collection_of	Non-Resident Population	Non-Resident Person

4.13. Non-Resident Population

It is the collective of individuals who are not registered with the Registry of the Resident Population in a given municipality in a given time. It can be a tourist or a person who is temporally living in a particular place without the duties required of the residents.

4.13.1. Stereotype <<subkind>>

4.13.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Resident Population	Tourist Population
is_collection_of	Non-Resident Population	Non-Resident Person
specializes	Human Being Population	Non-Resident Population

4.14. Person

It is every human being with capacity to influence an urban system.

4.14.1. Stereotype <<kind>>

4.14.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Non-Resident Person
specializes	Person	Resident Person
specializes	Person	Child
specializes	Person	Teenager
specializes	Person	Adult
specializes	Person	Living Person
specializes	Person	Deceased Person
specializes	Agent	Person

Relationship	Generalization	Specialization
specializes	Natural Agent	Person
is_collection_of	Human Being Population	Person

4.15. Population

It is a collection of *Agents* of the same taxonomic class, counted or sampled at a given location or area, given a time interval.

4.15.1. Stereotype <<collective>>

4.15.2. Relationships

Relationship	Generalization	Specialization
is_composed_of	Urban System	Population
specializes	Population	Human Being Population
specializes	Population	Non-Human Being Population
specializes	Population	Human Being Population
is_collection_of	Population	Agent

4.16. Resident Person

It is a person who is enlisted with the Resident Population Registry in a particular local authority area in a given time. The classification of a Resident Person as a <<role>> derives from residency being an incidental characteristic of a human being.

4.16.1. Stereotype <<role>>

4.16.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Resident Person
is_collection_of	Resident Population	Resident Person

4.17. Resident Population

It refers to the collective of people enlisted with the Resident Population Registry in a particular local authority area in a given time. The classification of a Resident Person as a <<role>> derives from residency being an incidental characteristic of a human being.

4.17.1. Stereotype <<subkind>>

4.17.2. Relationships

Relationship	Generalization	Specialization
is_collection_of	Resident Population	Resident Person
specializes	Human Being Population	Resident Population

4.18. Teenager

It is the last phase of the childhood that a human being goes through (13 to 18 years).

4.18.1. Stereotype <<phase>>

4.18.2. Relationships

Relationship	Generalization	Specialization
specializes	Person	Teenager

4.19. Tourist

It is a role played by a person who is traveling or visiting a place for pleasure or interesting.

4.19.1. Stereotype <<role>>

4.19.2. Relationships

Relationship	Generalization	Specialization
specializes	Non-Resident Person	Tourist
component_of	Tourist Population	Tourist

4.20. Tourist Population

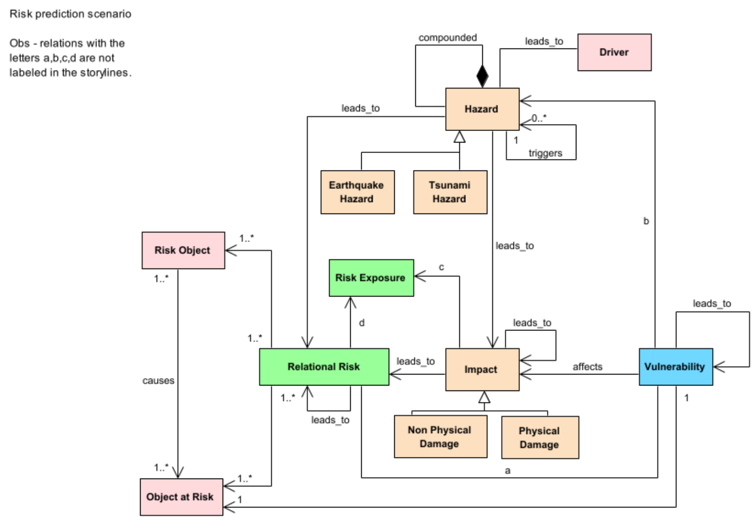
It is a collective of people who is traveling or visiting a place for pleasure or interesting.

4.20.1. Stereotype <<subkind>>

4.20.2. Relationships

Relationship	Generalization	Specialization
is_collection_of	Tourist Population	Tourist
specializes	Non-Resident Population	Tourist Population

5. Ontology of Risk from Storylines



5.1. Driver

It encompasses both natural and human-induced factors, processes, or conditions that result in a direct or indirect alteration of a system. Examples include climate change, uncontrolled urbanization, physical vulnerability of infrastructure to natural disasters, limited emergency response plans, and early warning systems.

Available at: https://civil-protection-knowledge-network.europa.eu/eu-overview-risks

5.1.1. Stereotype <<category>>

5.1.2. Relationships

Relationship	Generalization	Specialization
leads_to	Driver	Hazard

5.2. Earthquake Hazard

5.2.1. Stereotype <<situation>>

5.2.2. Relationships

Relationship	Generalization	Specialization
specializes	Hazard	Earthquake Hazard

5.3. Hazard

It is the possibility of a physical event or event pattern, which could be either natural or human-caused, that has the capacity to result in loss of life, injury, or other detrimental health effects, as well as property, infrastructure, livelihoods, service provision, ecosystems, and environmental resource damage and loss.

5.3.1. Stereotype <<situation>>

5.3.2. Relationships

Relationship	Generalization	Specialization
b	Vulnerability	Hazard
compounded	Hazard	Hazard
leads_to	Hazard	Impact
leads_to	Hazard	Relational Risk
specializes	Hazard	Earthquake Hazard
specializes	Hazard	Tsunami Hazard
triggers	Hazard	Hazard
leads_to	Driver	Hazard

5.4. Impact

It is a type of one or more resulting events from realized risks. In the context of climate change, the consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability.

Impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial. In the model, only the type of adverse impact.

Impacts are also defined as the quantification of the overall potential damage and losses that a reference event may generate in the same area and in a set timeframe.

5.4.1. Stereotype <<situation>>

5.4.2. Relationships

Relationship	Generalization	Specialization
affects	Vulnerability	Impact
c	Impact	Risk Exposure
leads_to	Impact	Relational Risk
leads_to	Impact	Impact
leads_to	Hazard	Impact
specializes	Impact	Non-Physical Damage

Relationship	Generalization	Specialization
specializes	Impact	Physical Damage

5.5. Non-Physical Damage

Decreased integrity, size, efficiency (function), or conditions considered to be advantageous or positive by a community, resulting from an adverse event. Depending on applications, damage can be measured in different ways, using appropriate metrics for each type of risk analysis. In this sense, damage may be physical or non-physical (social).

5.5.1. Stereotype <<situation>>

5.5.2. Relationships

Relationship	Generalization	Specialization
specializes	Impact	Non-Physical Damage

5.6. Object at Risk

The object at risk is understood as something that ought to be allowed to last and therefore deserves attention and care. Definition available at DOI: 10.1080/13669877.2010.515313

5.6.1. Stereotype <<mixin>>

5.6.2. Relationships

Relationship	Generalization	Specialization
causes	Risk Object	Object at Risk
mediates	Relational Risk	Object at Risk
inheres_in	Vulnerability	Object at Risk

5.7. Physical Damage

Decreased integrity, size, efficiency (function), or conditions considered to be advantageous or positive by a community, resulting from an adverse event. Depending on applications, damage can be measured in different ways, using appropriate metrics for each type of risk analysis. In this sense, damage may be physical or non-physical (social).

A measure of social disruption, in terms of deterioration of social relations and functions, that a natural or anthropogenic event causes to a community in the short to medium term (i.e., homelessness).

5.7.1. Stereotype <<situation>>

5.7.2. Relationships

Relationship	Generalization	Specialization
specializes	Impact	Physical Damage

5.8. Relational Risk

It is a relational entity that links risk objects and objects at risk.

Risk is defined by IPCC v.6 as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems.

In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.

In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making (see also risk management, adaptation and mitigation).

In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs) (see also risk trade-off). Risks can arise, for example, from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.

5.8.1. Stereotype <<relator>>

5.8.2. Relationships

Relationship	Generalization	Specialization
a	Vulnerability	Relational Risk
d	Relational Risk	Risk Exposure
leads_to	Relational Risk	Relational Risk
leads_to	Hazard	Relational Risk
leads_to	Impact	Relational Risk
mediates	Relational Risk	Risk Object
mediates	Relational Risk	Object at Risk

5.9. Risk Exposure

Risk exposure is a measure of the vulnerability of an urban system or of its components to adverse events (negative impacts) or uncertainty.

5.9.1. Stereotype <<relator>>

5.9.2. Relationships

Relationship	Generalization	Specialization
— c	Impact	Risk Exposure
— d	Relational Risk	Risk Exposure

5.10. Risk Object

The risk object is considered, under certain contingent circumstances and in some causal way, to constitute a threat to the valued object at risk. In urban systems, in particular, risk-oriented urban systems, a risk object is called Driver.

5.10.1. Stereotype <<category>>

5.10.2. Relationships

Relationship	Generalization	Specialization
— causes	Risk Object	Object at Risk
— mediates	Relational Risk	Risk Object

5.11. Tsunami Hazard

5.11.1. Stereotype <<situation>>

5.11.2. Relationships

Relationship	Generalization	Specialization
◁— specializes	Hazard	Tsunami Hazard

5.13. Vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

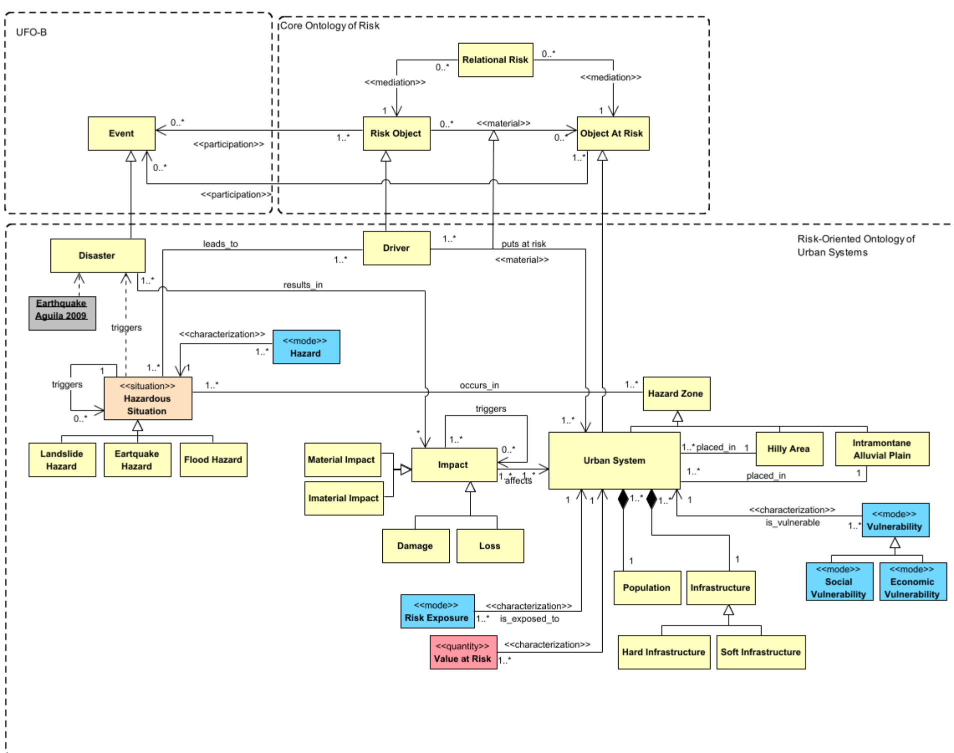
Vulnerability expresses the relationship between the intensity of an adverse event, the features of the elements at risk (assets, community, system, environment) that affect their behavior, and the measure of the damage resulting from the event (response). Uncertainty in assessing vulnerability is due to insufficient knowledge of the features affecting the response and the possible effects on the elements exposed to an event. Vulnerability is defined in different ways depending on the types of risk being assessed. In seismic risks, vulnerability is the probability that an element at risk, belonging to a specific behavioral class (vulnerability class), experiences or exceeds a damage threshold (according to a predetermined scale of damage) upon the occurrence of an event of an assigned intensity. In flood risks, vulnerability expresses the expected damage to the elements at risk, the extent of damage ranging from 0 (no damage) to 1 (total destruction).

5.13.1. Stereotype **<<mode>>**

5.13.2. Relationships

Relationship	Generalization	Specialization
a	Vulnerability	Relational Risk
affects	Vulnerability	Impact
b	Vulnerability	Hazard
leads_to	Vulnerability	Vulnerability
inheres_in	Vulnerability	Object at Risk

6. Ontological Model from storyline WS 4



6.1. Damage

6.1.1. Relationships

Relationship	Generalization	Specialization
specializes	Impact	Damage

6.2. Disaster

A 'serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses, and impacts' (UNGA, 2016).

See also Exposure, Hazard, Risk and Vulnerability.

6.2.1. Relationships

Relationship	Generalization	Specialization
results_in	Disaster	Impact
triggers	Hazardous Situation	Disaster
specializes	Event	Disaster
instance_of	Earthquake Aguila 2009	Disaster

6.3. Driver

6.3.1. Relationships

Relationship	Generalization	Specialization
leads_to	Driver	Hazardous Situation
puts_at_risk	Driver	Urban System
specializes	Risk Object	Driver

6.5. Earthquake Hazard

6.5.1. Relationships

Relationship	Generalization	Specialization
specializes	Hazardous Situation	Earthquake Hazard

6.6. Economic Vulnerability

6.6.1. Stereotype <<mode>>

6.6.2. Relationships

Relationship	Generalization	Specialization
specializes	Vulnerability	Economic Vulnerability

6.7. Event

Event comes from an ontology of perdurants UFO-B/UFO (Foundational Ontology). Events are individuals composed by temporal parts, they happen in time in the sense that they extend in time accumulating temporal parts.

In UFO:

i) an event exists only if at least one object is participating on it.

ii) when an object is participating in an event, he is playing a role in this event.

iii) Events can be bearer of qualities.

iv) Every event is framed by a time interval (start time and end time). A time interval is associated with a temporal structure, which is analogous with a quality structure.

v) Events can change the world by changing the State of Affairs.

Events are entities under the rules of Extensional Mereology, i.e.:

i) No event is part of itself.

ii) If event X is part of event Y then event Y is not part of event X.

iii) If event X is part of event Y and event Y is part of event Z then event X is part of event Z.

iv) If event Y is part of event X then there is an event Z disjoint from Y which is also part of X.

v) Two events are the same if and only if they are composed of the same parts.

In the storylines:

Event is an occurrence or change of a particular set of circumstances.

NOTE 1 An event can be one or more occurrences that can have several causes.

NOTE 2 An event can consist of something not happening (impossible event). E is an impossible event if and only if P (E) = 0

NOTE 3 An event can sometimes be referred to as an “incident” or “accident”.

NOTE 4 An event without consequences can also be referred to as a “near miss”, “incident”, “near hit” or “close call”.

6.7.1. Relationships

Relationship	Generalization	Specialization
specializes	Event	Disaster
participates	Risk Object	Event
participates	Object At Risk	Event

6.8. Flood Hazard

6.8.1. Relationships

Relationship	Generalization	Specialization
specializes	Hazardous Situation	Flood Hazard

6.9. Hard Infrastructure

It is the tangible, physical assembly of structures such as roads, bridges, builds, tunnels, railways, etc.

6.9.1. Relationships

Relationship	Generalization	Specialization
specializes	Infrastructure	Hard Infrastructure

6.10. Hazard

In a specific geographic area and a given timeframe (reference period), the probability of occurrence of a potentially harmful natural or anthropogenic event of an assigned intensity. The latter may be codified in various ways depending on the features of risk analysis.

6.10.1. Stereotype <<mode>>

6.10.2. Relationships

Relationship	Generalization	Specialization
inheres_in	Hazard	Hazardous Situation

6.11. Hazard Zone

It is a geographic zone with the probability of occurrence of a potentially harmful natural or anthropogenic event considering the evaluation of both risk exposure and vulnerability dispositions of this place.

6.11.1. Relationships

Relationship	Generalization	Specialization

Relationship	Generalization	Specialization
occurs_in	Hazard Zone	Hazardous Situation
specializes	Hazard Zone	Urban System
specializes	Hazard Zone	Hilly Area
specializes	Hazard Zone	Intramontane Alluvial Plain

6.12. Hazardous Situation

1) In UFO-B, A situation triggers an atomic event iff there is a disposition that is activated by the situation and that is manifested by the event,

2) A situation is the set of things that are happening and the conditions and dispositions that exist at a particular time and place.

3) A hazardous situation is the state of affairs in which both the vulnerability and exposure dispositions of a valuable object to risk are aligned.

6.12.1. Stereotype <<situation>>

6.12.2. Relationships

Relationship	Generalization	Specialization
leads_to	Driver	Hazardous Situation
occurs_in	Hazard Zone	Hazardous Situation
triggers	Hazardous Situation	Disaster
triggers	Hazardous Situation	Hazardous Situation
specializes	Hazardous Situation	Earthquake Hazard
specializes	Hazardous Situation	Flood Hazard
specializes	Hazardous Situation	Landslide Hazard
inheres_in	Hazard	Hazardous Situation

6.13. Hilly Area

6.13.1. Relationships

Relationship	Generalization	Specialization
placed_in	Urban System	Hilly Area

Relationship	Generalization	Specialization
specializes	Hazard Zone	Hilly Area

6.14. Immaterial Impact

6.14.1. Relationships

Relationship	Generalization	Specialization
specializes	Impact	Immaterial Impact

6.15. Impact

6.15.1. Relationships

Relationship	Generalization	Specialization
affects	Impact	Urban System
results_in	Disaster	Impact
triggers	Impact	Impact
specializes	Impact	Damage
specializes	Impact	Loss
specializes	Impact	Immaterial Impact
specializes	Impact	Material Impact

6.16. Infrastructure

It refers to the basic physical and organizational structures and facilities that a country, a city or an organization needs and uses in order to work effectively.

6.16.1. Relationships

Relationship	Generalization	Specialization
specializes	Infrastructure	Hard Infrastructure
specializes	Infrastructure	Soft Infrastructure
is_composed_of	Urban System	Infrastructure

6.17. Intramontane Alluvial Plain

6.17.1. Relationships

Relationship	Generalization	Specialization
placed_in	Urban System	Intramontane Alluvial Plain
specializes	Hazard Zone	Intramontane Alluvial Plain

6.18. Landslide Hazard

6.18.1. Relationships

Relationship	Generalization	Specialization
specializes	Hazardous Situation	Landslide Hazard

6.19. Loss

6.19.1. Relationships

Relationship	Generalization	Specialization
specializes	Impact	Loss

6.20. Material Impact

6.20.1. Relationships

Relationship	Generalization	Specialization
specializes	Impact	Material Impact

6.21. Object At Risk

6.21.1. Relationships

Relationship	Generalization	Specialization
specializes	Object At Risk	Urban System
participates	Object At Risk	Event
is_put_at_risk_by <<material>>	Risk Object	Object At Risk
mediates	Relational Risk	Object At Risk

6.22. Population

6.22.1. Relationships

Relationship	Generalization	Specialization
is_composed_of	Urban System	Population

6.23. Relational Risk

Risk emerges from situated cognition that establishes a relationship of risk between risk object (driver) and object at risk.

The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change. In the context of DRR risk can arise from potential impacts of an event. Relevant adverse consequences include those on lives, livelihoods, health and well-being, economic, social and cultural assets and investments, infrastructure, services (including ecosystem services), ecosystems and species.

Risks result from dynamic interactions between hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure, and vulnerability may each be subject to uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socio-economic changes and human decision-making (see also risk management, adaptation and mitigation). risks may also result from the potential for responses (to climate change effects or to specific events) not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs) (see also risk trade-off).

Risks can arise, for example, from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions, as well as risk mitigatio actions.

6.23.1. Relationships

Relationship	Generalization	Specialization
mediates	Relational Risk	Risk Object
mediates	Relational Risk	Object At Risk

6.24. Risk Exposure

1) Exposure or risk exposure is a measure of the vulnerability of an urban system or of its components to adverse events (negative impacts) or uncertainty.

2) Risk Exposure as a Disposition is the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

6.24.1. Stereotype <<mode>>

6.24.2. Relationships

Relationship	Generalization	Specialization
exposes	Risk Exposure	Urban System

6.25. Risk Object

6.25.1. Relationships

Relationship	Generalization	Specialization
specializes	Risk Object	Driver
puts_at_risk	Risk Object	Object At Risk
participates	Risk Object	Event
mediates	Relational Risk	Risk Object

6.26. Social Vulnerability

6.26.1. Stereotype <<mode>>

6.26.2. Relationships

Relationship	Generalization	Specialization
specializes	Vulnerability	Social Vulnerability

6.27. Soft Infrastructure

6.27.1. Relationships

Relationship	Generalization	Specialization
specializes	Infrastructure	Soft Infrastructure

6.29. Urban System

Urban systems refer to two interconnected systems-first, the comprehensive collections of city elements with multiple dimensions and characteristics:

a) encompass physical, built, socioeconomic-technical, political, and ecological subsystems.

b) integrate social agent/constituency/processes with physical structure and processes; and

c) exist within broader spatial and temporal scales and governance and institutional contexts; and second, the global system of cities and towns.

6.29.1. Relationships

Relationship	Generalization	Specialization
affects	Impact	Urban System
is_exposed_to	Risk Exposure	Urban System
is_vulnerable	Vulnerability	Urban System
placed_in	Urban System	Hilly Area
placed_in	Urban System	Intramontane Alluvial Plain
component_of	Urban System	Population
component_of	Urban System	Infrastructure
specializes	Hazard Zone	Urban System
specializes	Object At Risk	Urban System
inheres_in	Value at Risk	Urban System
specializes	Driver	Urban System

6.30. Value at Risk

Value or Value at Risk refers to the level of significance of an object as perceived by an individual, quantified by its monetary value or other established measure.

6.30.1. Stereotype <<quantity>>

6.30.2. Relationships

Relationship	Generalization	Specialization
inheres_in	Value at Risk	Urban System

6.31. Vulnerability

1) The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

2) Vulnerability expresses the relationship between the intensity of an adverse event, the features of the elements at risk (assets, community, system, environment) that affect their behavior, and the measure of the damage resulting from the event (response). Uncertainty in assessing vulnerability is due to insufficient knowledge of the features affecting the response of and the possible effects on the elements exposed to an event. Vulnerability is defined in different ways depending on the types of risk being assessed. In seismic risks, vulnerability is the probability that an element at risk, belonging to a specific behavioral class (vulnerability class), experiences or exceeds a damage threshold (according to a predetermined scale of dam\age) upon the occurrence of an event of an assigned intensity. In flood risks, vulnerability expresses the expected damage to the elements at risk, the extent of damage ranging from 0 (no damage) to 1 (total destruction).

6.31.1. Stereotype <<mode>>

6.31.2. Relationships

Relationship	Generalization	Specialization
is_vulnerable	Vulnerability	Urban System
specializes	Vulnerability	Social Vulnerability
specializes	Vulnerability	Economic Vulnerability

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Appendix A – Risk Storylines

Storyline 1.1

Settlement context (reference to the defined settlement archetypes, if applicable – please refer to the SC reported in the Miro board: https://miro.com/app/board/uXjVMalthng=/)

SC_03 – Contesto insediativo in area metropolitana sulla linea di costa/Rischi climatici, biologici e na-tech

Description of the urban context (urban configuration, building typologies, infrastructures, ...)

Mid-range North Adriatic city port mainly devoted to trade, industry, and tourism. Despite the proximity to the sea, the territory presents a hilly to mountainous morphology. The city is divided into different climatic zones depending on the proximity to the sea or on altitude and it is crossed by some small rivers coming from the plateau that surrounds the urban area. The urban context mainly develops along the coastline. There are two major roads and one of them runs all along the coast.

Dimension / population (spatial extent in km^2, resident population, other measures, if known)

~80 km^2, 200,000 inhabitants (data refer to the whole city, but scenario can also be restricted to a single neighborhood, if needed)

Reference hazards (and their potential interrelationships)

Cascading NaTech multi-hazard scenario:

Earthquake TRIGGERING tsunami TRIGGERING pollutants release from a gasifier located on the coast.

Exposure types (key exposed systems/subsystems/elements and functions, if known)

Inhabitants, built-up area, road network, industrial sites, port infrastructure.

There is a pine forest on the coast that has a very high recreational and touristic value. This element can represent both an exposed element (that can be damaged) but also as a mitigation element, able to partially contrast the effect of the tsunami on the built-up area behind.

Vulnerability types (key vulnerabilities if known)

Industrial plants are located along the coast and close to population and residential areas. Moreover, some of them might be not well maintained and/or underpowered (i.e. not designed to resist a multi-hazard scenario).

The road network is not enough redundant and there is only one main road that connects the industrial sites and the port with the surroundings.

Risks (key risks if known)

- Loss of human lives because of the impacts of the earthquake and the tsunami (short-term effect).
- Loss of human lives and health risks (long-term effects) due to the release of chemicals from the industrial plant.

- Physical damage on the built-up area, including the collapse and/or destruction of some buildings because of the earthquake and/or tsunami.
- Systemic risks due to:

  - interruption of the road network
  - interruption of the port trades

Stakeholders

Civil Protection department, municipality, road network manager, industrial site manager, citizenships.

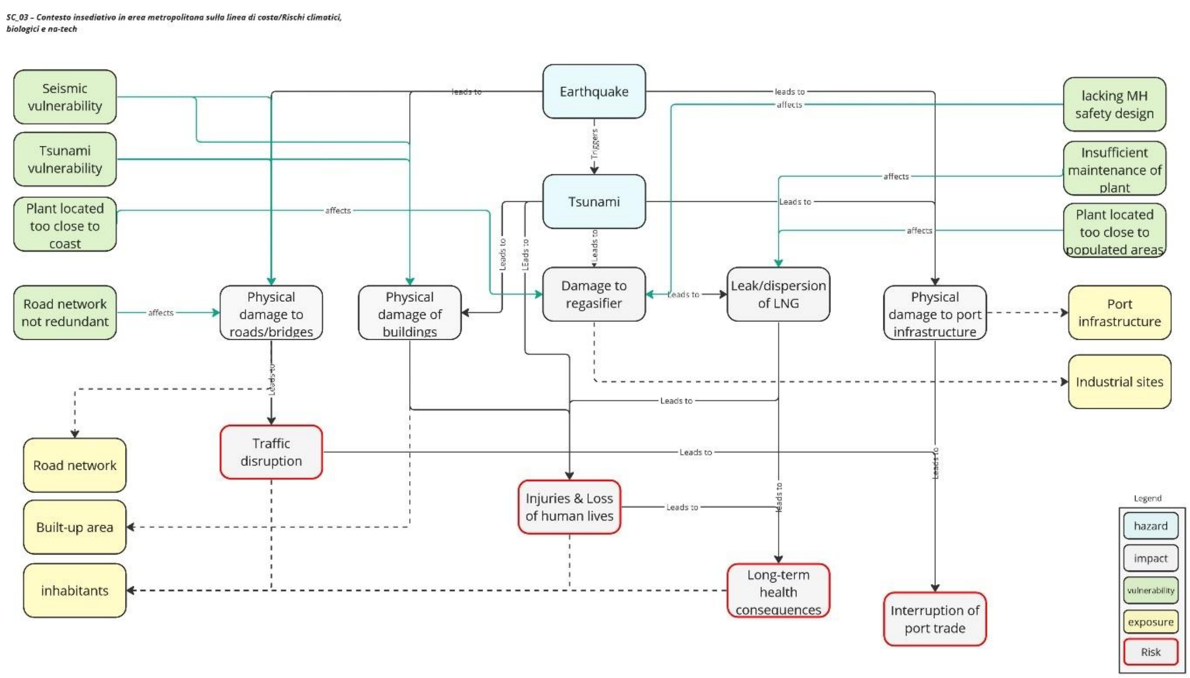
Data Relevant (availability of data relevant for the scope of the project, along with specific type)

none

Other relevant notes

none

Impact chain



Storyline 1.2

Settlement context (reference to the defined settlement archetypes, if applicable – please refer to the SC reported in the Miro board: https://miro.com/app/board/uXjVMalthng=/**)**

None of the SC reported in the Miro board

Description of the urban context (urban configuration, building typologies, infrastructures, ...)

Social housing neighborhood, located on a flood plain.

Dimension / population (spatial extent in km², resident population, other measures, if known)

~1 km^2, 5,000 inhabitants

Reference hazards (and their potential interrelationships)

Independent hazards:

- Heat waves
- Compound urban and riverine flooding

Exposure types (key exposed systems/subsystems/elements and functions, if known)

Households

Vulnerability types (key vulnerabilities if known)

Natural hazards can interact with local socio-economic vulnerabilities, leading to significant risks. More specifically, fuel poverty (the condition in which households cannot afford to keep adequately warm or cold at a reasonable cost, given their income) can significantly increase vulnerability to heat waves.

On the other side, the inadequate level of maintenance of the social houses due to the low public investment can play a role in increasing the magnitude of urban flooding, because of the low maintenance of the local drainage network. Moreover, social vulnerability can lead to a lower level of risk awareness, leading to a higher vulnerability to flooding for the people leaving in the basement/ ground floor of the buildings.

Risks (key risks if known)

- Health issues due to the amplified heatwaves impacts.
- Socio-economic risk for the households
- Physical damages to the building due to the flood

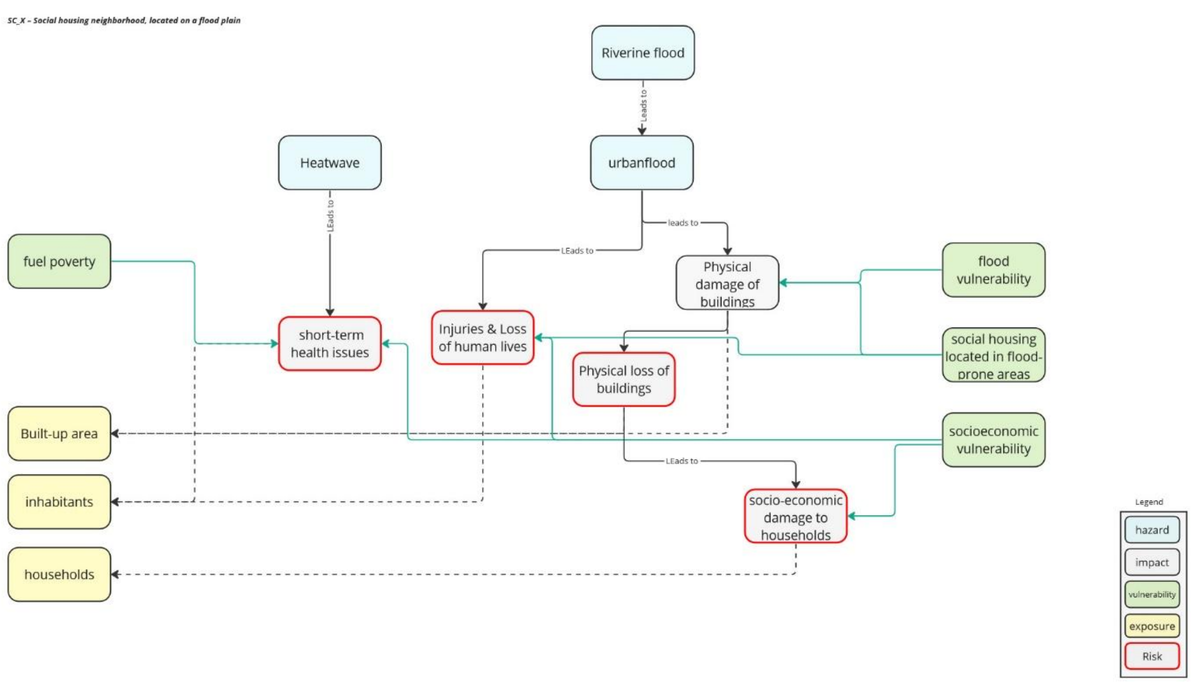
Stakeholders

Households, municipality, social housing managers.

Data Relevant (availability of data relevant for the scope of the project, along with specific type)

Other relevant notes

Impact chain



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Storyline 2

Settlement context (reference to the defined settlement archetypes, if applicable – please refer to the SC reported in the Miro board: https://miro.com/app/board/uXjVMalthng=/**)**

Context id	Description	Settlement features	Built-up features	Risks
SC_XX	Contesto insediativo in area metropolitana in pianura di origine tettonica/Rischi geofisici, idraulici, climatici e biologici	Insediamento storico dell'entroterra in pianura di origine tettonica	Centro storico caratterizzato da tessuto compatto; eventuale tessuto residenziale diffuso di recente espansione a ridosso di infrastrutture di viabilità a scala territoriale. Presenza di attività dei settori primario e secondario (agricole e manifatturiere).	Rischi geofisici di tipo sismico con amplificazione di sito, liquefazione, di stabilità del terreno, rischi idraulici con presenza di alluvioni improvvise, rischi climatici con ondate di calore e piogge abbondanti, rischi biologici con inquinamento atmosferico e dei suoli.

Description of the urban context (urban configuration, building typologies, infrastructures, ...)

A medium-sized town with high population density located on a vast low plain, with scattered vegetation and in the absence of rivers. The historic centre is mainly made up of 3 and 4-stories buildings in a compact urban fabric, surrounded by a residential fabric of more recent expansion close to the road infrastructure. Presence of small manufacturing activities in the town and extended farming and agricultural activities in the surrounding lands.

Dimension / population (spatial extent in km², resident population, other measures, if known)

~50 km^2, 50'000 inhabitants

Reference hazards (and their potential interrelationships)

Seismic events and pluvial floods.

A medium-to-high intensity earthquake strikes the city, causing relevant damage to several of the dated buildings of the historic town, and low damage to the external road infrastructure. Subsequent pluvial flooding would affect primarily the urbanized area, characterized by a low permeability of the soil, preventing the efficient management of the emergency phase– including the rescue and evacuation of the inhabitants- and then the recovery phase in the town.

In the long-lasting recovering phase, the evacuation of part of the population and its relocation to temporary housing outside of the town could exacerbate the pluvial flooding risk and its impact on the agricultural sector.

Exposure types (key exposed systems/subsystems/elements and functions, if known)

Inhabitants, built environment, manufacturing activities in the city, agricultural activities in the lands, transport infrastructures.

Vulnerability types (key vulnerabilities if known)

Presence of a compact fabric of dated buildings vulnerable to earthquakes.

Temporary urbanization for the management of the recovery phase may potentially increases the risk of pluvial flooding if the design of new area is not conceived in a multirisk perspective.

A significant part of the population and several productive activities are jointly exposed and vulnerable to both risks, leading to severe socioeconomic impacts.

Risks (key risks if known)

Geophysical risks related to seismic hazards, hydraulic risks related to sudden floods, climatic risks related to more frequent extreme precipitation events.

Stakeholders

Civil Protection department, municipality, inhabitants, small artisans, agricultural industry.

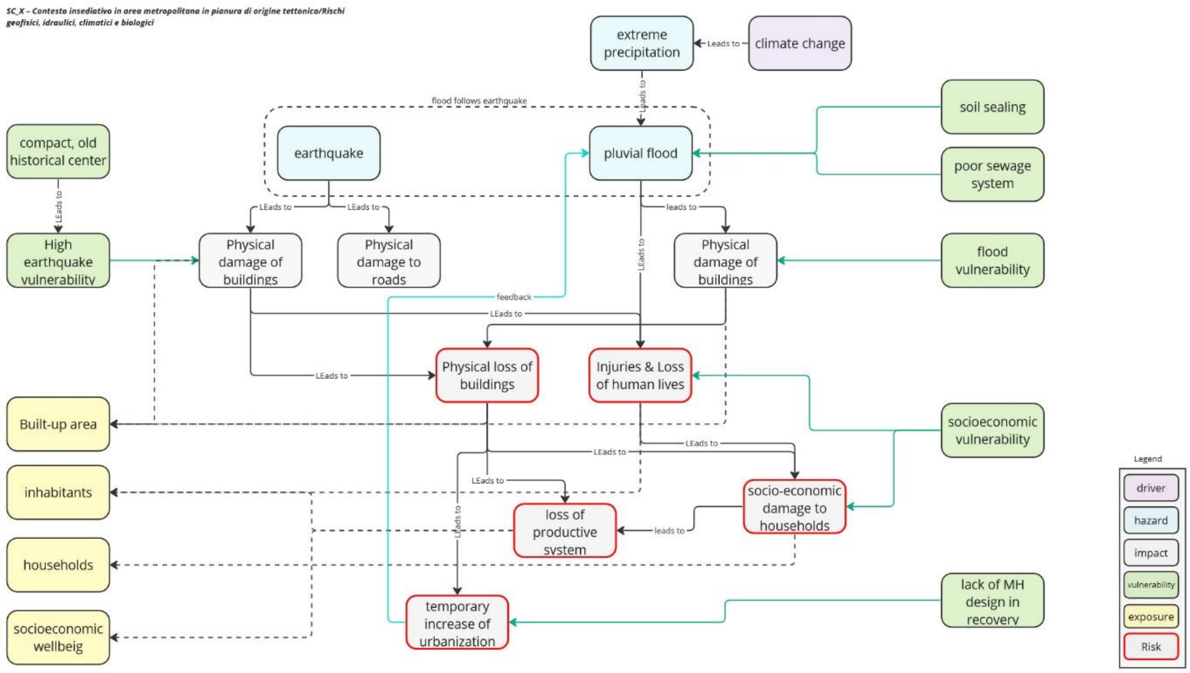
Data Relevant (availability of data relevant for the scope of the project, along with specific type)

Data provided by Civil Protection and municipality actors – past seismic events, soil studies and seismic zonation, past precipitations and climate data.

Other relevant notes

The planning of the recovery phase following the seismic emergency should be multi-risk oriented. For example, selecting areas for the relocation of the earthquake-stricken population should consider both the site seismic hazard and the potential increment of pluvial flooding risk (due to further urbanization of farmlands).

Impact chain



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Storyline 3

Settlement context (reference to the defined settlement archetypes, if applicable – please refer to the SC reported in the Miro board: https://miro.com/app/board/uXjVMalthng=/**)**

SC_04 – Contesto insediativo in area metropolitana collinare/Rischi geofisici, idraulici, climatici e biologici

Description of the urban context (urban configuration, building typologies, infrastructures, ...)

City with dense urban residential building tissue in a hilly landscape. The presence of many buildings contributed to a high soil impermeability and covering of the small river network. Moreover, the road network is constrained into a limited space in between of the residential buildings.

Dimension / population (spatial extent in km², resident population, other measures, if known)

~80 km^2, 200,000 inhabitants (data refer to the whole city, but scenario can also be restricted to a single neighborhood, if needed)

Reference hazards (and their potential interrelationships)

Compound and cascading multi-hazard scenario:

Aqueduct/ pipeline leakages as predisposing factor COMPOUNDING with a relatively intense rainfall event (not necessarily an extreme event) which are TRIGGERING a landslide that is affecting the road network with indirect effects on mobility and reachability of critical infrastructures (e.g., an hospital).

Exposure types (key exposed systems/subsystems/elements and functions, if known)

Inhabitants, built-up area, road network, critical infrastructures (e.g., hospital).

Vulnerability types (key vulnerabilities if known)

The high density of built-up area affects the soil permeability and water infiltration rates. The aqueduct/pipe is not well maintained (i.e. acting as a predisposing factor in terms of soil saturation). The road network is not enough redundant and there is only one main road that connects the hospital. Other roads exist but the time needed to reach the hospital increases.

Risks (key risks if known)

Direct loss of human lives due to the impact of the landslide on the road.

Undirect increase of probability for the loss of human lives due to the increase of time to reach the hospital for the same people affected by the landslide and for all the other people affected by any other hazard.

Physical damage on the road and the built-up area, including the collapse and/or destruction of some buildings and other infrastructure (e.g., aqueduct) due to the direct effect of the landslide.

Systemic risks due to:

- interruption of the road network / other infrastructures (e.g., aqueducts)
- indirect reduction of functionality for the hospital

Stakeholders

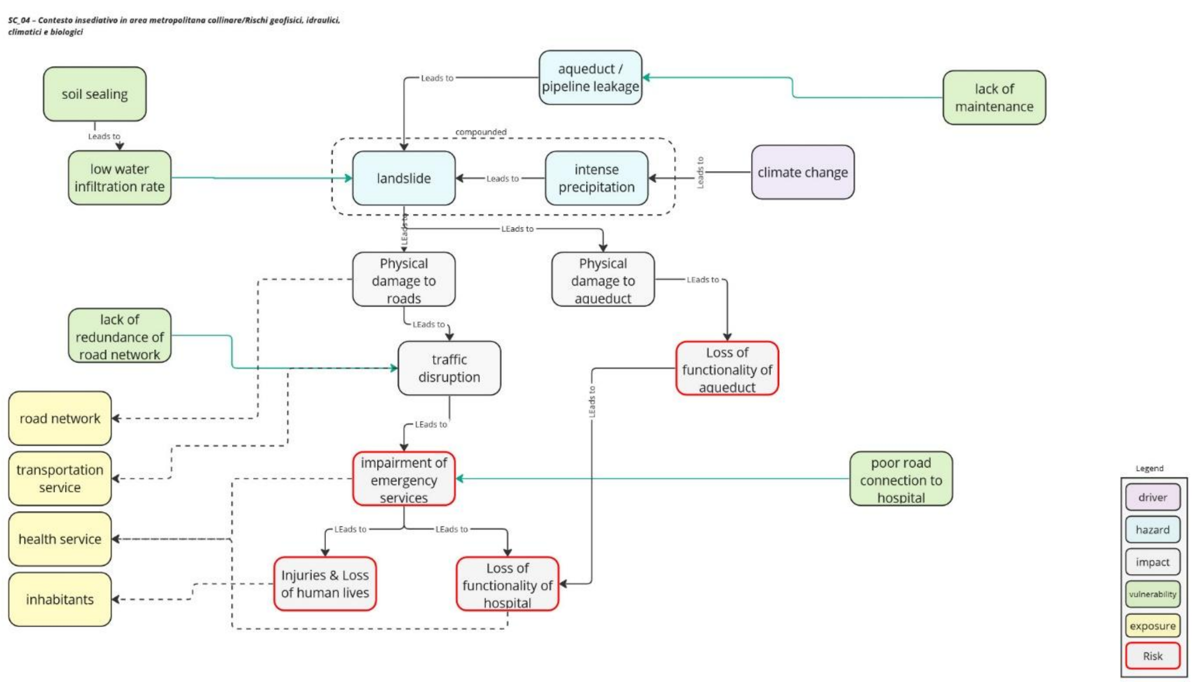
Civil Protection department, municipality, road network manager, building constructors and citizenships.

Data Relevant (availability of data relevant for the scope of the project, along with specific type)

Existence, location and functionality data of the road network, hospital, built-up areas, aqueduct. Physical condition of the area in terms of slope and land cover. Soil moisture, precipitation data and climate trends.

Other relevant notes

Impact chain



Storyline 4

Settlement context (reference to the defined settlement archetypes, if applicable – please refer to the SC reported in the Miro board: https://miro.com/app/board/uXjVMalthng=/**)**

SC_04 – Contesto insediativo in area metropolitana collinare/Rischi geofisici, idraulici, climatici e biologici

Settlement context in hilly metropolitan area/Geophysical, hydraulic, climatic and biological risks

Description of the urban context (urban configuration, building typologies, infrastructures, ...)

Small district with medium population density displaced along a hillside with medium to high vegetation. Mainly made up of 3(4)-story buildings with scattered independent houses around the top of the hill. Residential district is crossed by a two-lane road and secondary smaller arteries. Complex orographic context. Railway passes through the plateau at the foothills and an oil refinery is present in the same area.

Dimension / population (spatial extent in km^2, resident population, other measures, if known)

~1 km^2, 8’000 inhabitants

Reference hazards (and their potential interrelationships)

Convective phenomena -> high intensity precipitations -> floods -> landslides -> biological and chemical hazards due to exposure (oil refinery) – socioeconomical impact due to buildings and presence of railway

Exposure types (key exposed systems/subsystems/elements and functions, if known)

Inhabitants (mostly over 60 years old), Oil refinery – potential bigger area involved due to diffusion of pollutants, railway – socioeconomic impacts.

Vulnerability types (key vulnerabilities if known)

Presence of railway and industry. Some buildings are dated and require maintenance. As well as roads on the hill. Recent logging of the area increases vulnerability of the terrain for landslides.

Risks (key risks if known)

Mainly related to potential risks for industry and railway involvement.

Stakeholders

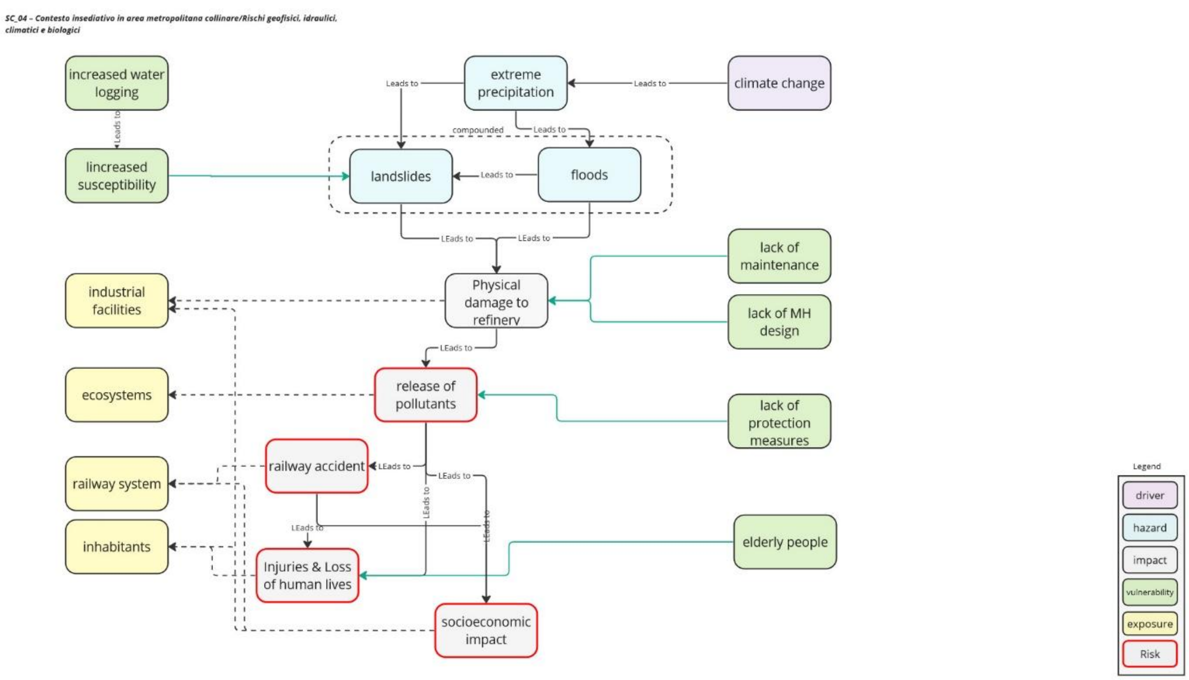
Civil Protection department, municipality, state railways, industry management.

Data Relevant (availability of data relevant for the scope of the project, along with specific type)

Data from Civil Protection and municipality – past convective events, precipitations, terrain assessment, climate change trends.

Other relevant notes

Impact chain



Appendix B – Dictionary of Terms (Preliminary Glossary)

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Adaptive capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences	Social Sciences	IPCC AR6 WG II Annex II (MA, 2005: Appendix D: Glossary. In: Ecosystems and Human Well–being: Current Status and Trends. Findings of the Condition and Trends Working Group [Hassan, R., R. Scholes and N. Ash(eds.)], Millennium Ecosystem Assessment (MA), Island Press, Washington DC, USA, pp. 893–900)
Adverse Event	A phenomenon of natural or anthropogenic origin that may damage elements at risk. *See* "Event".	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Awareness	Risk awareness is about realizing that since we live in a dangerous world, we therefore are acknowledged of the probability of suffering damage or health detriments because of natural or man-made hazards (Renn, 1983). “High-risk awareness, while not sufficient to motivate behavior alone, is typically a prerequisite for improving disaster preparedness [[22], [23], [24], [25]]. Ignorance of potential risk can result in no, or delayed, mitigation actions and a higher casualty rate when disasters strike.” It is also noticed that risk awareness is not only a (logical) prerequisite of disaster	Social Sciences	Renn, O. (1983) Technology, risk and public perception, Appl. Systems Anal., 4, 50-65. Arce, R. S. C., Onuki, M., Esteban, M., & Shibayama, T. (2017). Risk awareness and intended tsunami evacuation behavior of international tourists in Kamakura City, Japan. International Journal of Disaster Risk Reduction, 23, 178-192 Mondino, E., Scolobig, A., Borga, M., & Di Baldassarre, G. (2020). The role of experience and different sources of knowledge in shaping flood risk awareness. Water, 12(8), 2130. Boyer-Villemaire, U., Bernatchez, P., Benavente, J., & Cooper, J. A. G. (2014). Quantifying community's functional awareness of coastal changes and hazards from citizen perception analysis in Canada, UK, and Spain. Ocean & coastal management, 93, 106-120.

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	preparedness since regression models recognize it as a causal factor (statistical predictor) of evacuation willingness, resilience, and preparedness (target variables) in many papers. "Risk awareness can be defined as knowledge of the presence of a risk, while risk perception can be defined as a broader 'intuitive risk judgment'". "Functional awareness. This level of consciousness sufficient to influence behavior is represented by a set of indicators that reflect the perception 1) of dreadfulness, 2) of uncertainty, and 3) behavioral change". 'the extent of common knowledge about disaster risks, the factors that lead to disasters and the actions that can be taken individually and collectively to reduce exposure and vulnerability to hazards' (UN, 2009, pp. 22–23) We treated risk awareness as the other concept influencing resilience and vulnerability and we defined it as the collective acknowledgment of a risk and potential risk prevention and mitigation actions, fostered by risk communication.		United Nations (UN). (2009). UNISDR terminology for disaster risk reduction. Morsut, C., Kuran, C., Kruke, B. I., Orru, K., & Hansson, S. (2022). Linking resilience, vulnerability, social capital, and risk awareness for crisis and disaster research. Journal of Contingencies and Crisis Management, 30(2), 137-147.

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Capacity (or capability)	The combination of all the strengths, attributes, and resources that are available within an organization, community, or society to manage and mitigate disaster risks and strengthen resilience. Capacity may involve infrastructure, institutions, and human knowledge and skills, as well as collective attributes, such as social relations, leadership, and management.	Social Sciences	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Cascading Events	A sequence of consecutive events that are characterized by a causal relationship with one another (e.g. an earthquake triggering a landslide, which causes the collapse of a building and casualties), or a temporal interaction between the different phenomena that the same triggering event may independently generate (e.g. a flood may cause power failures or road traffic interruptions, which are independent of one another, but which may both affect the function of the same hospital). Cascading events may be mapped through a temporal sequence consisting of a single chain of events, i.e., the occurrence of an event that triggers a single event tree, and a sequence of multiple and parallel chains of events, i.e., the occurrence of an event that triggers multiple and parallel chains of events. In this instance, the temporal	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	sequence is made up of a sequence of events that do not necessarily have a causal relationship with one another. For instance, cascading events triggered by volcanic eruptions can generate several parallel phenomena (earthquake, ash fall, pyroclastic flows, tsunamis, lahars, etc.) causing multiple and independent event trees		
Cascading Impacts	Cascading impacts from *extreme weather/climate events* occur when a hazard generates a sequence of secondary events in natural and *human systems* that result in physical, natural, social, or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional and are associated more with the magnitude of *vulnerability* than with that of the hazard (modified from Pescaroli and Alexander, 2015).	Climate Risk	IPCC AR6 WG II Annex II
Casualties	The number of people killed and injured by a natural or anthropogenic even	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Circular Economy	A system with minimal input and operational losses of materials and energy through extensive reduction, reuse, recycling, and recovery activities. Ten strategies for circularity include: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover. References - Kirchherr, J., Reike, D. and Hekkert, M. (2017): Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling 127, 221-232, https://doi.org/10.1016/j.resconrec.2017.09.005 - Potting, J., A. Hanemaaijer, R. Delahaye, J. Ganzevles, R. Hoekstra, and J. Lijzen, 2018: Circular Economy: What We Want To Know and Can Measure. 20 pp. - Korhonen, J., A. Honkasalo, and J. Seppälä, 2018: Circular Economy: The Concept and its Limitations. Ecol. Econ., 143, 37–46, https://doi.org/10.1016/j.ecolecon.2017.06.041 - Haupt, M., C. Vadenbo, S. Hellweg, 2017. "Do we have the right performance	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	indicators for the circular economy? Insight into the Swiss waste management system. J of Industrial Ecology, vo. 21, iss. 3.		
Cities	Cities are open systems, continually exchanging resources, products and services, waste, people, ideas, and finances with the hinterlands and broader world. Cities are complex, self-organizing, adaptive, and constantly evolving. Cities also encompass multiple actors with varying responsibilities, capabilities, and priorities, as well as processes that transcend the institutional sector-based approach to city administration. Cities are embedded in broader ecological, economic, technical, institutional, legal, and governance structures that enable or constrain their systemic function, which cannot be separated from wider power relations. Urban processes of a physical, social, and economic nature are causally interlinked, with interactions and feedback that result in both intended and unintended impacts on emissions. See also	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	City region, Peri-urban areas, and Urban.		
City Region	The areal extent of an individual city's material associations and economic or political influence. The city region concept accepts that rural livelihoods and land uses can be incorporated within the functional activities of a city. This will include dormitory settlements, sources for critical inputs of water, some food, and waste disposal. See also *Region*, *Cities*, *Urban* and *Urban systems*.	Climate Risk	IPCC AR6 WG II Annex II
City Region	The areal extent of an individual city's material associations and economic or political influence. The city region concept accepts that rural livelihoods and land uses can be incorporated within the functional activities of a city. This will include dormitory settlements, sources for critical inputs of water, some food, and waste disposal.	Climate Risk	IPCC AR6 WG II Annex II
Climatic Driver (Climate Driver)	A changing aspect of the climate system that influences a component of a human or natural system. *See* Non-climatic driver.	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Climatic Impact-drivers (CIDs)	Climatic impact drivers (CIDs) are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems. Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions.	Climate Risk	IPCC AR6 WG II Annex II
Community	The community comprises groups of actors (e.g. individuals, organizations, businesses) that share a common identity or interest. The concept of community is dynamic and multi-layered including the community as a place-based concept (e.g. inhabitants of a flooded neighborhood), as a virtual and communicative community within a spatially extended network (e.g. members of crisis management in a region), and/or as an imagined community of individuals who may never have contact with each other but who share an identity or interest.	Social sciences	Kruse S., Abeling T., Deeming H., Fordham M., Forrester J., Jülich S., Karancy N., Kuhlicke C., Pelling M., Pedoth L., Schneiderbauer S. (2017): Conceptualizing community resilience to natural hazards – the emBRACE framework. Natural Hazards and Earth System Sciences. Volume 17, pp. 2321-2333, https://doi.org/10.5194/nhess-17-2321-2017, 2017.

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Community of interest	The interest-based conception of community broadly refers to individuals coming together around a common concern or sentiment with which they identify personally and collectively (Ijaz 2022). The degree of integration or cohesiveness among members of an interest community can vary markedly based on the mode, frequency, and intensity of interaction; levels of personal commitment; and perceptions of relative closeness. Concerning spatially focused communities of interest, Keller (1995) discusses the mobilization of grassroots political action in response to environmental disasters. She introduces the idea of an emergent interest community among inhabitants living within an area of contamination. The newly defined socio-spatial boundaries of such a community can be tied to the interests or goals of those defining the situation. The relative degree of solidarity is often viewed as an indicator of "communityness," which suggests that the communalization of a shared interest can facilitate social relationships, cohesiveness, and agency. Messer, Shriver, and Adams (2015) concur that community identification can	Social sciences	Suzanne Keller, Ecology and Community, 19 B.C. Envtl. Aff. L. Rev. 623 (1992), http://lawdigitalcommons.bc.edu/ealr/vol19/iss3/16. Ecology and Community (core.ac.uk) Messer, C. M., Shriver, T. E., Adams, A.E. 2015. Collective Identity and Memory: A Comparative Analysis of Community Response to Environmental Hazards. Rural Sociology 80(3):314-339. Collective Identity and Memory: A Comparative Analysis of Community Response to Environmental Hazards - Messer - 2015 - Rural Sociology - Wiley Online Library Hoggett, P. (1997). "One: Contested communities". In Contested Communities. Bristol, UK: Policy Press. Retrieved Mar 20, 2023, from https://bristoluniversitypressdigital.com/view/book/9781447366 Ted K. Bradshaw (2008) The Post-Place Community: Contributions to the Debate about the Definition of Community, Community Development, 39:1, 5-16, DOI: 10.1080/15575330809489738

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	influence how residents respond to environmental threats, including varied aspects of participation, mobilization, and agency (pp. 317–318). Also, of relevance here are "intentional communities," which Hoggett (1997) defines as a sense of commonality other than (though not necessarily exclusive of) place, for example, shared values, beliefs, and practices (p. 8). Bradshaw (2008) coined the term "post-place community" to designate a spatially dispersed network of people who share a sense of solidarity and identity (p. 5). Instead of focusing on place or common residence, he emphasizes that the essential facet of community is the presence of social relations or bonds. Thus conceived, community can exist in the absence of place attachment, but not without some collective sense of belonging.		

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Community of interest (as used in TS3, WP4, task 4.1)	The interest-based conception of community pertains to groups of actors who establish a collective identity based on their shared concerns, purposes, and goals (Briard & Carter, 2013; Henri & Pudelko, 2003). What sets a community of interest apart is that its members may reside in disparate locations, and have sporadic or even absent contact, yet still maintain a shared identity rooted in a common topic of interest. A community of interest can emerge within an existing community of place, but it is formed based on additional elements beyond the mere sharing of physical space. For instance, Keller introduces the concept of residents in a contaminated area who strengthen their connections due to a shared concern (Keller, 1992). Before the disaster, these residents only had a common identity rooted in their shared location. However, after the disaster, they developed shared concerns and a collective determination to mobilize and address the challenges posed by the disaster. In this scenario, rallying around a common issue has fostered social relationships and agency among the affected community members. Additional examples of a community of interests are	Social sciences	Henri, F., & Pudelko, B. (2003). Understanding and analyzing activity and learning in virtual communities: Activity and learning in virtual communities. *Journal of Computer Assisted Learning*, *19*(4), 474–487. https://doi.org/10.1046/j.0266-4909.2003.00051.x Briard, S., & Carter, C. (2013). Communities_of_Practice_Interest.pdf. Ontario Centre of Excellence for Child and Youth Mental Health. https://www.niagaraknowledgeexchange.com/wp-content/uploads/sites/2/2014/05/Communities_of_Practice_Interest.pdf

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	individuals who share the same occupation (e.g., farmers, rangers, businessmen, and fishermen) as well as individuals who share common concerns, needs, or objectives related to a specific topic or context (e.g., students, members of religious groups, landowners, women, people with disabilities, indigenous minorities, representatives of civil protection associations, and civil society actors).		
Community of place	The place-based view of the community offers an image of people living nearby and going about their daily affairs in ways that bring them into regular contact with one another (Ijaz 2022). Propinquity provides opportunities for community members to develop social networks through which they can access information, resources, and support. Sustained interactions within a shared space can, in turn, influence identity formation such that residents come to think of themselves as members of a community (Miller, 1992). It is also possible to conceive of a community as a "functional region" that is socially constituted by local inhabitants' thoughts and actions (Morgan & Moss, 1965, p. 349).	Social sciences	Ijaz, M. 2022. Communities of place, interest, and Communion. Social work. Communities of place, interest, and Communion (social work.pk) Byron Miller (1992) Collective Action and Rational Choice: Place, Community, and the Limits to Individual Self-Interest, Economic Geography, 68:1, 22-42, DOI: 10.2307/144039 Morgan, W. B., Moss, R. P. 1965. Geography and ecology: the concept of the community and its relationship to the environment. Annals of the Association of American Geographers, 55(2):339-350. DOI: 10.1111/j.1467-8306.1965.tb00522.x

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Community of place (as used in TS3, WP4, task 4.1)	A group of individuals who share a common physical or online space as the primary basis of their connection and interaction (Christenson & Jerry W, 1989). A community of place emerges when individuals, due to their shared physical presence or frequenting of a specific space, develop a collective identity and perceive themselves as members of a community (Miller, 1992). The transition from merely coexisting in the same space to sharing a common identity occurs as individuals in the community of place also share social experiences, meanings, and actions. Examples of a community of place are individuals who live in the same urban neighborhood or residents of a remote mountain settlement.	Social sciences	Miller, B. (1992). Collective Action and Rational Choice: Place, Community, and the Limits to Individual Self-Interest. *Economic Geography*, *68*(1), 22. https://doi.org/10.2307/144039
Community of practice	Members of a community of practice are informally bound by what they do together and by what they have learned through their mutual engagement in these activities (Wenger 1998). A community of practice is thus different from a community of interest or a geographical community, neither of which implies a shared practice. A community of practice defines itself along three dimensions: 1. What it is about: its joint enterprise as	Social sciences	Wenger, E. 1998. Communities of practice: learning as a social system. Systems thinker, 9(5). The Systems Thinker – Communities of Practice: Learning as a Social System - The Systems Thinker

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	understood and continually renegotiated by its members 2. How it functions: the relationships of mutual engagement that bind members together into a social entity 3. What capability it has produced: the shared repertoire of communal resources (routines, sensibilities, artifacts, vocabulary, styles, etc.) that members have developed over time. Communities of practice develop around things that matter to people. As a result, their practices reflect the members' understanding of what is important.		
Community of practice (as used in TS3, WP4, task 4.1)	Building on the definition given by the social-learning theorist Etienne Wenger, a community of practice consists of a heterogeneous group of actors (e.g., individuals, associations, governmental and non-governmental agencies, and organizations) that share a common interest or concern - the domain-, and collaborate to manage and address it (Etienne, 1998). The actors that compose the community operate as a network, fostering regular interactions and establishing relationships among its members. Wassermann and Faust define a social network as a collection of actors	Social Sciences	Wenger, E. 1998. Communities of practice: learning as a social system. Systems thinker, 9(5). The Systems Thinker – Communities of Practice: Learning as a Social System - The Systems Thinker

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	(individuals, groups, or organizations) and the relationships that exist between them; relational ties are channels for the transfer of resources, skills, and knowledge (Wasserman & Faust, 1994). The activities conducted within a community of practice extend beyond the routine tasks and established responsibilities of actors' daily work or personal lives. Instead, activities are understood as new practices in which community members gradually jointly learn how to perform. A community of practice defines itself in doing, meaning that activities in which members engage are not pre-defined pre-institutionalized, or formalized. Through their collaboration, community members engage in a collective learning process to enhance their skills and deepen their knowledge to better act within the domain. Through a process of social learning, participants' understanding of a particular domain evolves as they engage in interactions with others, transcending individual perspectives and becoming embedded within a larger social framework (Reed et al., 2010). A community of practice is distinguished from a community of interests or of place, neither of which		

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	implies a shared practice. An example of a community of practice in the realm of DRR and CCA is a network of actors (comprising, citizens, researchers from diverse disciplines - including climate scientists, urban planners, and agronomists-, policymakers, community leaders, and NGOs) that organize regular meetings, workshops, and knowledge-sharing events to enhance the resilience and preparedness of a certain territory in response to climate-related risks within their specific geographical context.		
Community-based adaptation	Local, community-driven adaptation. Community-based adaptation focuses attention on empowering and promoting the adaptive capacity of communities. It is an approach that takes context, culture, knowledge, agency, and preferences of communities as strengths.	Social Sciences	IPCC AR6 WG II Annex II
Community-based adaptation	Community-based adaptation (CBA) is an empowerment-based approach that encourages community-level leadership in assessing risks, planning strategies, prioritizing the use of investment resources, implementing measures, and monitoring the results of climate change	Social Sciences	Mfitumukiza, D., A. S. Roy, B. Simane, A. Hammill, M. F. Rahman, S. Huq. 2020. Scaling local and community-based adaptation. Global Commission on Adaptation Background Paper. Rotterdam and Washington, DC. Available online at www.gca.org/global-commission-on-adaptation/report/papers

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	adaptation-related interventions. The approach targets communities as a whole: people who live in a defined administrative unit, share a common culture, values, and norms, or are exposed to shared shocks and stresses. CBA involves the use of participatory processes to engage and empower community members to build close partnerships with local governments; and to strengthen community leadership and local capacities.		
Compound risks	Compound risks arise from the interaction of *hazards*, which may be characterized by single extreme events or multiple coincident or sequential events that interact with exposed systems or sectors.	Climate Risk	IPCC AR6 WG II Annex II
Compound weather/climate events	The terms 'compound events', 'compound extremes', and 'compound extreme events' are used interchangeably in the literature and this report and refer to the combination of multiple drivers and/or hazards that contribute to societal and/or environmental risk (Zscheischler et al., 2018).	Climate Risk	IPCC AR6 WG II Annex II
Confidence	"[c]onfidence denotes the subjective expectation of receiving trustworthy information from a person or an institution" In general terms, confidence tends to be	Social Sciences	Renn, O., & Levine, D. (1991). Credibility and trust in risk communication (pp. 175-217). Springer Netherlands.

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	used about the perceived technical ability / scientific competence of risk managers and risk-controlling institutions in providing reliable assessment and solutions to risk. Confidence enhances cognitive inference on other's ability to manage complex scientific/technical issues rather than affective ones.		
Consequence	The outcome of an event affects objectives. NOTE 1 An event can lead to a range of consequences. NOTE 2 A consequence can be certain or uncertain and can have positive or negative effects on objectives. NOTE 3 Consequences can be expressed qualitatively or quantitatively. NOTE 4 Initial consequences can escalate through knock-on effects.	Risk Managem ent	ISO/FDIS 31000:2009(E)
Consistent reasoning	A sequence of logically chained propositions, having semantic cohesion, compactness, and congruity, as well as logical connection and lack of contradiction, which are developed to support possible actions that a decisionmaker is called to take	Social Sciences	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

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Damage	Decreased integrity, size, efficiency (function), or conditions considered to be advantageous or positive by a community, resulting from an adverse event. Depending on applications, damage can be measured in different ways, using appropriate metrics for each type of risk analysis. In this sense, damage may be physical or social.	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Damage Level	The physical damage to an exposed element caused by a natural or anthropogenic event may be regarded as a continuous or discrete variable. A discrete variable defines various damage levels that progressively include all possible consequences that an element at risk may sustain.	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Damage Scenario	A description, including in terms of probability, of the overall damage caused in a given geographic area by a single natural or anthropogenic event taken as a reference scenario.	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Danger	Synonym of adverse event	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

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Disaster	A 'serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNGA, 2016). See also Exposure, Hazard, Risk, and Vulnerability.	Climate Risk	IPCC AR6 WG II Annex II
Disaster Risk	The likelihood over a specified period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.	Climate Risk	IPCC AR6 WG II Annex II
Disaster Risk Management (DRM)	Processes for designing, implementing, and evaluating strategies, policies, and measures to improve the understanding of current and future disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, prevention and protection, response and recovery practices, with the explicit purpose of	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	increasing human security, well-being, quality of life and sustainable development (SD).		
Disaster Risk Reduction (DRR)	Denotes both a policy goal or objective and the strategic and instrumental measures employed for anticipating future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience.	Climate Risk	IPCC AR6 WG II Annex II
Disaster Risk Reduction (DRR) (as used in TS3, WP2, task 2.1)	Denotes both a policy goal or objective and the strategic and instrumental measures employed for preventing, preparing for, responding to, and recovering from future disaster risk; reducing existing exposure, hazard, or vulnerability; and improving resilience.	Climate Risk	IPCC AR6 WG II Annex II
Driver	It encompasses both natural and human-induced factors, processes, or conditions that result in a direct or indirect alteration of a system. Examples include climate change, uncontrolled urbanization, physical vulnerability of infrastructure to natural disasters, limited emergency response plans, and early warning systems.	Climate Risk	IPCC AR6 WG II Annex II
Early Warning Systems (EWS)	The set of technical and institutional capacities to forecast, predict, and communicate timely and meaningful warning information to enable individuals, communities, managed ecosystems, and organizations threatened by a hazard to	Climate Risk	IPCC AR6 WG II Annex II

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	prepare to act promptly and appropriately to reduce the possibility of harm or loss. Dependent upon context, EWS may draw upon scientific and/or indigenous knowledge, and other knowledge types. EWS is also considered for ecological applications, for example, in conservation, where the organization itself is not threatened by hazards but the ecosystem under conservation is (e.g., coral bleaching alerts), in agriculture (e.g., warnings of heavy rainfall, drought, ground frost, and hailstorms) and in fisheries (e.g., warnings of storms, storm surges, and tsunamis) (UNISDR 2009; IPCC, 2012a).		
Earth System Models	A coupled *atmosphere–ocean* general circulation model (AOGCM) in which a representation of the *carbon cycle* is included, allowing for interactive calculation of atmospheric *carbon dioxide (CO_2)* or compatible emissions. Additional components (e.g., atmospheric chemistry, *ice sheets*, dynamic vegetation, nitrogen cycle, but also urban or crop models) may be included.	Climate Risk	IPCC AR6 WG II Annex II
Economic Loss	A measure of the expected direct or indirect economic losses of the elements exposed to an adverse event. A direct economic loss is associated with physical	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18.

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	damage or with the cost of reinstating the function of an element. An indirect economic loss is the cost deriving from the reduced services and/or productivity of the damaged element, e.g. deterioration of health care, communication, and other services, reduction of tourist flows and production volumes, loss of clients and suppliers		https://doi.org/10.4408/IJEGE.2023-01.O-01
Ecosystem Services	Ecological processes or functions have monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or biodiversity maintenance, (2) provisioning services such as food or fiber, (3) regulating services such as climate regulation or carbon sequestration, and (4) cultural services such as tourism or spiritual and aesthetic appreciation.	Climate Risk	IPCC AR6 WG II Annex II
Element at Risk	Human or natural elements (people, buildings, infrastructure, activities and movable assets, natural environment) that are present in the area exposed to potentially harmful events, whose state, conditions, and/or function may be damaged, altered, or destroyed by an adverse event that is assumed to be a reference event	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

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Event	Event occurrence or change of a particular set of circumstances. NOTE 1 An event can be one or more occurrences and can have several causes. NOTE 2 An event can consist of something not happening. NOTE 3 An event can sometimes be referred to as an “incident” or “accident”. NOTE 4 An event without consequences can also be referred to as a “near miss”, “incident”, “near hit” or “close call”.	Risk Managem ent	ISO/FDIS 31000:2009 (E), 2.19
Event Scenario	The spatial and temporal pattern of the intensity of a specific natural or anthropogenic event of an assigned probability (taken as a reference scenario). Here, intensity defines a quantity representing the severity of the adverse event at any point in the area investigated	Risk Managem ent	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Event Tree	An inductive graph is used to analyze a time series of events or subsequent consequences having a causal relationship between them. The chances of a transition from one event to the subsequent one can be evaluated by using an assigned probability.	Risk Managem ent	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Exposure	1) Exposure or risk exposure is a measure of the vulnerability of an urban system or its components to adverse events	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	(negative impacts) or uncertainty. 2) The presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected.		
Exposure	Quantity and quality of elements at risk in a geographic area where an event is expected. Exposure may be identified in various ways, depending on the type of risk analysis adopted.	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Ground Instability	Natural ground instability refers to upward, lateral, or downward strains and angular distortions of the ground that can be caused by a range of natural geological hazards. The magnitude of these strains varies significantly depending on the intensity of triggering actions as well as on several other natural constraints (e.g., time-independent predisposing conditions and time-dependent preparatory factors). Significant natural ground instability has the potential to cause substantial damage to some buildings and structures	Geological Risk	https://www.thefreelibrary.com/High-Point+Rendel+given+crucial+coast+role-a0131219552
Hazard	In a specific geographic area and a given timeframe (reference period), the probability of occurrence of a potentially harmful natural or anthropogenic event of	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18.

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	an assigned intensity. The latter may be codified in various ways depending on the features of risk analysis.		https://doi.org/10.4408/IJEGE.2023-01.O-01
Impacts	The consequences of realized risks on natural and human systems, where risks result from the interactions of climate-related hazards (including extreme weather/climate events), exposure, and vulnerability. Impacts generally refer to effects on lives, livelihoods, health and well-being, ecosystems and species, economic, social, and cultural assets, services (including ecosystem services), and infrastructure. Impacts may be referred to as consequences or outcomes and can be adverse or beneficial.	Climate Risk	IPCC AR6 WG II Annex II
Impacts	The quantification of the overall potential damage and losses that a reference event may generate in the same area and in a set timeframe.	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Intensity of an Adverse Event	A variable representing the severity of an adverse event at each point of the area being investigating	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Key Risks	Key risks have potentially severe adverse consequences for humans and social-ecological systems resulting from the	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	interaction of climate-related hazards with vulnerabilities of societies and systems exposed.		
Likelihood	Chance of something happening. NOTE 1 In risk management terminology, the word "likelihood" is used to refer to the chance of something happening, whether defined, measured, or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically (such as a probability or a frequency over a given period). NOTE 2 The English term "likelihood" does not have a direct equivalent in some languages; instead, the equivalent of the term "probability" is often used. However, in English, "probability" is often narrowly interpreted as a mathematical term. Therefore, in risk management terminology, "likelihood" is used with the intent that it should have the same broad interpretation as the term "probability" has in many languages other than English.	Risk Managem ent	ISO/FDIS 31000:2009(E)
Mitigation (of Climate Change)	A human intervention to reduce emissions or enhance the sinks of greenhouse gases.	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Mitigation Measures (of Climate Change)	In climate policy, mitigation measures are technologies, processes, or practices that contribute to mitigation, for example, renewable energy technologies, waste minimization processes, and public transport commuting practices.	Climate Risk	[IPCC AR6 WG II Annex II]
Multi-Hazard Assessment	An assessment of the probabilities of occurrence of adverse events of a different nature. These events, whether concatenated or not, and with no chronological relationship, threaten the same elements at risk in a given geographic area.	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Multi-Risk Assessment	An assessment, in the same geographic area, of the overall risk arising from a series of possible adverse events and their interactions with the different specific vulnerabilities of the exposed elements. A multi-risk approach implies a multi-hazard perspective and dynamic multi-vulnerability. This includes events that occur simultaneously or follow one another within a short time because they depend on one another, because they are caused by the same triggering event or danger (cascading events), or because they threaten the same elements at risk (vulnerable/exposed elements) without any temporal coincide	Risk Management	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
New Urban Agenda	The New Urban Agenda was adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, on 20 October 2016. It was endorsed by the United Nations General Assembly at its 68th plenary meeting of the 71st session on 23 December 2016.	Climate Risk	IPCC AR6 WG II Annex II
Non-climatic driver (Non-climate driver)	An agent or process outside the climate system that influences a human or natural system.	Climate Risk	IPCC AR6 WG II Annex II
Pathway(s)	The temporal evolution of natural and/or human systems towards a future state. Pathway concepts range from sets of quantitative and qualitative scenarios or narratives of potential futures to solution-oriented decision-making processes to achieve desirable societal goals. Pathway approaches typically focus on biophysical, techno-economic, and/or socio-behavioral trajectories and involve various dynamics, goals, and actors across different scales. See also Scenario.	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Physical Damage	A measure of the quantitative or functional reduction of the state of elements at risk before an adverse event. For instance, physical damage to buildings and infrastructure can be assessed in discrete terms by estimating the damage level reached, or in continuous terms by using an appropriate metric that associates damage with a continuous variable. Physical damage to people is generally assessed, continuously or discretely, by considering the number of people killed and injured See "Damage"	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Preparedness	The knowledge and capacities developed by governments, response and recovery organizations, communities, and individuals to effectively anticipate, respond to, and recover from the impacts of likely, imminent, or current disasters. Preparedness actions are carried out within the context of disaster risk management/reduction, based on disaster risk assessments, connected with early warning systems, and include activities such as contingency planning and associated training and field exercises.	Risk Management	UNDRR, 2017

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Prevention	Activities and measures to avoid existing and new disaster risks, typically with a long-term perspective and adopted in peacetime, by implementing both structural and non-structural measures acting on the different risk components.	Risk Management	UNDRR, 2017
Recovery	The restoring or improving livelihoods and health, as well as economic, physical, social, cultural, and environmental assets, systems, and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and "building back better", to avoid or reduce future disaster risk.	Risk Management	UNDRR, 2017
Reference Event	An adverse event is taken as a reference for defining a specific damage and/or impact scenario. See "Adverse event" and "Event"	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Reference Period	The timeframe considered by risk analysis	Risk Management	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

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Residual Risk	The risk related to climate change impacts remains following adaptation and mitigation efforts. Adaptation actions can redistribute risk and impacts, with increased risk and impacts in some areas or populations, and decreased risk and impacts in others.	Climate Risk	IPCC AR6 WG II Annex II
Resilience	The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, adapt to, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. On the psychological level, resilience indicates "the process and outcome of successfully adapting to difficult or challenging life experiences, especially through mental, emotional, and behavioral flexibility and adjustment to external and internal demands" (American Psychological Association, 2023). Several factors contribute to how individuals adapt to adversities, with both personal and social factors involved: on the one side, a critical role is played by individuals' view of, and approach to, the world; on the other side, resilience is also a	Social Sciences	UNISDR (https://www.undrr.org/terminology) American Psychological Association (2023). Trust. In APA Dictionary of Psychology. Ellis, W., Dietz, W. H., & Chen, K. D. (2022). Community Resilience: A Dynamic Model for Public Health 3.0. Journal of public health management and practice: JPHMP, 28(Suppl 1), S18–S26. https://doi.org/10.1097/PHH.0000000000001413 Norris, F. H., Stevens, S. P., Pfefferbaum, B., Wyche, K. F., & Pfefferbaum, R. L. (2008). Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. American journal of community psychology, 41(1-2), 127–150. https://doi.org/10.1007/s10464-007-9156-6 Pfefferbaum, R. L., Pfefferbaum, B., Van Horn, R. L., Klomp, R. W., Norris, F. H., & Reissman, D. B. (2013). The Communities Advancing Resilience Toolkit (CART): an intervention to build community resilience to disasters. Journal of public health management and practice: JPHMP, 19(3), 250–258. https://doi.org/10.1097

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	function of the quality and availability of social resources. In this respect, community resilience has emerged as a critical construct to support and foster healthy adaptation at the individual and community levels (as evidenced by globally high levels of mental and behavioral health and quality of life) in the aftermath of disasters (Pfefferbaum et al., 2013). Community resilience emerges from primary sets of adaptive capacities, such as economic development, social capital, information and communication, and community competence, which function in the face of unknowns and together provide a strategy for disaster readiness (Norris et al., 2008). Thus, community resilience is relational, as it involves actual and coordinated interactions among different actors, and is place-based, as it varies on specific demographical, historical, jurisdictional, and economic features characterizing the community's residents (Ellis et al., 2022). Given the specificity of community resilience development in different contexts, decision-making skills, flexibility, cooperation, and trusted sources of information are central features for its		

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	building and restoration (Pfefferbaum et al., 2013).		
Resilience	For a system, community, or society exposed to risks, the possibility of withstanding, coping with, adapting to, changing, and recovering from the effects of a harmful event in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions via risk management.	Social Sciences	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Resilience (disaster resilience)	In disaster research, the resilience concept bridges theory and practice and emphasizes the importance of community, societal, and governance aspects in reducing the risks and impacts of hazardous processes. Within the context of the DRR discourse, resilience does not mean bouncing back to a pre-event state. Instead, it denotes the capacity of systems to move forward by modifying their internal dynamics and recombining their structures and processes for positive transformation and change toward	Social Sciences	Wyss R., Luthe T., Pedoth L., Schneiderbauer S., Adler C., Apple M., Erazo Acosta E., Fitzpatrick H., Haider J., Ikizer G., Imperiale AJ, Karanci N., Posch E., Saidmamatov O., Thaler T. (2022). Mountain Resilience: A Systematic Literature Review and Paths to the Future. Mountain Research and Development. 42(2), A23-A36. https://doi.org/10.1659/MRD-JOURNAL-D-21-00044.1

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	enhanced DRR at all levels of society (Manyena 2009; Koontz et al 2015; Pelling et al 2015; Imperiale and Vanclay 2016a).		
Response	Actions taken directly before, during, or immediately after a disaster to save lives, reduce health impacts, ensure public safety, and meet the basic subsistence needs of the people affected. The institutional elements of response often include the provision of emergency services and public assistance by public and private sectors and community sectors, as well as community and volunteer participation.	Risk Management	[UNDRR, 2017](#)
Return Period	A return period of x time units, also known as a recurrence interval (sometimes repeat interval) is an estimate of the likelihood of an event, such as an earthquake, flood [1], landslide [2], rainfall intensity, a river discharge flow or any observable, to occur (or be overcome) on average every x time units. It is a statistical measurement typically based on historic data denoting the average recurrence interval over an extended period and is usually used for risk	Risk Management	http://abouthydrology.blogspot.com/2017/10/return-period_25.html

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	analysis (e.g., to decide whether a project should be allowed to go forward in a zone of a certain risk or to design structures to withstand an event with a certain return period). The following analysis assumes that the probability of the event occurring does not vary over time and is independent of past events.		
Risk	The potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of *climate change*, risks can arise from the potential *impacts* of climate change and human responses to climate change. Relevant adverse consequences include those on lives, *livelihoods*, health and *well-being*, economic, social, and cultural assets and investments, infrastructure, services (including *ecosystem services*), *ecosystems,* and species. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards. Hazards, exposure, and vulnerability may each be subject to	Climate Risk	IPCC AR6 WG II Annex II

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	uncertainty in terms of magnitude and likelihood of occurrence, and each may change over time and space due to socioeconomic changes and human decision-making (see also risk management, adaptation, and mitigation). In the context of climate change responses, risks result from the potential for such responses not achieving the intended objective(s), or from potential trade-offs with, or negative side-effects on, other societal objectives, such as the Sustainable Development Goals (SDGs) (see also risk trade-off). Risks can arise, for example, from uncertainty in implementation, effectiveness or outcomes of climate policy, climate-related investments, technology development or adoption, and system transitions.		
Risk	Effect of uncertainty on objectives NOTE 1 An effect is a deviation from the expected — positive and/or negative. NOTE 2 Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product, and process).	Risk Managem ent	ISO/FDIS 31000:2009 (E), 2.1

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	NOTE 3 Risk is often characterized by reference to potential events (2.19) and consequences (2.20), or a combination of these. NOTE 4 Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood (2.21) of occurrence. NOTE 5 Uncertainty is the state, even partial, of deficiency of information related to, understanding, or knowledge of an event, its consequence, or likelihood.		
Risk	A measure of the negative effects (in terms of damage, possibly including related losses) caused by adverse events in a given reference period and a certain geographic area. It may be expressed as the probability that, in the same period, a given level of damage and consequent losses (to/of people, buildings, infrastructure, economy, etc.) is reached, or as an expected level of damage, always in the same period. Risk should be understood as a cumulative assessment considering the overall potential damage that may be induced by different events of the same nature (seismic, volcanic, hydrogeological, etc.) in a set timeframe	Climate Risk	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Risk Analysis	process to comprehend the nature of risk and to determine the level of risk. NOTE 1 Risk analysis provides the basis for risk evaluation (2.26) and decisions about risk treatment (2.27). NOTE 2 Risk analysis includes risk estimation.	Risk Managem ent	ISO/FDIS 31000:2009(E), 2.23
Risk Analysis	Procedure to quantify risk to inform and justify decisions aimed at optimizing the planning and management of emergencies and developing political strategies for risk prevention and/or mitigation	Risk Managem ent	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01
Risk Assessment	The qualitative and/or quantitative scientific estimation of *risks*.	Climate Risk	IPCC AR6 WG II Annex II
Risk Driver	Risk drivers are processes or conditions that influence the level of disaster risk by increasing levels of exposure and vulnerability or reducing capacity. They include climate change, urbanization, environmental degradation, the changing security paradigm, and technological developments.	Climate Change	https://civil-protection-knowledge-network.europa.eu/eu-overview-risks
Risk Evaluation	risk evaluation process of comparing the results of risk analysis with risk criteria to determine whether the risk (2.1) and/or its magnitude is acceptable or tolerable NOTE Risk evaluation assists in the decision about risk treatment (2.27).	Risk Managem ent	ISO/FDIS 31000:2009(E), 2.26

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Risk governance	"The concept of risk governance comprises a broad picture of risk: not only does it include what has been termed 'risk management' or 'risk analyses, but it also looks at how risk-related decision-making unfolds when a range of actors is involved, requiring co-ordination and possibly reconciliation between a profusion of roles, perspectives, goals, and activities. Indeed, the problem-solving capacities of individual actors, be they government, the scientific community, business players, NGOs, or civil society as a whole, are limited and often unequal to the major challenges facing society today. Risks such as those related to increasingly violent natural disasters, food safety, or critical infrastructures call for coordinated effort amongst a variety of players beyond the frontiers of countries, sectors, hierarchical levels, disciplines, and risk fields. Finally, risk governance also illuminates a risk's context by taking account of such factors as the historical and legal background, guiding principles, value systems and perceptions as well as organizational imperatives." (p.11) "Risk Governance: Includes the totality of actors, rules, conventions, processes, and	Social Sciences	IRGC (2005) white paper on RISK GOVERNANCE TOWARDS AN INTEGRATIVE APPROACH (p. 11) Aven, T., Renn, O., (2010) Risk Management and Governance: Concepts, Guidelines and Applications, Springer Heidelberg Dordrecht London New York

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	mechanisms concerned with how relevant risk information is collected, analyzed, and communicated and management decisions are taken. Encompassing the combined risk-relevant decisions and actions of both governmental and private actors, risk governance is of particular importance in, but not restricted to, situations where there is no single authority to take a binding risk management decision but where instead the nature of the risk requires the collaboration and coordination between a range of different stakeholders. Risk governance however not only includes a multifaceted, multifactor risk process but also calls for the consideration of contextual factors such as institutional arrangements (e.g., the regulatory and legal framework that determines the relationship, roles, and responsibilities of the actors and coordination mechanisms such as markets, incentives, or self-imposed norms) and political culture including different perceptions of risk." (p. 21) "[R]isk governance includes the totality of actors, rules, conventions, processes, and mechanisms concerned with how relevant risk information is collected, analyzed, and		

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	communicated and management decisions are taken. Encompassing the combined risk-relevant decisions and actions of both governmental and private actors, risk governance is of particular importance in, but not restricted to, situations where there is no single authority to take a binding risk management decision but where, instead, the nature of the risk requires the collaboration of and co-ordination between a range of different stakeholders. Risk governance however not only includes a multifaceted, multi-actor risk process but also calls for the consideration of contextual factors such as institutional arrangements (e.g., the regulatory and legal framework that determines the relationship, roles, and responsibilities of the actors and co-ordination mechanisms such as markets, incentives or self-imposed norms) and political culture, including different perceptions of risk." (Aven & Renn, 2010: 50) "The term risk governance […] denotes not only the governmental actions taken towards the mitigation or prevention of risk consequences but the whole interplay of all relevant actors – and all actions that		

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	are undertaken to handle risks. The integration of so many different views interests, values, and norms creates a very complex structure, which is difficult to comprehend for the public and large parts of the affected groups as well. To ensure the functioning of such a complex and interdependent formation, where direct links between the different parties and tasks are often absent or too weak due to international or global dimensions of the risk problems, some general principles have to be set up to support a governance process with outcomes that are accepted or at least tolerated." (Aven & Renn, 2010: 64)		
Risk identification	Process of finding, recognizing, and describing risks. NOTE 1 Risk identification involves the identification of risk sources (2.18), events (2.19), their causes, and their potential consequences (2.20). NOTE 2 Risk identification can involve historical data, theoretical analysis, informed and expert opinions, and stakeholder (2.15) needs.	Risk Management	ISO/FDIS 31000:2009(E), 2.17
Risk Owner	person or entity with the accountability and authority to manage the risk	Risk Management	ISO/FDIS 31000:2009 (E), 2.9

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Risk perception	"The term risk perception has a long tradition.1 The term denotes the process of collecting, selecting, and interpreting signals about uncertain impacts of events, activities, or technologies."	Social Sciences	Wachinger, G., Renn, O., Begg, C., & Kuhlicke, C. (2013). The risk perception paradox—implications for governance and communication of natural hazards. Risk analysis, 33(6), 1049-1065.
Scenario	A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change (TC), prices) and relationships. Note that scenarios are neither predictions nor forecasts but are used to provide a view of the implications of developments and actions. See also Pathways.	Climate Risk	IPCC AR6 WG II Annex II
Scenario (Socio-economic)	A scenario that describes a possible future in terms of population, gross domestic product (GDP), and other socio-economic factors relevant to understanding the implications of climate change.	Climate Risk	IPCC AR6 WG II Annex II
Social Damage	A measure of social disruption, in terms of deterioration of social relations and functions, that a natural or anthropogenic event causes to a community in the short to medium term (i.e., homelessness). See "Damage".	Social Sciences	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Stakeholder	stakeholder person or organization that can affect, be affected by or perceive themselves to be affected by a decision or activity NOTE A decision maker can be a stakeholder.	Risk Managem ent	ISO/FDIS 31000:2009 (E), 2.15
Storyline	physically self-consistent unfoldings of past events, or of plausible future events, that have been proposed as a way of articulating the risk in such cases where we need to go beyond a purely probabilistic climate change perspective, with an emphasis on plausibility rather than probability.	Climate Risk	Shepherd, Theodore G., Emily Boyd, Raphael A. Calel, Sandra C. Chapman, Suraje Dessai, Ioana M. Dima-West, Hayley J. Fowler, et al. 2018. "Storylines: An Alternative Approach to Representing Uncertainty in Physical Aspects of Climate Change." Climatic Change 151 (3–4): 555–71. https://doi.org/10.1007/s10584-018-2317-9. Sillmann, Jana, Theodore G. Shepherd, Bart Van Den Hurk, Wilco Hazeleger, Olivia Martius, Julia Slingo, and Jakob Zscheischler. 2021. "Event-Based Storylines to Address Climate Risk." Earth's Future 9 (2). https://doi.org/10.1029/2020EF001783.
Susceptibility	If, due to lack of adequate information, the probability of occurrence of a given event in a specific geographic area in the reference period cannot be estimated, then the susceptibility of such area (i.e. its tendency to suffer a harmful event of an assigned intensity) is assessed	Social Sciences	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Trust	"Trust is one major objective in risk communication and also a prerequisite for many other objectives, we need a better understanding of the meaning and implications of the term trust."	Social Sciences	Renn, O., & Levine, D. (1991). *Credibility and trust in risk communication* (pp. 175-217). Springer Netherlands. Siegrist, M. (2021). Trust and risk perception: A critical review of the literature. Risk analysis, 41(3), 480-490. Siegrist et al. (2005) Perception of risk: the influence of general trust, and general confidence, Journal of Risk Research, 8:2, 145-156.
Trust (in communication)	"Trust in communication refers to the generalized expectancy that a message received is true and reliable and that the communicator demonstrates competence and honesty by conveying accurate, objective, and complete information". "For a better understanding of the function of trust, it is a significant fact that trust and complexity influence each other (Luhmann, 1989). Trust is a mechanism for the reduction of complexity; therefore, it enables people to maintain their capacity to act in a complex environment. At the same time, trust is needed to construct a more complex technical and social environment. "Although there is broad consensus on its importance, there is no agreement among social scientists on how to conceptualize trust (Cvetkovich and Lofstedt, 1999).	Social Sciences	

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Trust (in psychology)	"Trust is one major objective in risk communication and also a prerequisite for many other objectives." In psychology, trust refers to a "reliance on or confidence in the dependability of someone or something" (American Psychological Association, 2023). It involves "a psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another" (Rousseau et al., 1998, p. 395). Trust is not a unitary concept, as it necessarily involves a relationship between a trustor and a trustee, independently from the fact that the trustor and the trustee are single individuals, a community of individuals, organizations, or public entities. The general models of trust in psychology consider this relationship to operationalize the concept of trust. Two main models of trust might serve to explain how this relationship operates. Gillespie's model (2012) indicates that trust includes two distinct yet complementary components, that is, reliance and disclosure. Reliance is defined as the willingness of the trusting party to depend on a trustee and is expressed	Social Sciences	American Psychological Association (2023). Trust. In APA Dictionary of Psychology. Gillespie, N. (2012). Measuring trust in organizational context: an overview of survey-based measures. In Lyon, F., Mollering, G., & Saunders M. N. K (eds.) Handbook of Research Methods on Trust (pp. 175–188). Seattle, WA: Edward Elgar. McAllister, D. J. (1995). Affect-based and cognition-based trust as foundations for interpersonal cooperation in organizations. Acad. Manag. J. 38, 24–59. 10.2307/256727 Renn, O., & Levine, D. (1991). Credibility and trust in risk communication (pp. 175-217). Springer Netherlands. Rousseau, D. M., Sitkin, S. B., Burt, R. S., & Camerer, C. (1998). Not so different after all: a cross-discipline view of trust. Acad. Manag. Rev. 23, 393–404. 10.5465/AMR.1998.926617 Siegrist, M. (2021). Trust and risk perception: A critical review of the literature. Risk analysis, 41(3), 480-490. Siegrist et al. (2005) Perception of risk: the influence of general trust, and general confidence, Journal of Risk Research, 8:2, 145-156.

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	through the acceptance of the trustee's influence (e.g., by depending on the trustee's skills and judgment); disclosure is defined as the trustor's willingness to disclose relevant information to the trustee and is expressed through open communication and sharing of ideas with the trustee. McAllister's model (1995) highlights, in contrast, the cognitive and affective dynamics involved in trust: according to this model, trust is grounded upon the trusting parties' cognitive assessments of the trustee's skills and competence and upon the emotional ties linking individuals in a given community. To increase trust, it is thus imperative to operate on both trustors' and trustee's dynamics, communication, and reciprocal relationships		
Uncertainty	Scientific concepts used in risk assessment to describe all types of limitations in available knowledge at the time an assessment is conducted, with the agreed resources, that affect the probability of possible outcomes to the assessment		EFSA https://www.efsa.europa.eu/en/topics/topic/uncertainty-scientific-assessments

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Urban	The categorization of areas as 'urban' by government statistical departments is generally based either on population size, population density, economic base, provision of services, or some combination of the above. Urban systems are networks and nodes of intensive interaction and exchange including capital, culture, and material objects. Urban areas exist on a continuum with rural areas and tend to exhibit higher levels of complexity, higher populations, population density, intensity of capital investment, and a preponderance of secondary (processing) and tertiary (service) sector industries. The extent and intensity of these features vary significantly within and between urban areas. Urban places and systems are open with much movement and exchange between more rural areas as well as other urban regions. Urban areas can be globally interconnected facilitating rapid flows between them – of capital investment, of ideas and culture, human migration, and disease.	Climate Risk	IPCC AR6 WG II Annex II

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Urban Systems	Urban systems refer to two interconnected systems, the comprehensive collections of city elements with multiple dimensions and characteristics: a) encompass physical, built, socioeconomic-technical, political, and ecological subsystems; b) integrate social agent/constituency/processes with physical structure and processes; and c) exist within broader spatial and temporal scales and governance and institutional contexts; and second, the global system of cities and towns.	Climate Risk	IPCC AR6 WG II Annex II
Urbanization	Urbanization is a multi-dimensional process that involves at least three simultaneous changes: (i) land use change: transformation of formerly rural settlements or natural land into urban settlements; (ii) demographic change: a shift in the spatial distribution of a population from rural to urban areas; and (iii) infrastructure change: an increase in provision of infrastructure services including electricity, sanitation, etc. Urbanization often includes changes in lifestyle, culture, and behavior, and thus alters the demographic, economic, and social structure of both urban and rural areas. (Stokes and Seto 2019; Seto et al. 2014; UNDESA 2018)	Climate Risk	IPCC AR6 WG II Annex II

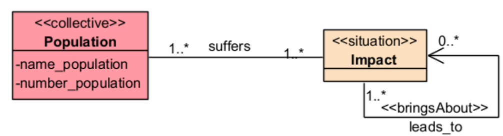
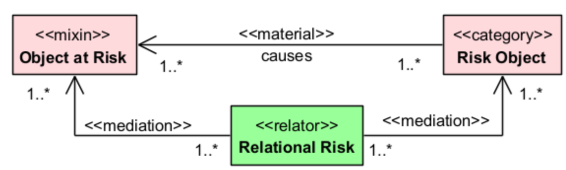
Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	References - Stokes, E. C. and K. Seto. 2019: Characterizing and measuring urban landscapes for sustainability. in: Environmental Research Letters 14.4: 045002. DOI: 10.1088/1748-9326/aafab8 - Seto K. C., S. Dhakal, A. Bigio, H. Blanco, G. C. Delgado, D. Dewar, L. Huang, A. Inaba, A. Kansal, S. Lwasa, J. E. McMahon, D. B. Müller, J. Murakami, H. Nagendra, and A. Ramaswami, 2014: Human Settlements, Infrastructure and Spatial Planning. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA - UNDESA (2019) World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420). New York: United Nations.		

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
Value	Value or Value at Risk refers to the level of significance of an object as perceived by an individual, quantified by its monetary value or other established measure.		
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.	Climate Risk	IPCC AR6 WG II Annex II
Vulnerability	Vulnerability expresses the relationship between the intensity of an adverse event, the features of the elements at risk (assets, community, system, environment) that affect their behavior, and the measure of the damage resulting from the event (response). Uncertainty in assessing vulnerability is due to insufficient knowledge of the features affecting the response and the possible effects on the elements exposed to an event. Vulnerability is defined in different ways depending on the types of risk being assessed. In seismic risks, vulnerability is the probability that an element at risk, belonging to a specific behavioral class (vulnerability class), experiences or exceeds a damage threshold (according to a predetermined scale of damage) upon	Social Sciences	Versace, P., Zuccaro, G., Albarello, D., & Scarascia Mugnozza, G. (2023). Natural and anthropogenic risks: proposal for an interdisciplinary glossary. Italian Journal of Engineering Geology and Environment, (1), 5–18. https://doi.org/10.4408/IJEGE.2023-01.O-01

Term	Definition given, including if necessary specific terminology used and reference to other glossary terms	Disciplines	Reference (authors, article/document title, year, publisher)
	the occurrence of an event of an assigned intensity. In flood risks, vulnerability expresses the expected damage to the elements at risk, the extent of damage ranging from 0 (no damage) to 1 (destruction).		

Appendix C – Basic Notions on UFO and OntoUML[26]

A diagram is composed of concepts (represented by rectangular boxes, also called classes in some modeling languages) and relationships (represented by lines). Both concepts and relationships are labeled. Both concepts and relationships are categorized using stereotypes (classes of OntoUML, for example, Kind, Subkind, Role) and relationships (e.g., generalization, material, characterization, formal, component_of, subcollection_of). Attributes are included in classes, for instance, Population has two attributes *"name_population"* and "number_population".

<table>
<tr><th>Relationship Type</th><th>Notation/Description</th><th>Example</th></tr>
<tr><td>Association</td><td>It is represented by a line with a label (e.g., suffers, leads_to) and a stereotype (e.g., brings_about). Also, an association can have a direction (called navigability) represented by an open arrow as seen in the self-association leads_to.</td><td>
</td></tr>
<tr><td>SubCollection_of</td><td>It is represented by a line with a with diamond at one end of the association. It has an optional label and the OntoUML stereotype is subCollectionOf.</td><td>
</td></tr>
<tr><td>Material</td><td>«Material» relations have material structure on their own and include examples such as employments, kisses, enrolments, flights, connections, and commitments. The relata of a material relation are mediated by individuals that are called relators.</td><td rowspan="2">
</td></tr>
<tr><td>Mediation</td><td>We define a relation of «Mediation» between a «Relator» and the entities it connects. Mediation is a type of existential dependence relation (a form of nonfunctional inherence). It can be derived from the relation between the relata and the qua individiuals that compose the relator and that inhere in the relata. A «Relator» must mediate at least two distinct individuals.</td></tr>
</table>

[26] Some excerpts were taken from https://ontouml.readthedocs.io/en/latest/intro/index.html

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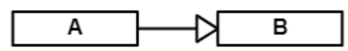
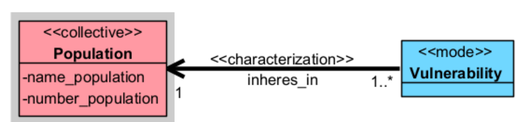
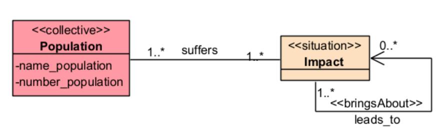
Component_of	«ComponentOf» is a parthood relation between two complexes. Transitivity holds for certain cases but not for others, it depends on context. The «ComponentOf» relation obeys the weak supplementation principle (at least 2 parts are required, may be of different types). Constraint: The classes connected to both association ends of this relation must represent universals whose instances are functional complexes. Examples: the car engine is part of a car.	 Composition: B consists of one or more A's
Generalization	it is the process of extracting shared characteristics from two or more classes and combining them into a generalized superclass. Shared characteristics can be attributes, associations, or methods. In the example, Class B is a superclass and Class A is a specialization of Class B (or Class A is a kind of Class B).	 Generalization: A "is a kind of" B
Characterization	«Characterization» is a relation between a *bearer type* and its *feature*. Feature is intrinsic (inherent) moment of its bearer type, and thus *existentially dependent* on the bearer. Feature may be stereotyped as «Quality» or «Mode». Feature *characterizes* a bearer type iff every instance of bearer exemplifies the feature.	

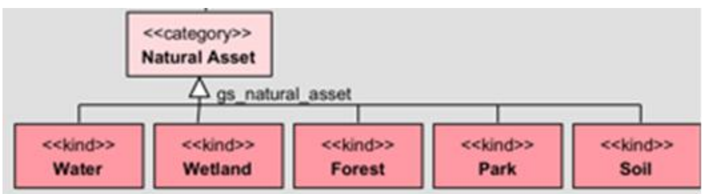
Another important definition in conceptual modeling, is cardinality. Cardinality is a mathematical term that refers to the number of elements in a set. In a model, cardinality defines how many instances of one entity are related to instances of another entity. It is possible to set a minimum and maximum cardinality in an association for each entity associated with.

Cardinalities	Description	Example
0	Zero instances of an entity related to an instance of another entity	 One or more populations suffer one or more impacts. One or more impact lead to none or many impacts.

1	One instance of an entity related to an instance of another entity	
N or *	Many instances of an entity related to an instance of another entity	Minimum 1, maximum many instances of agent associated to a one (and only one) instance of population. In other words, a population is a collective of 1 or many agents and one agent is an element of only one population.

1. Category and Kind

A *Category* is a rigid mix that requires no dependency specification. It is used to aggregate essential properties into individuals that follow different identity principles.



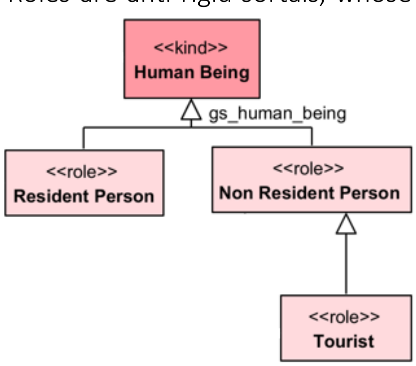
A *Kind* is a rigid concept that provides a principle of identity to its instances and does not require relational dependency to exist. *"An important postulate of UFO is: Every object must instantiate exactly one kind*" (Guizzardi 2005). The figure shows an example of categories of natural assets. This fragment is composed of a category (called *Natural Asset*), five kinds (called *Water, Wetland, Forest, Park,* and *Soil*) and a type of relationship called *generalization* (or *generalization-specialization*) symbolled by a line with arrow on the end. This fragment is read as follows: Natural Asset is a category (supertype) of the kinds Water, Wetland, Forest, Park, and Soil (subtypes). These kinds compose a generalization set called gs_natural_asset. In other words, the supertype *Natural Asset* is specialized in five subtypes: Water, Wetland, Forest, Park, and Soil.

2. Subkind

A *Subkind* is a *rigid sortal* that inherits its principle of identity from an identity provider, such as a *Kind,* a *Subkind*, a *Collective,* a *Category*). Examples, Woman and Man are *subkinds* of Person.

3. Role

Roles are anti-rigid sortals, whose instances are always specializations of a rigid sortal. They differ from Phases (Phase) due to the specialization condition, which in the case of *Roles* refers to a relational (extrinsic) condition of dependency (Relational dependence), that is, relationships in a certain context, mediated by a *Relator* or participants in an *event*. Example: a person plays a *student role* in an *enrollment* relationship in a university and plays a *husband role* in a *marriage* relationship. Another example is a person who plays the role of *resident* in an urban system.



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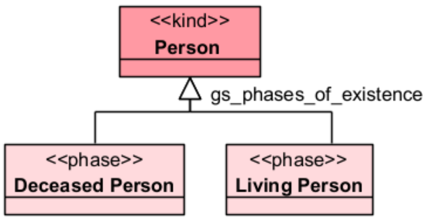
4. Phase

Phases are anti-rigid sortals whose instances are always specializations of a rigid construct. They differ from *Roles* because *Phases* refer to an intrinsic condition, that is, a Phase is a type that an object instantiates in a certain period due to its own intrinsic characteristics: “Phases constitute possible stages in the history of an *Individual*. Examples: (a) Alive and Deceased: as possible stages of a Person; (b) Caterpillar and Butterfly, phases of a Lepidopteran; (c) Town and Metropolis, phases of a city; (d) Boy, Teenager, and Adult as phases of a Person” (Guizzardi 2005).



Appendix D – Methodological Activities

1. **METHODOLOGICAL ACTIVITIES**

1.1 Choosing of Foundational Ontology

Unified Foundational Ontology (UFO)

1.2 Choosing a method for building ontologies

Agile's sprints + adaptation of *SABiO* Approach: Systematic Approach for Building Ontologies[4].

2. **DEVELOPMENT ACTIVITIES**

2.1 Eliciting Requirements Phase

RESULT:

- Document containing the project identification, list of requirements, competency questions, and ontologies identified.
- Package Diagram in UML with the modularization of the sub-ontologies (file. vpp).

- **Project Identification and Purpose**
- **Functional requisites**

Identify the set of functionalities that are related to the knowledge to be represented in an ontology. Functional requisites are those represented by ontology and extracted from the competency questions. The built ontology must answer these questions.

- **Non-functional requisites**

Identify the set of non-functional requisites that are related to quality, theories, business level, mandatory standards, and integration or interoperability.

- **Competency questions**

Identify and individualize with a unique number the competency questions.

- **Identification of sub-ontologies and modularization**

Build package diagrams in UML to identify the existing sub-ontologies, and how they are connected in terms of dependence. Also, from the list of competency questions, distributed into the modules of ontologies.

2.2 Research on domain and elicited requirements

RESULT:

- Technical report (deliverable document) containing the state of art, and theoretical application (in some cases).

2.3 Ontology Modeling and Formalization

Based on eliciting requirements and using a modeling tool, model the version of the ontologies. Rules and restrictions must be defined and formalized using derivation axioms and consolidation axioms. Consolidation axioms are existing restrictions and "exclude unintended interpretations over the structure of the ontology specification"[5]. On the other hand, derivation axioms are rules that "allow new knowledge to be derived from the previously existing knowledge represented in the ontology"[2]. Also, elaborate a dictionary of terms.

RESULT:
- Core ontology (models)
- Formal and informal axioms
- Dictionary of terms (glossary)

2.4 Ontology Design

From the (sprint of) ontologies built in the 2.3 step, identify the set of technical non-functional requisites, define the implementation platform, develop the architectural design (modularization tuning), and elaborate the detailed design for the ontologies.

The definition of an implementation platform is, among others, the choice of an operational ontology language to migrate from the axioms defined in the reference ontologies (ontology-driven conceptual models) to a language to be used by the operational ontology.

RESULT:
- Implementation platform defined.
- Document containing the set of technical non-functional requisites.
- Architectural design
- Ontology design specification

2.5 Ontology Implementation (Development team)

Based on the ontologies built on the last activities, the architectural and the detailed designs, we implement an operational ontology. An operational ontology is an ontology-based on an operational ontology language (e.g. RDF/OWL), which is fine-tuned for a specific business purpose.

RESULT:
- Operational ontology in Web Ontology Language (OWL)

2.6 Ontology Evaluation

To evaluate the ontology developed in each sprint, we will use two approaches:

1. First approach: Manual Reference Ontology Verification: analyze which concepts, relationships, and axioms are necessary (and sufficient) to answer each of the CQs.
2. Second approach: Validation through Instantiation: instantiate the ontologies using real-world data and storylines to assess whether the ontologies are semantically correct. Also, in some cases, use Alloy to instantiate the ontologies.

RESULT:
- Technical report containing the tests (verification and validation) applied to evaluate the ontology built.

3. DEVELOPMENT ACTIVITIES – SPRINT N.1

3.01 Partial eliciting requirements: competency requirements

3.02 Literature review

3.02.01 Systematic literature review
3.02.02 Writing of a deliverable document

3.03 ONTOLOGY - Population

3.03.01 Partial eliciting requirements
3.03.01 Building ontology including the taxonomy of population provided.
3.03.02 Glossary of the built ontology

3.04 ONTOLOGY - Infrastructure

3.04.01 Partial eliciting requirements
3.04.01 Building ontology including the taxonomy of infrastructure provided.
3.04.02 Glossary of the built ontology

3.05 ONTOLOGY – Risk-driven Urban Systems

3.05.01 Partial eliciting requirements
3.05.01 Building ontology including the taxonomy of risk-driven urban systems provided.
3.05.02 Glossary of the built ontology

Appendix E – Taxonomy of Hazards (UNSDR)

In this appendix the individual hazards type according to UNSDR are reported. For each hazard, the page of the related report is also listed.

Hazard Cluster	Specific Hazard	Page Number (UNDR Report)
CBRNE (Chemical, Biological, Radiological, Nuclear and Explosive)	Chemical Warfare Agents	408
CBRNE (Chemical, Biological, Radiological, Nuclear and Explosive)	Biological Agents	450
CBRNE (Chemical, Biological, Radiological, Nuclear and Explosive)	Radiation Agents	654
CBRNE (Chemical, Biological, Radiological, Nuclear and Explosive)	Nuclear Agents	657
CBRNE (Chemical, Biological, Radiological, Nuclear and Explosive)	Explosive agents	791
Construction/ Structural Failure	Building Collapse	659
Construction/ Structural Failure	Building, highrise, cladding	662
Construction/ Structural Failure	Structural Failure	665
Construction/ Structural Failure	Bridge Failure	668
Construction/ Structural Failure	Dam Failure	670
Construction/ Structural Failure	Supply Chain Failure	673
Construction/ Structural Failure	Critical Infrastructure Failure	676
Convective-Related	Downburst	29
Convective-Related	Lightning (Electrical Storm)	31
Convective-Related	Thunderstorm	33
Cyber Hazard	Misconfiguration of Software and Hardware	693
Cyber Hazard	Non-Conformity and Interoperability	695
Cyber Hazard	Malware	698
Cyber Hazard	Data Breach	700
Cyber Hazard	Data Security-Related Hazards	703
Cyber Hazard	Disrupt	705
Cyber Hazard	Outage	707
Cyber Hazard	Personally Identifiable Information (PII) Breach	709
Cyber Hazard	Internet of Things (IOT)-Related Hazards	712
Cyber Hazard	Cyberbullying	715

Environmental Degradation	Household Air Pollution	280
Environmental Degradation	Air Pollution (Point Source)	283
Environmental Degradation	Ambient (Outdoor) Air Pollution	286
Environmental Degradation	Land Degradation	289
Environmental Degradation	Soil Degradation	293
Environmental Degradation	Runoff / Nonpoint Source Pollution	295
Environmental Degradation	Salinity	297
Environmental Degradation	Biodiversity Loss	301
Environmental Degradation	(Forestry) Deforestation	304
Environmental Degradation	Forest Declines and Diebacks	306
Environmental Degradation	Forest Disturbances	309
Environmental Degradation	(Forestry) Forest Invasive Species	312
Environmental Degradation	(Forestry) Wildfires	315
Environmental Degradation	Desertification	318
Environmental Degradation	Loss of Mangroves	321
Environmental Degradation	Wetland Loss/Degradation	326
Environmental Degradation	Coral Bleaching	330
Environmental Degradation	Compressive Soils	332
Environmental Degradation	Soil Erosion	335
Environmental Degradation	Coastal Erosion and Shoreline Change	338
Environmental Degradation	Permafrost Loss	340
Environmental Degradation	Sand Mining	345
Environmental Degradation	Sea Level Rise	348
Environmental Degradation	Eutrophication	352
Extraterrestrial	Airburst	159
Extraterrestrial	Geomagnetic Storm (including energetic particles related to space weather, and solar flare radio blackout [R Scale])	162
Extraterrestrial	UV Radiation	164
Extraterrestrial	Meteorite Impact	167
Extraterrestrial	Ionospheric Storms	169
Extraterrestrial	Radio Blackout	171
Extraterrestrial	Solar Storm (Solar Radiation Storm) (S Scale)	174
Extraterrestrial	Space Hazard / Accident	177
Extraterrestrial	Near-Earth Object	179
Fisheries	and Aquaculture Marine Toxins	423
Fisheries	and Aquaculture Harmful Algal Blooms	427
Flood	Coastal Flood	35

Flood	Estuarine (Coastal) Flood	38
Flood	Flash Flood	40
Flood	Fluvial (Riverine) Flood	43
Flood	Groundwater Flood	45
Flood	Ice-Jam Flood Including Debris	47
Flood	Ponding (Drainage) Flood	49
Flood	Snowmelt Flood	5
Flood	Surface Water Flooding	53
Flood	Glacial Lake Outburst Flood	55
Flood	Drain and Sewer Flooding	772
Flood	Reservoir Flooding	775
Food	Safety Levels of Contaminants in Food and Feed	372
Food	Safety Antimicrobial Resistance	455
Food	Safety Foodborne Microbial Hazards (including human enteric virus and foodborne parasite)	459
Gases	Ammonia	355
Gases	Carbon Monoxide	358
Gases	Phosphine	398
Gases	Chlorine	400
Heavy	Metals Arsenic	360
Heavy	Metals Cadmium	363
Heavy	Metals Lead	366
Heavy	Metals Mercury	369
Human-Animal Interaction	Snake Envenomation	444
Human-Animal Interaction	Human-Wildlife Conflict	447
Hydrocarbons	Oil Pollution	402
Hydrocarbons	Benzene	405
Industrial Failure	Natech	717
Industrial Failure	Pollution	719
Industrial Failure	Explosion	723
Industrial Failure	Leaks and Spills	727
Industrial Failure	Soil Pollution	731
Industrial Failure	Fire	734
Industrial Failure	Mining Hazards	738
Industrial Failure	Safety Hazards Associated with Oil and Gas Extraction Activities	741
Infectious Disease (Aquaculture)	Shrimp disease (bacterial) - Acute Hepatic pancreatic necrosis	643

Infectious Diseases (Animal)	African Swine Fever (Animal)	598
Infectious Diseases (Animal)	Classical Swine Fever (Animal)	606
Infectious Diseases (Animal)	Rinderpest (Animal)	637
Infectious Diseases (Aquaculture)	Oyster Disease Aquaculture	645
Infectious Diseases (Human and Animal)	Anthrax	472
Infectious Diseases (Human and Animal)	Airborne Diseases	474
Infectious Diseases (Human and Animal)	Blood Borne Viruses	476
Infectious Diseases (Human and Animal)	Waterborne Diseases	479
Infectious Diseases (Human and Animal)	Foodborne Diseases	481
Infectious Diseases (Human and Animal)	Sexually Transmitted Diseases (Human)	483
Infectious Diseases (Human and Animal)	Neglected Tropical Diseases (Human)	485
Infectious Diseases (Human and Animal)	Vaccine-Preventable Diseases (Human)	487
Infectious Diseases (Human and Animal)	Vector Borne Diseases (VBD) (Human)	490
Infectious Diseases (Human and Animal)	Viral Hemorrhagic Fevers (Human)	494
Infectious Diseases (Human and Animal)	Antimicrobial Resistant Microorganisms (Human)	497
Infectious Diseases (Human and Animal)	Animal Diseases (Not Zoonoses)	500
Infectious Diseases (Human and Animal)	Zoonotic Diseases	502
Infectious Diseases (Human and Animal)	Diarrhoeal Diseases (Human)	504
Infectious Diseases (Human and Animal)	Prion Diseases	506
Infectious Diseases (Human and Animal)	Hepatitis B (Human)	508
Infectious Diseases (Human and Animal)	Hepatitis C (human)	510
Infectious Diseases (Human and Animal)	HIV and AIDS (Human)	512
Infectious Diseases (Human and Animal)	COVID-19 (SARS-CoV-2) (Human)	514
Infectious Diseases (Human and	Cholera (Human)	516

Animal)		
Infectious Diseases (Human and Animal)	Cryptosporidium (Human)	519
Infectious Diseases (Human and Animal)	Paratyphoid fever (Human)	521
Infectious Diseases (Human and Animal)	Typhoid Fever (Human)	523
Infectious Diseases (Human and Animal)	Hepatitis A (Human)	525
Infectious Diseases (Human and Animal)	Escherichia Coli (STEC) (Human)	527
Infectious Diseases (Human and Animal)	Listeriosis (Human)	530
Infectious Diseases (Human and Animal)	Shigellosis (Human)	532
Infectious Diseases (Human and Animal)	Avian Influenza (Human and Animal)	534
Infectious Diseases (Human and Animal)	Pandemic Influenza (Human)	537
Infectious Diseases (Human and Animal)	Seasonal Influenza (Human)	539
Infectious Diseases (Human and Animal)	Cysticercosis	541
Infectious Diseases (Human and Animal)	Leptospirosis (Human)	543
Infectious Diseases (Human and Animal)	Plague (Human)	546
Infectious Diseases (Human and Animal)	Leprosy	548
Infectious Diseases (Human and Animal)	Chikungunya	550
Infectious Diseases (Human and Animal)	Zika Virus (human)	552
Infectious Diseases (Human and Animal)	Diphtheria (Human)	554
Infectious Diseases (Human and Animal)	Measles (Human)	556
Infectious Diseases (Human and Animal)	Meningococcal Meningitis (Human)	558
Infectious Diseases (Human and Animal)	Pertussis (Human)	561
Infectious Diseases (Human and Animal)	Polio (Human)	563
Infectious Diseases (Human and	Smallpox (Human)	565

Animal)		
Infectious Diseases (Human and Animal)	Varicella and herpes zoster (Human)	567
Infectious Diseases (Human and Animal)	Yellow Fever (Human)	569
Infectious Diseases (Human and Animal)	Dengue (Human)	571
Infectious Diseases (Human and Animal)	Malaria (Human)	573
Infectious Diseases (Human and Animal)	Crimean-Congo Hemorrhagic Fever (Human)	576
Infectious Diseases (Human and Animal)	Ebola (Human)	578
Infectious Diseases (Human and Animal)	Lassa Fever (Human)	581
Infectious Diseases (Human and Animal)	Tuberculosis (Human and Animal)	584
Infectious Diseases (Human and Animal)	Middle East Respiratory Syndrome (MERS) (Human)	587
Infectious Diseases (Human and Animal)	Monkeypox (Human)	589
Infectious Diseases (Human and Animal)	Rabies (Animal and Human)	591
Infectious Diseases (Human and Animal)	Severe Acute Respiratory Syndrome (SARS) (Human)	594
Infectious Diseases (Human and Animal)	Rotavirus (Human)	596
Infectious Diseases (Human and Animal)	Vector-borne diseases (VBD) (Animals)	601
Infectious Diseases (Human and Animal)	Brucellosis (Animal)	603
Infectious Diseases (Human and Animal)	Contagious Bovine Pleuropneumonia (CBPP) (Animal)	609
Infectious Diseases (Human and Animal)	Contagious Caprine Pleuropneumonia (CCPP) (Animal)	612
Infectious Diseases (Human and Animal)	Foot and Mouth Disease Virus (Animal)	614
Infectious Diseases (Human and Animal)	Lumpy Skin Disease (Animal)	617
Infectious Diseases (Human and Animal)	New World Screwworm (NWS) (Animal)	619
Infectious Diseases (Human and Animal)	Newcastle Disease Virus (Animal)	622
Infectious Diseases (Human and	Peste Des Petits Ruminants (Animal)	624

Animal)		
Infectious Diseases (Human and Animal)	Q Fever	627
Infectious Diseases (Human and Animal)	Rift Valley Fever (Animal)	629
Infectious Diseases (Human and Animal)	Trypanosomiasis (Animal)	632
Infectious Diseases (Human and Animal)	West Nile Fever (Human)	634
Infectious Diseases (Human and Animal)	Trypanosomiasis (Human)	640
Infectious Diseases (Plant)	Bacterial Plant Disease	463
Infectious Diseases (Plant)	Fungal Plant Disease	466
Infectious Diseases (Plant)	Viral, Mycoplasma and Viroid Plant Disease Epidemics	469
Infrastructure Failure	Nuclear Plant Failure	679
Infrastructure Failure	Power Outage/ or Blackout	682
Infrastructure Failure	Emergency Telecommunications Failure	685
Infrastructure Failure	Water Supply Failure	687
Infrastructure Failure	Radio and Other Telecommunication Failures	690
Insect Infestation	Insect Pest Infestations	430
Insect Infestation	Locust	433
Invasive Species	Invasive Weeds	436
Invasive Species	Invasive Species	440
Lithometeors	Black Carbon (Brown Clouds)	57
Lithometeors	Dust storm or Sandstorm	60
Lithometeors	Fog	62
Lithometeors	Haze	64
Lithometeors	Polluted Air	66
Lithometeors	Sand haze	69
Lithometeors	Smoke	71
Marine	Ocean Acidification	73
Marine	Rogue Wave	75
Marine	Sea Water Intrusion	76
Marine	Sea Ice (Ice Bergs)	78
Marine	Ice Flow	80
Marine	Seiche	82
Marine	Storm Surge	84
Marine	Storm Tides	86

Marine	Tsunami	88
Marine	Marine Debris	757
Mental	Health Suicide Cluster	452
Other	Chemical Hazards and Toxins Asbestos	410
Other	Chemical Hazards and Toxins Aflatoxins	412
Other	Chemical Hazards and Toxins Fluoride - Excess or inadequate intake	414
Other	Chemical Hazards and Toxins Methanol	417
Other	Chemical Hazards and Toxins Substandard and Falsified Medical Products	420
Other Geohazard	Ground Shaking (induced earthquake, reservoir fill, dams, cavity collapse, underground explosion, impact, hydrocarbon fields, shale exploration, etc.)	240
Other Geohazard	Liquefaction (Groundwater Trigger)	243
Other Geohazard	Ground Fissuring	245
Other Geohazard	Subsidence and Uplift Including Shoreline Change	247
Other Geohazard	Shrink-Swell Subsidence	250
Other Geohazard	Sinkhole	252
Other Geohazard	Ground Gases (CH4, Rn, etc.)	255
Other Geohazard	Riverbank Erosion	258
Other Geohazard	Sand Encroachment	260
Other Geohazard	Aquifer Recharge (Systems Failure/ Outages)	262
Other Geohazard	Submarine Landslide	265
Other Geohazard	Rockfall	268
Other Geohazard	Landscape Creep	270
Other Geohazard	Sediment Rock Avalanche	272
Other Geohazard	Tsunami (Submarine Landslide Trigger)	274
Persistent	Organic Pollutants (POPs) Hazardous Pesticide Contamination in Soils	381
Persistent	Organic Pollutants (POPs) Dioxins and Dioxin-like Substances	393
Persistent	Organic Pollutants (POPs) Microplastics	395
Pesticides	Pesticides – Highly Hazardous	376
Pesticides	Residue of Pesticides	379
Pesticides	Insecticides	385
Pesticides	Fungicides	389
Precipitation-Related	Acid Rain	98
Precipitation-Related	Blizzard	100

Precipitation-Related	Drought	102
Precipitation-Related	Hail	106
Precipitation-Related	Ice Storm	108
Precipitation-Related	Snow	110
Precipitation-Related	Snow Storm	112
Pressure-Related	Depression or Cyclone (Low Pressure Area)	92
Pressure-Related	Extra-tropical Cyclone	94
Pressure-Related	Sub-Tropical Cyclone	96
Radiation	Radioactive Waste	649
Radiation	Radioactive Material	651
Seismogenic (Earthquakes)	Earthquake	182
Seismogenic (Earthquakes)	Ground Shaking (Earthquake)	184
Seismogenic (Earthquakes)	Liquefaction (Earthquake Trigger)	187
Seismogenic (Earthquakes)	Earthquake Surface Rupture, Fissures, and Tectonic Uplift/Subsidence	189
Seismogenic (Earthquakes)	Subsidence and Uplift, Including Shoreline Change (Earthquake Trigger)	191
Seismogenic (Earthquakes)	Tsunami (Earthquake Trigger)	193
Seismogenic (Earthquakes)	Landslide or Debris Flow (Earthquake Trigger)	197
Seismogenic (Earthquakes)	Ground Gases (Seismogenic)	200
Temperature-Related	Cold Wave	114
Temperature-Related	Dzud	116
Temperature-Related	Freeze	118
Temperature-Related	Frost (Hoar Frost)	120
Temperature-Related	Freezing Rain (Supercooled Rain)	122
Temperature-Related	Glaze	124
Temperature-Related	Ground Frost	126
Temperature-related	Heatwave	128
Temperature-Related	Icing (Including Ice)	131
Temperature-Related	Thaw	133
Terrestrial	Avalanche	135
Terrestrial	Mud Flow	137
Terrestrial	Rock slide	139
Transportation	Air Transportation Accident	777
Transportation	Inland Water Ways	779
Transportation	Marine Accident	781
Transportation	Rail Accident	784
Transportation	Road Traffic Accident	787

Volcanogenic	Subsidence and Uplift, Including Shoreline Change (Magmatic/Volcanic Trigger)	237
Volcanogenic (volcanoes and geothermal)	Lava Flows (Lava Domes)	203
Volcanogenic (Volcanoes and Geothermal)	Ash/Tephra Fall (Physical and Chemical)	207
Volcanogenic (Volcanoes and Geothermal)	Ballistics (Volcanic)	210
Volcanogenic (Volcanoes and Geothermal)	Pyroclastic Density Current	213
Volcanogenic (Volcanoes and Geothermal)	Debris Flow/Lahars/Floods	216
Volcanogenic (Volcanoes and Geothermal)	Landslide (Volcanic Trigger)	218
Volcanogenic (Volcanoes and Geothermal)	Ground Shaking (Volcanic Earthquake)	221
Volcanogenic (Volcanoes and Geothermal)	Volcanic Gases and Aerosols	223
Volcanogenic (Volcanoes and Geothermal)	Tsunami (Volcanic Trigger)	226
Volcanogenic (Volcanoes and Geothermal)	Lightning (Volcanic Trigger)	230
Volcanogenic (Volcanoes and Geothermal)	Urban Fire (During/Following Volcanic Eruption)	233
Waste	Disaster Waste	745
Waste	Solid Waste	747
Waste	Wastewater	749
Waste	Hazardous Waste	751
Waste	Plastic Waste	753
Waste	Electronic Waste (E-Waste)	759
Waste	Healthcare Risk Waste	762
Waste	Landfilling	764
Waste	Tailings	767
Waste	Waste Treatment Lagoons	770
Wind-Related	Derecho	141
Wind-Related	Gale (Strong Gale)	143
Wind-Related	Squall	145
Wind-Related	Subtropical Storm	147
Wind-Related	Tropical Cyclone (Cyclonic Wind, Rain [Storm] Surge)	149
Wind-Related	Tropical Storm	152

Wind-Related	Tornado	154
Wind-Related	Wind	156

Appendix F – Taxonomy Return for Buildings

Attribute group	#	Attribute	Sub-attribute - Level 1	Sub-attribute - Level 2	HAZARD							
					Seismic	Flood	Landslide	Fire	Wind	Pollution	Heat wave	
Occupancy	1	Occupancy	original occupancy									
			occupancy of the ground floor									
			number of occupants	daily/nightly use								
				seasonal use								
			Cultural heritage asset	artistic assets								
Building features	2	Age of construction	retrofit age	retrofit level								
			maintenance									
			Decay of materials / existing damage	affected components								
				damage cause								
	3	Number of stories	height of structure (m)									
			number of stories below ground									
	4	Average plan surface										
Vertical structural system	5	Material type	material technology	material properties								
	6	Gravity load system	material GLS									
	7	Lateral load resisting system	direction									
			material LLS	Infills material								
			ductility/quality									

			details									
			column-wall density									
			seismic code level	lateral load coefficient								
	8	**Partitions walls**	connection efficiency									
Building configuration and regularity	**9**	**Building position in the block**	aggregate shape									
	10	**Plan regularity**	plan shape	plan ratio								
			specific vulnerability factors									
	11	**Elevation regularity**	specific vulnerability factors									
Building horizontal diaphragms	**12**	**Floor system material**	floor type	floor connection								
	13	**Ceilings**	connection efficiency									
	14	**Roof shape**	roof covering material									
			roof system material									
			roof connections									
			thermal / acoustic insulation, water protection, covering positions									
			standing-out elements	slenderness, size and								

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				material								
Hydrological aspects	**15**	**Ground floor hydrodynamics**	height of ground floor above ground									
			protection measures									
Foundation and soil conditions	**16**	**Foundation system**	geotechnical conditions									
	17	**Soil class**										
	18	**Topography of the area**										
Fire building performance	**19**	**Fire safety**	safety measure type	performance fire level								
				design								
Building envelope	**20**	**Exterior walls**	thermal / acoustic insulation and position									
			decorations and moldings									
			finishings									
	21	**Openings / Windows**	windows protection									
Building exterior technical elements	**22**	**Cornice construction technique**	intrados shape	finishing								
			extrados inclination	finishing								
			face height	finishing								
			parapet height and thickness	material and type								
			shape factor									
	23	**Balcony construction technique**	intrados shape	finishing								
			extrados inclination	finishing								
			face height	finishing								

			parapet height and thickness	material and type								
			shape factor									
	24	**Household drain system material**	anchoring	material								
			junction	material								
			position									
			shape factor									

Table 1: Occupancy

Group (a): Occupancy

	ID	Attribute 1		ID	Level 1 (L1)		ID	Level 2 (L2)	
macro-classification		**Building occupancy class**	**Definition**		**4 Sub-attributes**			**3 Sub-attributes**	
	--	occupancy unknown							
Residential	RES	Residential, unknown type			**1.1 Original occupancy**	**Definition**			
	RES1	Single dwelling	This includes various dwelling sizes, from a small home to a castle	--	original occupancy unknown				
	RES2	Multi-unit, unknown type		OO=	same as at present				
	RES2A	2 Units (duplex)		(ID)	occupancy class (use the ID in column B)	if different			
	RES2B	3-4 Units							
	RES2C	5-9 Units			**1.2 Occupancy of the ground floor**	**Definition**			
	RES2D	10-19 Units		--	ground floor occupancy unknown				
	RES2E	20-49 Units		GO=	same as the other storeys				
	RES2F	50+ Units		(ID)	occupancy class (use the ID in column B)	if MIX or hybrid			
	RES3	Temporary lodging							
	RES4	Institutional housing			**1.3 Number of occupants**	**Definition**		**1.3.1 Daily/nightly use**	**Definition**
	RES5	Mobile home		--	number of occupants unknown		--	D/N use unknown	

Commercial and public	COM	Commercial and public, unknown type	
	COM1	Retail trade	
	COM2	Wholesale trade and storage (warehouse)	
	COM3	Offices, professional/technical services	
	COM4	Hospital/medical clinic	
	COM5	Entertainment	Restaurants, bars, cafes
	COM6	Public building	
	COM7	Covered parking garage	
	COM8	Bus station	
	COM9	Railway station	
	COM10	Airport	
	COM11	Recreation and leisure	Smaller sport facilities, leisure centres
Mixed use	MIX	Mixed, unknown type	
	MIX1	Mostly residential and commercial	
	MIX2	Mostly commercial and residential	
	MIX3	Mostly commercial and industrial	
	MIX4	Mostly residential and industrial	
	MIX5	Mostly industrial and	

OC:#	number of occupants	average number along the year

D:#	Daily presence (in percentage)	
N:#	Nightly presence (in percentage)	

	1.3.2 Seasonal use	Definition
--	seasonal use unknown	
HO:#	Holiday presence (in percentage)	may be greater than 100%, being referred to the average
WE:#	Week end presence (in percentage)	

	1.4 Cultural heritage asset	
--	unknown	
CHNO	no CH	
WHS	Unesco World Heritage Site	if different or MIX
CHN	Listed at national level	
CHL	Cultural relevance (local)	

	1.4.1 Artistic assets	Definition
--	unknown	
IAA	Immovable AA (frescoes, stuccoes, ...)	
MAA	Movable AA (paintings, statues, ...)	
AAN	No artistic assets	

		commercial	
	MIX6	Mostly industrial and residential	
Industrial	IND	Industrial, unknown type	
	IND1	Heavy industrial	
	IND2	Light industrial	
Agriculture	AGR	Agriculture, unknown type	
	AGR1	Produce storage	It includes grain storage, and also hay, silage, fruit, vegetables, etc.
	AGR2	Animal shelter	Example: shelter for cows during the winter, but it may not necessarily have to do with the rearing.
	AGR3	Agricultural processing	This includes abatoirs
Assembly	ASS	Assembly, unknown type	
	ASS1	Religious gathering	
	ASS2	Arena	
	ASS3	Cinema or concert hall	
	ASS4	Other gatherings	Clubs, societies, political parties, function

			centres, etc.
Government	GOV	Government, unknown type	
	GOV1	Government, general services	
	GOV2	Government, emergency response	
Education	EDU	Education, unknown type	
	EDU1	Pre-school facility	
	EDU2	School	
	EDU3	College/university, offices and/or classrooms	
	EDU4	College/university, research facilities and/or labs	
Other occupancy type	OCO	Other occupancy type	

Table 2: Age of Construction

Group (b): Building features

ID	**Attribute 2**		**ID**	**Level 1 (L1)**		**ID**	**Level 2 (L2)**	
	Age of construction	**Definition**		**3 sub-attributes**			**3 Sub-attributes**	
--	Year unknown							
Y	Y:n, Exact date of construction			**2.1 Retrofit age**	**Definition**		**2.1.1 Retrofitting level**	**Definition**
YBET	YBET:a-b, date of construction upper/lower bound		--	retrofit unknown		--	retrofitting level unknown	
YAPP	YAPP:n, Approximate date of construction		NOR	No retrofit		LO	Local strengthening interventions	
			YPRE	YPRE: n, Latest possible date of retrofit		ST	Global strengthening interventions	
						RE	Global retrofitting interventions	

	2.2 Maintenance	**Definition**
--	Maintenance unknown	
MP	Poor overall physical condition/maintenance	
MM	Moderate overall physical condition/maintenance	
MG	Good overall physical condition/maintenance	

	2.3 Decay of materials / existing damage	**Definition**		**2.3.1 Affected components**	**Definition**
--	Decay/damage unknown		--	unknown	
DD	Decay and damage		VE	Vertical structural elements	
DE	Decay of materials		HO	Horizontal diaphragms	

DA	Existing damage	
NODD	Nor decay either damage	

RO	Roof	
PW	Partition walls	
CE	Ceilings	
TC	Technical components	Plaster, cornices, …

	2.3.2 Damage cause	Definition
--	unknown	
SE	Soil settlements	
EQ	Earthquake	
ER	Erosion due to wind and weathering	
MO	Moisture (rising humidity, flood)	
PO	Pollution	
FI	Fire	

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Table 3: Number of stories **Group (b):** Building features

ID	Attribute 3		ID	Level 1 (L1)	
	Number of stories	**Definition**		**2 sub-attributes**	
--	Number of stories unknown				
H	H:n, exact number of stories above ground			**3.1 Height of structure (m)**	**Definition**
HLR	Low rise	1-2 stories	--	Height unknown	
HMR	Mid rise	3-5 stories	HHT	HHT:n, total height of the structure, measured from the ground floor. Float specifying the height of the structures in meters. (HHT>= 1)	
HHR	High rise	>5 stories	HHI	HHI:n, inter-storey height (average). Float specifying the average floor height in meters. (HHI>= 1)	
			HHI	HHI:n, inter-storey height (average). Float specifying the average floor height in meters. (HHI>= 1)	
				3.2 Number of stories below ground	**Definition**
			--	Number of stories below ground unknown	
			HBEX	HB:n, exact number of stories below ground (same as number of basements)	
			HBAPP	HBAPP:n, approximate number of stories below ground	

Table 4: Average plan surface **Group (b):** Building features

ID	Attribute 4	
	Average plan surface	**Definition**
--	Plan surface unknown	
A	A:n, exact plan surface (in square meters)	
ABET	ABET:a-b, Upper and lower bound for the plan surface	
AAPP	AAPP:n, Approximate plan surface	
AEDES	AEDES:id, classification AeDES form, from A to R	A(<50m2), B(50-70), C(70-100), D(100-130), E(130-170), F(170-230), G(230-300), H(300-400), I(400-500), L(500-650), M(650-900), N(900-1200), O(1200-1600), P(1600-2200), Q(2200-3000), R(>3000m2)

Table 5: Material of the Structural System **Group (c):** Vertical structural system

ID	Attribute 5		ID	Level 1 (L1)		ID	Level 1.1 (L1.1)	
	Material type	**Definition**		**1 sub-attribute**			**1 sub-attribute**	
--	Unknown material							
				5.1 Material technology	**Definition**		**5.2 Material properties**	**Definition**
C	Concrete, unknown reinforcement		--	Unknown concrete technology		--	Unknown concrete class	
CU	Concrete, unreinforced *		CIP	Cast-in-place concrete		CFCK	Concrete compressive strength (Mpa)	
CR	Concrete, reinforced		PC	Precast concrete				
SRC	Concrete, composite with steel section		CIPPS	Cast-in-place prestressed concrete				
			PCPS	Precast prestressed concrete				
S	Steel		--	Steel, unknown		--	Steel connections, unknown	
			SL	Cold-formed steel members		WEL	Welded connections	
			SR	Hot-rolled steel members		RIV	Riveted connections	
			SO	Steel, other		BOL	Bolted connections	
ME	Metal (except steel)		--	Metal, unknown				
			MEIR	Iron				
			MEO	Metal, other				
M	Masonry, unknown reinforcement		--	Masonry unit, unknown		--	Mortar type unknown	
MUR	Masonry, unreinforced		ADO	Adobe blocks		MON	No mortar	
MCF	Masonry, confined		ST	Stone, unknown technology		MOM	Mud mortar	
MR	Masonry, reinforced		STRUB	Rubble (field stone) or semi-dressed stone		MOL	Lime mortar	

			STDRE	Dressed stone		MOC	Cement mortar	
			CL	Fired clay unit, unknown type		MOCL	Cement:lime mortar	
			CLBRS	Fired clay solid bricks		--	Stone, unknown type	
			CLBRH	Fired clay hollow bricks		SPLI	Limestone	
			CLBLH	Fired clay hollow blocks or tiles		SPSA	Sandstone	
			CB	Concrete blocks, unknown type		SPTU	Tuff	
			CBS	Concrete blocks, solid		SPSL	Slate	
			CBH	Concrete blocks, hollow		SPGR	Granite	
			MO	Masonry unit, other		SPBA	Basalt	
						SPO	Stone, other type	
				Only for Masonry, reinforced (MR)				
			--	Masonry reinforcement unknown				
			RS	Steel-reinforced				
			RW	Wood-reinforced				
			RB	Bamboo-, cane- or rope-reinforced				
			RCM	Fibre reinforcing mesh				
			RCB	Reinforced concrete bands				
E	Earth, unknown reinforcement		--	Unknown earth technology				
EU	Earth, unreinforced		ETR	Rammed earth				
ER	Earth, reinforced		ETC	Cob or wet construction				
			ETO	Earth technology, other				
W	Wood		--	Wood, unknown				
			WHE	Heavy wood				
			WLI	Light wood members				
			WS	Solid wood				
			WWD	Wattle and daub				

			WBB	Bamboo			
			WO	Wood, other			
HYB	Hybrid or composite (mixed) materials		HYB(material_a-material_b), two main materials of the LLRS from the following material list:				
			CR	Concrete, reinforced			
			CU	Concrete, unreinforced			
			S	Steel			
			M	Masonry, unknown reinforcement			
			MUR	Masonry, unreinforced			
			MCF	Masonry, confined			
			MR	Masonry, reinforced			
			MUR-ST	Stone masonry, unreinforced			
			ER	Earth, reinforced			
			EU	Earth, unreinforced (or mud)			
			W	Wood			
INF	Informal materials						
MATO	Other material						

Comment:

* For level 1, only CIP or PC options available

** In case of MR add information on reinforcement

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Table 6: Gravity Load System

Group (c): Vertical structural system

ID	Attribute 6		ID	Level 1 (L1)	
	Type of gravity load system	**Definition**		**1 sub-attribute**	
--	Unknown gravity load system				
GFM	Moment frame			**6.1 Material GLS**	**Definition**
GFINF	Infilled frame		--	structural material unknown	
GFBR	Braced frame		(ID)	structural material (C/S/M/E/W)	use generic code from attribute 5
GPB	Post and beam				
GWAL	Wall				
GWP	Wall with posts inside				
GDUAL	Dual frame-wall system				
GFLS	Flat slab/plate or waffle slab				
GFLSINF	Infilled flat slab/plate or infilled waffle slab				
GO	Other lateral load-resisting system				
GHV **	LHV(sys_a-sys_b), hybrid LLRS in height (a= primary system and secondary system)				
GHP **	LHV(sys_a-sys_b), hybrid LLRS in plan (a= primary system and secondary system)				

** Options for hybrid systems are the same as above

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Table 7: Lateral Load-Resisting System

Group (c): Vertical structural system

ID	**Attribute 7**		**ID**	**Level 1 (L1)**		**ID**	**Level 2 (L2)**	
	Type of lateral load-resisting system	**Definition**		**5 sub-attributes**			**2 sub-attributes**	
--	Unknown lateral load-resisting system							
LN	No lateral load-resisting system			**7.1 Direction**	**Definition**			
LGLS	Same as gravity load system		--	no or unknown distinction for the 2 directions				
LFM	Moment frame		LDIR	Longitudinal direction (street)				
LFINF	Infilled frame		TDIR	Transversal direction (street)				
LFBR	Braced frame							
LPB	Post and beam			**7.2 Material LLS**	**Definition**		**6.1.1 Infills material**	**Definition**
LWAL	Wall		--	structural material unknown		--	Infill material unknown	To be filled only in case att.7 is LFINF
LWP	Wall with posts inside			structural material - use generic code from attribute 5 (C/S/M/E/W)		IM	Unreinforced masonry	
LDUAL	Dual frame-wall system					IM-CL	Unreinforced masonry, fired clay bricks	
LFLS	Flat slab/plate or waffle slab					IM-CLB	Unreinforced masonry, fired clay hollow blocks or tiles	
LFLSINF	Infilled flat slab/plate or infilled waffle slab					IM-AAC	Unreinforced masonry, AAC blocks (aerated autoclaved blocks)	
LO	Other lateral load-resisting system					IM-FAB	Unreinforced masonry, flyash bricks	

LHV **	LHV(sys_a-sys_b), hybrid LLRS in height (a= primary system and secondary system)	
LHP **	LHV(sys_a-sys_b), hybrid LLRS in plan (a= primary system and secondary system)	

** Options for hybrid systems are the same as above

IM-CBH	Unreinforced masonry, hollow concrete blocks	
IM-CBS	Unreinforced masonry, solid concrete blocks	
IM-ST	Unreinforced stone masonry	
IMR	Reinforced masonry	
IMR-CL	Reinforced masonry, clay brick	
IMR-CB	Reinforced masonry, concrete block	

	7.3 System ductility / quality details	**Definition**
--	Ductility unknown	
DNO	Non-ductile	
DUL	Low ductility	
DUM	Moderate ductility	
DUH	High Ductility	
DBD	Equipped with base isolation and/or energy dissipation devices	
NOC	Masonry walls poorly connected	
TR	Presence of tie rods	
RB	Presence of ring beams	

	7.4 Columns-Wall density	Definition
--	columns-wall density unknown	
DCW	DCW:n Percentage specifying the density or ratio between the area of columns and/or walls and the area of the building plan (%)	

	7.5 Seismic code level	Definition
--	Code level unknown	
CDN	No code design	
CDL	Low earthquake resistance design	
CDM	Medium earthquake resistance design	
CDH	High earthquake resistance design	

	7.5.1 Lateral load coefficient	Definition
--	Unknown coefficient	
LFC	LFC:n, n lateral force coefficient in percentage (%)	

Table 8: Partition walls

Group (c): Vertical structural system

ID	Attribute 8		ID	Level 1 (L1)	
	Type of partition walls	**Definition**		**1 sub-attribute**	
--	Unknown type of partition walls				
PB	Brick partition wall			**8.1 Connection efficiency**	**Definition**
PBR	Reinforced brick partition wall		--	connection efficiency unknown	
PHC	Hollow clay brick partition wall		PCP	Poor connection	
PCB	Concrete blocks partition wall		PCGW	Well-connected but weak	
PG	Glass partition wall		PCG	Well connected	
PSB	Straw board partition				
PM	Metal lath partition wall				
PW	Wooden partition wall				

Brick Partitions Wall

Reinforced Brick Wall

Hollow & Clay Brick Partition Wall

Concrete Partitions Wall

Glass Partitions Wall

Straw Board Partitions

Plaster Slab Partition Wall

Metal lath Partition Wall

A.C. sheet or G.I. Sheet Partitions Wall

Wooden Partition Wall

Lumber Partitions

Asbestos Cement Partitions

Double Glazed Window

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Table 9: Building position in the block **Group (d):** Building configuration and regularity

ID	**Attribute 9**		**ID**	**Level 1 (L1)**	
BP	**Building Position in the Block**	**Definition**		**1 sub-attribute**	
--	Building Position unknown				
BPD	Detached building	Not attached to any other building (spaced apart a distance equal to or more than 4% of the height of the lower building)		**9.1 Aggregate shape**	**Definition**
BP1	Head building (adjoining building on one side)	One adjacent building (semi-detached building in North America), e.g., end of a row	--	No information	
BP2	Corner building (adjoining buildings on two consecutive sides)	Corner building with two adjacent buildings (on adjacent sides)	AL	Aggregate in line	
BP3	Intercluded building (adjoining buildings on two opposite sides)	Intercluded building in a row with two adjacent buildings (on opposite sides)	ALS	Aggregate L-shaped	
BP4	Inner building (adjoining buildings on three sides)	More connected configuration	ACS	Aggregate C-shaped	
			AWC	Aggregate with internal court	
			AIRR	Aggregate with irregular shape	

Table 10: Plan regularity

Group (d): Building configuration and regularity

ID	Attribute 10		ID	Level 1 (L1)		ID	Level 2 (L2)	
	Plan regularity	**Definition**		**2 sub-attributes**			**1 sub-attribute**	
--	Unknown plan regularity							
PR	Regular in plan			**10.1 Specific vulnerability**	**Definition**			
PIR	Irregular in plan		--	No information				
			TOR	Torsion eccentricity				
			REC	Re-entrant corner				
			LP	Protuberance in plan				
			EM	Eccentric Mass concentration				
			FD	Flexible diaphragms				
			IRHO	Other horizontal irregularity				
				10.2 Plan shape	**Definition**		**10.2.1 Plan ratio**	**Definition**
			--	Unknown plan shape		--	Unknown plan ratio	
			PLFSQ	Square, solid		PR:#	Plan ratio, float number	
			PLFSQO	Square, with an interior opening (e.g. a "donut")		PBSR:#	Plan building sleeve ratio	Ratio between the length and the width of the slee
			PLFR	Rectangular, solid				
			PLFRO	Rectangular, with an opening				
			PLFL	L-shape				
			PLFA	A-shape				
			PLFB	B-shape				

PLFC	Curved, solid (e.g. circular, elliptical, ovoid)	
PLFCO	Circular, with an opening	
PLFD	Triangular shape, solid	
PLFDO	Triangular shape, with an opening	
PLFE	E-shape	
PLFF	F-shape	
PLFH	H-shape	
PLFS	S-shape	
PLFT	T-shape	
PLFU	U-shape	
PLFX	X-shape	
PLFY	Y-shape	
PLFI	Irregular plan shape	

Table 11: Elevation regularity

Group (d): Building configuration and regularity

ID	Attribute 11	
	Elevation regularity	**Definition**
--	Unknown elevation regularity	
VR	Regular in elevation	
VIR	Irregular in elevation	

ID	Level 1 (L1)	
	1 sub-attribute	
	11.1 Specific vulnerability	**Definition**
--	No information	
SOS	Soft story	
CRW	Cripple wall	
SHC	Short column	
POP	Pounding potential	
SET	Setback	
CHV	Change in vertical structure (includes large overhangs)	
IRVO	Other vertical irregularity	

Table 12: Floor system material **Group (e):** Building horizontal diaphragms

ID	Attribute 12		ID	Level 1 (L1)		ID	Level 2 (L2)	
	Floor system material	**Definition**		**1 sub-attribute**			**1 sub-attribute**	
--	Floor material, unknown							
FN	No elevated or suspended floor material	single-storey building		**12.1 Floor system type**	**Definition**		**12.1.1 Floor connections**	**Definition**
FM	Masonry		--	Masonry, unknown		--	diaphragm connection unknown	
			FM1	Vaulted masonry		FWCN	Floor-wall diaphragm connection not provided	
			FM2	Shallow-arched masonry		FWCP	Floor-wall diaphragm connection effective	
			FM3	Composite cast-in-place reinforced concrete joists and masonry floor system	In case of absence of a continuous RC slab			
FE	Earthen		--	Earthen, unknown				
FC	Concrete		--	Concrete, unknown				
			FC1	Cast-in-place beamless reinforced concrete floor				
			FC2	Cast-in-place beam-supported reinforced concrete floor				
			FC3	Precast concrete floor with reinforced concrete topping				
			FC4	Precast concrete floor without reinforced concrete topping				
			FC5	Composite cast-in-place reinforced concrete joists,	If the continuous			

				slab and masonry floor system	RC slab is present
FME	Metal		--	Metal, unknown	
			FME1	Metal beams, trusses, or joists supporting light flooring	
			FME2	Metal beams supporting precast concrete slabs	
			FME3	Composite steel deck and concrete slab	
			FME4	Steel profiles and small brick vaults	
FW	Wood		--	Wood, unknown	
			FW1	Wooden beams or trusses and joists supporting light flooring	
			FW2	Wooden beams or trusses and joists supporting heavy flooring	
			FW3	Wood-based sheets on joists or beams	
			FW4	Plywood panels or other light-weight panels for floor	
FO	Floor material, other				

Table 13: Ceilings

Group (e): Building horizontal diaphragms

ID	**Attribute 13**		**ID**	**Level 1 (L1)**	
	Type of ceilings	**Definition**		**1 sub-attribute**	
--	Unknown type of ceilings				
CEA	Exposed or tightly attached ceiling			**13.1 Connection efficiency**	**Definition**
CW	Wattle false ceiling		--	connection efficiency unknown	
CG	Gypsum false ceiling		CCP	Poor connection	
CT	Wooden false ceiling		CCGW	Well-connected but weak	e.g., RC floors with brittle hollow bricks
CM	Metal or mineral fibre false ceiling		CCG	Well connected	
CPVC	PVC false ceiling				

Brick Partitions Wall
Reinforced Brick Wall

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Table 14: Roof shape

Group (e): Building horizontal diaphragms

ID	Attribute 11		ID	Level 1 (L1)		ID	Level 2 (L2)	
	Roof shape	**Definition**		**5 sub-attributes**			**1 sub-attribute**	
--	Unknown roof shape							
RSH1	Flat			**14.1 Roof covering material**	**Definition**			
RSH2	Pitched with gable ends		--	Unknown roof covering				
RSH3	Pitched and hipped		RMN	Concrete roof without additional covering				
RSH4	Pitched with dormers		RMT1	Clay or concrete tile				
RSH5	Monopitch		RMT2	Fibre cement or metal tile				
RSH6	Sawtooth		RMT3	Membrane roofing				
RSH7	Curved		RMT4	Slate				
RSH8	Complex regular		RMT5	Stone slab				
RSH9	Complex irregular		RMT6	Metal or asbestos sheets				
RSHO	Roof shape, other		RMT7	Wooden and asphalt shingles				
			RMT8	Vegetative				
			RMT9	Earthen				
			RMT10	Solar panelled roofs				
			RMT11	Tensile membrane or fabric roof				
			RMTO	Roof covering, other				
				14.2 Roof system material	**Definition**			

--	Unknown roof system and material
RM	Masonry, unknown
RM1	Vaulted masonry
RM2	Shallow-arched masonry
RM3	Composite masonry and concrete roof system
RE	Earthen, unknown
RE1	Vaulted earthen roof
RC	Concrete, unknown
RC1	Cast-in-place beamless reinforced concrete roof
RC2	Cast-in-place beam-supported reinforced concrete roof
RC3	Precast concrete roof with reinforced concrete topping
RC4	Precast concrete roof without reinforced concrete topping
RME	Metal or steel, unknown
RME1	Metal or steel beams or trusses supporting light roofing
RME2	Metal or steel beams supporting precast concrete slabs
RME3	Composite steel deck and concrete slab
RWO	Wood, unknown
RWO1	Wooden structurewith light roof covering
RWO2	Wooden beams or trusses with heavy roof covering
RWO3	Wood-based sheets on rafters or purlins
RWO4	Plywood panels or other light-weight panels for roof

RWO5	Bamboo, straw or thatch roof	
RFA	Fabric, unknown	
RFA1	Inflatable or tensile membrane roof	
RFAO	Fabric, other	
RO	Roof material, other	

	14.3 Roof connections	
--	Roof connection unknown	
RWCN	Roof-wall diaphragm connection not provided	
RWCP	Roof-wall diaphragm connection present (the connection transfers in-plane forces from floor to wall and restrains wall outward displacements)	
RTDN	Roof tie-down not provided	
RTDP	Roof tie-down present (a connection that provides vertical attachment of roof to wall in order to restrain roof from upward displacement, lift-off due to wind)	

	14.4 Thermal / acoustic insulation, water protection, coating positions	**Definition**
--	Unknown	the different layers are listed from bottom to top
WICV	water protection + insulation + covering (ventilated)	ventilated roofs are referred to pitched roofs only
WICNV	water protection + insulation + covering (non-ventilated)	non-ventilated roofs are referred to both flat (where ventilated roofs do not exist)

		and pitched roofs
IWCV	insulation + water protection + covering (ventilated)	
IWCNV	insulation + water protection + covering (non-ventilated)	
IW	insulation + water protection (no covering)	
W	water protection only (no covering)	possible only if 14.1 is RMT3
N	no insulation, no water protection, no covering	possible only if 14.1 is RMN
WCV	water protection + covering (ventilated)	
WCNV	water protection + covering (non-ventilated)	
CV	only covering (ventilated)	
CNV	only covering (non-ventilated)	

	14.5 Standing-out elements	**Definition**		**14.5.1 Slenderness, size and material**	**Definition**
--	Unknown		--	Unknown	
SN	No standing-out elements		MSlS	Masonry Slender and small	
SC	Presence of chimneys		MStS	Masonry Stocky but small	
SCO	Presence of chimneys and other soaring elements		MSlB	Masonry Slender but big	
SON	Presence of other soaring elements only		MStB	Masonry Stocky and big	
			CSlS	Concrete Slender and small	
			CStS	Concrete Stocky but small	

CSlB	Concrete Slender but big	
CStB	Concrete Stocky and big	
FCSlS	Fibre-cement Slender and small	
FCStS	Fibre-cement Stocky but small	
FCSlB	Fibre-cement Slender but big	
FCStB	Fibre-cement Stocky and big	
SSlS	Steel Slender and small	
SStS	Steel Stocky but small	
SSlB	Steel Slender but big	
SStB	Steel Stocky and big	
WSlS	Wood Slender and small	
WStS	Wood Stocky but small	
WSlB	Wood Slender but big	
WStB	Wood Stocky and big	

Table 15: Ground floor hydrodynamics

Group (f): Hydrological aspects

ID	Attribute 15	
	Ground floor hydrodynamics	**Definition**
--	Ground floor hydrodynamics unknown	
GFO	Ground floor plan fully open (no walls)	Openings of façades that are potentially exposed to flows
GFH	Ground floor plan partially open (i.e. with at least 50% of walls)	
GFN	Not open	

ID	Level 1 (L1)	
	2 sub-attributes	
	15.1 Height of ground floor above ground (m)	**Definition**
--	Height unknown	
HGF	HGF:n, height of the ground floor in meters	
HGFA	HGFA:n, average height of the ground floor in meters	

	15.2 Protection measures	**Definition**
--	unknown	
PMN	no protection measure	
PMB	Floodboards fixed to doors and windows	

Table 16: Foundation System

Group (g): Foundation and soil conditions

ID	**Attribute 16**		**ID**	**Level 1 (L1)**	
	Foundation System	**Definition**		**1 sub-attribute**	
--	Unknown foundation system				
FOSSL	Shallow foundation, with lateral capacity	Lateral capacity denotes some form of specific lateral support, e.g. tie-beams, foundation walls, inclined piles, piles or piers on wide spread footings, etc.		**16.1 Geotechnical conditions**	**Definition**
FOSN	Shallow foundation, no lateral capacity		--	geotechnical conditions unknown	
FOSDL	Deep foundation, with lateral capacity		FLS	land subject to subsidence	
FOSDN	Deep foundation, no lateral capacity		FLL	land subject to slow landslide	
FOSO	Foundation, other		FLW	land with shallow water table	

Table 17: Soil class

Group (g): Foundation and soil conditions

ID	Attribute 17	
	Soil class	**Definition**
--	Unknown soil class	
SCA	Soil class A	
SCB	Soil class B	
SCC	Soil class C	
SCD	Soil class D	
SCE	Soil class E	
VS30:#	Average Shear wave velocity in the first 30 m	
VSEQ:#	Equivalent Shear wave velocity	

Table 18: Topography of the area

Group (g): Foundation and soil conditions

ID	Attribute 18	
	Topography of the area	**Definition**
--	Slope of the ground unknown	
TD	HD:n, slope of the ground (n=float in degrees).	
T1	Topography class T1 - flat area or average inclination <15°	
T2	Topography class T2 - slope with average inclination >15°	
T3	Topography class T3 - ridge with average inclination between 15° and 30°	
T4	Topography class T4 - ridge with average inclination greater than 30°	

Table 19: Fire protection

Group (h): Fire building performance

ID	Attribute 19		ID	Level 1 (L1)		ID	Level 2 (L2)	
	Fire safety	**Definition**		**1 sub-attribute**			**2 sub-attributes**	
--	Fire safety unknown							
FR/PFP	structural resistance/passive structural fire protections			**19.1 Safety measure type**	**Definition**		**19.1.1 Performance fire level**	**Definition**
AFP	Active fire protection		--	Safety measure unknown		--	Performance fire level unknown	
FC	Compartmentalization		FR	no passive fire protection	applicable to FR/PFP	PLI		
EVAC	Evacuation		FRPB	plaster boards		PLII		
			FRPS	sprays		PLIII		not applicable to EVAC
			FRPIC	intumescent coatings		PLIV		not applicable to AFP/FSH, FC, EVAC
			FC	fire control	applicable to AFP	PLV		not applicable to AFP/FSH, FC, EVAC
			FDA	detection and alarm				
			FSH	smoke and heat			**19.1.2 Design**	**Definition**
			FS	stability	applicable to FC	--	Design unknown	
			TS	thermal sealing		ND	no design	
			TI	thermal insulation		PRED	prescriptive code	
			WS	width of the stairs	applicable to EVAC	PERD	performance based design	
			EVPL	presence of an evacuation plan				

Table 20: Exterior Walls **Group (j):** Building envelope

ID	Attribute 20		ID	Level 1 (L1)	
	Exterior walls	**Definition**		**3 sub-attributes**	
--	Unknown material				
EWSLM	Single-layer masonry	Various type of masonry units (clay bricks, stone, blocks)		**20.1 Thermal / acoustic insulation and position**	**Definition**
EWSLC	Single layer concrete cast-in-place	Cast in-place concrete	--	unknown	
EWSLCP	Single layer concrete panel	Precast concrete panels	NI	No insulation	
EWSLG	Single layer glass	Glass curtain walls, storefront glass systems	PU	Insulation position unknown	Insulation present but position unknown
EWSLW	Single-layer Wood	X-Lam panel or similar	EI	External insulation	
EWSLE	Single-layer Earth	Adobe, cob, rammed earth, bajareque, quincha, sod, banco, etc.	SI	Sandwich insulation	
EWSLCB	Single-layer Cement-based boards	Fibre cement or asbestos boards, e.g., GRC, FRC	II	Internal insulation	
EWMLM	Multi-layer masonry	Various type of masonry units (clay bricks, stone, blocks) separeted in several layers			
EWMLMC	Multi-layer masonry with air cavity	Cavity walls ("muro a cassetta"), eventually with different type of masonry units (clay bricks, stone, blocks)		**20.2 Decoration and moldings**	**Definition**
EWMLCP	Multi-layer concrete panel	Precast concrete panels	--	unknown	
EWMLG	Multi-layer glass	Double skin glass with air cavity in the form of small solar green house	ND	No decoration and moldings	
EWMLV	Vegetative	Matting, palm, thatch, straw, etc.	LD	Large decoration and moldings	More than 15% of the facade surface
EWMLM	Mixed panel	Prefabricated mixed material panels on metal structure	MD	Moderate decoration and moldings	5-15%
EWMLO	Other	-	SD	small decoration and moldings	Less than 5%

	20.3 Finishings	Definition
--	unknown	
BF	Brut finishings	
PF	Plaster finishings	
SBF	Stone board finischings	
VFS	Ventilated facade with stone board	
VFC	Ventilated facade with clay board	
VFM	Ventilated facade with metal sheet	
TF	Tile	
WF	Wood planks, wood shingles	
MS	Metal sheet	
O	Other	

Table 21: Openings / Windows

Group (j): Building envelope

ID	**Attribute 21**		**ID**	**Level 1 (L1)**	
	Openings / Windows	**Description**		**1 sub-attribute**	
--	Openings unknown				
WOL	Large openings (i.e., more than 50% of the wall surface area is occupied by windows and/or doors)			**21.1 Window protection**	**Definition**
WOM	Moderate openings (i.e., from 20% to 50% of the wall surface area is occupied by windows and/or doors)		--	Protection unknown	
WOS	Small openings (i.e., less than 20% of the wall surface area is occupied by windows and/or doors)		PRO	Protected windows	
WON	No openings		PNO	Non protected windows	