

Digitalization and Spatial Documentation of Post-Earthquake Temporary Housing in Central Italy: An Integrated Geomatic Approach Involving UAV and a GIS-Based System

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## Article

# Digitalization and Spatial Documentation of Post-Earthquake Temporary Housing in Central Italy: An Integrated Geomatic Approach Involving UAV and a GIS-Based System

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**Abstract:** Geoinformation and aerial data collection are essential during post-earthquake emergency response. This research focuses on the long-lasting spatial impacts of temporary solutions, which have persisted in regions of Central Italy affected by catastrophic seismic events over the past 25 years, significantly and permanently altering their landscapes. The paper analyses the role of geomatic and photogrammetric tools in documenting the emergency process and projects in post-disaster phases. An Atlas of Temporary Architectures is proposed, which defines a common semantic and geometric codification for mapping temporary housing from territorial to urban and building scales. The paper presents an implementation of attribute specification in existing official cartographic data, including geometric entities in a 3D GIS data model platform for documenting and digitalising these provisional contexts. To achieve this platform, UAV point clouds are integrated with non-metric data to ensure a complete description in a multiscalar approach. Accurate topographic modifications can be captured by extracting very high-resolution orthophotos and elevation models (DSM and DTM). The results have been validated in Visso (Macerata), a small historical mountain village in Central Italy which was heavily damaged by the seismic events of 2016/2017. The integrated approach overcomes the existing gaps and emphasizes the importance of managing heterogeneous geospatial emergency data for classification purposes. It also highlights the need to enhance an interoperable knowledge base method for post-disaster temporary responses. By combining geomatic tools with architectural studies, these visualization techniques can support national and local organizations responsible for post-earthquake management through a 3D modelling method to aid future transformations or interventions following other natural disasters.

**Keywords:** post-earthquake early recovery; temporary housing; GIS; UAV photogrammetry; 3D spatial database; implementation geographical standards; point clouds; Central Italy; emergency response



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## 1. Introduction

Since the late 20th century 1900s, there has been a global increase in natural and anthropogenic unnatural disasters worldwide, leading to recurrent endemic conditions [1–3]. The severity of disasters such as earthquakes threatens the safety and security of vulnerable residents, particularly in terms of housing damage and impact on the landscape [4]. Disaster management consists of four phases: mitigation, preparedness, response, and recovery [5]. Scholars are increasingly interested in post-disaster recovery and temporary housing [2,6–8], with a focus on developing sustainable solutions [9–11], examining socio-economic impacts [12,13], improving decision-making methods [14–16], and broadening

knowledge of components and processes [14,17]. Many studies highlight the importance of analytical and numerical methods in facilitating specific actions for assessing damage and ensuring safety (e.g., AEDES sheets) [18,19]. However, the majority of research that proposes multiscale and interdisciplinary approaches during emergency phases focuses on historical centres and the vulnerabilities of masonry building aggregates, adopting integrated methodologies for data acquisition and information management. Meanwhile, there is a lack of adequate spatial documentation and architectural design of temporary housing [2,20]. Emergency conditions require quick decision-making and collaboration between private and public entities [21], resulting in new settlement patterns and geographical configurations. Temporary housing involves four distinct stages [9,22,23]: emergency shelter, temporary shelter, temporary housing, and permanent housing [9,23–25]. Two main temporal phases can be distinguished in the Italian context, excluding the reconstruction phase. The first emergency phase includes relief through the use of mobile structures (tent camps, shelters, or housing containers), followed by a second phase, corresponding to the early recovery, of medium-term prefabricated structures where the survivors can reside temporarily for some years. Considering the physical and temporal long-term permanence of the second period, this research investigates the architectural solutions and their spatial effects for monitoring changes in urban areas. The narrative on their landscaping impact is often overlooked [26], although buildings and recognisable infrastructural basements persist longer than planned in a state of use (at least 10/15 years), underuse, or abandonment for decades in Italian territories [27,28]. This unsatisfactory condition is underestimated to the point that even official cartographic studies have so far omitted to describe the transformative consequences of the phenomenon.

#### *Post-Emergency Temporariness in the Italian Context*

Over the last 70 years, Italy has been struck by numerous natural disasters, including earthquakes, landslides, and floods, resulting in significant damages. The history of seismic events in Italy [26,29] reveals that since the country's unification in 1861, it has experienced 36 devastating earthquakes, on average one every 4–5 years. Following the earthquakes in Irpinia in 1982, the government established the Dipartimento di Protezione Civile Nazionale (DPCN), tasked with coordinating and managing all emergencies in Italy and abroad in collaboration with other special regional entities such as the Commissario Straordinario per la Ricostruzione, Ufficio Speciale Ricostruzione (USR), and the Casa Italia Department, as well as local institutions. Emergency projects have been executed through extraordinary measures and procedures, deviating from existing plans and urban regulations [21,30]. As a result, various temporary settlements are dispersed throughout the Italian territory, often leading to new irreversible configurations [26], remaining in a state of use, abandonment, or leaving infrastructural footprints for decades [27,31,32].

Thanks to the collaborative efforts of several Italian public institutions, including the Istituto Nazionale di Statistica (ISTAT), Istituto Nazionale di Geofisica e Vulcanologia (INGV), Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), and DPCN, there are various interactive catalogues available that document the risks of natural disasters in Italian municipalities [33–35], as well as the historical and geographical characteristics of seismic-prone areas [36]. In terms of emergency response, only DPCN, USR, and regional official portals document temporary solutions through interactive GIS platforms [37], gathering regulatory and design information. However, there are still gaps and obstacles that hinder the effective use of data for emergency planning and monitoring the post-disaster state of use, which this research aims to address.

#### 1. Lack of updating of public cartography databases.

Many regions in Italy, especially in sprawling urbanized, remote, and mountainous contexts, have outdated cartography that does not comply with current European standards. As a result, these territories lack adequate cartography representing pre- and during-disaster states, and subsequent spatial modifications, like long-lasting temporary housing, are not documented. This research proposes adding attributes for selected features related

to the typology, category of use, and condition of use of the temporary buildings, within existing data specification structures.

2. Lack of temporary data availability from a systemic perspective.

Temporary cities created during disasters require emergency services beyond housing settlements, such as administrative, commercial, agricultural, educational, and social-health facilities, as well as recreational centres. Unfortunately, these facilities are often not mapped or not easily identifiable on regional or municipal maps from a comprehensive perspective. This research argues that incorporating detailed information into a unified GIS system could improve urban mapping precision, providing better documentation for planning, managing, and monitoring these temporary settlements.

3. Lack of integration and interoperability procedures.

Current emergency solutions and documentation are stored in diverse and unorganised databases managed by the DPCN or specific regional organisations, leading to fragmented data and limited integration with other emergency services and platforms. This study maintains that each regional or municipal technical office should archive files and projects with the same coding to ensure a systemic and interoperable view. Additionally, photogrammetric flights can be used to document the modification of territories and construct a GIS map linked to other specific emergency structures at the national level.

4. Lack of adequate or detailed representation scale information.

Open Data reconstruction and other open-source GIS platforms often only geolocalize temporary architectures in point format without accurately representing the perimeter or building footprint. This research recommends that to improve the representation of the built environment, each municipal technical office, particularly in small historical villages, should create GIS maps compliant with the national map.

5. Lack of three-dimensional representation.

Current GIS maps for emergency response only offer a 2D representation and fail to capture the actual orographic changes. Digital Surface Models (DSMs) and Digital Terrain Models (DTMs) can be extracted using geomatic survey tools to gain more accurate knowledge of the modifications. This study shows that this would provide a comprehensive overview of the built environment, including the volume of structures and infrastructure.

The proposed solutions aim to overcome the limitations of outdated cartography, unorganized temporary data, and 3D representations by providing a more accurate semantic and geometric codification of territories affected by disaster events. This research proposes a structured “Atlas of Temporary Architectures” for post-disaster response, employing a multiscale approach that can provide different levels of detail, to support emergency management authorities and increase collective awareness of available infrastructures throughout Italy. An integrated information system is developed, and pre-existing data specifications are harmonised to document these urban elements, widespread in small municipalities, using 3D surveying methodologies such as aerial photogrammetry and Unmanned Aerial Vehicles (UAVs).

This research investigates the severe seismic sequences that struck Central Italy from August 2016 to January 2017, affecting four regions (Abruzzo, Lazio, Marche, and Umbria), 10 provinces, and 139 municipalities. The Marche Region was the most affected, with extensive damage in 86 out of 139 municipalities [30,38]. In the last 25 years, other devastating earthquakes have affected the same regions, such as Umbria–Marche 1997 and L’Aquila 2009. The small village of Visso, one of Marche’s municipalities, is presented as a case study to validate the methodological framework. Overall, this research emphasizes the importance of managing heterogeneous geospatial data to systemize a complex issue, providing a reliable and quantitative analysis methodology for classifying and coding the post-disaster response.

The article is structured as follows: Section 2 discusses the role of geomatic tools, cartography, and GIS systems in post-disaster scenarios and their relevance in the emer-

gency phase in the Italian context. Section 3 describes the materials and methodology for the spatial data integration and documentation necessary to conceptualise the Atlas of Temporary Architectures. Section 4 presents its application results, including the case study that involves data collection, survey processing, and representation. Finally, Section 5 discusses the critical results and implications for the future.

## 2. Related Works

### *Geomatics and Cartography's Role in the Post-Disaster*

Emergency response and early recovery phase are crucial in the overall success of disaster management. The duration of these recovery phases depends on the specific characteristics of the affected area. Geospatial data plays a vital role in monitoring changes and providing timely, spatial, and descriptive information in disaster management. However, accessing spatial data sets during emergencies is often slow, which poses challenges for organisations that need to respond promptly. Additionally, the scale becomes an issue when using geospatial information for local-level disaster management, as many technologies are primarily developed for regional or global use. Therefore, it is essential for research and applications to prioritize the adaptation of geospatial analysis techniques specifically for local disaster management.

In this domain, the increased use of 3D acquisition techniques has highlighted the advantages of 3D data. Thanks to the development of new computer vision algorithms, the time required for creating 3D point clouds through integrated aerial and terrestrial photogrammetry techniques has significantly decreased, while automation has improved. Among others, UAVs have emerged as reliable tools for data acquisition, enabling the production of high-resolution 3D models. These drones have been particularly valuable in post-earthquake emergency scenarios, as they can efficiently document the state of an area and ensure the safety of all personnel involved [39]. The combination of UAVs and photogrammetric methods has been successfully employed in reconnaissance missions following major earthquakes in L'Aquila, Italy in 2009 [40,41], Kumamoto, Japan in 2016, Amatrice, Italy in 2016 [42,43], Kaikoura, New Zealand in 2016, and Lesvos, Greece in 2017 [44]. To effectively monitor the post-disaster status and track the progress of recovery efforts, it is crucial to have high-resolution geospatial data for a detailed representation of the disaster. Studies have indicated that the utilization of 2.5D data (models in which each point on the surface can accept only a single elevation) can enhance traditional 2D approaches and increase the dependability of identifying building collapses through the observation of changes in elevation by using pre- and post-earthquake light detection and ranging (LiDAR) digital surface models (DSMs) [45]. Their technique required calculating the average height difference between the DSMs for each building and manually setting a threshold value to detect collapse. Obtaining pre-event LiDAR data can pose difficulties as it may be outdated or unavailable, particularly in less developed regions.

Additionally, obtaining post-event LiDAR data may not be immediate. To resolve these operational issues, drones can be used as an alternative means to acquire 2.5D and 3D data, which can be quickly obtained for emergency mapping. Aerial imagery captured with drones can create orthomosaics, DSMs, and photorealistic 3D models in point clouds with colour and textured meshes, all with sub-decimetre resolution [46–48].

Regarding this matter, it is important to highlight the distinction between early recovery, which involves the construction of temporary buildings, and medium- to long-term reconstruction. Many studies and applications that utilize photogrammetric techniques tend to focus on the existing historical damaged urban context, rather than capturing the urban changes resulting from emergency responses. As a result, attention is now shifting from traditional satellite-based approaches for emergency mappings [49,50] to integrated drone-based photogrammetry surveys [19]. These surveys can assist in identifying collapsed building roofs debris in the vicinity, or assessing the levels of structural damage through oblique perspective of building facades, including facades themselves [51]. Although consolidated studies specifically addressing the temporary phase are limited, numerous

studies on the recovery process remain relevant. Leveraging drones for mapping purposes can aid in assessing long-term needs and monitoring the progress of reconstruction efforts by evaluating the extent of building damage and detecting changes across all reconstruction phases, including the destruction of historical artefacts and the transformation of temporary settlements. Furthermore, drone-based 3D mapping could facilitate subsequent ground-based assessments, enable the cataloguing of building damage, and support the planning and monitoring of reconstruction endeavours and transformations in temporary housing.

Another important approach to enhance post-disaster management is the so-called City modelling. It plays a crucial role in managing and planning territories, especially in monitoring and regulating built environments. The representation of buildings has progressed from graphical models to digital and semantic ones, facilitated by information systems that associate diverse types of information with complex 3D geometries [52]. Urban-scale semantic enrichment of 3D data allows for the documentation of building characteristics based on project type and level of representation. Levels of detail (LoDs) are used to manage and describe geometric and semantic details at different levels. There are five distinct LoDs: LOD0—regional, landscape; LOD1—city, region; LOD2—city neighbourhoods, projects; LOD3—architectural models (exterior), landmarks; and LOD4—architectural models (interior). However, CityGML 3.0 comprises only LODs 0–3, and the interior of objects are integrated with these LODs, while LOD4 is absent [53]. City models are created using active or passive sensors mounted on terrestrial, aerial, or satellite platforms. UAS data is one method for creating city models, using a framework that automatically extracts building footprints in three main steps: (i) separating ground and non-ground measurements using a progressive morphological filter; (ii) identifying non-ground measurements for buildings using a region-growing algorithm based on the plane-fitting technique; and (iii) deriving raw footprints from segmented building measurements by connecting boundary points, then simplifying and adjusting them to remove measurement noise [53].

Rubinowicz et al. explored the possibility of creating 3D city models in CityGML LoD1 using two data sources available in Poland, the Database of Topographic Objects (BDOT10k) and LiDAR data collected within the ISOK project. To facilitate research and practical applications in spatial, urban, and architectural planning, the authors developed C++ software capable of handling LoD1 models [54]. More current proposals address methods for the agile modelling of heritage environments in LOD2, using GIS software [55]. Compared to previous studies, the present work aims to improve the spatial knowledge of temporary housing solutions at various levels using UAV data surveys. The specific objectives are:

1. To enhance the existing national geospatial standards by integrating new fields related to emergency entities and developing a specific codification system with new concepts, attributes, and relationships to improve the current cartography.
2. To integrate different emergency databases with geomatic techniques to create an Atlas tool for mapping temporary housing entities at various scales of representation, from territorial to settlement scales.
3. To extract digital surface/terrain models (DSM/DTM) to understand the actual orographic modifications of temporary settlements and develop a realistic three-dimensional model (2.5D).
4. To use GIS applications to organise, support, and create harmonised spatial documentation of temporary solutions.

### 3. Materials and Methods

#### 3.1. Materials and Cartography Gaps

Effective decision-making and designing of temporary recovery in emergency management require accurate and timely information sharing [56]. The US National Research Council [57] has emphasized the importance of free and rapid access to geospatial information in emergency response and housing recovery planning, as it enhances community resilience. The success of the emergency process, recovery phase, and future transforma-



tions depend on the availability of relevant databases describing the affected territory's characteristics. However, available databases for individual organisations could often be inconsistent, incomplete, or nonuniform. Therefore, this work aims to develop a methodology for mapping temporary housing by harmonizing data from official emergency platforms with geomatic surveys and non-metric data, using a GIS-based approach. To guide the construction of a comprehensive mapping framework, the research has organised the information systems into three categories: (1) fundamental and open-source data (basic data), (2) specific data related to the second emergency response (emergency data), and (3) image data [58]. This complex dataset becomes the primary source of knowledge, implemented thanks to extensive fieldwork (Table 1).

**Table 1.** Available datasets for post emergency knowledge.

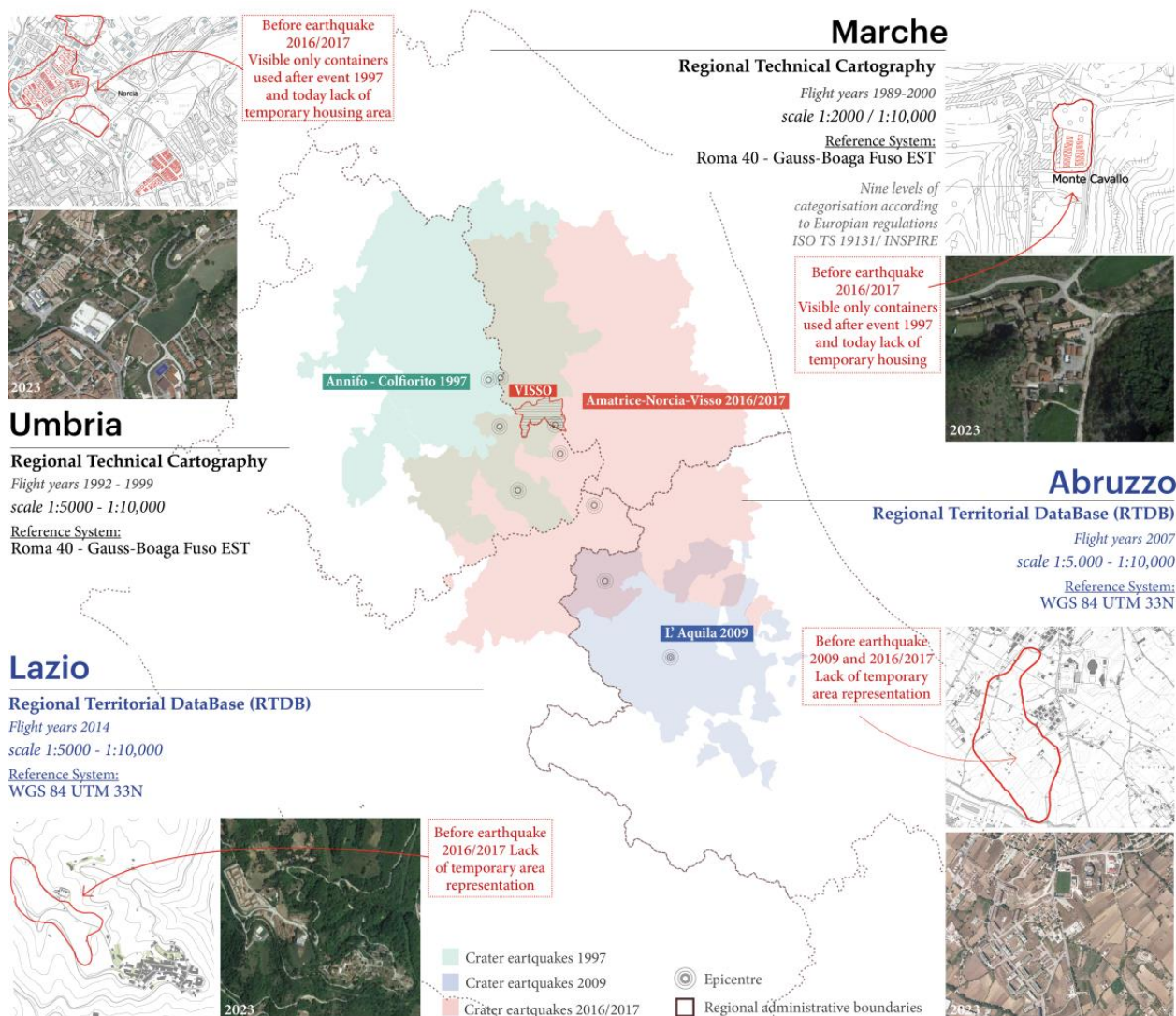
Categories	Typology	Specific Data	
BASE DATA Fundamental basic data	Spatial Dataset	Geodatabase territoriali nazionali (Technical map, Geotopographical Databases)	
		Historical cartography (IGM Military Geographical Institute)	
		Cadastral maps	
		Administrative boundaries (from ISTAT)	
		Regional or national thematic risk data (ISPRA portal)	
	Dati Open Source	Satellite images (Google Earth™ mapping service or Street View) or Open Street Map	
EMERGENCY/DISASTER SPECIFIC DATA	Institutional disaster and recovery database	National Institute of Geology and Volcanology (INGV)	
		National Civil Protection Department (DPCN) section Earthquake in Central Italy (temporary housing and container maps, regulation, Ordinances Civil Protection Department)	
		Special Reconstruction Offices of different regions (USR/USRA/USRC/SMEA)	
		Emergency information in earthquake page in regional web portals	
			Emergency and reconstruction documents from technical offices of local administration
			Extraordinary Commissioner for Earthquake Reconstruction 2016 website (Open data, regulations and reports)
		Specific research project database	University research projects Projects by regional mapping agencies Third mission or external professional collaboration projects with direct survey
	Voluntary Activities and Crowdsourcing	Participatory mapping (ActionAid—Mapillary) or Photographic documentation	
	Non-spatial data	Data in tabular form as census data, contacts of all emergency managers, inventory of essential resources (National Institute of Statistics ISTAT—Sisma 2016 page)	
	OPEN DATA Reconstruction platforms	OpenData L'Aquila, OpenData Ricostruzione Special Reconstruction Offices WebGis	
IMAGINE DATA	Raster data	National Geoportal Historical Orthophotos	
		Satellite Orthofoto	
		High resolution orthophoto (20 cm/pix) Marche, Abruzzo (2019); Lazio, Umbria (2020) from aerial photogrammetry	
		Very-high resolution orthophoto, DSM, DTM (5 cm/pix) from UAV photogrammetry	

To collect data, official databases are combined with information from specific projects that the research has access to and data from voluntary and participatory activities to fill in any missing information that is still needed. No regional, national, or international geodatabase is available that can accurately identify all existing temporary architectures

or establish a clear semantic framework to define the provisional post-event condition without ambiguity.

### Cartographic Gaps and Material Retrieval Difficulties

A deep knowledge of the territory and the importance of cartographic data play a crucial role in the crossed area between several regions in Central Italy which has been struck by three devastating earthquakes in the last 25 years (Figure 1). According to proposed standards for technical mapping by the Italian Geodetic Commission in the 1970s and harmonization with European directives from 2007 (Intesa GIS), the current regional cartographic base should be updated every five years for the territorial scale. This means that these architectures, which typically persist in use for about ten to fifteen years [27,28,32], would be fully represented in cartographic representations. However, as shown in Figure 1, the obsolete updating of official numerical cartography highlights the lack of any indication of temporary entities in all four damaged regions, despite their actual permanence over time. Without support from updated orthophotos or direct local knowledge, it is difficult to understand the current post-earthquake situation.



**Figure 1.** The territory considered and the extension of the municipalities affected by the three seismic events and the current cartographic reference bases. The municipalities affected in 1997 are shown in green, those affected in 2009 in blue, and those affected by the recent events of 2016/2017 in red.



This condition presents a difficulty in emergency management operations and a chronic gap for all multiscale documentation, multi-level planning, and other project transformations that require specific circumstantial metric surveys. In these situations, integration with data from cadastral maps is one way to achieve uniformity and consistency. In the Marche region, where the case study is located, two territorial Regional Technical Cartography (CTR) levels are available. Both are outdated in terms of acquisition time (1999/2000 flight) and lack of a universal reference system (Gauss-Boaga/Roma40 Fuso Est—EPSG: 3004), but compliant in nine information levels with INSPIRE regulations.

### 3.2. *Atlas of Temporary Architectures: Spatial Data Integration and Documentation Tool for Mapping the Post-Emergency Recovery Phase in Post-Disaster*

One way to assess the impact of temporary architecture on territories is to map them [59]. However, incomplete pre-existing cartography and fragmented databases collected in post-emergency years necessitate finding methods for spatial data integration. To provide empirical evidence of this issue, this research proposes an Atlas of Temporary Architectures of post-disaster, a tool for geospatial digitalisation and archiving of emergency solutions. The aim is to be scalable to different case studies from local to regional scale, interoperable for other domains, and easily accessible by multiple types of users. Figure 2 shows the multiscale development process, summarised in four steps:

1. Classification of six typologies of temporary post-earthquake architecture divided into residential and non-residential categories, related to the emergency regulatory documentation.
2. Definition of geometric features (point, linear, areal, or multi-polygon) and level of representation (2D/3D) at three different scales of representation (topographical, urban, and settlement).
3. Definition of geometric features extracted by UAV survey following selected official technical cartographic specifications
4. Definition of the non-geometric attribute structure (media, design documentations, alphanumeric, and hypertextual) connected to the single entities to harmonise and implement the existing cartography

The methodological pipeline (Figure 3) shows the production process of Atlas's information divided into four stages data collection, acquisition, processing, and integration. This involves using hybrid and multiscale datasets and conducting a case study operative validation. The methodology aims to reuse existing geospatial knowledge by implementing specific attributes of selected entities based on national standards. Identification of emergency elements and the observation scales was conducted between August 2020 and January 2023. This survey helps recognise the widespread phenomenon at the building scale and the need to map them using a structured classification. The first stage of data collection is crucial for semantic analysis, categorisation, and the development of an ontological integrated system [58] at the territorial scale. It is divided into two macro-categories:

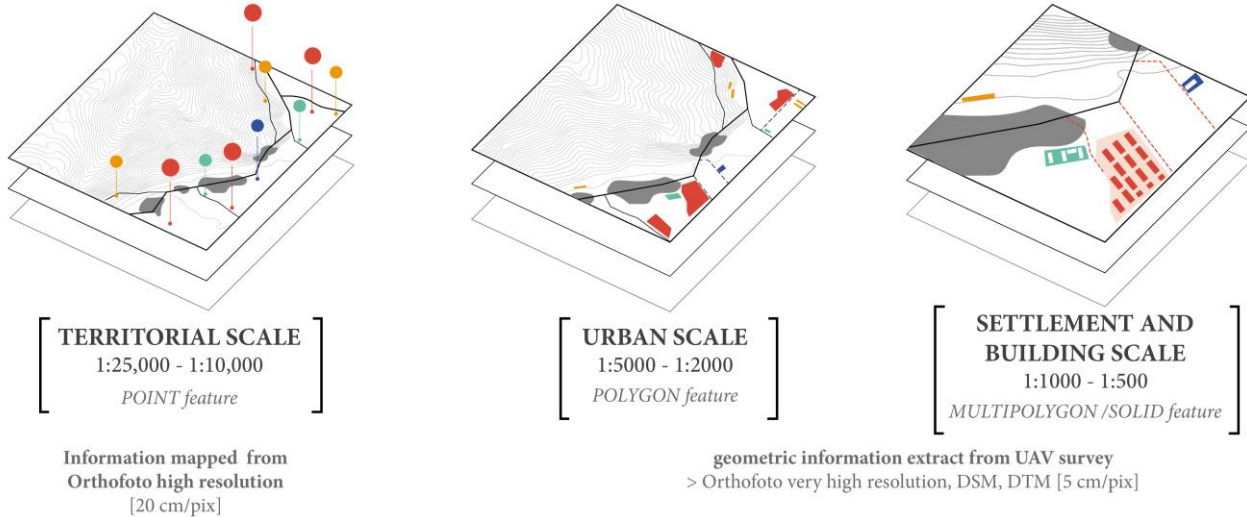
- *base data* available in the four-earthquake region (e.g., structured existing spatial cartographic dataset, national and regional geoportals, thematic risk data, open-source data, and satellite data)
- *emergency/disaster data* includes institutional databases on the topic, data from specific research projects, volunteered geographic information (VGI), and non-spatial information (e.g., spatial maps, documentation, and regulations).

The second and third stages operate on a single case study, and the fourth stage integrates and harmonizes the information processed on a GIS system (QGIS) to create the multiscale Atlas of Temporary Architectures and validate the conceptual model structure.

**01 | Definition of temporary post-earthquake architectures use categories**

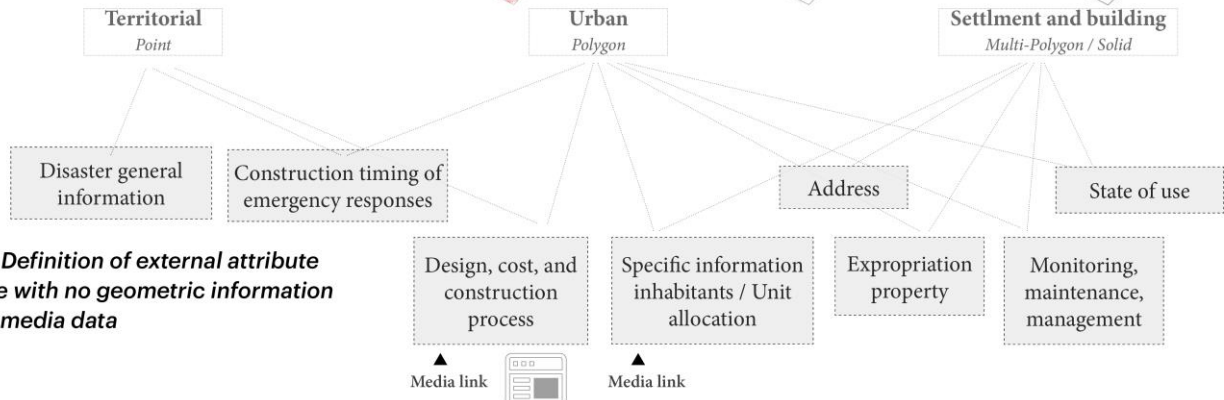
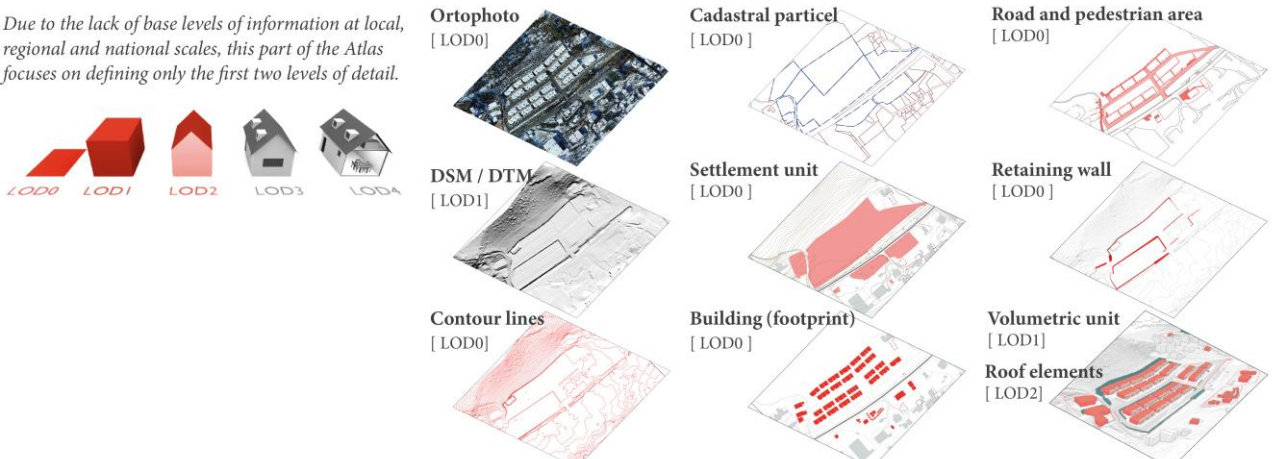


**02 | Definition of three representation scales**



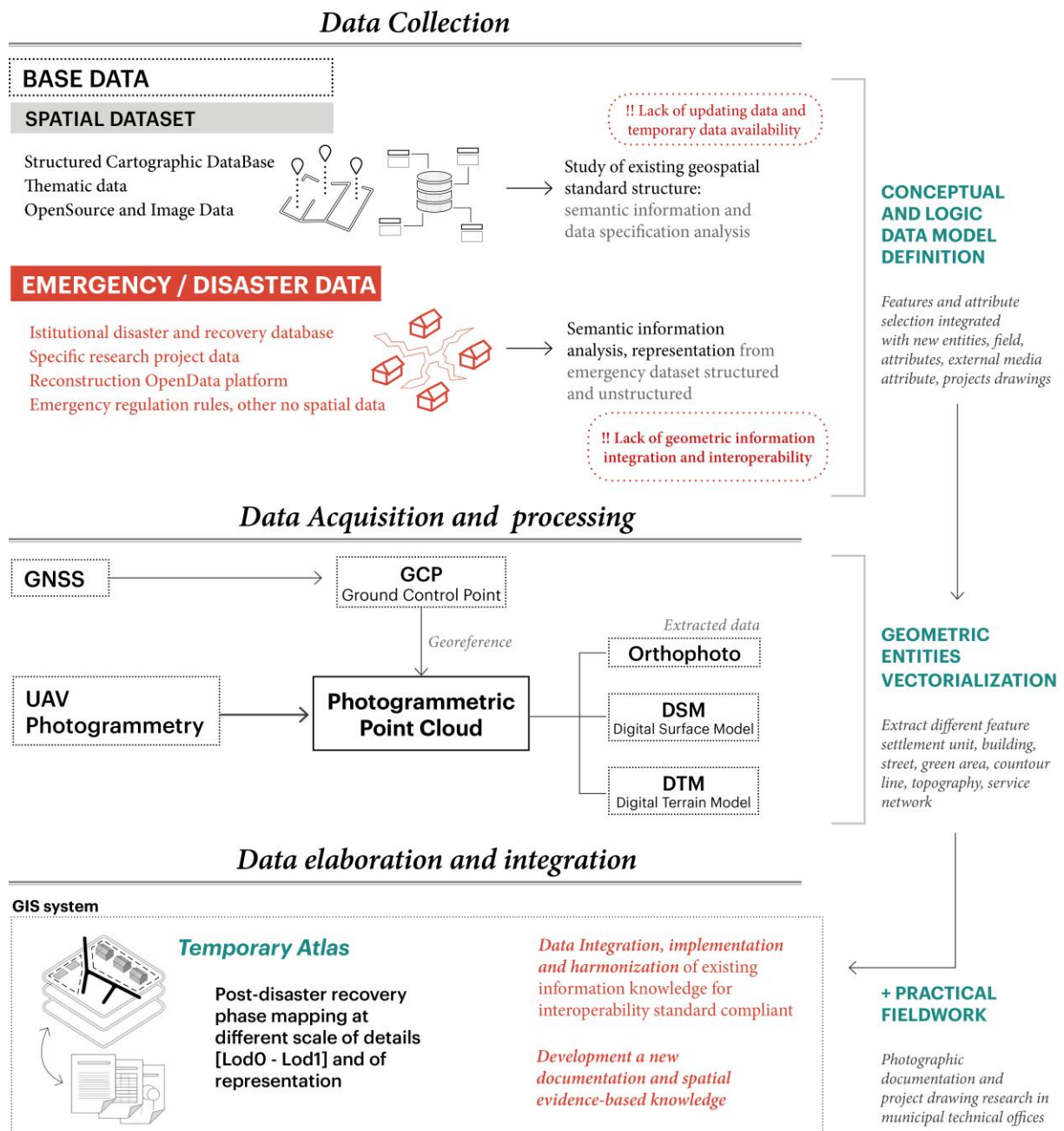
**03 | Definition level of detail and geometry feature**

Due to the lack of base levels of information at local, regional and national scales, this part of the Atlas focuses on defining only the first two levels of detail.



**04 | Definition of external attribute table with no geometric information and media data**

Figure 2. The multiscale development process of the Temporary Atlas.



**Figure 3.** The methodological pipeline of the process of production of Atlas information.

### 3.2.1. Data Collection and Semantic Analysis for Information Extraction

The research is based on the theories of Geospatial Semantics [60,61], which is a recognised subfield in GIScience that focuses on “understanding GIS content and formalizing this understanding” [60]. Geospatial semantics play a crucial role in improving the interoperability of distributed systems in GIS, as highlighted by Hu [61]. To critically interpret and reuse existing knowledge in defining spatial concepts and geometric and semantic features for post-disaster temporary conditions, the research examines data specifications and standards. The approach is structured in different phases, taking reference from studies on spatial documentation and ontologies [47,62–64]:

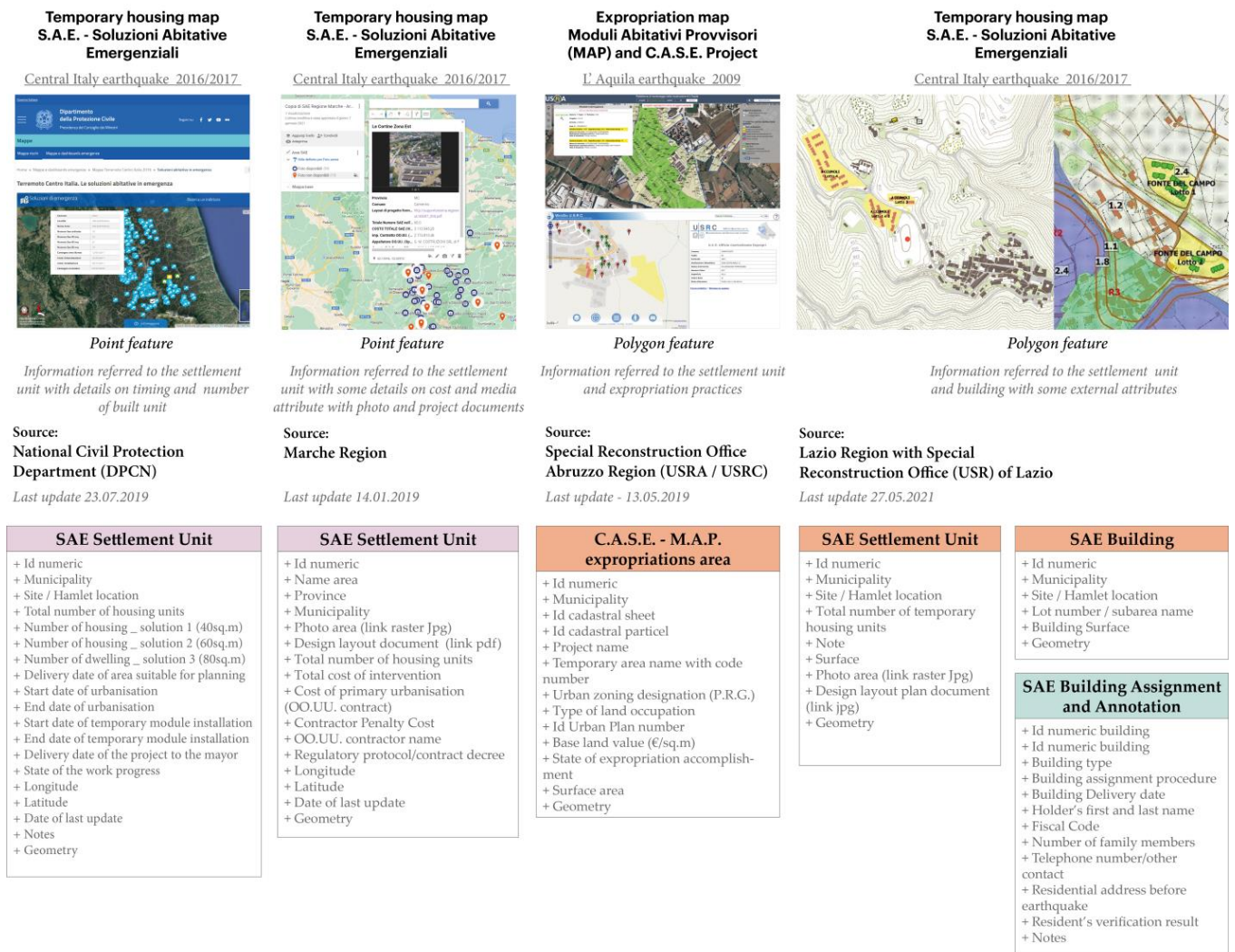
- Analysis of the attributes of the Standards of Geographic Information data specifications currently in use in Europe (INSPIRE, CityGML) and in Italy (DataBase GeoTopografico (DBGT)) to select the entities and the levels of the detail representation (Lod0–Lod2) for the representation of homogeneous data in GIS environment.



- Conceptualisation of the semantic structures of databases and documents concerning the temporary post-earthquake response (DPCN database, specific regional or research project).
- Comparison of conceptual models, identification of entities to be harmonised, definition of key terms as attributes, and specific enumeration to be integrated into the standards.
- Definition of the spatial components, geometry, and attributes to be implemented to visualise the temporary spatial information and to structure the Atlas.

During the initial phase of the research, national and international standards were examined to identify if there were any specific coding or features related to emergency or transitional conditions. European standards like INSPIRE and CityGML highlighted the importance of efficient data sharing procedures during emergency situations among different levels of government. Within these standards, specific references to non-permanent structures were found in the INSPIRE Data specification of the Land-Use theme, particularly in the “OtherResidentialUse” subcategory of the Residential Use category, while the INSPIRE Data specification of the Building theme also included direct references to shelters as an unconventional building type. There was also an explicit mention of an Atlas of Precarious Buildings and the possibility of associating additional properties with the abstract spatial object type common to “Building and building unit info”. However, the research observed a lack of structured coding or semantic attributes for temporary structures in national numerical cartographies (Figure 1). Currently, the only generic attribute term used for temporary structures is “barrack, container” to describe minor buildings. To address these limitations, the study aims to develop a specific codification and categorization system with new concepts, attributes, and relationships. This system will enhance the current cartography and facilitate the creation of an Atlas tool for mapping temporary housing entities at various scales of representation.

Among the four regions of Central Italy, the Lazio and Abruzzo regions have a cartographic structure that complies with the European INSPIRE directive. In the research, the author uses the technical specifications of the Lazio region’s DBGTT, which was last updated in 2017 [65], to select relevant features and understand their implementation. The conceptual model presented in the research focuses on the first two levels of detail of CityGML model 2D and 3D (LoD0 and LoD2). Specific features from DBGTT are chosen to be correlated with the temporary area and supplemented with additional features (Figure 4). The research also examines the data properties and attributes of selected official post-emergency spatial databases). For instance, interactive expropriation maps of parcels used for temporary purposes available through the Open Data reconstruction for the 2009 L’Aquila post-earthquake, and interactive maps from the DPCN and Marche Region representing the geolocation of temporary settlements with attributes related to timing, construction process, costs, and media links. Furthermore, the research also analyses the geometric and semantic specifications of an experimental project of the Lazio Region to support the editing of the PSR program of the damaged municipalities. This experimental project is the only attempt by a regional cartographic office to work in collaboration with special reconstruction offices. It aims to represent these provisional entities in spatial form, integrating them with other external attributes, and building-specific annotations related to other planning and risk documents in place or to be revised.



**Figure 4.** The data structures of four selected thematic spatial databases. To ensure immediate readability of the information and direct correspondence between the different geometrical or textual types of the analysed entities (points, lines, polygons, multi-polygons, tables with annexes), a different colour code is used for each table.

### 3.2.2. Conceptual Model and Data Harmonisation of Temporary Information

An analytical approach has been used to select specific attributes from emergency datasets in order to propose a conceptual and logical model that guides the creation of a spatially implementable database. Figure 5 represents a schematization of this conceptual model, which aims to extend the attributes contained in the cartographic data specifications standards harmonised with information from emergency thematic databases. The aim is to create a georeferenced geometric documentation that makes data transparent and accessible, supporting design requirements and visualisation scales. The conceptual model includes a selection of geometric (punctual, linear, and solid multipolygon features) and raster objects/entities useful for documenting temporary settlements at various scales ranging from geographic to building levels (Figure 5), with a specific enumeration for classification and with external attributes. The goal is to provide a single data model to facilitate integration and the development of a comprehensive and coherent spatial database for temporary settlements. This ensures that data is transparent and accessible, supporting design requirements and visualisation scales. In detail, the conceptual model “entities–relationships” with specified cardinalities includes:



1. A selection of geometric and raster objects/entities is deemed useful for documenting temporary settlements (from national DBGT, European INSPIRE, and CityGML standards).
2. The inclusion of a specific enumeration for classifying temporary dwellings (Figure 5), allows for the implementation of attributes related to the conditions of use, category of use, or typology information for the building and settlement units features.
3. Systematisation and relationship with external attributes (such as textual, tabular, alphanumeric, project annexes, photographic documentation), further enhance the transparency and comparability of information regarding the construction of temporary housing. These additions aid in identifying actors involved in the process, provide details on costs and intervention timelines, and explain building management. (from DPCN documents and platforms, other regional open data, from platforms and official reconstruction documents).

The current data in various databases is incomplete when it comes to representing all types of temporary buildings involved. The blue frames and labels in the schematic model identify features that have been added or implemented with new attributes, compared to the existing standards, in order to better describe the temporary condition.

The definition of “building” in INSPIRE allows for flexibility in interpreting the concept of building permanence, encompassing structures that are theoretically designed to be mobile or usable for a short period but are, in practice, used permanently [66]. Based on this definition and other recommendations, the research proposes extending the “building” definition to include temporary dwellings and services. This differs from the Italian specifications, which classify them as minor buildings. The presented conceptual model includes new attributes for temporary settlement types, state of use, building type, and building use category. These attributes align with the European code list for building nature value, current use value, and condition of construction value. These new attributes would be added to the code lists for unit settlements and building features.

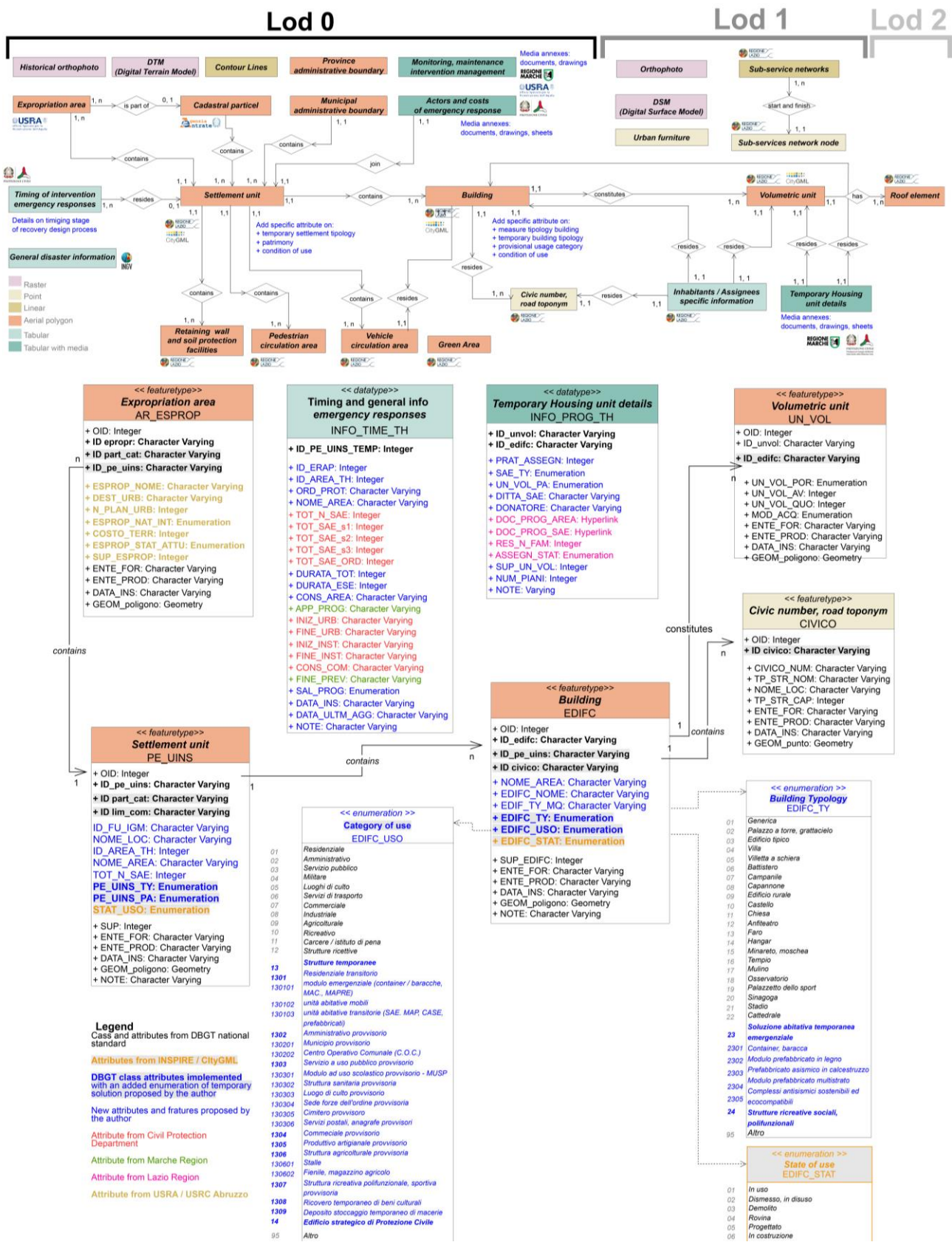


Figure 5. Scheme of the conceptual model showing the sources of the various entities and an extract of the attribute implementation and enumeration of the building feature with information on post-earthquake temporariness.

## 4. Results

### 4.1. Visso, Small Mountain Village as an Application Case Study

Among the 44 municipalities primarily affected by the seismic events of 2016/2017, Visso (MC) (OCDPC 101/2020) was selected as the testbed application. Located on the border between the Marche and Umbria regions, Visso is a small mountain municipality renowned for its medieval fortified village. It is situated in the Alta Valnerina Valley within the Monti Sibillini National Park, where five valleys converge. Like many municipalities in the Central Apennines, Visso frequently faces emergencies, such as seismic activity, landslides, and slope instability. The aftershocks on 26 and 30 October 2016, with epicentres recorded within the municipal territory near the historical centre, confirmed Visso's position as one of the areas with highest seismic risk in Italy. These sequences, following the events on 24 August 2016, had devastating consequences, rendering 94.75% of the buildings uninhabitable. The entire historic centre, neighbouring hamlets, and villages were designated as a 'red zone' due to extensive collapses. Currently, more than 70% of the population has been displaced, and the residents are living in eight S.A.E. (Soluzioni Abitative in Emergenza) temporary settlements spread scattered throughout the valley. These settlements (Figure 6) vary in size, morphology, and location, while maintaining a complex relationship with the surrounding context. Visso, second only to Camerino, has the highest number of temporary housing units relative to the number of residents in the seismic area. There are six main S.A.E. areas around the destroyed urban centre, with two additional isolated settlements in the hamlet, totalling 228 temporary housing units (112 units of 40 sqm, 72 units of 60 sqm, and 44 units of 80 sqm) [37,67]. Approximately 80% of the current resident community, amounting to around 700 out of 961 residents, live in temporary housing (ISTAT, 2023). In addition to the damages caused by the 1997 earthquake, certain small hamlets such as Aschio, Croce di Visso, Fematre, Riofreddo, and Rasenna still have prefabricated wooden structures that were established after the earthquake and are still in use today.

In response to the complex regulatory framework, numerous municipalities in the earthquake-affected region of Central Italy have established collaborations with research departments of Italian universities. Since November 2020, Visso has initiated technical-scientific collaboration involving the Municipal Administration and Technical Office, as well as the SIMAU department of Università Politecnica delle Marche, along with other external agencies, such as Flyengineering s.r.l. These collaborations aim to support the development and implementation of Extraordinary Reconstruction Programmes (P.S.R.) to address the seismic emergency and to facilitate guidelines for reconstructing destroyed historic centres, providing regulatory simplifications and urban planning exemptions [68]. The cartographic framework of Visso, similar to many other mountain municipalities in the Marche region, reveals significant deficiencies in terms of updates and levels of detail that do not align with the current post-disaster situation. In this context, UAV surveys play a crucial role in understanding the urban transformation resulting from the emergency. They facilitate multiscale and 3D metric cartographic digitization, aiding in the updating of spatial documentation.

### 4.2. Data Acquisition: 3D Survey, Digital Photogrammetry, and UAV Data Integration

Documenting a mountainous context, such as the upper Macerata area in the Apennines, is a complex task requiring various geomatic techniques and sensors during the survey and post-processing phases [69]. To support the drafting of the P.S.R., Flyengineering s.r.l. conducted UAS photogrammetric surveys in specific urban areas of interest: Visso, Croce, and Aschio. The objective was to integrate and update the existing data, as well as gain insights into the state of the destroyed structures. The survey aimed to accurately document and represent the current condition of the historical hamlets in both 2D and 3D, providing support for urban reconstruction planning activities. Although the P.S.R. did not explicitly focus on temporary architecture, the information and planning considerations



often addressed only the general perimeter localization, forgetting building footprints, primary infrastructures, roads, and other relevant geometries.



**Figure 6.** Some examples of temporary settlements in Visso. Photos of drone survey, Marche region portal and Ilaria Tonti.

The survey was organised into two phases. In the initial phase, flight planning was conducted, and ground control points (GCPs) were measured using GNSS (Global Navigation Satellite System). These GCPs were essential for georeferencing, calibration, and orientation of the photogrammetric images. In the second phase, the survey area was manually flown and images were acquired. For the GNSS survey a GeoMax 'Zenith35 Pro TAG' was used to acquire the coordinates of the points of the network (Figure 7). Out



of the total points, 68 were used for georeferencing the photogrammetric survey. The GNSS receiver has a horizontal accuracy of  $8 \text{ mm} \pm 1 \text{ ppm}$  (rms) and a vertical accuracy of  $15 \text{ mm} \pm 1 \text{ ppm}$  (rms) in RTK (Real Time Kinematic) mode. The coordinates acquired by the GNSS were provided in the WGS 84/UTM zone 33N coordinate system (EPSG:32633). For aerial photogrammetry, DJI's "Phantom 4 Pro" VTOL UAV was utilized. The integrated camera of the UAV features a 1-inch CMOS sensor and can acquire 20 MPix stills images.



**Figure 7.** Some examples of Ground Control Points (GCPs). On the left the reference points are numbered in green in the KML file, on the right two photos of the GNSS instrument during the survey. Source: Flyengineering s.r.l.

During the UAV flights, a total of 1981 images were acquired, covering the entire historic town centre and five valley floors. The flights were conducted at a variable flight height, while maintaining an approximate distance of 100 m to the survey objects. The overlap and sidelap between images were approximately 70%, resulting in an average GSD (Ground Sample Distance) of 2.63 cm/pix. The georeferencing of the photogrammetric model using the 68 GCPs resulted in an RMS error of 2.2 cm.

#### 4.3. Data Processing and Point Cloud Segmentation

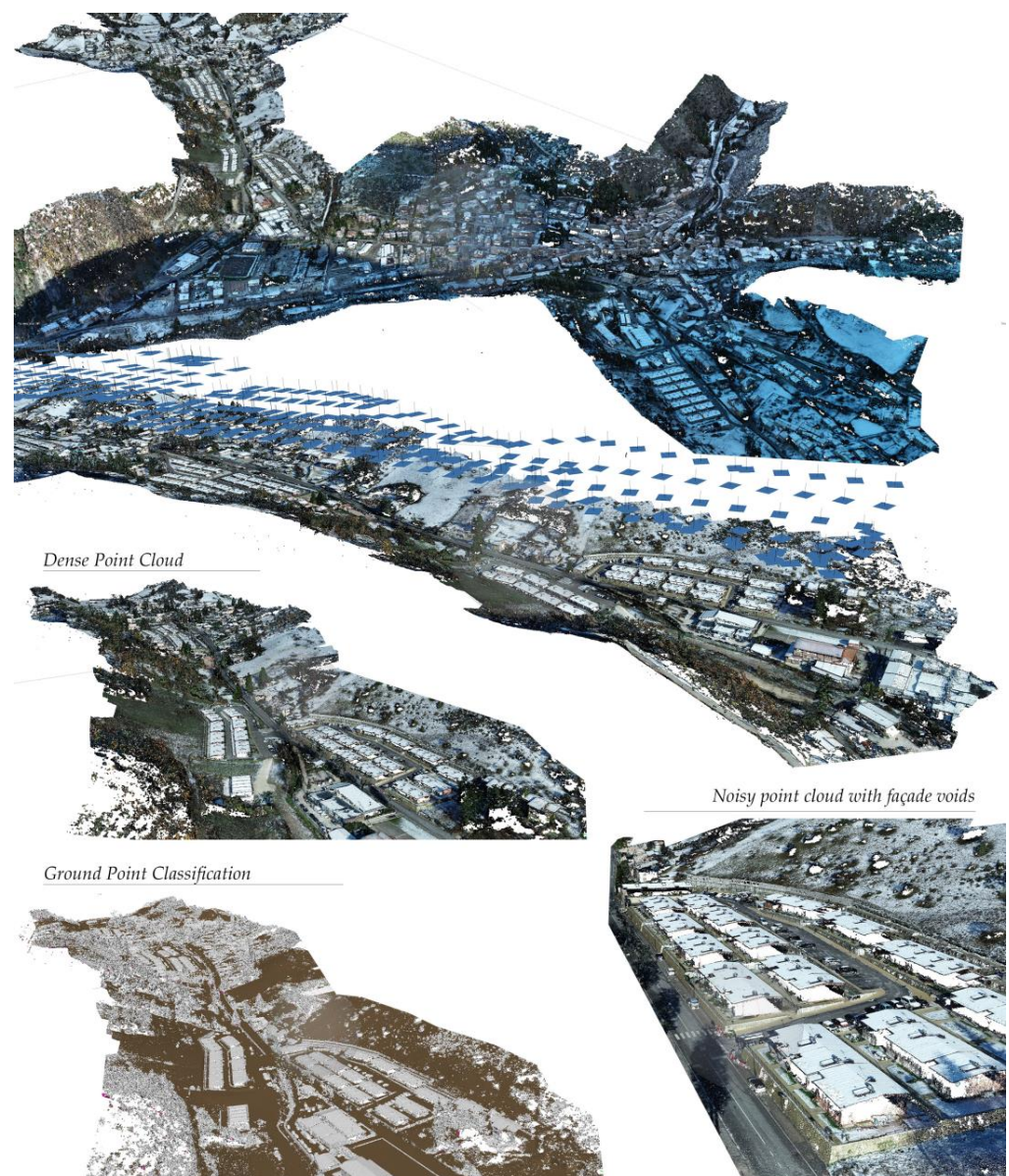
To achieve the goal of detailed and multiscale digital documentation, high-resolution aerial photogrammetry images were utilized in the research. These images enabled the accurate and geometric documentation of the temporary post-earthquake area at various scales, ranging from territorial and urban to building level, including the identification of architectural elements specific to the temporary settlements in Visso (Section 4.2). The general processing and elaboration workflow were set up as follows:

1. UAV photogrammetric data processing to generate orthophotos, DSMs, and DTMs.
2. Selection of temporary categories from the Atlas conceptual model (Section 3.2.2) for application in the Visso case study.
3. Manual digitalization of temporary features for all spatial entities at the settlement scale, based on the processed orthophotos and following the conceptual model.
4. Definition of contour lines and extraction of morpho-orographic sections for the temporary settlements.
5. Construction of the three-dimensional model to extraction of height information of building and retaining walls.

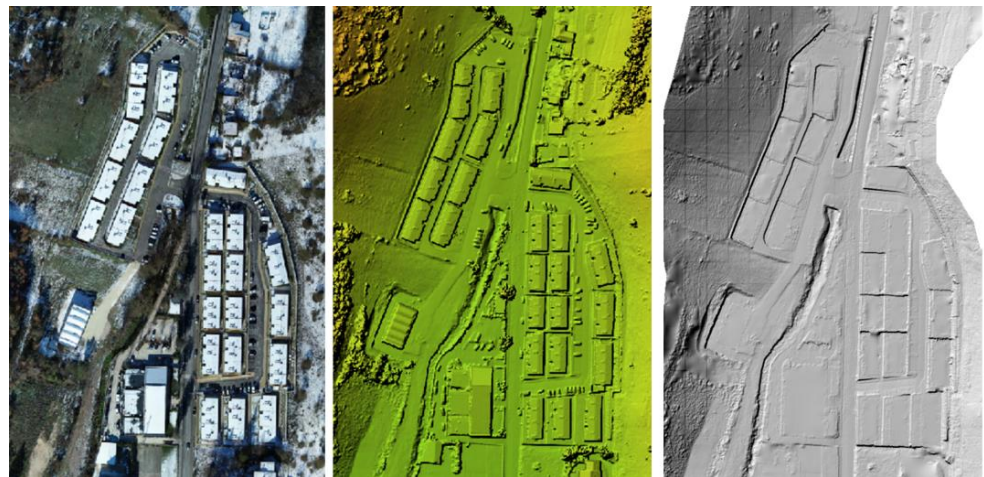
The survey primarily focused on pre-existing damaged buildings in the historical centre, but the paper aims to explore the possibility of extracting a high level of detail for temporary housing settlements using solely nadiral aerial photogrammetry. This accurate



process can reveal emergent orographic modifications that may not be immediately recognizable from orthophotos. The photos acquired during the aerial photogrammetric survey were oriented using a Structure-from-Motion (SfM) approach which recognised 1,310,445 tie points. The subsequent generation of a dense point cloud resulted in 1,136,343,847 points, from which a 3D mesh representing the urbanised portion of the Visso municipal area was generated. Orthophotos, digital surface models (DSM), and digital terrain models (DTM) were then generated and exported using the Agisoft Metashape software. The process is illustrated below, in a sequence of images (Figures 8 and 9). Despite the complex topography of the valley and the temporary settlements, a reliable dense cloud with a high metric resolution of approximately 5 cm was successfully generated.



**Figure 8.** The point cloud provides territorial coverage over the main centre of Visso, where the S.A.E. areas are located. The post-processing of the nadiral photogrammetric data from the UAV (Phantom 4) was carried out using Agisoft Metashape software, resulting in the extraction of a dense point cloud and ground point classification. Zooming in on a portion of the point cloud reveals the presence of noise and voids in the facade.



**Figure 9.** From left: Orthophoto (5 cm), Digital Surface Model DSM (5cm), and Digital Terrain Model (DTM) extracted after ground point classification.

However, it should be noted that the UAV survey was primarily planned for updated orthophotos and planimetric applications, with a specific focus on assessing damages in the historic centre. Therefore, studying the three-dimensional aspects of temporary settlements was not the main objective. Nevertheless, during the point cloud processing phase of the nadiral photogrammetric survey, voids and points with high noise were expected to emerge in the façades. Due to the intricate topography, the terrain classification algorithm parameters had to be carefully chosen to generate DTMs. The height and distances of the temporary buildings, retaining walls, and slopes are often very close, creating difficulties in automatically classifying the ground floor. The maximum angle was set to  $20^\circ$ , the maximum distance from the point to 0.1 m, and the cell size to 30 cm for the “Classify Ground Points” function. Despite these adjustments, situations where buildings were closely located near retaining walls or under complex orographic conditions with similar elevations sometimes posed difficulties for the algorithm to segment the ground floor (Figure 8) accurately.

#### 4.4. From Data to Spatial Digitalisation Using GIS System

All elements have been georeferenced to satisfy the demand of geometric and semantic documentation of temporary solutions at different scales of representation. This allows for creating a comprehensive database that collects, harmonizes, and links geometric and non-geometric data, including project documentation, emergency regulations, and construction and management information. The output obtained from the UAV survey was used to produce accurate 2D and 3D maps, integrating other collected data in the GIS domain in the WGS84/UTM 33N—ETRF 2000 reference system. To achieve this, the open-source software Quantum GIS (QGIS) was utilized. To enhance accuracy, building recognition from orthophotos was complemented by local fieldwork. Harmonisation and semantic integration were organised on the same GIS platform, focusing on three scales of representation:

- Territorial/Topographical scale (1:25,000/1:10,000) represents temporary features in a punctual format and with different categorisation. The research compares high-resolution orthophotos (20 cm/pix or 5 cm/pix if available) with the national cadastral map.
- Urban scale of the temporary city (1:5000/1:2000) identifies relevant perimeters and building footprints for all temporary settlements.
- Settlement and individual city objects (1:1000/1:500) manual redrawing of spatial entities (buildings, settlement unit, roads, retaining walls and other related elements, green areas, and contour lines) for the eight S.A.E. temporary areas and other bordering architecture, following the conceptual and logical model.

The Table 2 shows all the collected data and extracted in QGIS.

**Table 2.** The collected data used in QGIS.

Representation Scale	Output Layer/Features	Type Geometry	REFERENCE SYSTEM	Source	Note
Settlement and building scale (1:1000–1:500)  Urban scale (1:2000–1:5000)	Transporation - Vehicle circulation area (AC_VEI) - Pedestrian circulation area (AC_PED) - Secondary roads (AR_VMS)	Vectorial polygon	WGS 84 UTM 33N	Manual vectorialization of Orthophoto from UAV survey	
	Building - Volumetric unit (UN_VOL) - Building (EDIFC) - Roof element (ELE_CP)	Vectorial multi-polygon	WGS 84 UTM 33N	Manual vectorialization of Orthophoto from UAV survey	The feature contains attributes: - elevations (number of floor) - altitude (footprint on the ground)
	Retaining wall and soil protection facilities - Retaining and ground support wall (MU_SOS)	Vectorial polyline	WGS 84 UTM 33N	Manual vectorialization of Orthophoto from UAV survey	The feature contains attributes: - elevations
	Green Area (AR_VRD)	Vectorial multi-polygon	WGS 84 UTM 33N	Manual vectorialization of Orthophoto from UAV survey	
	Subservices networks Water distribution network Water drainage network Electricity network Gas distribution network Telecommunications and cabling networks	Raster (PDF)/Vectorial polyline	WGS 84 UTM 33N	Manual vectorialization from raster official executive drawings project (georeferred in GIS)	Executive project documentation provided by the Unique Project Manager of the Marche Region for the construction of S.A.E. area, exclusive use for research activities
	Transporation - Vehicle circulation area (AC_VEI) - Pedestrian circulation area (AC_PED) - Secondary roads (AR_VMS)	Vectorial polygon	WGS 84 UTM 33N	Manual vectorialization of Orthophoto from UAV survey	
	Settlement unit (PE_UINS)	Vectorial multi-polygon	WGS 84 UTM 33N	Manual vectorialization of Orthophoto from UAV survey	
	Contour lines (CV_LIV)	Vectorial Curve-polygon	WGS 84 UTM 33N	Vectorialization of DTM from UAV survey	
	Digital Terrain Model (DTM)	raster	WGS 84 UTM 33N	Extraction from UAV survey	
	Hillshade Digital Surface Model (DSM)	raster	WGS 84 UTM 33N	Extraction from UAV survey	
	Orthophoto (5 cm/pix)	raster	WGS 84 UTM 33N	Extraction from UAV survey	
	Orthophoto (20 cm/pix)	raster ECW / GeoTIFF	WGS84— ETRF2000 EPSG: 9067	AGEA (Agenzia per le Erogazioni in Agricoltura) Marche Region flight 2019	Orthophotos licensed for the aims of this research
	Marche region Technical Map (base cartography) Flight years 1989–1990 scale 1:2000	Vectorial (DXF) Raster	WGS 84 UTM 33N Converted from Roma 40—Gauss-Boaga Fuso EST	Marche region portal <a href="https://www.regione.marche.it/Regione-Utile/Paesaggio-Territorio-Urbanistica/Cartografia/Repertorio/Cartatecnica2000#Download-DXF">https://www.regione.marche.it/Regione-Utile/Paesaggio-Territorio-Urbanistica/Cartografia/Repertorio/Cartatecnica2000#Download-DXF</a> (accessed on 30 June 2023)	Cartographic base updated with new information
	Cadastral map	WMS (Vector/raster)	WGS84— ETRF2000 EPSG: 9067 (RDN2008— EPSG:6706)	Agenzia delle entrate <a href="https://www.agenziaentrate.gov.it/portale/web/guest/schede/fabbricatiterreni/consultazione-cartografia-catastale/servizio-consultazione-cartografia">https://www.agenziaentrate.gov.it/portale/web/guest/schede/fabbricatiterreni/consultazione-cartografia-catastale/servizio-consultazione-cartografia</a> (accessed on 30 June 2023)	Cartographic base is used to verify the presence of settlements and buildings that have not yet been registered and can be attributed to the emergency development process. The system is integrated with high-resolution orthophotos provided by AGEA (GSD 20 cm/pix)

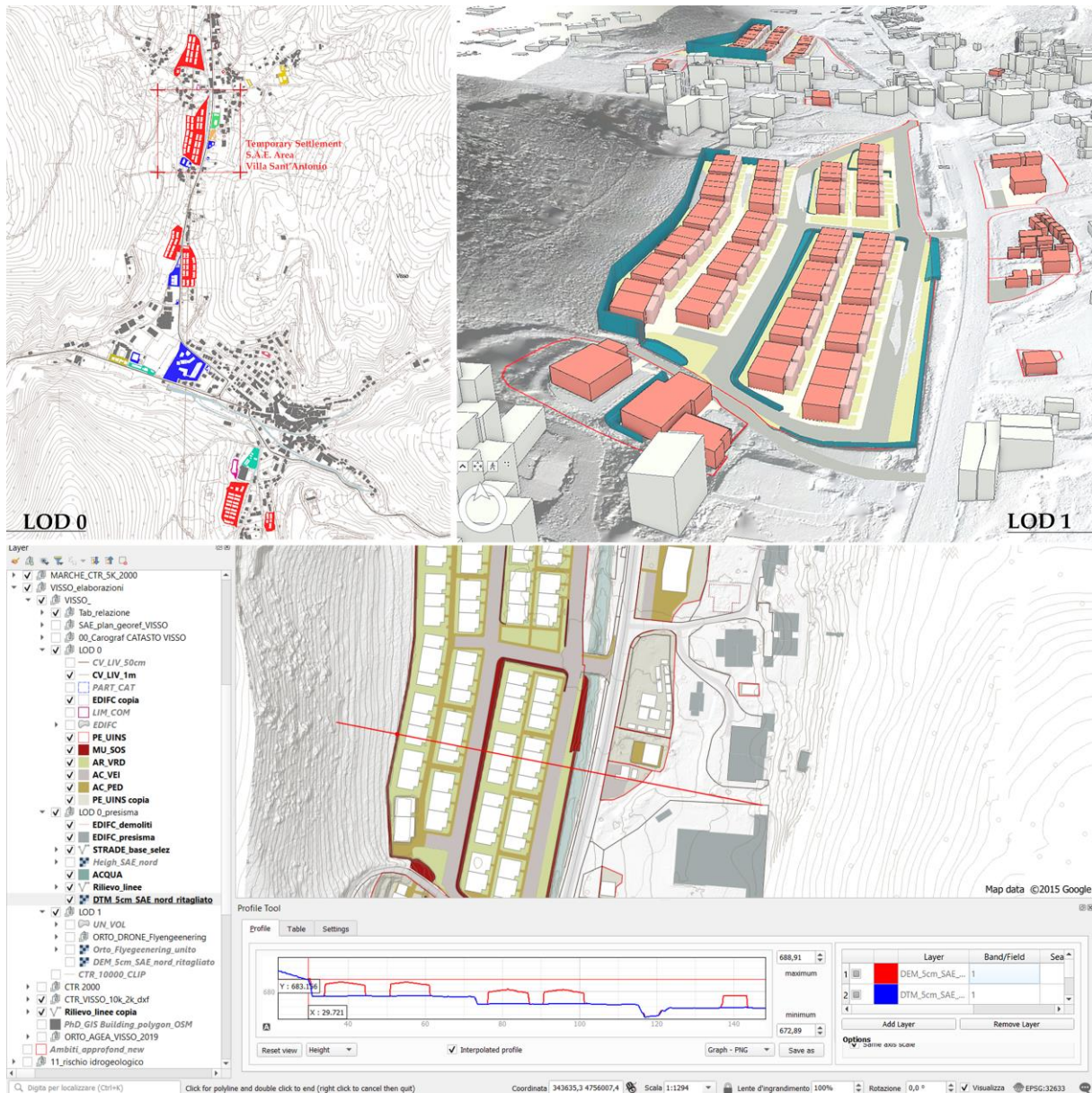


Table 2. Cont.

Representation Scale	Output Layer/Features	Type Geometry	REFERENCE SYSTEM	Source	Note
	DPCN—Dipartimento Protezione Civile Nazionale—Earthquake seismic in Centro Italia 2016/2017 S.A.E., containers and MAPRE maps	Vector point (CSV)	WGS84	<a href="https://mappe.protezionecivile.gov.it/it/mappe-e-dashboards-emergenze/mappe-terremoto-centro-italia-2016/soluzioni-abitative-emergenza">https://mappe.protezionecivile.gov.it/it/mappe-e-dashboards-emergenze/mappe-terremoto-centro-italia-2016/soluzioni-abitative-emergenza</a> (accessed on 30 June 2023)	General information (emergency regulations, text, sheets and tables) used as attribute of new entities to all scale of representations
	S.A.E. and MAPRE maps, costs, emergency ordinance	Vector point (CSV)/Raster	WGS84	Marche region portal <a href="https://www.google.com/maps/d/u/0/viewer?mid=1Uvms09-j32fvffTlnUJJqxdkOLDA4gPZ&amp;ll=43.06005992525631%2C13.088461436448382&amp;z=17">https://www.google.com/maps/d/u/0/viewer?mid=1Uvms09-j32fvffTlnUJJqxdkOLDA4gPZ&amp;ll=43.06005992525631%2C13.088461436448382&amp;z=17</a> (accessed on 30 June 2023)	Interactive map created in google map with attribute and media, sheets, table, design drawing, ordinance documents used to populate the attributes at all scale of representations
Territorial scale (1:10,000–1:25,000)	Municipal, provinces and regional administrative unit	vector polygon	WGS 84 UTM 33N	ISTAT 2023 <a href="https://www.istat.it/it/archivio/222527#:~:text=1%20confini%20delle%20unit%C3%A0%20amministrative,in%20contestazione%20e%20isole%20amministrative">https://www.istat.it/it/archivio/222527#:~:text=1%20confini%20delle%20unit%C3%A0%20amministrative,in%20contestazione%20e%20isole%20amministrative</a> (accessed on 30 June 2023)	
	Characteristics of the territories affected by the 2016/2017 earthquake	Sheets (DBMS)	-	ISTAT—Sisma 2016 <a href="https://www.istat.it/it/archivio/199364">https://www.istat.it/it/archivio/199364</a> (accessed on 30 June 2023)	Data in table form: census data, demographic data, contact details of all emergency managers, inventory of essential resources used as attribute at territorial scale.
	Marche Regional Technical Map (CTR—Cartografia Tecnica Regionale base cartography) First Publication 2000 Flight years 1989–2000 scale 1:10,000	Vectorial (DXF) Raster WMS	WMS in UTM/ED50 Fuso 33	Marche region portal <a href="https://www.regione.marche.it/Regione-Utile/Paesaggio-Territorio-Urbanistica/Cartografia/Repertorio/Cartatecnicanumerica110000">https://www.regione.marche.it/Regione-Utile/Paesaggio-Territorio-Urbanistica/Cartografia/Repertorio/Cartatecnicanumerica110000</a> (accessed on 30 June 2023)	Cartographic base updated with new information

After the conceptual and logical model was developed, the first LODs were populated with pre-disaster features derived from the Technical Map (1.2000) updated with new geometries and attributes obtained from high-resolution satellite images and 3D metric UAV survey data. The shapefiles corresponding to LOD0 and LOD1 were organized according to the Lazio DBGTT standard, incorporating new reference IDs to establish connections with thematic information tables.

To accurately describe the topography of temporary settlements, DSM and DTM raster layers were used with QGIS tools and algorithms, which allowed for the definition of contour lines and extraction of heights for the emergency buildings and retaining walls. For example, the QGIS “zonal statistics” algorithm was used to estimate elevation metrics, providing various statistics for each zone of a polygonal vector layer based on the raster layer values within those zones [19]. The calculation of building height was determined by the difference between the median DSM value and the minimum DTM value. Additionally, profile sections (Figure 10) were extracted using the “terrain profile” QGIS plugin, which confirmed the sequential arrangement of emergency structures in relation to significant landforms and the extensive dimensions of these settlements.



**Figure 10.** LODs of temporary housing in Visso case study, with an extracted section of the S.A.E. Villa S. Antonio. QGIS project with the 3D map.

To visualize and query 2D geometric entities and 2.5D models of buildings and retaining walls, the external databases were connected in GIS using a simple join function and direct relation to specific IDs. For enabling multiscale analyses, the 3D model visualization was realized with the “3D Map” QGIS function, allowing customization of visualization styles and properties and querying individual geometries using the standard 2D selection window display. Thanks to the relationship between objects, navigating the attribute tables and obtaining additional information about the entities in the database became possible. Figure 11 shows a database query applied to a unit settlement, displaying the photo and associated documents describing the design details.



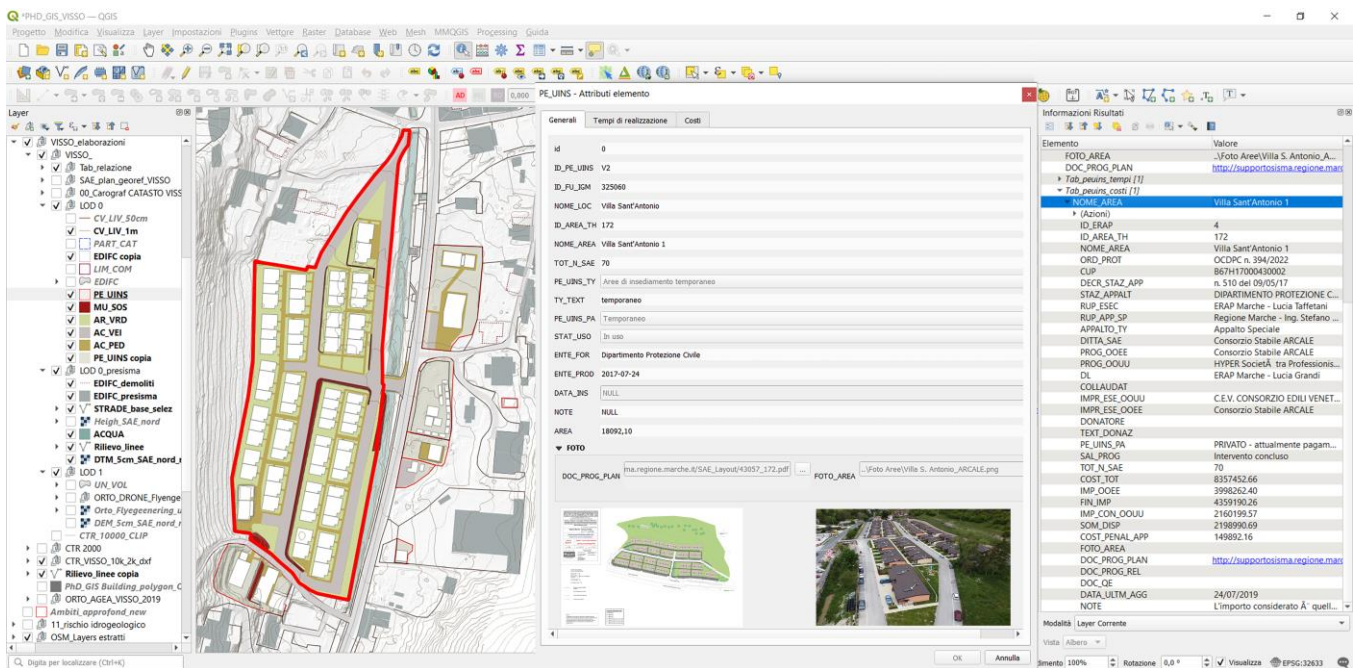


Figure 11. QGIS DB with an attribute query with media link of a temporary unit settlement.

## 5. Discussion and Conclusions

The emergency response to post-earthquake events in Italy has resulted in the creation of long-lasting temporary architectures, leading to significant changes to landscapes and ongoing management challenges. However, the existing official national cartographies lack consistent data representation and updated information on emergency features in their semantic specifications. To address these limitations, going beyond point geolocation of the territorial scale, this study has applied consolidated tools to develop a multiscale knowledge base methodology that provides detailed geometric information (e.g., buildings, roads, pedestrian areas, slopes) and new semantic attributes for temporary housing transformations. This research highlights the importance of enhancing the interoperability between different domains, data models, and software. Utilizing UAV surveys and post-processed data, the contribution analysed the orographic and morphological changes in the case study, establishing connections between temporary structures and damaged buildings. The integration of data specifications and geomatic survey tools expanded the methodology. This could make it applicable to other disaster-affected areas and enables a transition from a two-dimensional scale to a three-dimensional restitution of simplified volumes (LoD0–LoD2). The proposed methodology employs INSPIRE data meeting the requirements of different application domains, and it could be used: (1) to extend the modelling of physical phenomena with large-scale 2D and 3D mapping, detailing the medium and settlement scale data; (2) to estimate the impact of risk and emergency domain, and support risk management by identifying all the different building, settlement or governmental services used in the case of hazard emergency with 3D geometry; and (3) to understand urban expansion with integrated monitoring to structure a land-use classification for post-disaster temporary responses. According to the principles underlined by the European SENDAI framework for disaster risk reduction, this research mainly addresses point four of “enhancing disaster preparedness for effective response and to “Build Back Better” in recovery, rehabilitation and reconstruction” [70,71], emphasizing the importance of introducing new semantic specifications for post-emergency conditions and integrating geomatic surveys and tools as a standard practice. These steps are crucial for generalizing and standardizing the representation language of post-emergency provisional elements, leading to a better understanding and their potential adoption by relevant technical offices, including those in small municipal administrations. This integrated approach utilizes existing emergency

data, aerial and terrestrial photogrammetry data, and regulatory and project documents to implement data standards and inform future generations about disaster losses, damage databases, and the management of temporary recovery infrastructures [72]. The originality of the Atlas of Temporary Architectures in post-seismic scenarios lies in the integration of two-dimensional spatial documentation with high-resolution aerial photogrammetry orthophotos and three-dimensional documentation by UAV surveys. A possible limitation of the proposed method is the potential restrictions on the UAV flight in the survey area. Regulations governing the flight of UAVs around the world differ from one country to another, therefore it is recommended to always adhere to the regulations in force in the survey area. However, given the public interest nature of this type of activity, obtaining the necessary permits from the competent authorities to fly even in prohibited areas should be simple.

Future works should focus on different topics, including: (1) improving utilization of UAVs and additional geomatic tools to study landform modification in emergency situations; (2) developing algorithms for the automated extraction of geometry to minimise manual vectorization time using machine learning approaches; (3) utilizing geometric data to generate simplified 3D BIM models to aid systemic spatial documentation; (4) integrating with numerical methods for coherent site selection in relation to degrees of vulnerability and for the evaluation of possible transformation scenarios; (5) developing of a complete Spatial Data Infrastructure, as (or realised as) an Application Domain Extension (ADE) in a compliant CityGML dataset, based on the proposed conceptual model to extend the applicability of a specific semantic domain for post-emergency recovery in similar contexts, allowing interoperability between different environments, such as GIS, BIM, and existing documentation.

In conclusion, the absence of a consolidated framework for mapping temporary housing that becomes permanent currently complicates the entire workflow and means it does not go beyond the experimental. However, the shared post-emergency 3D multiscale geodatabase system offers the opportunity to establish a detailed and interoperable archive with other compliant maps and the storage of processual and design documents. While the proposed method and tool focused on the effects of the emergency response to seismic risk in Italy, they can also be considered applicable to different types of natural and man-made disasters that require the organization of temporary post-emergency camps and other structures involving significant urban transformations. This framework could be utilized to study the geospatial documentation of the effects of global crises that result in the permanence of previously considered transitory situations, such as refugee camps, enabling a systemic dialogue between risk prevention, management issues, and future directions in emergency planning. It could also support experts in studying initial temporary urban expansions and the design requirements for future urban transformation scenarios. For example, the detailed soil knowledge obtained from photogrammetric data, as highlighted in this contribution, helps implement preventive measures, such as reserving sites for temporary housing, thereby avoiding further land consumption. This research represents a step closer to making information about post-emergency temporary phenomena transparent, accessible, measurable, and manipulable in order to support design requirements and different visualisation scales.

**Author Contributions:** Conceptualization, I.T.; methodology, I.T.; software, I.T. and F.P.; validation, I.T.; formal analysis, I.T.; investigation, I.T.; resources, I.T.; data curation, I.T. and F.P.; writing—original draft preparation, I.T., F.P. and R.P.; writing—review and editing, I.T., F.P., R.P., A.M.L. and E.S.M.; visualization, I.T.; supervision, I.T.; project administration, I.T. and A.M.L. All authors have read and agreed to the published version of the manuscript.

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