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Operational Sectorization for Earthquake Response: A Mixed-Methods Quality Analysis and Revised Generation Approach for Switzerland and Liechtenstein

GEO 511 Master's Thesis

Author: Michael Fehr, 19-729-011

Supervised by: Dr. Tumasch Reichenbacher, Thomas Kühni (Thomas.Kuehni@soe-ods.ch), Sandro Nardi (Sandro.Nardi@risktec.io)

Faculty representative: Prof. Dr. Sara Irina Fabrikant

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Universität Zürich[UZH]

Department of Geography, University of Zurich
Master of Science in Geography
Specialisation: Geographic Information Visualization and Analysis

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Supervisors:
Dr. Tumasch Reichenbacher, UZH
Thomas Kühni, EDO
Sandro Nardi, risktec

Faculty Member: Prof. Dr. Sarah Fabrikant

Author: Michael T. Fehr, Neumarkt 17, 8001 Zürich
Matriculation number: 19-729-011
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Abstract

Post-earthquake building usability and damage assessment in Switzerland and Liechtenstein is coordinated through the TERMOT platform of the Earthquake Damage Organisation (EDO), which partitions the two countries into approximately 513,000 pre-defined operational sector polygons that structure expert team deployment following a damaging earthquake. Despite their operational significance, these sectors have never been subjected to a systematic, scientifically grounded quality evaluation, and their underlying generation algorithm has never been compared against alternative approaches.

This thesis develops and applies a sequential mixed-methods framework to fill this gap. A qualitative content analysis following Mayring (2014) of a stratified sample of 60 Swiss sectors identifies three recurring structural problem categories: Size and Workload Imbalance (36.7% of sectors), Spatial Inefficiency (33.3%), and Boundary Incoherence (20.0%), all traceable to a single algorithmic root cause: infrastructure-line geometry applied before building distribution is considered. These categories are operationalised into quantitative GIS metrics and validated through Cohen's Kappa, with two of three primary metrics meeting the threshold for substantial agreement ($\kappa = 0.964$ and $\kappa = 0.669$).

A revised sector generation algorithm is developed that inverts the generative logic: density-adaptive K-Means clustering of building locations replaces infrastructure lines as the primary input, with infrastructure features applied as hard boundary constraints through constrained Voronoi tessellation. Applied as a proof-of-concept across six municipalities spanning urban, intermediate, and rural settlement contexts, the revised approach reduces the proportion of sectors with at least one identified structural problem.

A three-step scenario-based application (pre-earthquake workload scoring, post-earthquake priority classification, and operational team allocation) demonstrates how structurally improved sectors can be integrated with SED ShakeMap inputs, the ERM-CH23 exposure model, and the Swiss Rapid Impact Assessment (RIA) system to support deployment decisions at sector granularity. Applied to a hypothetical Mw 6.0 Bern scenario, the framework produces operationally differentiated priority classifications and a structured Action Plan that respects cantonal jurisdictional constraints.

The thesis makes three contributions: the first systematic metric-based quality assessment of a nationally pre-computed post-earthquake sector library, a design separation between geometric partitioning and workload assignment not previously applied to disaster-response sectorization, and an operational link between upstream Swiss earthquake risk products and downstream field deployment at sector granularity. The revised pipeline requires no new data sources beyond those already integrated in TERMOT, offering a direct pathway to national implementation.

Keywords: earthquake response, spatial sectorization, GIS-based quality assessment, K-Means clustering, Voronoi tessellation, Mayring content analysis, crisis management, TERMOT, EDO

Acknowledgement

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I would also like to thank Thomas Kühni, CEO of the Earthquake Damage Organisation, for his immense support of this thesis in his role as an external supervisor. He continuously enabled access to key documents, systems, and contacts, and supported the project with valuable insights and encouragement throughout its entire duration.

Last but not least, I would like to thank Sandro Nardi, my third supervisor and colleague at risktec, as well as Samuel Wildhaber. While Sandro Nardi and Samuel Wildhaber laid the foundation for this research by connecting the relevant people, topics, and prior work, I learned a great deal from their extensive domain knowledge and the substantial preparatory work they have contributed to this field. I would also like to thank Noe Javet for his valuable support in the technical implementation and programming aspects of this thesis, which was instrumental in overcoming practical challenges and advancing the development of the proposed approach.

With the completion of this thesis, an important, long and formative academic chapter comes to an end. Over the past eleven years, professional work and academic studies, from HMS through KME to the master's degree at University of Zurich, went hand in hand. It is with joy and a sense of pride that I reach this point and submit this thesis. I am deeply grateful to my family and friends for their continued support, understanding, and encouragement during this journey, which has now reached a meaningful conclusion.

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Abbreviations

BABS	Federal Office for Civil Protection *(German: Bundesamt für Bevölkerungsschutz)*
BAFU	Federal Office for the Environment *(German: Bundesamt für Umwelt)*
BZG	Federal Act on Civil Protection and Civil Defence *(German: Bevölkerungs- und Zivilschutzgesetz)*
EDO (SOE)	Earthquake damage organization *(German: Schadenorganisation Erdbeben)*
GWR	Federal Register of Buildings and Dwellings *(German: Gebäude- und Wohnregister)*
KFO	Cantonal Emergency Management Organization *(German: Kantonale Führungsorganisation)*
SED	Swiss Seismological Service *(German: Schweizerischer Erbebendienst)*

1. Introduction

Earthquakes, though infrequent, remain one of the highest-impact natural hazards in Switzerland (BABS, 2023). Effective post-earthquake response requires rapid coordination among stakeholders, clearly defined organisational structures, and access to reliable spatial information to support situational awareness and decision-making (Alexander, 2015; UNISDR, 2015). The Earthquake Damage Organisation (EDO) and its digital platform TERMOT play a central role in this process, using predefined spatial units called sectors to guide expert teams and ensure consistent communication across the affected area, focusing on the building usability assessment and management of building damages. This thesis examines the sector concept underlying TERMOT and proposes a new sector generation approach to support a more efficient and resilient earthquake response in Switzerland and Liechtenstein.

1.1 Motivation

Earthquakes are among the most impactful natural hazards in Switzerland and pose a significant risk to society, infrastructure, and the national economy (SED, 2023). Past events, such as the 1356 Basel earthquake, one of the most destructive seismic events in Central European recorded history, illustrate that destructive earthquakes can occur even in regions of moderate tectonic activity (Fäh et al., 2009). Modern risk assessments repeatedly identify earthquakes as high-impact, low-frequency events with the potential to cause widespread damage and long-term societal disruption (BABS, 2025). Switzerland's combination of dense settlement patterns, complex topography, and interconnected critical infrastructure means that even a moderate seismic event could have disproportionate consequences for public safety and economic continuity (BABS, 2026).

In this context, rapid and coordinated post-earthquake building usability assessment is essential to restore normality, support affected populations, and prioritise reconstruction efforts. Post-earthquake response operations require the mobilisation of numerous expert teams, including engineers and insurance specialists, who must work under time pressure, often in partially inaccessible or damaged environments, and with rapidly evolving situational information (BABS, 2018, 2021).

To address these challenges, Switzerland has established the Earthquake Damage Organisation (EDO), referred to in German as Schadenorganisation Erdbeben (SOE). The organisation orchestrates the personnel and provides the technical resources required after a major earthquake to assess damaged buildings regarding their usability and estimate the expected costs of reconstruction or repair. In addition, EDO supplies cantons with building data and the necessary IT infrastructure to support the assessment of building habitability and the estimation of reconstruction costs. These estimates form an important basis for potential requests for federal financial assistance and for insurance compensation. The digital platform TERMOT supports these processes by enabling the coordination and documentation of post-earthquake building assessments across Switzerland and Liechtenstein (SOE, 2021b).

A core element of the operational workflow within TERMOT is the subdivision of Switzerland and Liechtenstein into so called sectors. These are small spatial units used to distribute assessment tasks among expert teams and to structure the overall field operation (SOE, 2023, 2024). While the sector concept is fundamental to EDO operations (will be further described in Chapter 2) its current design has evolved historically and lacks systematic scientific evaluation. Enhancing the sector design could significantly improve both countries emergency response capability by enabling clearer spatial organisation, task allocation, better resource management, and a more robust digital workflow.

This thesis is motivated by both scientific curiosity and direct practical relevance. On the one hand, it contributes to the academic field of spatial optimisation in crisis management, applying and extending established GIS and geospatial methods to a real-world coordination problem. On the other hand, the results of this work may be directly integrated into an operational system. This rare combination, where academic research directly shapes a live national emergency platform, makes this thesis not only scientifically meaningful, but also a genuine contribution to Switzerland's earthquake preparedness.

1.1.1 Problem Statement

The current sector definitions in the TERMOT platform are generated through an automated, rule-based geo-processing pipeline that subdivides the territory of Switzerland and Liechtenstein into spatial units based on a combination of administrative boundaries, hydrological features, road and rail networks, and land cover data (Cotovanu, 2023). Buildings from the Federal Register of Buildings and Dwellings (GWR) are then spatially joined to these units, and the resulting polygons are iteratively merged or split to enforce a building count range of 10 to 30 buildings per sector.

While this approach produces a nationally consistent and reproducible set of sectors, the resulting sector library has, to the author's knowledge, never been subjected to a systematic, empirically grounded quality evaluation since its operational deployment. Known technical limitations have been documented in internal reviews, but their aggregated effect on sector quality, and the question of whether the generative logic itself reproduces these limitations structurally rather than incidentally, remain open.

Specific algorithmic choices can raise concerns. The subdivision of sectors exceeding 30 buildings is performed through quadrant-based splitting, which recursively divides polygons into four equal geometric parts regardless of the underlying street network, topography, or accessibility. This produces sector boundaries that can cut across roads, and natural barriers, creating units that are geometrically regular but operationally difficult to assess as a coherent spatial unit. Additionally, the land cover data used to define urban settlement boundaries has been identified as partially outdated, potentially leading to misclassification of urban and rural areas and inappropriate sector granularity in affected regions (Cotovanu, 2023).

These observations point to a broader structural question: whether the existing sector generation pipeline produces operationally suitable sectors across the heterogeneous Swiss settlement landscape, or whether its reliance on geometric criteria alone introduces systematic deficiencies that only become visible under empirical examination. This question motivates the systematic assessment and redesign work developed in this thesis.

1.2 Objective of Thesis

The overarching goal of this thesis is to provide actionable recommendations for improving the sector-generation approach in TERMOT, thereby supporting the broader mission of enabling rapid, consistent, and resilient post-earthquake building assessment across Switzerland and Liechtenstein.

To reach this goal, the research pursues five sub-objectives, each defined as a distinct analytical action. These sub-objectives structure the methodology described in Chapter 3 and map directly onto the research questions formulated in Section 1.2.2.

- **Analysis of the status quo**: The existing sector system is examined using both qualitative observations and quantitative indicators. Rather than assessing individual sectors in isolation, the analysis aims to identify recurring patterns of structural deficiencies across all sectors. These patterns are subsequently abstracted and organised into problem categories that serve as the empirical foundation for all subsequent steps.

- **Development of a quantitative assessment framework**: The identified problem categories are operationalised through a set of quantitative metrics. These metrics translate qualitative problem patterns into measurable, reproducible indicators of sector quality, enabling consistent assessment across the entire study area. This framework forms the basis for both the evaluation of the existing system and the comparison with the improved approach.

- **Development of an improved sector generation approach**: Building on the empirically identified problem categories and informed by insights from expert interviews and scientific literature, a revised sector generation approach is introduced. The new approach explicitly targets the structural deficiencies identified in step 1 above and is therefore directly derived from empirical findings rather than conceptual assumptions alone.

- **Quantitative validation and comparison**: The existing and the newly developed sector approaches are evaluated using the same set of metrics defined in the second sub-objective, enabling a direct, transparent, and reproducible comparison. Improvements are thereby empirically demonstrated rather than merely inferred.

- **Earthquake-specific application**: The validated sector system is extended to an earthquake-specific operational context. The improved sectors are interpreted as operational units supporting workload estimation, prioritisation, and resource allocation under post-earthquake conditions. This step explicitly distinguishes between pre-event processes, focused on sector quality and workload potential, and post-event processes, centred on prioritisation and allocation logic.

1.2.1 Research Gap

As introduced above, the automated generation of operational sectors is a core component of the TERMOT platform, enabling the structured assignment of field experts to geographically defined work units across Switzerland and Liechtenstein. Despite its operational importance, the existing sector generation approach has not been subjected to a systematic, scientifically grounded quality evaluation. The system was developed under practical engineering constraints, prioritising functional completeness over methodological rigour in the spatial partitioning logic.

A closer review of the scientific literature, developed in detail in Section 2.2.5, reveals that this is not an isolated omission. Post-earthquake spatial response has been studied primarily through event-specific structures such as cordons and red zones (Shrestha et al., 2022; Underwood et al., 2020), while international procedural frameworks for rapid building evaluation such as the ATC-20 (ATC, 2005), or the FEMA P-2055 (FEMA, 2019), define how individual buildings should be inspected but do not prescribe a pre-computed, nationally complete spatial partition to support that process. The use case addressed by TERMOT, a nationally pre-computed, building-level sector library, designed to serve both preparedness and operational response from the same geometric basis has, to my knowledge, no documented equivalent in the scientific literature or in international practice.

This combination defines a two-level gap. At the system level, the existing TERMOT approach, which polygonises geographic features and applies fixed building count thresholds, does not account for building density variation or the structural heterogeneity of Switzerland's diverse settlement typologies, and has never been empirically validated. At the field level, the broader question of how such a pre-computed, nationally complete sector library should be designed, evaluated, and operationalised has received limited scientific scrutiny despite its relevance for earthquake-prone countries implementing comparable preparedness systems.

This thesis addresses both levels. Chapter 3 introduces a systematic evaluation framework, combining qualitative content analysis with quantitative GIS metrics and Cohen's Kappa validation, to identify and categorise recurring deficiency patterns in the existing sector library. Building on these findings, it develops a revised, data-driven sector generation approach as a proof-of-concept, applied across a representative set of municipalities covering urban, intermediate, and rural contexts, and extends the revised system into an earthquake-specific operational framework for workload estimation, priority classification, and team allocation.

1.2.2 Research Questions

The research is guided by one main research question and three sub-questions. The sub-questions structure the analytical process and correspond to the methodological stages described in Chapter 3. The research is situated within the field of applied GIScience, drawing on methods from spatial analysis, geoprocessing, and cartographic representation to address an operational challenge in emergency management. The main research question is:

How can spatial analysis and GIS-based methods be used to systematically assess and improve the quality of the TERMOT sector system as an operational geographic framework for post-earthquake building usability- and damage assessment in Switzerland and Liechtenstein?

The three sub-questions are:

- **Research Question 1:** What spatial and structural deficiencies characterise the existing TERMOT sectors, and which GIS-based metrics and spatial indicators are suitable for operationalising these deficiencies into reproducible quantitative measures of sector quality?

- **Research Question 2:** How can an improved, GIS-based sector generation approach be designed that explicitly addresses the identified deficiencies, and to what extent does this approach demonstrate measurable spatial improvements over the existing system when evaluated using the same quantitative assessment framework?

- **Research Question 3:** How can the validated sector system be applied as a spatially explicit operational framework for workload estimation, geographic prioritisation, and resource allocation in a post-earthquake scenario?

1.3 Scope of Thesis

This thesis focuses on the analysis, evaluation, and improvement of the sector system used within the TERMOT platform of the EDO. The research is structured along two thematic phases: a general analytical phase concerned with the geometric and spatial quality of sectors independent of any specific event, and an earthquake-specific application phase in which the improved sectors are interpreted as operational units under post-earthquake conditions.

The thematic focus lies exclusively on building assessment, covering the building usability assessment and the damage assessment, as defined within the EDO framework (SOE, 2021b). The assessment of infrastructure such as roads, utilities, or transport networks falls outside the scope of this thesis. Similarly, the research addresses the sector system as a spatial planning component and does not evaluate the broader operational effectiveness of post-earthquake response, nor does it examine the full civil protection system of Switzerland and Liechtenstein. The institutional scope is limited to the EDO and its operational tool TERMOT, including the roles of cantonal authorities and cantonal building insurances as key stakeholders in the damage assessment process.

Within TERMOT, the analytical focus is specifically on sector definitions and their spatial quality. Improvements to other components of the TERMOT platform, such as its user interface, data infrastructure, or reporting functionality, are not within the scope of this work.

1.3.1 Study Area

The study area of this thesis comprises the entire national territories of Switzerland and the Principality of Liechtenstein, corresponding to the full operational extent of the EDO. All buildings are integrated into the TERMOT platform, organised into predefined sectors for use during post-earthquake response (Cotovanu, 2023). The analysis draws on national geodata including the GWR building register, swissTLM3D topographic datasets, swissBOUNDARIES3D administrative boundaries, and the existing EDO sector geometries. By situating the research within the exact geographical and institutional context of the EDO system, the thesis examines sector structures as they exist and are operationally deployed across both countries.

1.4 Structure of the Thesis

This thesis is organised into six chapters that follow a coherent analytical logic, progressing from theoretical foundations through empirical analysis to practical application and conclusion.

Chapter 2 establishes the theoretical and institutional context of the research. It introduces earthquake risk theory and the specific seismic hazard situation in Switzerland and Liechtenstein, before describing the crisis management structures that govern post-earthquake response and the relevant legal and regulatory frameworks. The chapter further introduces the EDO and the TERMOT platform and examines the concept of sectorization in crisis management, both from a theoretical perspective and as currently implemented in TERMOT.

Chapter 3 presents the methodology in detail. Following an overview of the overall research design, the chapter describes the data collection process, including document analysis, expert interviews, and a targeted literature review, from which the requirements for well-designed sectors are derived. The analytical framework is then developed, involving both a qualitative and quantitative assessment of the existing sector system. Building on these findings, a revised sector generation approach is designed and described. The chapter concludes with the validation strategy, which compares the existing and new sectors using the same set of metrics, and a scenario-based application that extends the improved sectors to an earthquake-specific operational context covering workload estimation, prioritisation, and resource allocation as a proof of concept.

Although the methodology and results are closely interrelated, they are presented in separate chapters, ensuring that the analytical framework is fully established before the findings are introduced.

Chapter 4 presents the results corresponding to each methodological phase: the identified limitations of the current sectorization, the outcomes of the new sector generation, the validation results, and the findings of the scenario-based application.

Chapter 5 discusses and interprets the key findings in relation to the existing literature, reflects on the implications for practice, and acknowledges the limitations of the research.

Chapter 6 concludes the thesis by summarising the main findings, answering the research questions, and providing recommendations for the further development of the TERMOT sector system, followed by an outlook on future research directions.

The remaining chapters include an overview of the literature referenced in this thesis, the appendix with supporting material, as well as a personal declaration.

2. Theoretical Background

This chapter establishes the theoretical and institutional foundations necessary to contextualise the research presented in this thesis. It begins with an introduction to earthquake risk theory and the specific seismic situation in Switzerland and Liechtenstein, before examining the crisis management structures that govern the post-earthquake response in both countries, including relevant legal and regulatory frameworks. The chapter concludes with a detailed discussion of the EDO and the TERMOT platform, as well as the concept of sectorization in crisis management and its current implementation.

2.1 Earthquake Risks

Earthquake risk is the central hazard context of this thesis. Understanding what earthquake risk means, how it is measured, and how it manifests specifically in Switzerland and Liechtenstein is a prerequisite for understanding why a well-organised post-earthquake response, and by extension a well-designed sector system, is necessary. This chapter introduces the theoretical foundations of earthquake risk before applying them to the specific geographic and institutional context of this research.

2.1.1 Earthquake Risk Theory

Earthquakes are natural ground vibrations caused by sudden releases of accumulated stress in the Earth’s crust, typically along geological fault zones (BABS, 2026). Earthquake risk is commonly understood as the result of multiple interacting components encompassing physical, environmental, and socioeconomic dimensions (Wisner et al., 2004). In its most widely applied form, it combines information about seismic hazard, the conditions of the local environment, the vulnerability of the built environment, and the people and assets exposed to potential damage (Wiemer et al., 2023). This conceptual framework has become foundational in geographic disaster risk research and provides the theoretical lens through which the consequences of seismic events can be assessed and managed.

The Swiss Seismological Service (SED) at ETH Zürich operationalises earthquake risk through four interacting factors: earthquake hazard, local soil conditions, vulnerability of buildings, and affected people and assets (Wiemer et al., 2023). Together, these four components determine earthquake risk:

Earthquake Risk =
Earthquake Hazard + Local Soil Conditions + Vulnerability of Buildings + Affected People & Assets

Earthquake hazard refers to the probability that ground shaking of a given intensity will occur at a specific location within a defined time period (Kramer, 1996). It is derived from three main categories of input data: knowledge of regional tectonics and geology, historical earthquake catalogues documenting past seismic activity, and wave propagation models that describe how seismic energy travels through the Earth's crust (Wiemer et al., 2016). Together, these inputs allow experts to estimate where earthquakes of different magnitudes may occur, how frequently they are expected to happen, and how probable certain levels of ground shaking are at a given location. Hazard is typically expressed through probabilistic seismic hazard analysis (PSHA), which produces hazard maps showing the likelihood of exceeding certain ground motion levels and serves as the scientific basis for seismic building codes and risk management decisions (Cornell, 1968; Wiemer et al., 2016).

Local soil conditions describe how the properties of the ground at a specific site influence the intensity of shaking experienced at the surface. Soft or loose soils can significantly amplify seismic waves compared to hard bedrock, meaning that two locations with identical seismic hazard may experience very different levels of ground shaking depending on their subsurface geology (Kramer, 1996). This factor is treated separately from hazard in the SED model because it operates at a finer spatial scale and has a direct, measurable effect on building damage patterns (Wiemer et al., 2023).

Vulnerability of buildings describes the susceptibility of structures to sustain damage when exposed to seismic shaking. It is influenced by factors such as construction type, building age, structural design, and maintenance condition (Wiemer et al., 2023). In the context of geographic risk assessment, vulnerability is not solely a physical property but also reflects social, institutional, and spatial dimensions that shape how communities are able to cope with and recover from hazard events (Wisner et al., 2004). For buildings specifically, vulnerability is often expressed through fragility curves, which relate ground motion intensity to the probability of reaching or exceeding a defined damage state (Kahandawa et al., 2018).

Affected people and assets refer to the number of people, buildings, and economic values located in areas exposed to seismic hazard. High exposure does not automatically imply high risk, but combined with significant hazard and vulnerability, it determines the potential scale of human and financial losses following an earthquake (Wisner et al., 2004).

This four-component framework illustrates why the same earthquake can have vastly different consequences depending on where it strikes and what is built there (Figure 1). A moderate earthquake in a densely populated urban area with old buildings on soft ground poses a far greater risk than a stronger earthquake in a sparsely inhabited rural region with modern, earthquake-resistant construction on solid bedrock (Wiemer et al., 2023).

Figure 1: The four components leading to Earthquake risk (Wiemer et al., 2023)

Beyond direct physical damage, earthquakes trigger a cascade of secondary consequences, including building closures, displacement of residents, disruption of critical infrastructure, and substantial economic losses from repair and reconstruction (Khakurel et al., 2023). The post-earthquake inspection and building assessment process is a critical early step in managing these consequences, as it determines which buildings can be re-entered and thereby directly affects the duration of displacement and the pace of recovery (Khakurel et al., 2023). This underscores the importance of efficient and well-organised building assessment operations – which is precisely the operational context this thesis addresses.

2.1.2 Earthquake Risk in Switzerland and Liechtenstein

In Switzerland, seismic activity is primarily related to the large-scale tectonic interaction between the African and Eurasian plates, which gradually builds up stresses that are periodically released in sudden ruptures. The resulting seismic waves propagate through the Earth's crust and can produce strong ground shaking at the surface (BABS, 2026). Switzerland experiences moderate but significant seismicity, and national risk analyses consistently classify earthquakes as one of the most severe natural hazards in the country in terms of potential damage (BABS, 2020b, 2026).

The Swiss Seismological Service records on average between 1,000 and 1,500 earthquakes per year in Switzerland and its immediate neighbouring regions, of which Swiss citizens actually feel somewhere between 10 and 20 per year, usually those with a magnitude of 2.5 or above as shown in Figure 2 (SED, 2023). On average, a destructive earthquake with a magnitude of approximately 6 can be expected every 50 to 150 years in Switzerland or its neighbouring regions (SED, 2023).

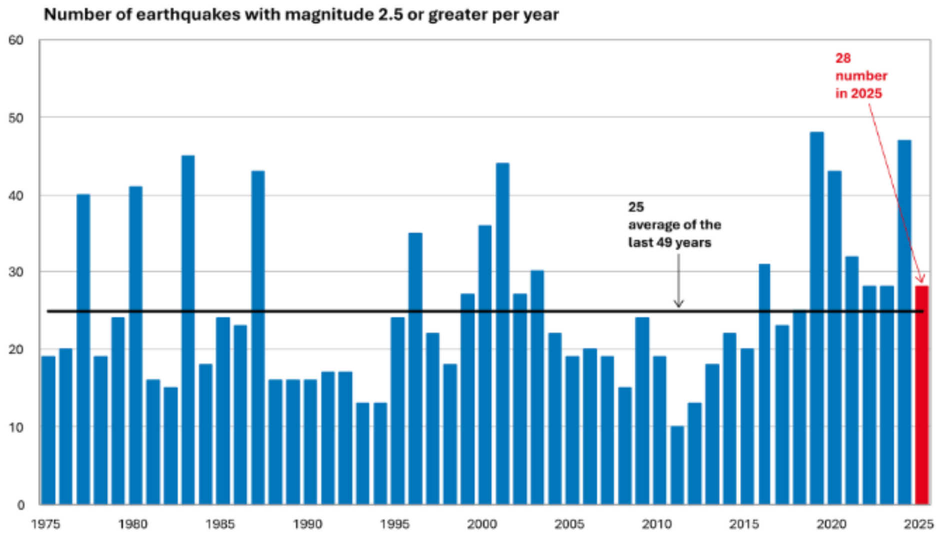


Figure 2: Number of earthquakes with magnitude 2.5 or greater per year (SED, 2023)

The seismic hazard across Switzerland is spatially heterogeneous. Compared to other European countries, Switzerland has a moderate earthquake hazard, but displays regional differences, the canton of Valais having the highest hazard, followed by Basel, Grisons, the St. Gallen Rhine Valley, Central Switzerland and then the rest of the country as shown in Figure 3 below (SED, 2023). These zones are reflected in the official earthquake zone classification of the Swiss building code SIA 261, which categorises cantons into hazard zones ranging from zone 1 (low hazard) to zone 3b (highest hazard) (Wenk, 2005). The Canton of Valais, with hazard zones 3a and 3b, represents the highest seismic hazard in the country, while most other cantons fall within zones 1 and 2 (BABS, 2018).

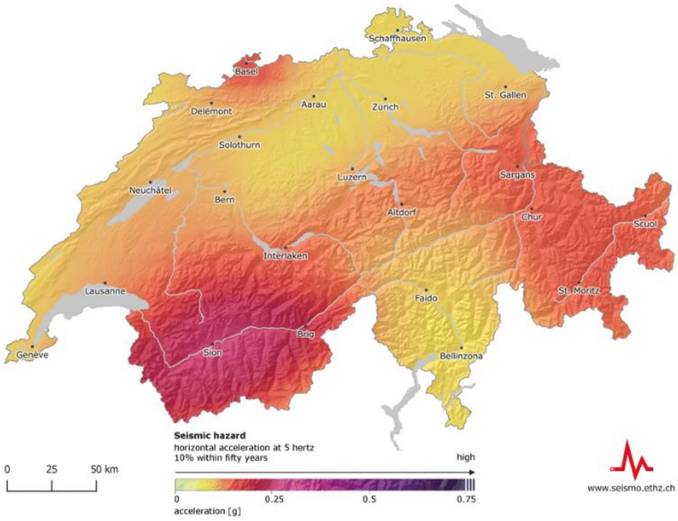


Figure 3: Earthquake Hazard Map of Switzerland (SED, 2023)

However, seismic hazard alone does not determine the overall risk. As established in Section 2.1.1, earthquake risk results from the combination of seismic hazard, local soil conditions, the vulnerability of buildings, and the concentration of people and economic assets (Wiemer et al., 2023).

While earthquake hazard estimates how often and how strongly the ground could shake at given locations in the future, earthquake risk describes the effects on buildings and the associated financial and human losses. The greatest earthquake risk is in the cities of Basel, Geneva, Zurich, Lucerne and Bern, in that order, as shown in Figure 4. Although the earthquake hazard in these regions differs, all five cities have, by virtue of their size, many people and assets that would be affected by an earthquake. In addition, these cities have many buildings, some particularly vulnerable and often located on soft ground that amplifies seismic waves. In terms of expected building damage at the cantonal level, the cantons of Bern, Valais, Zürich, Vaud, and Basel-Stadt are estimated to experience the most severe losses (Wiemer et al., 2023).

Liechtenstein, while not independently covered by a national seismological service, lies within the seismic zone of the St. Gallen Rhine Valley and shares the same exposure context as the surrounding Swiss cantons. Figure 4 below shows the earthquake risk map of Switzerland and Liechtenstein.

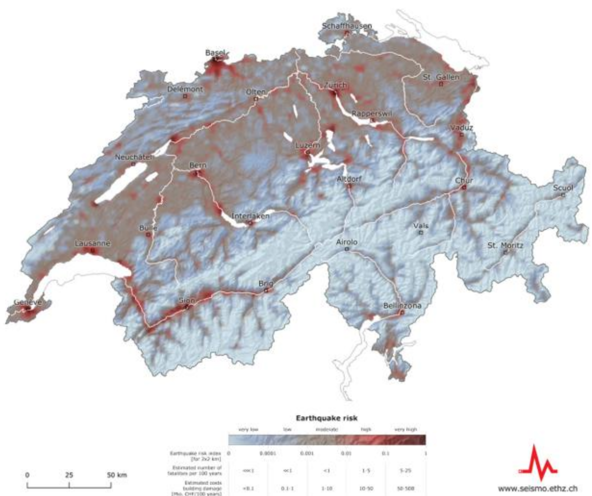


Figure 4: Earthquake Risk Map of Switzerland and Liechtenstein (SED, 2023)

Released in 2023 by the Swiss Seismological Service (SED) at ETH Zurich in collaboration with partner institutions, the Earthquake Risk Model for Switzerland (ERM-CH23) is the first nationally consistent, fully probabilistic earthquake risk model for the country. It integrates seismic hazard, local site effects, building vulnerability, and the spatial distribution of people and assets to produce quantitative estimates of expected building damage, economic losses, casualties, and displacement (Wiemer et al., 2023).

The potential consequences of a major earthquake in Switzerland are substantial. Based on the national Earthquake Risk Model ERM-CH23, destructive earthquakes over a 100-year period could cause economic damage of CHF 11 to 44 billion to buildings and their contents alone, with between 150 and 1,600 fatalities and approximately 40,000 to 175,000 people made homeless (Wiemer et al., 2023). A particularly illustrative historical reference is the 1356 Basel earthquake, the strongest seismic event in Central European recorded history. If a comparable event were to occur today, it would result in approximately 3,000 deaths and building damage estimated at CHF 45 billion (*SED Overview*, 2026).

These figures underscore why rapid and well-organised post-earthquake building assessment is a critical component of Switzerland's emergency preparedness. As shown in representative earthquake scenarios for Switzerland, a magnitude 5.9 event in Central Switzerland alone could require the assessment of up to 120,000 buildings, affecting 460,000 residents and leaving up to 90,000 people temporarily homeless (BABS, 2018). The scale of such an operation highlights the need for an efficient spatial organisation of assessment teams, which is precisely the problem this thesis addresses through the analysis and optimisation of the TERMOT sector system.

2.2 Crisis Management and Sectorization

The earthquake risk context outlined in Section 2.1 makes clear that a major seismic event in Switzerland would overwhelm the routine capacities of emergency services and require a coordinated, multi-level organisational response. Effective disaster response requires mechanisms to coordinate multiple organizations, assign responsibilities, allocate personnel and resources, and maintain situational awareness of the affected area (Auf der Heide, 1989; Bigley & Roberts, 2001; Quarantelli, 1988). Immediately following a major earthquake, response operations typically unfold across several overlapping phases. The initial phase is characterised by chaos, limited situational awareness, and spontaneous self-rescue by affected populations. Emergency services initiate search and rescue operations, fire suppression, and hazard containment, while operators of critical lifeline infrastructure begin restoring essential services such as electricity, water, and telecommunications (BABS, 2026). Effective response during this phase depends on rapid coordination among multiple organisations and the ability to manage information, personnel, and resources under conditions of high uncertainty (Comfort, 2007).

In Switzerland and Liechtenstein, earthquake response is embedded within a structured crisis management framework designed to coordinate actors across federal, cantonal, and organisational levels. This chapter describes how Switzerland has structured its crisis management for such scenarios. It begins with the general principles of integral risk management and the institutional responsibilities in the event of an earthquake (2.2.1), before introducing the specific organisational framework of the Earthquake Damage Organisation and its operational tool TERMOT (2.2.2–2.2.3). The chapter concludes by examining the concept of sectorization as the spatial backbone of post-earthquake building assessment operations (2.2.4-2.2.6).

2.2.1 Crisis Management Systems in CH and LI in case of an Earthquake

Switzerland's approach to managing natural hazard risks is grounded in the principle of integral risk management, which encompasses the continuous identification, analysis, and evaluation of risks, as well as the planning and implementation of measures across all responsible actors (BABS, 2022). Responsibility for protection against natural hazards follows the principle of subsidiarity: municipalities and cantons bear primary responsibility, while the Confederation assumes a strategic leadership role and provides financial and technical support (BABS, 2022).

Integral risk management in Switzerland is conceived as a continuous and cyclical process that spans the entire disaster management spectrum, from prevention and preparedness to response, recovery, and long-term reconstruction (see Figure 5 below). The approach aims to reduce risks to an acceptable level by systematically identifying hazards, analysing potential impacts, evaluating their acceptability, and implementing coordinated measures to reduce vulnerabilities and improve resilience. Importantly, the model emphasises that risk reduction measures should be considered across all phases of the disaster cycle and should involve all relevant actors, including federal and cantonal authorities, emergency services, infrastructure operators, private organisations, and the population itself (BABS, 2022).

Within this framework, disaster management activities are commonly structured into several interconnected phases. Preventive measures aim to reduce vulnerability before an event occurs through legal regulations, spatial planning, building standards, and organisational preparedness. Preparedness measures focus on establishing operational capabilities, including warning systems, emergency plans, training, and resource planning.

When an event occurs, response activities concentrate on rescue operations, damage control, and emergency measures to protect people and critical infrastructure. These are followed by phases of restoration and recovery, during which essential services are re-established and damaged infrastructure is repaired or rebuilt, ideally in a way that increases long-term resilience (BABS, 2022).

In the case of an earthquake, this multi-level structure is activated across all administrative tiers simultaneously. Directly following a major earthquake, the response unfolds across several overlapping phases, as mentioned above. The SED generates a ShakeMap, a spatial representation of ground-shaking intensity, which is typically published within a few minutes of the earthquake origin time. The map provides emergency managers with a rapid overview of the spatial distribution of shaking and areas where damage is likely, thereby supporting the prioritisation of response actions. For earthquakes with a magnitude of 2.5 or greater, both a ground shaking map and a full ShakeMap are produced automatically, serving as an essential decision-support tool for resource deployment (Swiss Seismological Service (SED), 2024).

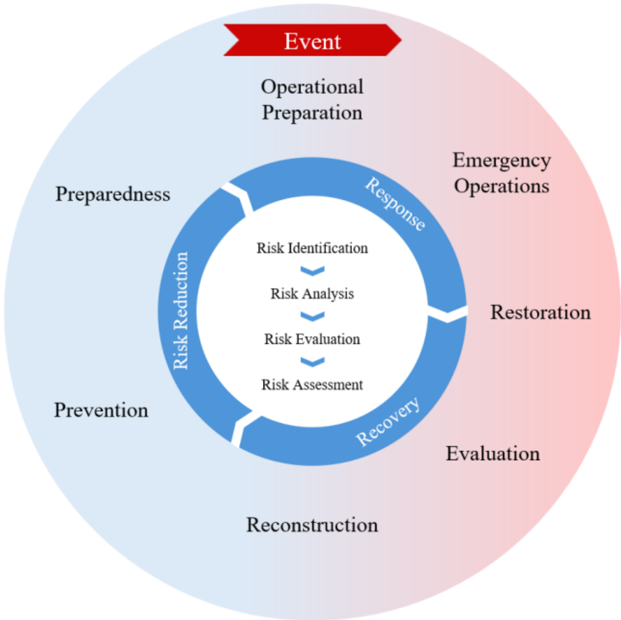


Figure 5: Integral Risk Management Model. Own illustration based on (BABS, 2022)

A critical component of the post-earthquake response is the systematic assessment of buildings to determine habitability. Large numbers of people are made temporarily homeless following a destructive earthquake, and many cannot return to their homes until buildings have been individually inspected and cleared (BABS, 2026). This process can take days to weeks and requires a large, coordinated deployment of specialist building assessment experts across the affected area, as shown in Figure 6 below. The organisation and spatial coordination of this assessment effort is the central mandate of the EDO, which is described in detail in the following chapters.

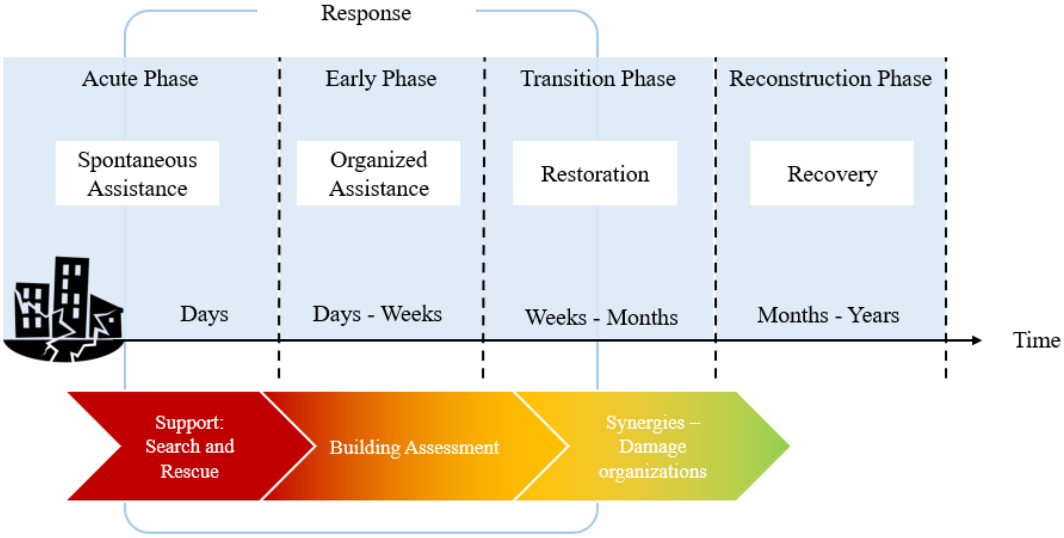


Figure 6: Phases of event response following an earthquake. Own illustration based on (BABS, 2021)

From a Legal perspective, earthquake risk management and disaster response in Switzerland are embedded in a multi-level legal and institutional framework. While this framework does not prescribe specific methodologies for operational planning tasks such as spatial sectorization, it establishes the boundary conditions within which such concepts must function.

The central legal basis is the Federal Act on Civil Protection and Civil Defence (Bevölkerungs- und Zivilschutzgesetz, BZG, 2021), which establishes the principle of subsidiarity: operational responsibility for disaster response lies primarily with the cantons, while the federal level provides coordination and strategic guidance (BZG, 2021). In the event of a major earthquake, affected cantons assume operational leadership through their cantonal crisis management structures, with additional support escalating through inter-cantonal assistance to federal and, in extreme cases, international bodies, as illustrated in Figure 7 (BABS, 2018). This has a direct spatial implication for sector design: because building assessment experts are allocated and authorised at the cantonal level, any sector system must strictly respect cantonal boundaries.

Two technical guidelines are of particular direct relevance. The "Handbuch Gebäudebeurteilung nach einem Erdbeben" (BABS, 2021) defines the national methodology for rapid post-earthquake building usability assessments and specifies the procedural requirements that expert teams must follow in the field, requirements that the sector system must be designed to support. The "Leitfaden Gebäudebeurteilung nach Erdbeben - organisatorische Aspekte" (BABS, 2018) provides guidance on how cantons should organise large-scale assessment operations, including team structures and deployment logic. Together, these instruments define the procedural framework within which TERMOT sectors must function operationally.

In Liechtenstein, civil protection is governed by the Zivilschutzgesetz (BSchG, 2007). Due to the country's centralised governance structure, operational responsibility rests with national rather than regional authorities, and large-scale disaster response relies on cross-border cooperation with Switzerland.

A full overview of the legal and policy framework is provided in Appendix A (Table 21)

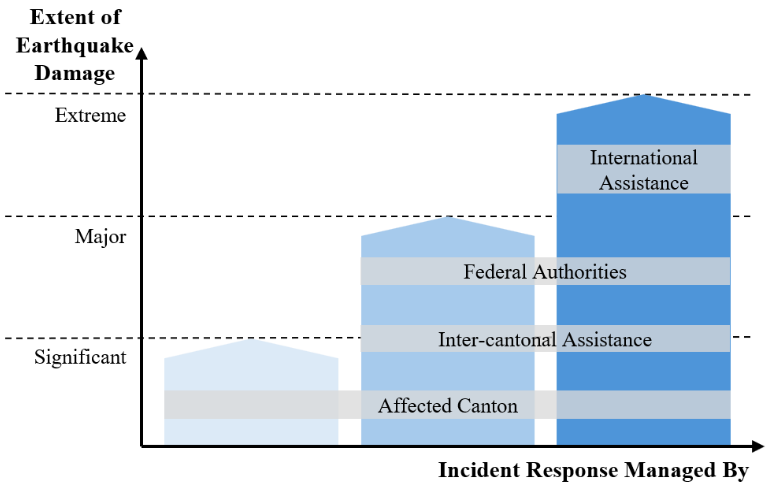


Figure 7: Escalation of response responsibilities depending on the extent of earthquake damage in Switzerland (own illustration based on (BABS, 2018)).

Beyond the legal and institutional structures outlined above, the operational response to earthquakes in Switzerland is increasingly embedded in a coordinated dynamic earthquake risk framework developed by the Swiss Seismological Service and ETH Zurich. Building on ERM-CH23, this framework encompasses the full sequence from seismic monitoring through ShakeMaps and Rapid Impact Assessment to recovery and rebuilding efforts (Böse et al., 2024). ShakeMaps serve as the primary input for the Rapid Impact Assessment system, which estimates damage, economic losses, and shelter needs at national, cantonal, and municipal levels. The framework explicitly identifies the spatial allocation of assessment resources and the identification of priority deployment areas as key steps in the post-earthquake response chain. These are steps that presuppose a well-structured and operationally sound sector system as their spatial foundation. The TERMOT platform and the EDO's building usability assessment operation represent Switzerland's institutional implementation of this response layer, and the sector system examined in this thesis is the spatial infrastructure on which that implementation depends.

2.2.2 Earthquake Damage Organisation

The Earthquake Damage Organisation (EDO), known in German as Schadenorganisation Erdbeben (SOE), is the national body responsible for coordinating building usability and damage assessment following an earthquake in Switzerland and Liechtenstein. Formally established in June 2021 as a public–private association, the EDO is jointly supported by the Swiss cantons, the Principality of Liechtenstein, cantonal building insurers, and private insurance companies (SOE, 2021b, 2021c). Its creation addressed a previously identified gap in Switzerland's earthquake preparedness: prior to its establishment, post-earthquake building assessments were largely decentralised, with cantons responsible for coordinating expert deployment individually and without a shared national framework (SOE, 2021a).

The EDO coordinates two distinct but sequential post-earthquake assessment workflows. The first, building usability assessment, determines whether individual buildings are safe to enter or occupy. This workflow is highly time-critical: it must begin immediately after an earthquake event, as residents cannot return to their homes until their buildings have been individually cleared. Assessment teams work outward from the epicentre, consist exclusively of engineers, and are pre-allocated to cantons by the Federal Office for Civil Protection (BABS). The second workflow, damage estimation, quantifies the financial costs of repair or reconstruction for insurance and federal compensation purposes. It is less time-pressured, proceeds once the most urgent safety assessments are underway, and involves a broader pool of experts such as engineers, architects, and insurance specialists who are allocated directly to sectors without prior cantonal assignment. Damage estimation teams work inward from the outer damage zones towards the epicentre (SOE, 2024; S. Wildhaber, 2022).

Both workflows use the same spatial sector structure within TERMOT, EDOs digital platform, but follow different operational logics, involve different expert pools, and proceed in opposite spatial directions across the affected area.

This dual mandate positions the EDO at the intersection of civil protection and the insurance sector. On the public safety side, it supports cantonal authorities in determining building occupancy. On the insurance side, it provides standardised damage data enabling both cantonal building insurers and private insurers to process claims efficiently (SOE, 2021b). Federal institutions including the SED, BABS, and the Federal Office for the Environment (BAFU) support the EDO through technical expertise and coordination with national earthquake preparedness measures (SOE, 2024).

The coordination and documentation of both workflows is enabled through the digital platform TERMOT, which is described in detail in the following section.

2.2.3 TERMOT

As introduced above, the EDO operates a dedicated digital platform called TERMOT, which supports both preparedness activities and operational response following an earthquake. Figure 8 presents a screenshot of the dashboard of TERMOT. The platform serves as the central technical infrastructure of the EDO by consolidating building data, coordinating expert deployment, and enabling the structured documentation of building assessments and damage estimates (SOE, 2024). The technical architecture of the TERMOT platform was originally defined as part of the detailed system concept developed during the establishment phase of the EDO (Arbeitsgruppe SOE, 2020)

TERMOT operates across two distinct phases: a preparatory phase and an event response phase: During the preparatory phase, which corresponds to the period before any earthquake occurs, the platform remains inactive but maintains a continuously updated database of buildings in Switzerland and Liechtenstein. This database is primarily based on the Federal Register of Buildings and Dwellings (GWR), which is updated quarterly. In addition, the system stores pre-generated spatial sectors in a dedicated sector library. These sectors define the operational units used for field deployment and are prepared in advance to allow rapid activation in the event of an earthquake (SOE, 2024).

Following a damaging earthquake, the EDO board initiates the event activation process within TERMOT. The platform displays all seismic events of magnitude 4.0 or higher recorded within the previous three months. After selecting the relevant event, the board defines a damage threshold based on the seismic risk model of the SED, which determines which municipalities are considered affected and must therefore be activated for damage assessment (SOE, 2024). The activation of an event triggers several automated processes in the background. First, building data from the GWR are refreshed to reflect the state of the building stock at the time of the earthquake. Second, insurance policy data are matched to the affected buildings. Third, the relevant sectors stored in the sector library are copied into the active event and spatially intersected with the affected building dataset. Finally, the public self-service portal for damage reports is activated. According to the operational documentation of the EDO, the complete activation process typically requires approximately three to four hours before the system becomes fully operational for authorised users (SOE, 2024).

Once activated, TERMOT becomes the central coordination platform for all stakeholders involved in the response. The system provides an event dashboard that offers a real-time overview of affected municipalities, the number of buildings requiring assessment, the allocation of expert teams, and the progress of building inspections (SOE, 2024).

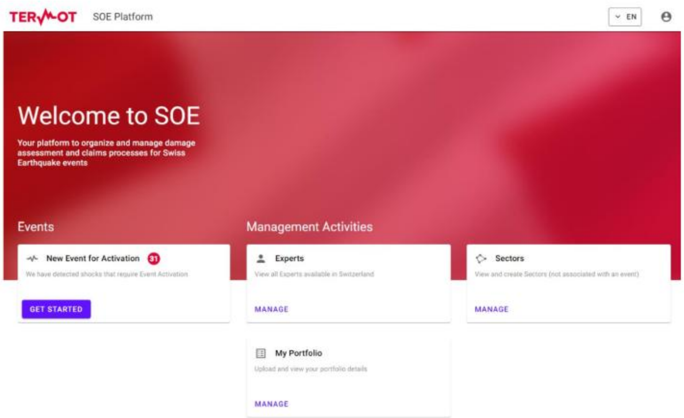


Figure 8: Screenshot of the SOE platform dashboard showing available tiles in the inactive TERMOT platform with role-based access.

The deployment of experts follows a structured workflow coordinated across multiple organisational levels. The BABS determines the number of experts allocated to each canton through the federal resource management process (ResMaB). Cantonal representatives subsequently assign these experts to municipalities, while team administrators allocate them to individual sectors within the TERMOT system. The EDO can mobilise a large pool of trained damage estimation experts, including engineers, architects, and insurance specialists. These experts conduct field inspections of damaged buildings and estimate repair or reconstruction costs. The inspection teams operate according to a four-eyes principle, where two experts jointly assess each building to ensure the reliability and consistency of the evaluation (SOE, 2024).

Experts in the field use TERMOT Mobile (Figure 9) to access their assigned buildings, record inspection results, document damage, and enter habitability assessments and cost estimates directly from their smartphone or tablet. The app is available for both Android and Apple devices, functions offline to ensure usability in post-earthquake field conditions and integrates map navigation to support wayfinding in the affected area (SOE, 2024).

The mobile application supports two principal workflows as described in previously: the building usability assessment and damage estimation workflows respectively. The system is designed to process up to 300,000 damage estimates within one year of a major earthquake event (SOE, 2024).

TERMOT also integrates a public self-service portal that allows property owners to report damage to their buildings. These reports are reviewed by designated administrators before being linked to the corresponding damage case within the system.

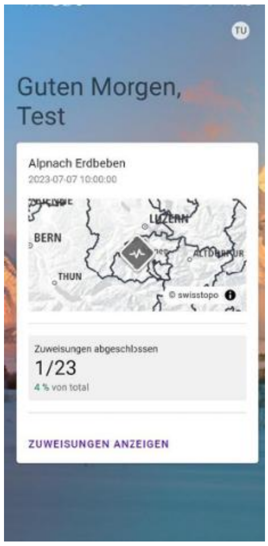


Figure 9: Screenshot of Home screen of TERMOT Mobile

Given the involvement of numerous stakeholders, the platform uses a role-based access system. Cantonal authorities can access only data within their jurisdiction, while insurance companies can view only their own policy information associated with affected buildings. This access structure ensures data security while maintaining operational transparency across the multi-stakeholder organisation (SOE, 2024). Independent security assessments have confirmed that the platform is built on modern and secure technologies and that access to sensitive data is strictly controlled through authenticated user accounts and role-based permissions. External penetration testing conducted in 2023 did not identify critical security vulnerabilities that would compromise the system's operation (Compass Security Schweiz AG, 2023).

A central element of the TERMOT platform is the concept of spatial sectors, which structure the entire field operation. Each sector groups approximately 10 to 30 buildings into a geographically coherent unit that can be assigned to an expert team, scheduled for inspection, and tracked for completion (SOE, 2024). The target range of 10 to 30 buildings per sector reflects an operationally defined workload unit established by the EDO (SOE, 2023), consistent with typical inspection capacities reported in rapid post-earthquake building safety evaluation procedures, where one assessment team can inspect approximately 20 to 30 buildings per working day depending on accessibility and damage complexity. Designing sectors within this range therefore supports balanced workload distribution and efficient allocation of inspection teams during post-event operations (ATC, 2005; FEMA, 2019). In practice, the current sector system deviates from this target. Because sectors are generated from a top-down geospatial process based on administrative and infrastructure features (see Section 2.2.6), the resulting geometries are not adjusted to building density. Many sectors therefore contain fewer than 10 buildings while others contain none at all. Figure 10 shows the approximate counts of each spatial unit, with the caveat that the ~513,000 sectors include both building-bearing and empty units. The extent of these deviations, and their operational implications, form a central focus of Chapter 4. As shown in Figure 10, sectors sit between the municipal and building levels.

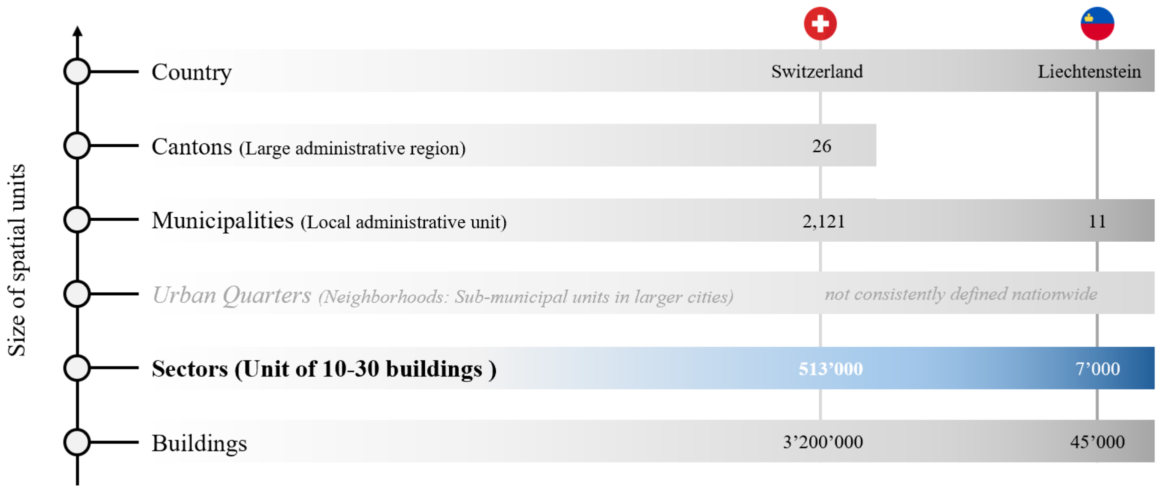


Figure 10: Sectors in Spatial Context for Switzerland and Liechtenstein

The sector structure therefore determines how efficiently expert teams can be deployed, how rapidly the affected building stock can be assessed, and how effectively operational progress can be monitored. Poorly designed sectors, for example those that are too large, too small or spatially fragmented, can create inefficiencies throughout the response process. Conversely, well-designed sectors support balanced workloads, efficient team deployment, and effective coordination of large-scale building assessments.

Understanding and improving the design of these operational sectors therefore represents a key challenge in the implementation of the TERMOT system. This issue forms the central focus of the present thesis.

2.2.4 Sectorization in Crisis Management

As mentioned in the previous chapters, spatial sectorization is a fundamental organizational principle in large-scale disaster response. When a disaster affects extensive geographic areas and large numbers of buildings or people, a coordinated response requires that the affected territory be divided into bounded, manageable operational units (Auf der Heide, 1989; Jiang & Yuan, 2019). Incident management doctrine therefore divides the incident area into geographically defined operational units in order to organize responsibilities and coordinate activities across complex operational environments (Federal Emergency Management Agency, 2017). Without such spatial structure, coordinating hundreds of experts across thousands of buildings spread over multiple cantons would be operationally unmanageable.

The time-critical nature of earthquake response distinguishes it from most other natural hazard scenarios. Unlike hazards that develop gradually and allow for preparatory action in the hours before impact, earthquakes provide no forewarning (BABS, 2020a; Kramer, 1996). Within minutes of a major event, emergency managers must deploy resources, communicate with local authorities, and initiate building assessment operations across a potentially wide and heterogeneous geographic area (Alexander, 2015). This means that all spatial structures used to coordinate response, including sectors, must ideally be fully defined, validated, and ready for activation before any earthquake occurs (ATC, 2005; FEMA, 2019; SOE, 2024). There is no time to define sectors after the fact. This requirement fundamentally shapes the design challenge: sectors must be operationally sound under uncertainty and across diverse spatial contexts, because they cannot be refined once the response clock has started.

The design of spatial operational units involves several inherent trade-offs. Sectors must be small enough to allow a response team to complete its assigned tasks within a defined time window, yet sufficiently large to justify the logistical overhead associated with deployment and coordination. In addition, sector boundaries should ideally align with physical features that structure movement and navigation on the ground while also respecting administrative boundaries that define jurisdictional responsibilities. Finally, sectors must typically be defined in advance to enable preparedness and rapid activation, even though the spatial distribution of actual disaster impacts remains uncertain. These requirements make sector design a complex spatial planning problem that involves balancing operational workload, geographic coherence, and institutional constraints (Caunhye et al., 2012; Galindo & Batta, 2013; Kalcsics et al., 2005).

The quality of this spatial design can directly influence the efficiency of disaster response operations, as well-balanced operational units facilitate the coordinated deployment of teams and resources across affected areas (Galindo & Batta, 2013). This thesis examines this problem in the specific context of the EDO's TERMOT platform, where pre-defined sectors structure the entire post-earthquake building usability assessment operation. The theoretical foundations of sector design are reviewed in Section 2.2.5, followed by a description of how sectors are currently defined in TERMOT in Section 2.2.6.

2.2.5 Theoretical Foundations of Sector Design

The design of spatial operational units for disaster response draws on several intersecting theoretical traditions, each offering different conceptual tools for understanding what makes a sector well or poorly suited to its purpose.

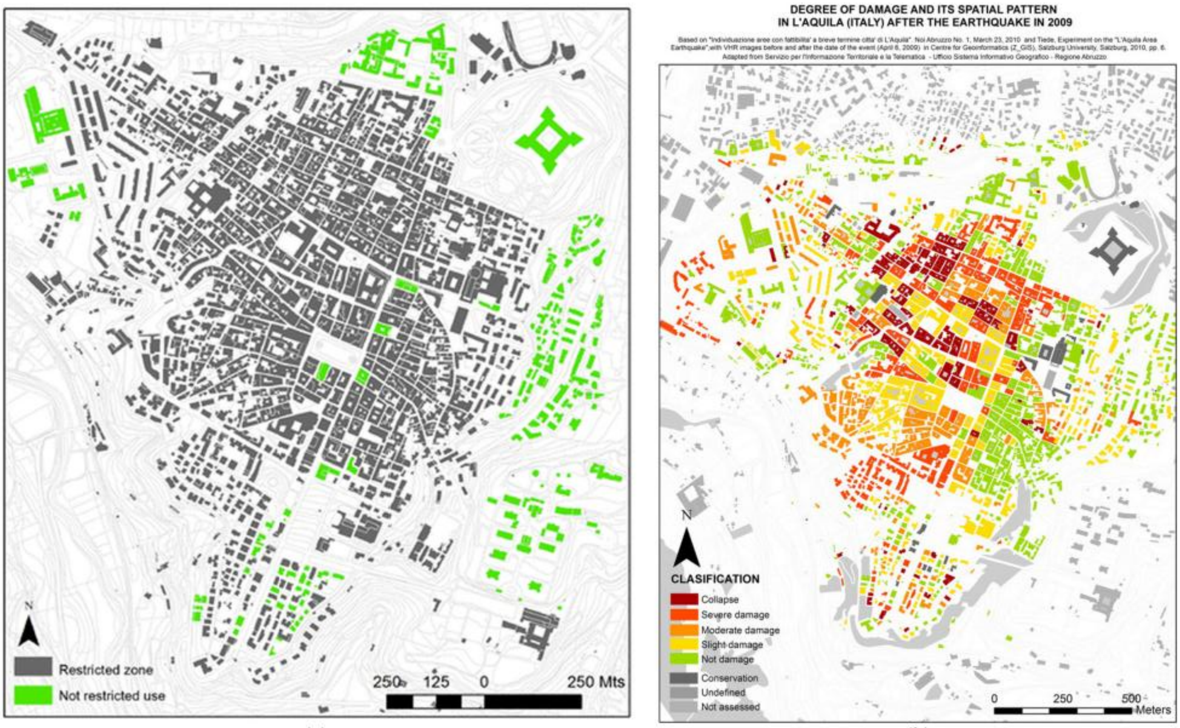
In emergency management practice, spatial sectorization has long been recognized as essential for organizing large-scale disaster response. By dividing a disaster zone into bounded areas of responsibility, it enables parallel execution of response activities, supports hierarchical coordination, and reduces the cognitive and logistical complexity facing individual teams and commanders (Auf der Heide, 1989; Quarantelli, 1988). Operational response frameworks from countries with established earthquake preparedness programmes reflect this principle explicitly: the New Zealand National Society for Earthquake Engineering, for example, recommends dividing affected areas into geographic sectors managed by dedicated Building Evaluation Officers, with each sector assigned to a specific team responsible for rapid and detailed inspections (NZSEE, 1998). The subdivision of an affected area into clearly identified spatial units provides a shared operational reference structure, enabling response organizations to assign responsibility unambiguously, communicate progress, and adapt resource allocation as the operation develops.

From an operations research perspective, classical formulations such as the Maximal Covering Location Problem aim to optimize service provision over spatially distributed demand under resource constraints (Church & ReVelle, 1974). In disaster response contexts, these models inform both the strategic placement of resources and the implicit definition of service areas that structure operational deployment. A large body of research applies optimization approaches to emergency management systems after earthquakes, including evacuation planning, shelter location, and logistics coordination (Kaveh et al., 2020).

A particular challenge for disaster-response sectorization is spatial heterogeneity: areas with different building densities, damage severities, and terrain conditions impose very different operational demands on teams, even when sectors appear geometrically comparable. This heterogeneity means that naive spatial partitioning will systematically produce unbalanced workloads, with direct consequences for response efficiency. Consequently, the design of operational sectors must consider not only geometric partitioning but also expected workload distribution across space (Kalcsics et al., 2005).

Geographic Information Systems play a central enabling role in this process by integrating heterogeneous spatial datasets such as building inventories, infrastructure networks, administrative boundaries, and hazard information into a unified analytical framework. This integration allows spatial analysis, visualization, and decision support for disaster response planning (Erden & Coşkun, 2010; Goodchild, 2007). The combination of multiple spatial datasets, including building registries, road networks, and administrative boundaries, within a common GIS environment enables automated and reproducible delineation of operational zones at large spatial scales. GIS-based spatial partitioning methods allow the generation of operational zones that reflect both geographic constraints and operational requirements.

Empirical evidence illustrates both the utility and the limitations of spatial sectorization in disaster response. The Mw 6.2 Christchurch earthquake of 22 February 2011 caused severe damage in the central business district and surrounding urban areas of Christchurch, New Zealand (Kaiser et al., 2012). In response, authorities established cordon zones around the heavily damaged Christchurch central business district (CBD) to restrict public access and enable systematic building safety assessments, demolition activities, and recovery planning. Cordons can be understood as spatial control mechanisms in disaster response, defined as "a barrier established by an authority to temporarily exclude the public from a defined area," allowing authorities to manage access while enabling emergency services and technical experts to operate within the restricted zone (Underwood et al., 2020). Following the Christchurch earthquake, a large-scale rapid building safety evaluation programme was implemented in which engineering teams inspected tens of thousands of buildings across the affected area (Gallagher et al., 2012). Such programmes are typically structured around standardised rapid evaluation procedures that define inspection tiers, team composition, and building posting systems, most notably the ATC-20 procedures, which have become the international reference framework for post-earthquake building safety evaluation (ATC, 2005). The immediate purpose of the cordon was to ensure "public health and safety in the face of potential safety hazards, including damaged buildings" and ongoing aftershocks (Underwood et al., 2020). By controlling access to damaged areas, the cordon created a spatially defined operational environment in which search and rescue operations, building inspections, and demolition activities could be carried out in a coordinated manner. However, research also demonstrates that such spatial response structures can generate complex governance and societal challenges. While the Christchurch cordons provided an effective framework for controlling access and organizing response operations, they also had significant social, economic, and legal implications. In particular, cordon management requires balancing safety objectives with broader societal concerns, as disaster managers must reconcile the need to reduce risk with the fact that "a cordon may require the balancing of risk management for public safety against the constraint to property rights and public access" (Underwood et al., 2020). Comparative research on post-earthquake cordons in Christchurch and L'Aquila, further demonstrates that the design and management of spatial response zones has consequences extending beyond logistical coordination, affecting governance, recovery processes, and community resilience (Shrestha et al., 2022).



(a) (b)

Figure 11: (a) Restricted zone and (b) damage to buildings in central L'Aquila after the 2009 earthquake. Figure reprinted from Contreras (2016) and Contreras et al. (2014), respectively. Source: (Underwood et al., 2020)

Across these perspectives, a common tension in sector design becomes apparent. Pre-defined, standardized sectors support preparedness, reproducibility, and rapid deployment, but may fail to reflect the heterogeneous and spatially irregular patterns of actual disaster impacts (FEMA, 2019). Event-specific or adaptive zoning approaches offer greater functional alignment with real damage patterns but must be generated under conditions of time pressure and limited information. Managing this tension more effectively through principled sector design is a central challenge for spatial sectorization in disaster management and provides the conceptual basis for the analysis carried out in this thesis.

While spatial sectorization is widely used in disaster response, the specific combination of features defining the TERMOT sector system has no direct equivalent documented in the scientific literature or in international practice. Three comparative observations clarify this position.

First, the operational spatial units established in large post-earthquake responses, such as the Christchurch central business district cordon in 2011 (Underwood et al., 2020) and the L'Aquila red zone in 2009 (Contreras et al., 2016), were defined reactively after the event, shaped by the observed damage footprint, and bounded to the affected urban core. They served as access-control perimeters rather than as operational partitions for structured building assessment at national scale.

Second, the international reference frameworks for post-earthquake building evaluation, including the ATC-20 rapid evaluation procedures (ATC, 2005), or the FEMA P-2055 building safety evaluation guidelines (FEMA, 2019), define procedural standards for how individual buildings are inspected and posted, and recommend that affected areas be subdivided into geographic sectors managed by dedicated teams. However, none of these frameworks prescribe a pre-computed, nationally complete spatial partition to be activated on demand, the operational delineation of sectors is left to the responding jurisdiction at the time of response.

Third, the existing scientific literature on disaster-response sectorization focuses almost exclusively on event-specific spatial coordination: cordon management, access control, and the organisation of field teams in the immediate aftermath of an event (Shrestha et al., 2022; Underwood et al., 2020). The complementary problem of how to pre-compute an operationally usable sector library at national scale, across heterogeneous settlement contexts and before any event has occurred, has received markedly less attention.

The TERMOT system therefore occupies a methodologically distinctive position at the intersection of emergency management practice, territorial design theory, and GIS-based disaster response planning. This intersection has received limited scientific scrutiny, despite the system's operational significance. The present thesis is, to my knowledge, the first study to systematically evaluate and redesign a sector library of this type.

2.2.6 Current Sector Definition in TERMOT

In TERMOT, sectors are pre-generated, static spatial units that partition Switzerland and Liechtenstein into operational areas for post-earthquake building assessment and damage estimation. Sector boundaries are derived through a top-down geospatial process combining administrative boundaries, transport and landscape infrastructure, and land cover features from datasets including swissBOUNDARIES3D, TLM_STRASSE, TLM_GEWAESSER, and TLM_OEV, which are polygonised to form contiguous sector geometries (Cotovanu, 2023).

Building data from the Federal Register of Buildings and Dwellings (GWR) are assigned to sectors only in a subsequent step through spatial point-in-polygon analysis. Post-processing algorithms are then applied to refine the geometries: sectors containing more than 30 buildings are subdivided using recursive quadtree splitting, while sectors containing fewer than 10 buildings are dissolved and merged with adjacent sectors. The target range of 10 to 30 buildings per sector (described in the previous chapter) in urban areas reflects the estimated workload manageable by an expert team within a defined assessment period, although rural sectors may contain fewer buildings due to lower settlement densities. The underlying datasets and processing steps are examined in detail in Section 3.3.

The system distinguishes between two sector types:

- **Library Sectors**: Pre-created sectors covering all of Switzerland and Liechtenstein, accessible during the preparedness phase for planning and familiarization purposes
- **Active Event Sectors**: Sectors activated or created after an earthquake event, which can be copied from library sectors, drawn manually, or generated automatically based on the earthquake footprint

Each sector is assigned a unique identifier that encodes cantonal and municipal information (see Figure 12). This ensures that all operational actors including EDO, cantonal authorities, insurers, and expert teams work with a consistent and unambiguous spatial reference system. In the operational workflow, sectors serve as the primary unit for assigning tasks to expert teams, tracking assessment progress, and coordinating parallel field operations across the affected area. By aggregating buildings into comparable spatial units, sectors also support prioritisation during the initial response phase, enabling coordinators to identify areas with higher building concentrations or potential damage clusters requiring priority inspection (SOE, 2024). Figure 13 below shows a screenshot of TERMOT where a municipality has been divided into sectors.

Given their central role in the operational workflow, the structure and characteristics of the current sector system are examined in more detail in this thesis. The following chapters analyse the spatial properties of the existing sectors and their implications for post-earthquake building assessment. The analytical methods used to examine the sector system and to establish the empirical basis for subsequent problem identification and redesign are described in Section 3.3.

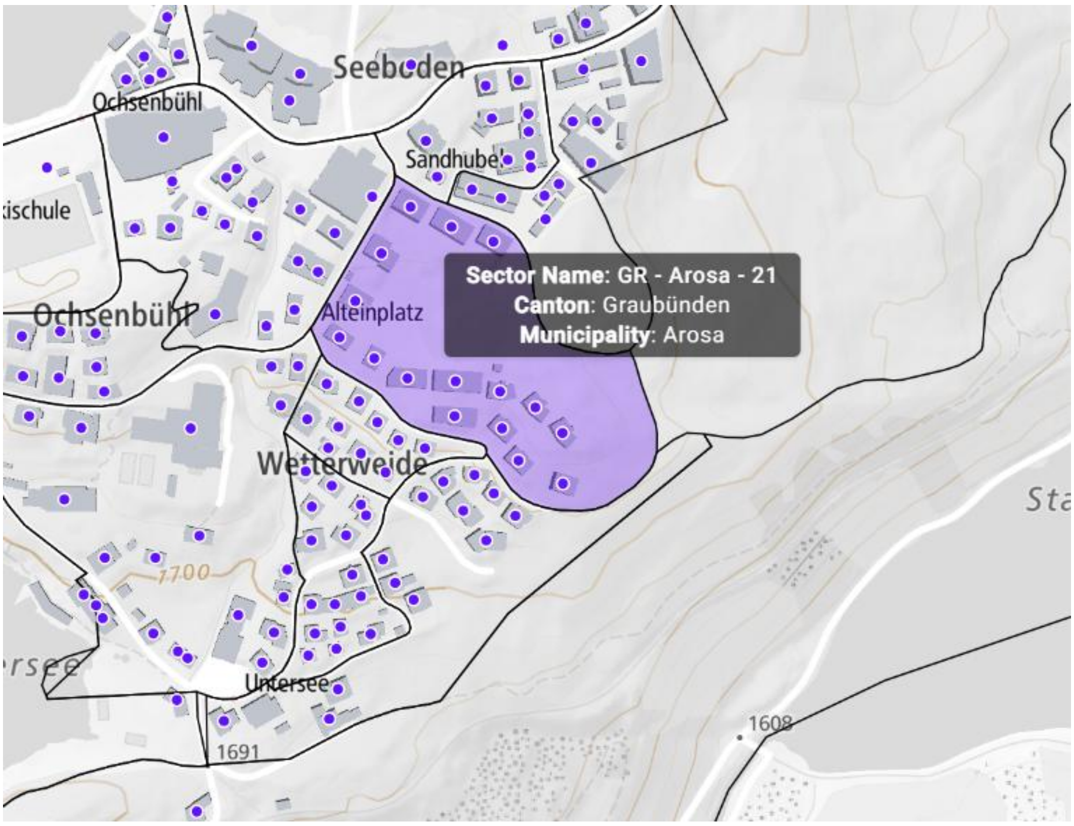


Figure 12: Screenshot of a Sector in TERMOT

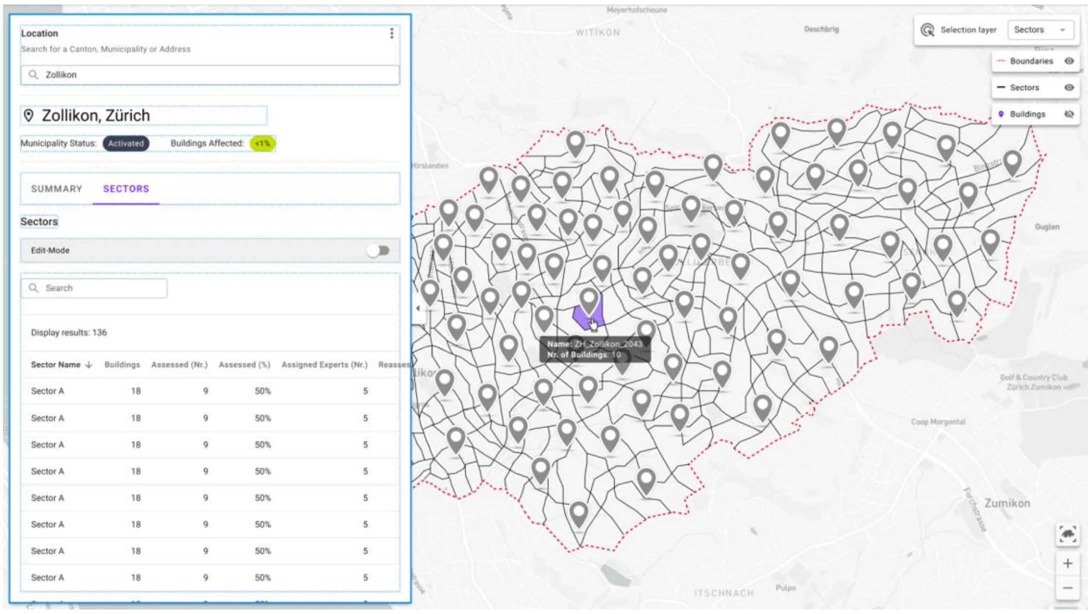


Figure 13: Screenshot of Municipality divided into Sectors in TERMOT

3. Methodology

This chapter describes the methodological framework applied to investigate and improve the sector concept underlying the TERMOT platform. The study employs a sequential mixed-methods design that integrates both qualitative and quantitative analytical techniques (Creswell & Creswell, 2018). The methodology is structured in two consecutive stages. The first stage focuses on the systematic analysis and redesign of the existing sector system. It proceeds through four sequential steps:

1. a status quo analysis combining qualitative analysis and a quantitative assessment framework of sector characteristics
2. the identification of structural deficiencies based on empirically observable patterns
3. the development of a revised sector generation approach grounded in explicit, quantifiable design criteria
4. the validation of the new approach through comparative quantitative assessment against the existing system

The status quo analysis operates at the individual sector level, examining the structural characteristics of 60 sample sector independently. The validation of the revised approach is conducted at the municipality level, comparing the distribution of sector quality metrics across all sectors within each of the six proof-of-concept municipality between the existing and revised systems.

The second stage extends the improved sector system to earthquake-specific operational conditions. Once structurally sound sectors have been established, the focus shifts to their application within a simulated event context. This includes the estimation of assessment workload per sector, the prioritisation of sectors based on expected damage intensity, and the allocation of expert teams under realistic resource constraints.

Together, both stages form a coherent methodological progression, from structural optimisation of spatial units to their operational deployment in crisis management scenarios.

3.1 Research Design: Overall Approach and Phases

The research follows a structured, problem-oriented design that links empirical observation, quantitative measurement, and iterative development along a clear analytical logic. As introduced above, qualitative methods serve a supportive role in structuring and interpreting observed patterns, while quantitative methods dominate the evaluation and validation phases. The methodology is structured to address the five sub-objectives defined in Chapter 1.2. This chapter describes how these elements are sequenced across the study and provides the rationale for each methodological step, as shown in Figure 14.

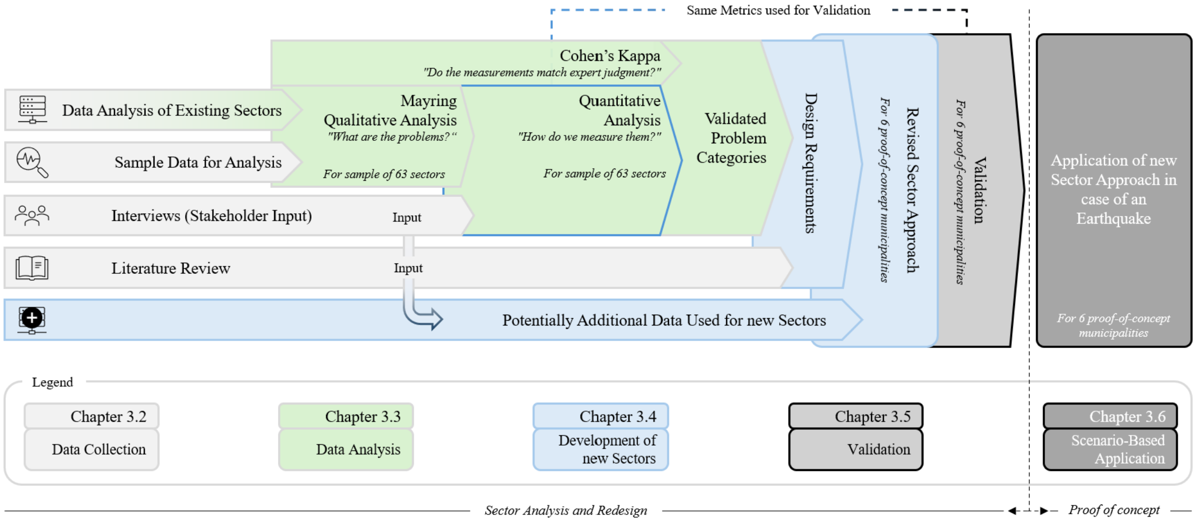


Figure 14: Overview of the methodological framework, illustrating the sequencing of analytical steps, data sources, and outputs across Chapters 3.2 to 3.6 (full overview in Appendix C).

The process begins with an analysis of the status quo of the existing sector system, drawing on the data sources described in Section 3.2. Sector quality is examined using both qualitative observations and quantitative indicators, as detailed in Section 3.3. The qualitative component follows the principles of qualitative content analysis as described by Mayring, in which recurring patterns are identified from the material through inductive category formation, which means, problem categories are derived directly from what is empirically observable in the data, rather than being defined in advance by theoretical assumptions (Mayring, 2014). Importantly, the objective of this step is not to assess individual sectors in isolation, but to identify these recurring patterns of structural issues consistently across all sectors nationwide.

The identified problem categories are then operationalised through quantitative metrics. This translation from qualitative problem patterns into measurable indicators is a key methodological step: it ensures that sector quality can be assessed consistently and reproducibly across diverse settlement contexts rather than relying on subjective case-by-case judgements. The resulting analytical framework serves a dual purpose: it provides the basis for evaluating the existing sector system and directly informs the requirements for an improved approach. Sequential mixed-methods designs are commonly applied when qualitative findings are used to inform subsequent quantitative operationalisation (Johnson et al., 2007). The framework is designed for extensibility to the full national dataset, whereas within this study it is applied to a sample set for validation and to the proof-of-concept municipalities for comparative evaluation.

The methodology first validates whether quantitative metrics reproduce the qualitative problem classifications by comparing both approaches on the same sector sample. This consistency is assessed using Cohen's Kappa, ensuring that the metrics reliably operationalize the identified problem categories and can be extended beyond the sample.

Building on these empirical findings, a revised sector generation approach is developed in Section 3.4. The redesign is explicitly derived from the identified problem categories and supplemented by additional input from expert interviews, relevant scientific literature, and additionally analyzed geospatial data sources introduced in Section 3.4. This grounding in empirical evidence is central to the methodological approach: design decisions can be traced back to observable deficiencies in the existing system.

The effectiveness of the redesigned sectors is subsequently assessed through quantitative validation in Section 3.5. Both the existing and the new sector systems are evaluated using the same set of metrics applied in the status quo analysis, enabling a direct, transparent, and reproducible comparison. This parallel evaluation ensures that improvements are empirically demonstrated rather than merely inferred.

Finally, Section 3.6 extends the validated sector system to an earthquake-specific application context. The improved sectors are interpreted as operational units for post-event use, supporting workload estimation, prioritisation, and resource allocation. This stage introduces an explicit temporal distinction that structures the analytical logic: pre-event processes focus on sector quality and workload potential, while post-event processes are centred on prioritisation and allocation logic, which can only be applied once a specific earthquake scenario and its associated intensity distribution are known. This distinction reflects the operational reality of earthquake response, in which both preparedness and rapid situational adaptation are essential.

3.2 Data Collection

This chapter provides an overview of the data sources used throughout this study (see also Figure 15). A distinction is made between existing spatial and documentary data which form the empirical foundation of the analysis and additional data sources consulted to inform the development of the new approach, which will be described further in Section 3.4. The data sources described here underpin all subsequent analytical steps. How they are used in practice is explained in the context of the respective analysis methods in Section 3.3.

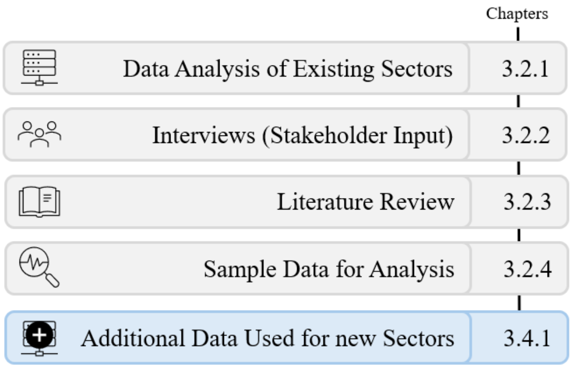


Figure 15: Overview of all data sources used across the study and where to find it.

3.2.1 Existing Documentations of Sector Design in TERMOT

The qualitative component of this study draws on a body of existing documentation produced in the context of the TERMOT platform and the EDO more broadly. This material was not collected specifically for this thesis but was systematically reviewed to reconstruct the design logic of the existing sector system and to understand the operational requirements it is intended to fulfil. The primary sources consulted include the internal process documentation maintained in the project internal Azure DevOps (ADO) wiki page, which covers the technical architecture of the platform, data pipeline specifications, and the automated sector generation workflow. These articles document the iterative development of the sector creation algorithm, including design decisions, known limitations, and outcomes from working sessions held between the development team and operational stakeholders. Complementing this, the EDO-specific operational documents referenced in Chapter 2, provide the organisational and procedural context within which the sectors must function.

In addition, information on buildings and insurance policies is provided by cantonal building insurers and private insurance companies through formal data-sharing agreements. These agreements regulate the transfer, storage, and processing of building-related information required for damage assessment and insurance processing (SOE, 2021a). As this data is subject to confidentiality obligations and has no direct bearing on sector geometry or spatial structure, it was not incorporated into the analysis conducted in this thesis.

Together, these sources establish what the sector system is expected to achieve from an operational perspective, and how its current form came to be. The insights derived from this review inform both the qualitative problem assessment in Section 3.3.1 and the design requirements for the revised approach.

3.2.2 Interviews (Stakeholder Input)

To complement the documentary review, semi-structured interviews were conducted with key stakeholders involved in the development, operation, and use of the TERMOT platform. Semi-structured interviews are widely used in exploratory research contexts where expert knowledge is required while maintaining comparability across interviews (Brinkmann & Kvale, 2018). Access to these experts was facilitated through the thesis supervisor, Thomas Kühni, CEO of the EDO, who provided direct introductions to relevant individuals across the organisational landscape.

Seven interviews were conducted in total, covering a deliberately broad range of perspectives. The interviewees included:

- Thomas Kühni (CEO, EDO), and supervisor of this thesis,
- Sandro Nardi (CTO, risktec; technical lead of the TERMOT implementation), and supervisor,
- Marco Peyer (CPO, risktec; project lead of TERMOT)
- Samuel Wildhaber (Digital Product Engineer, risktec; project manager TERMOT)

who together represent the strategic and technical leadership behind the platform.

Note: Input from Thomas Kühni (CEO, EDO) was gathered through ongoing bi-weekly supervision meetings between November 2025 and March 2026 rather than a discrete interview session and is therefore cited in the context of supervisory guidance rather than as a standalone expert interview.

Operational and field perspectives were provided by

- Yves Steiger (Scientific Collaborator, National Emergency Operations Centre NEOC; specialist in resource management and national earthquake preparedness planning),
- Nicolas Brieger (Manager Vertical Mobility, TCS; focusing on the use of TERMOT in the context of drone-supported building assessments),
- Chantal Camenisch (Division of Civil Protection, Planning and Projects, Canton of Bern; platform user).

The insurance and damage assessment perspective was represented by

- Antje Horvath (Head of Insurance Division and Damage Expert, Gebäudeversicherung Solothurn; platform user).

All interviews followed a semi-structured format, allowing for consistency across conversations while preserving the flexibility to explore topics in greater depth where relevant. Rather than a fixed questionnaire, an interview guide was used to structure the discussions around key thematic areas without constraining the responses of interviewees. The interview guide is provided in Appendix B. The findings are synthesised and reported in Section 4.1.4 as well as part of the requirements summary in chapter 4, where they inform the design criteria for the revised sector approach alongside insights from the documentary review and literature.

3.2.3 Literature Review

In addition to the documentary review and stakeholder interviews, a structured review of relevant academic literature was conducted, focusing on spatial sectorization and zone-based operational planning approaches in post-disaster emergency management contexts. This review examines how comparable organisations and response frameworks define, structure, and optimise spatial units for large-scale field operations. Rather than being presented as a standalone chapter, the literature is integrated throughout the thesis to directly support the development of the conceptual framework and methodological approach. The core theoretical foundations derived from this review are synthesised in Section 2.2.5, where they inform the analytical lens and design principles applied in this study.

3.2.4 Sample Data for Qualitative Analysis

While the quantitative metrics defined in Section 3.3 are designed to be applicable across the full national dataset of existing TERMOT sectors, their application in this study is conducted across the 60-sector sample for validation purposes and across the proof-of-concept municipalities (see Table 1) for comparative evaluation. The qualitative analysis requires a manageable and representative sample that can be examined in sufficient depth. To this end, a dedicated sector sample was constructed, drawing from municipalities classified according to the official Swiss municipal typology (BFS, 2024).

A stratified random sampling approach with QGIS and Microsoft Excel was applied to ensure representation across all three primary settlement categories urban, intermediate, and rural, as well as across all nine sub-types of the BFS typology. The sampling approach follows the principle of maximum variation sampling, which aims to capture a wide range of possible conditions rather than statistical representativeness and falls under the umbrella of "Purposive or Purposeful Sampling" (Patton, 2002). The final sample comprises 63 municipalities in total: 60 drawn from Switzerland and 3 from Liechtenstein, covering 20 of the 26 Swiss cantons.

Since each municipality covers multiple sectors, one sector was randomly selected with Microsoft Excel per municipality, yielding in 63 sectors in total. Selecting exactly one sector per municipality prevents analytical bias towards larger municipalities, ensuring that each settlement context carries equal weight in the analysis regardless of size.

The resulting distribution (approximately 40% urban, 30% intermediate, and 30% rural, see Figure 16) deliberately deviates from Switzerland's actual population-weighted settlement distribution. This reflects a maximum variation sampling strategy, in which the goal is not statistical representativeness but comprehensive coverage of the full range of settlement contexts in which sectors must function. All nine BFS typology categories are represented in the sample, including less common. Within each typology layer, municipalities were selected to maximise geographic diversity across the study area, reducing the risk of regional clustering.

This sampling strategy is designed to surface recurring structural patterns and challenges in sector design across diverse spatial contexts, providing the information-rich case basis required for the qualitative analysis in Section 3.3.

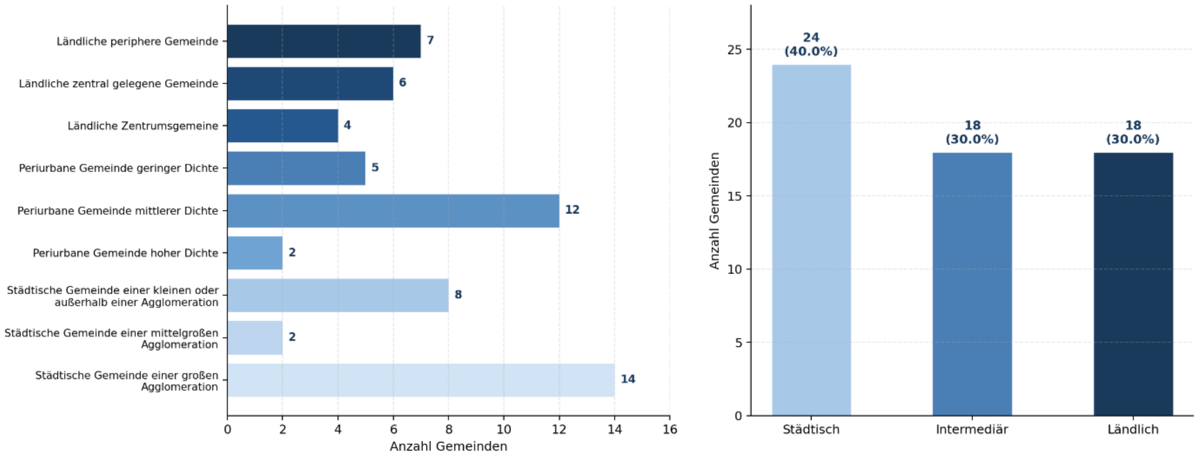


Figure 16: Sample distribution across the nine BFS municipal typologies (left) and three primary settlement categories (right). German labels reflect official BFS typology nomenclature. ("Städtisch = urban, "Intermediär" = Intermeidate, "Ländlich" = rural)

In addition to the 63-sector qualitative sample, six municipalities were selected as proof-of-concept cases for the quantitative validation and scenario-based application (see Table 1). The selection was guided by three criteria: coverage of the full range of BFS settlement typologies (urban, intermediate, rural), computational feasibility within the proof-of-concept scope, as well as geographic alignment with the hypothetical Mw 6.0 Bern earthquake scenario applied in Section 3.6 and Section 4.5. Four municipalities lie in cantons Bern and Solothurn, directly within the simulated epicentral zone, while Gais (AR) and Ormont-Dessus (VD) lie at greater distances, providing meaningful seismic intensity variation across the sample. This allows the same six municipalities to serve both the structural quality evaluation and the operational scenario application without requiring separate test cases for each purpose.

Table 1: Overview of proof-of-concept municipalities selected

Municipality	Canton	BFS Typology (3)	BFS Typology (9)	Total Sectors (n)
Brienzwiler	BE	Rural	Rural peripheral municipality	75
Lengnau (BE)	BE	Urban	Urban municipality outside agglomeration	121
Schwanden bei Brienz	BE	Intermediate	Rural centre municipality	43
Gais	AR	Intermediate	Rural centre municipality	381
Bettlach	SO	Urban	Urban municipality outside agglomeration	100
Ormont-Dessus	VD	Rural	Rural peripheral tourism municipality	365

3.3 Data Analysis

This part describes the analytical methods used to examine the existing TERMOT sector system and to prepare the empirical basis for subsequent problem identification and redesign. The data analysis focuses on understanding how the current sectors are generated, structured, and populated with buildings, and how these characteristics influence sector quality and workload potential. Emphasis is placed on transparency and reproducibility throughout the analytical process, as the same data structures and metrics are later reused for the evaluation and validation of the redesigned sector approach in Section 3.5.

The analysis proceeds in two complementary steps. First, the existing sector generation process is examined in detail, including its underlying algorithm, geospatial input layers, and known limitations to establish a clear understanding of how the current sectors came to be and where systematic weaknesses originate. Second, the analytical method and evaluation criteria are introduced, combining qualitative content analysis of the sector sample with quantitative metrics applied. A synthesis of findings, summarising the empirically derived requirements that directly inform the development of the revised sector approach, as well as the results of the data analysis are presented in Chapter 4.

3.3.1 Sector Generation Analysis

The existing TERMOT sector geometries are based on an automated geo-processing workflow that integrates multiple official Swiss geospatial datasets. The sector generation pipeline is implemented in Python, primarily using GeoPandas for spatial operations, and draws on the following input datasets (Cotovanu, 2023):

- **Swisstopo Administrative Units:** Municipality boundaries defining the spatial extent of administrative units across Switzerland. These polygons serve as the primary container for sector generation, ensuring sectors respect administrative boundaries.
- **SwissTLM Regio (Swiss Topographic Landscape Model):** This comprehensive dataset provides multiple layers essential for sector boundary definition:
    - River Lines: Watercourses serving as natural boundaries
    - Land Cover Polygons: Land use classification including built-up areas, vegetation, and other surface types
- **SwissTLM 3D:** Three-dimensional topographic data including:
    - TLM Strasse Lines: Road and street network forming the primary basis for sector delineation
    - TLM Eisenbahn Lines: Railway infrastructure serving as additional boundaries
- **Federal Register of Buildings and Dwellings (GWR):** Point locations and attributes of all registered buildings in Switzerland (~3.2 million buildings). Building locations are used for spatial assignment to sectors and for computing sector-level statistics.

The sector generation process follows a three-stage geo-processing workflow, as described below:

1. **Boundary Feature Preparation:** The first stage focuses on the preparation and consolidation of linear features that serve as potential sector boundaries. Multiple datasets are processed and combined to create a comprehensive network of splitting lines. River lines, street networks, railway lines, and boundaries derived from land cover polygons are used as candidate separators. To avoid excessive fragmentation, land cover polygons are first dissolved and converted into linear boundaries, applying a minimum size threshold to remove negligible features. All boundary features are subsequently unified into a single feature layer, forming an initial network of potential sector split lines. The unified boundary dataset undergoes geometric processing to ensure suitability for polygon creation. This includes intersection detection, topology correction, and removal of duplicate or invalid geometries. These steps ensure that the resulting line network forms a clean and consistent basis for spatial partitioning.

2. **Polygon Creation and Building Assignment**: In the second stage, the prepared boundary lines are converted into polygon geometries representing preliminary sector candidates. Using polygonisation operations, the unified line network is transformed into a large set of closed polygons. This step produces approximately 927,000 polygon candidates across Switzerland, representing all spatial units defined by the intersection of administrative, natural, and infrastructural boundaries. Subsequently, building point data from the Federal Register of Buildings and Dwellings (GWR), comprising approximately 3.2 million buildings, are assigned to the polygon layer using a point-in-polygon spatial join. Each building is linked to exactly one polygon, enabling the computation of sector-level building counts and related attributes. Due to geometric edge cases (such as buildings located on polygon boundaries or within complex geometries) the assignment process is performed iteratively. Buildings that cannot be reliably assigned in the initial pass are re-processed until complete and consistent coverage is achieved.

3. **Optimisation and Refinement**: The third stage focuses on transforming the initial polygon set into operationally practical sectors suitable for deployment of assessment teams. First, very small polygons containing fewer than ten buildings are identified. At this stage, approximately 736,000 such small sectors exist. These polygons are merged with adjacent sectors to reduce fragmentation and avoid inefficient operational units. The merging process respects municipal boundaries and prioritises spatially coherent neighbouring sectors. Second, sectors exceeding an upper building threshold of 30 buildings are identified. Approximately 807,000 sectors remain after the initial merging step. These larger sectors are subdivided using additional geometric splitting procedures to ensure manageable workload sizes for assessment teams. Following the splitting process, secondary merging is applied to eliminate newly created small sectors with fewer than ten buildings. This additional consolidation step further reduces fragmentation and results in a final set of approximately 513,000 sector polygons. Finally, a cleanup step is performed to ensure topological validity and consistency. This includes removal of sliver polygons, validation of geometries, completion of sector attributes, and generation of unique sector identifiers. The resulting dataset consists of operationally usable sector polygons, each associated with building counts and relevant metadata.

Figures 17–19 illustrate the processing steps of the sector generation workflow, from the aggregation of input polylines through polygonisation to the final cleanup and sector refinement stages (Cotovanu, 2023).

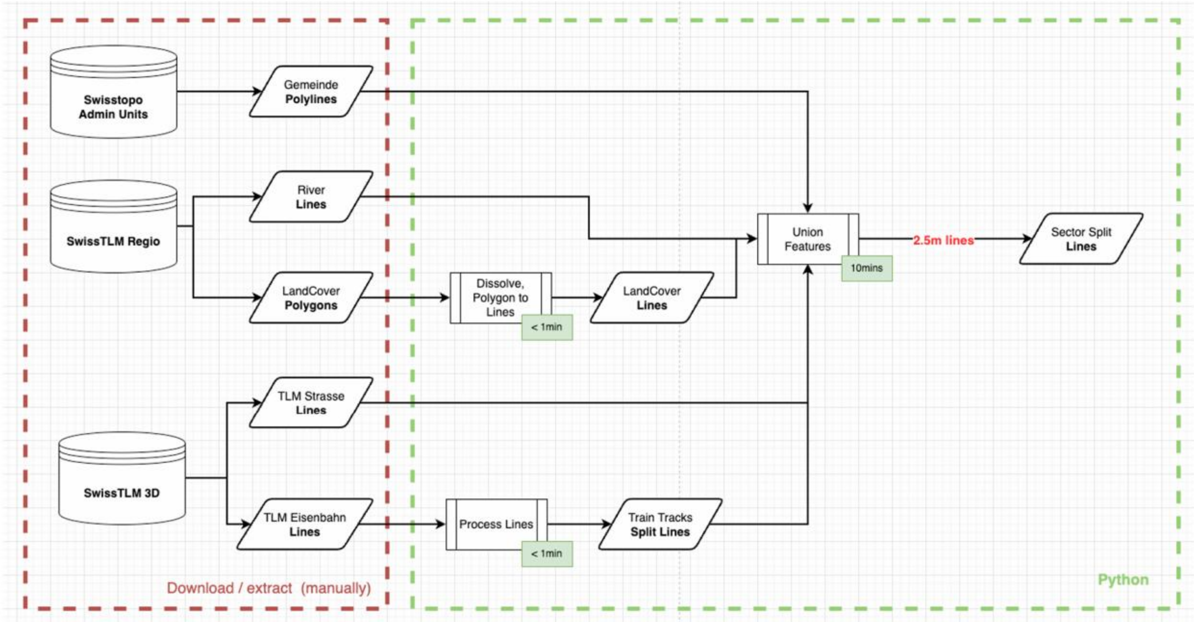


Figure 17: Processing Steps of Sector Generation: Aggregate Input Polylines

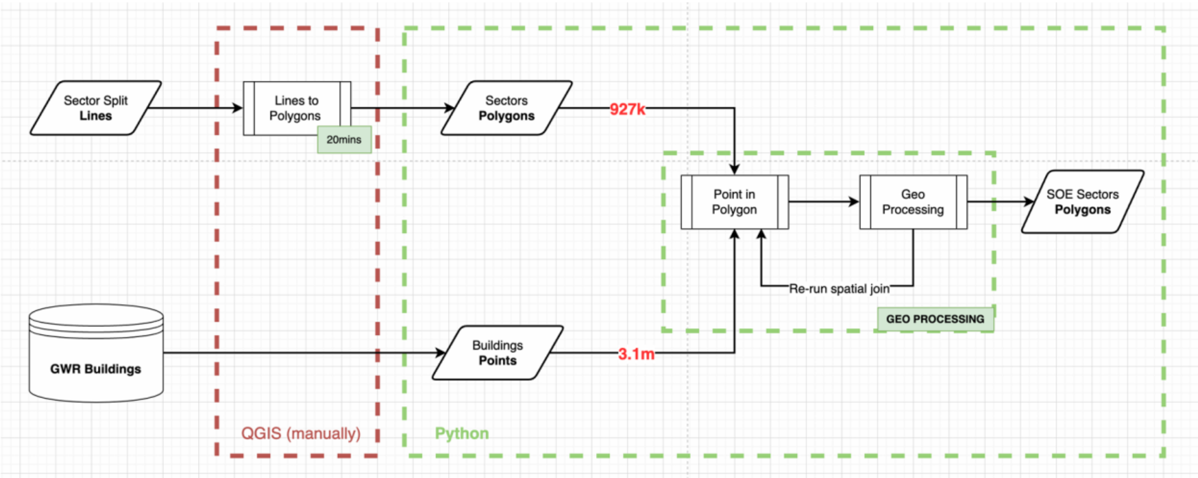


Figure 18: Processing Steps of Sector Generation: Polygonisation

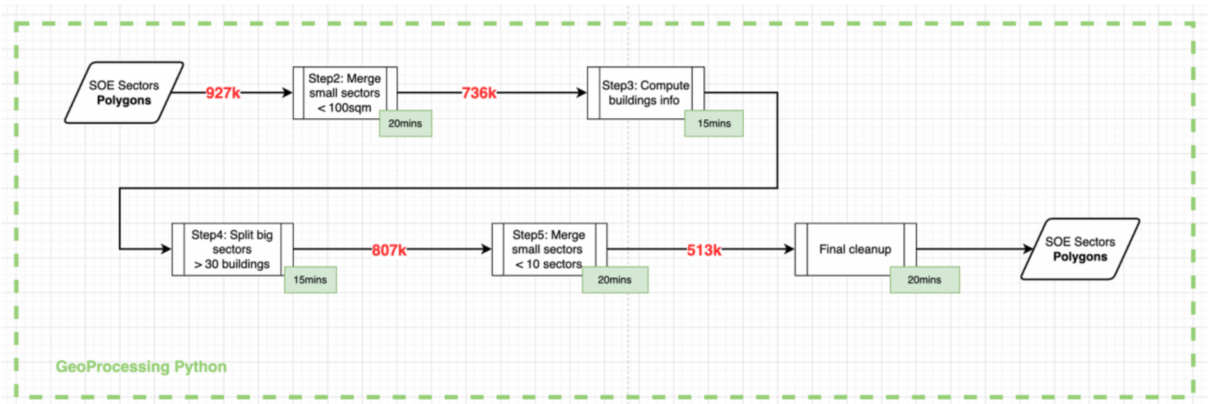


Figure 19: Processing Steps of Sector Generation: Cleanup, Merge Buildings, Divide & Merge Sectors

3.3.2 Sector Quality Analysis Method

The assessment of existing sector quality follows a three-step analytical framework that moves from qualitative categorisation to quantitative measurement and is verified through Cohen's Kappa, an analytical consistency check that confirms whether the quantitative measurements align with the qualitative problem classifications derived. This progression is deliberate: the qualitative step first identifies what kinds of structural problems exist, and the quantitative step then measures how frequently and severely these problems occur across the sample. The validation through Cohen's Kappa ensures that the measurements match expert judgement before the framework is applied to the proof-of-concept evaluation and, in future work, extended to the full national dataset.

1. **Qualitative Analysis after Mayring**: The qualitative analysis of existing sector quality follows the framework of qualitative content analysis as described by Philipp Mayring. This approach is particularly well-suited to the present study because it provides a systematic, rule-bound procedure for deriving categories inductively from empirical material, without imposing predefined classifications onto the data. Rather than starting from a theoretical typology of sector problems, the analysis allows problem categories to emerge directly from what is observable in the sampled sectors. A process Mayring terms “inductive category formation” (Mayring, 2014). This ensures that the resulting problem typology is grounded in the actual characteristics of the existing sector system rather than in conceptual assumptions about what problems might exist.

   The analysis was conducted using a structured analytical worksheet prepared specifically for this purpose. For each of the 63 sampled sectors, a standardised screenshot was captured in QGIS at a uniform scale of 1:2750, ensuring visual comparability across all sectors regardless of their geographic location or settlement context. These screenshots were embedded in an Excel-based analytical sheet alongside a comprehensive set of metadata attributes for each sector, including: sample number, country, canton, municipality, administrative unit identifier, total sector count within the municipality, the randomly selected sector name and polygon ID, municipal typology classification at three levels of aggregation, sector area in both square metres and square kilometres, building count, and building density in buildings per square kilometre. This metadata provided the spatial and statistical context necessary to interpret each sector's visual characteristics within its broader settlement environment.

   The analytical process itself followed four sequential steps as per Mayring's (2014) inductive category formation procedure. The first step covered material collection and paraphrasing: each sector was visually inspected using its QGIS screenshot and documented through two complementary written descriptions: first an observed features list enumerating all visible structural characteristics without interpretation, and second a neutral description synthesising these observations into a concise, evaluatively neutral characterisation. The second step focused on generalisation and first reduction: the neutral descriptions were abstracted to a common level of generality, grouped into thematically related preliminary problem indications, and condensed into precise problem statements capturing the essential structural issue. The third step focused on category formation and validation: problem statements derived across all sectors were inductively grouped into a final set of distinct problem categories, each operationally defined to ensure consistent and unambiguous applicability. In the fourth step, category coding, each sector was coded against all identified categories using a binary scheme (1 = problem present, 0 = problem absent), producing a structured coding matrix that forms the empirical basis for the subsequent quantitative analysis and validation. The three Liechtenstein municipalities included in the overall sample are excluded from the quantitative stages of the analysis, as described in Section 3.2.4, with the qualitative and quantitative steps applied to the Swiss sector sample only.

The outcome of this process is a structured, empirically grounded typology of sector problem categories that directly informs the quantitative metrics defined below and the design requirements for the revised sector approach developed in Section 3.4. Figure 20 below shows the conceptual workflow of the qualitative analysis.

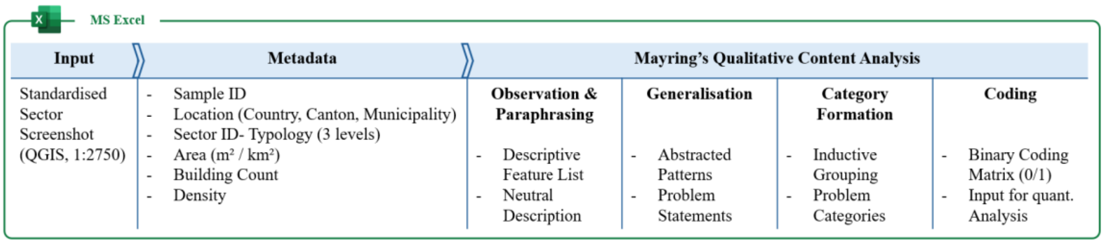


Figure 20: Conceptual workflow of the Excel-based qualitative sector analysis, illustrating the integration of spatial metadata and the application of Mayring's (2014) inductive category formation procedure.

2. **Evaluation Criteria (Quantitative Analysis):** The second analytical step translates the qualitatively derived problem categories into quantitative metrics. For each problem category identified through the Mayring process, one or more measurable indicators are defined that operationalise the underlying structural issue as a computable variable. This translation is a critical methodological step: it ensures that sector quality can be assessed objectively and reproducibly beyond the sample-based qualitative observations. The metric framework is designed to be applicable across the full national dataset, where as within this study it is applied to the 60-sector Swiss sample for validation and later to the sectros within the proof-of-concept municipalities for comparative evaluation.

   The dimensions used to assess sector quality are not defined a priori but emerge directly from the problem categories identified through the Mayring qualitative content analysis. Each dimension corresponds to a distinct problem category and is operationalised through a set of metrics designed to capture its defining structural characteristic. For each dimension, a primary metric is defined for the purposes of Cohen's Kappa validation, and one or more supporting metrics provide additional descriptive characterisation. The primary metric is selected based on two criteria: it must directly operationalise the core structural problem identified qualitatively, and its threshold must be independently justifiable on operational or scientific grounds without reference to the qualitative coding. Supporting metrics characterise additional dimensions of the same problem. The full set of metrics, including their definitions, formulas, thresholds, and the problem categories from which they derive, is presented in Chapter 4.

   Each metric is defined by a precise formula and calculated uniformly. The metric scores computed for the existing sector system serve a dual purpose: they provide the empirical basis for characterising the current state of sector quality, and they are subsequently reused without modification in Section 3.5 to evaluate the redesigned sectors, enabling a direct and transparent like-for-like comparison.

3. **Validation of Analytical Consistency (Cohen's Kappa):** Before applying the quantitative metrics beyond the sample, an analytical consistency check is performed to verify that the quantitative measurements align with the qualitative problem classifications derived through the Mayring process. This step addresses a fundamental methodological question: do the quantitative metric scores reproduce what was identified through the visual inspection of the sector sample?

   If the two analytical approaches converge on the same sectors as problematic, this provides strong evidence that the metrics are valid operationalisations of the underlying problem categories, and that the framework can be reliably extended beyond the sample.

   This consistency is assessed using Cohen's Kappa (Cohen, 1960), a statistical measure that quantifies the degree of agreement between two sets of classifications beyond what would be expected by chance. Its application in the context of content analysis validation that includes the comparison of human judgement against quantitative classification, is well established in the methodological literature (Lombard et al., 2002; Mayring, 2014; McHugh, 2012). In this study, Cohen's Kappa is calculated for each problem category by comparing two binary classifications of the same sector sample: the qualitative coding derived from the Mayring analysis (1 = problem present, 0 = problem absent), and a binary classification derived from the corresponding quantitative metrics. Cohen's Kappa is computed as:

$$k = \frac{P_O - P_e}{1 - P_e}$$

   where P_O is the observed proportion of agreement between the two classifications (the share of sectors on which the qualitative coding and the metric-derived classification both assign the same label), and P_e is the expected proportion of agreement by chance, computed from the marginal class frequencies of both classifications. Kappa ranges from -1 (complete disagreement) through 0 (agreement equivalent to chance) to 1 (complete agreement). The subtraction of chance agreement in the numerator and its normalisation in the denominator is what distinguishes Kappa from raw percentage agreement: two classifications may agree by chance on a large proportion of cases simply because one class is rare, and Kappa corrects for this imbalance. To ensure methodological rigour, the threshold used to binarise each metric score is defined independently of the qualitative results, based on operational criteria. These thresholds are documented and justified for each metric in Chapter 4.

   A Kappa value of $\kappa \geq 0.61$ is set as the minimum threshold for acceptable agreement, following the classification proposed by Landis and Koch (see Table 2), above which agreement is considered substantial (Landis & Koch, 1977).

Table 2: Interpretation of Cohen's Kappa values, following Landis and Koch (1977). The threshold applied in this study (κ ≥ 0.61) corresponds to substantial agreement.

κ Value	Strength of Agreement
<0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

A Kappa value meeting or exceeding this threshold for a given problem category confirms that the quantitative metric reliably captures what was identified qualitatively, and that the category definition is sufficiently precise and operationally valid. Categories meeting this threshold are retained as validated problem categories and form the empirical foundation for both the full-dataset quantitative analysis and the design requirements developed in Section 3.4. The results of the Cohen's Kappa validation are reported in Chapter 4.

3.4 Development of new Sectors

This chapter describes the process and methods applied to develop a revised sector generation approach. The redesign draws on all inputs collected previously, including the existing documentation, stakeholder interviews, and literature review and is directly grounded in the problem categories and requirements established in Section 3.3 and presented in Section 4.2.

The chapter first presents the method itself, describing the four-phase geoprocessing pipeline and the design principles that guide it. It then documents the evaluation of additional geospatial data sources conducted in parallel with the method development, explaining which sources were considered, why most were excluded, and why the revised approach ultimately draws on the same dataset infrastructure already used by the existing algorithm.

3.4.1 Method Description

The revised sector generation approach was designed in direct response to the inputs collected across the three methodological phases preceding it: the qualitative and quantitative analysis of the existing system, the requirements consolidated from stakeholder interviews, and the relevant scientific literature on spatial sectorization and territorial design. Rather than redesigning the system from scratch, the approach deliberately targets the most structurally significant requirements identified in Section 4.2, while remaining implementable within a reproducible, nationally consistent geoprocessing pipeline.

A central conceptual shift underpins the revised approach: the deliberate decoupling of building count from sector geometry. In the existing TERMOT system, the target range of 10 to 30 buildings per sector is enforced as a hard geometric constraint embedded directly in the generation logic, meaning that sector shape is partially determined by staffing arithmetic rather than by the spatial structure of the built environment. The revised approach departs from this logic on purpose. Building count is no longer a generative constraint but an output attribute of the algorithm, to be managed through expert team assignment rather than through sector boundaries. This reframing is consistent with the operational model of the EDO, in which team size and deployment duration can be adjusted to reflect sector workload (SOE, 2024), and it allows sector boundaries to reflect geographic coherence rather than predefined workload targets. Workload balancing is accordingly relocated from sector generation (Section 3.4) to workload estimation and team assignment (Section 3.6), where it can be handled with greater operational flexibility.

Whether this reframing produces measurably better sectors in practice is evaluated through the comparative testing strategy described in Section 3.5 and reported in Chapter 4. From this conceptual shift, two design principles follow for the generation pipeline itself.

First, sector boundaries should emerge from the spatial distribution of operationally relevant buildings, with infrastructure features serving as hard boundary constraints rather than as primary geometry generators. In the existing algorithm, roads, railways, rivers, lakes, and land cover boundaries are the sole inputs to sector geometry, and buildings are only assigned to the resulting polygons in a subsequent step. In the revised approach, building clusters define the initial spatial groupings, and infrastructure features are applied as boundary constraints that refine those groupings where they cross meaningful physical or navigational barriers. This preserves the operational logic that sector boundaries should follow features recognisable in the field, while ensuring that the primary driver of sector shape is where buildings actually are.

Second, the pipeline is designed for reproducibility and national consistency, so that the same procedure can be applied uniformly across Switzerland and Liechtenstein, which was a requirement raised during the interviews with the stakeholders. Additionally, the pipeline uses only nationally available datasets, and thus, can be re-run with any update roll outs.

The approach is structured as a four-phase geoprocessing pipeline implemented in Python using GeoPandas, as well as QGIS as described below. The relevant codes used for this can be found here: GIVA / PUBLIC / MASTERs / Sector_Definition_Earthquakes_Michael_Fehr · GitLab

1. **Building Filtering**: The GWR building dataset is filtered to retain only buildings that are operationally relevant for post-earthquake assessment. Two filter criteria are applied. First, only buildings with GSTAT = 1004 (existing) are retained, excluding projected, under-construction, and demolished structures. Second, building categories (GKAT) that do not contribute to the EDO's building usability or damage estimation workflows are excluded. Table 3 provides an overview of all excluded GKAT codes and the rationale for each exclusion group.

   The exclusion criteria reflect three operational considerations. Agricultural buildings and alpine structures are excluded because they are not permanently inhabited and their inclusion would introduce isolated building points in sparsely populated terrain that distort cluster geometry without contributing meaningful assessment workload which is a requirement explicitly raised in stakeholder interviews (Nardi, 2025; S. Wildhaber, 2025). Infrastructure and transport objects, including garages, industrial facilities, and communication infrastructure, are excluded as they fall outside the scope of residential habitability assessment. Non-residential public buildings, including schools, hospitals, cultural facilities, and religious buildings are excluded because they are not subject to standard residential insurance claims and require specialist assessment protocols beyond the EDO mandate.

   Applied nationally, these filters retain approximately 65% of all registered GWR buildings, with higher exclusion rates in alpine cantons where agricultural and non-residential structures represent a disproportionately large share of the building stock. The filtering logic follows the feature engineering principle described by (Fang et al., 2025), who demonstrate that pre-filtering inputs based on operational relevance substantially improves the spatial coherence of density-based clustering results.

2. **Density-Adaptive Clustering**: The filtered buildings are clustered into spatially coherent groups within each municipality using K-Means clustering. The number of clusters k is not fixed but determined per municipality based on local building density, following a density-adaptive rule derived from the BFS municipal typology applied in the sampling strategy of Section 3.2.4. This ensures that urban municipalities with dense settlement patterns are subdivided into more

and smaller sectors, while rural and alpine municipalities receive fewer and larger sectors. K-Means was selected for its scientific citability and its established role in territorial design: (Kalcsics et al., 2005) identify it as one of the two core algorithmic approaches in the unified territorial design framework, and it has been applied in directly analogous operational sectorization contexts including airspace management (Trandac et al., 2005). K-Means clustering partitions a set of points into k groups by iteratively assigning each point to the nearest cluster centroid and recalculating centroids until assignments stabilise. In this study, the 'points' are individual building locations, and the algorithm groups buildings into spatially coherent clusters. DBSCAN was considered as an alternative density-based clustering method (Fang et al., 2025) but not adopted for the core pipeline, as K-Means produces a fixed number of clusters per municipality that can be directly calibrated to the density-adaptive rule, whereas DBSCAN's output cluster count depends on parameter tuning that is difficult to standardise nationally.

3. **Constrained Voronoi Tessellation**: The building clusters produced in Phase 2 are converted into sector polygon geometries using constrained Voronoi tessellation. One centroid is computed per cluster and used as the Voronoi seed. The tessellation is then constrained by two sets of hard boundaries: municipality boundaries, ensuring that sector geometries strictly respect administrative limits as required by the subsidiarity principle underlying the EDO's operational structure (Bevölkerungs- und Zivilschutzgesetz, BZG, 2021), and infrastructure features such as roads, rivers, lakes, and railways which act as splitting lines wherever they intersect Voronoi cells and the split makes sense. This dual constraint system ensures that sector polygons are both administratively valid and operationally coherent, following boundaries that field teams can recognise and navigate. Buildings located outside any cluster isolated structures in sparsely populated areas are assigned to the nearest sector through a spatial join, ensuring complete coverage with no unassigned buildings. The tessellation is implemented using Euclidean distance; a road-network-aware cost surface would better reflect real field accessibility but is reserved for future work (see Section 6.4).

4. **Post-Processing and Quality Control**: Geometric cleaning operations are applied to the generated sector polygons: sliver polygons below a defined area threshold are dissolved into adjacent sectors, and topological validity is verified. Sector-level attributes including building count, sector area, and building density are computed and stored as metadata. Each sector receives a unique identifier consistent with the naming convention used in the existing TERMOT system.

Table 3: GWR building categories (GKAT) excluded from Phase 1 filtering (Source: BFS, GWR Merkmalskatalog)

GKAT	Category (GWR)	Group	Reason excluded
1230	Gross-/Einzelhandelsgebäude	Commercial	*Not inhabited; no residential claims*
1241	Verkehrs-/Nachrichtenwesen	Infrastructure	*Transport infra; outside EDO scope*
1242	Garagengebäude	Infrastructure	*Not inhabited*
1251	Industriegebäude	Infrastructure	*Not inhabited; specialist assessment*
1261	Kultur-/Freizeitgebäude	Non-residential	*Not permanently inhabited*
1262	Museen und Bibliotheken	Non-residential	*Not inhabited; no residential claims*
1263	Schul-/Hochschulgebäude	Non-residential	*Not permanently inhabited*
1264	Krankenhäuser / Gesundheit	Non-residential	*Specialist protocols; outside EDO scope*
1271	Landwirtschaftliche Betriebsgebäude	Agricultural	*Not inhabited; inflates rural counts*
1272	Kirchen und Kultgebäude	Non-residential	*Not inhabited; no residential claims*
1273	Denkmäler	Non-residential	*Not inhabited; heritage assessment*
1274	Sonstige Hochbauten (Kasernen etc.)	Non-residential	*Military/correctional; outside EDO scope*
1275	Alpine Hütten / Sonderbauten	Alpine / remote	*Seasonally used; distorts cluster geometry**
1276	Sonderbauten (Tiefbau-related)	Alpine / remote	*Infrastructure objects; not habitable*

1277	Sonderbauten, weitere	Alpine / remote	*Not habitable*
1278	Sonderbauten, weitere	Alpine / remote	*Not habitable*

* Exclusion of alpine structures directly addresses stakeholder requirement (Nardi, 2025; S. Wildhaber, 2025); see Section 4.2.

The approach is demonstrated as a proof-of-concept across a representative sample of six municipalities (see table 1) spanning urban, intermediate, and rural settlement contexts, as defined in the sampling strategy of Section 3.2.4. This scope is intentional: the aim is not to produce a production-ready national dataset, but to demonstrate that the revised design principles produce measurably better sectors across the full range of spatial contexts in which TERMOT operates. The extension of the approach to a full national deployment is discussed as a future development pathway in Section 6.4. Table 4 summarises the key design differences between the existing and revised approaches across eight dimensions, illustrating how the two guiding principles translate into concrete methodological changes.

Table 4: Existing vs. revised sector generation approach

Dimension	Existing approach	Revised approach
Primary input	Infrastructure lines	Building cluster centroids
Role of buildings	Post-hoc assignment	Generative input
Role of infrastructure	Primary boundary generator	Hard boundary constraint
Building count	Generative constraint (10 - 30)	Output attribute (workload proxy)
Sector size scaling	Fixed national threshold	Density-adaptive per municipality
Boundary coherence	Coincidental	By design
Remote structures	Included by default	Filterable via GWR category
Workload balancing	Geometric post-processing	Assignment-level scoring

3.4.2 Additional Data Sources

Although the revised approach draws exclusively on data sources already integrated into the existing TERMOT pipeline, a systematic evaluation of additional geospatial sources was conducted to confirm this conclusion and document the reasoning behind it. These additional sources were identified through three channels: insights emerging from the stakeholder interviews, findings from the literature review, and a dedicated expert consultation with the “Amt für Raumentwicklung, Fachstelle Räumliche Daten und Analysen” of the Canton of Zurich, whose input provided practical guidance on relevant spatial datasets available within the Swiss geospatial data infrastructure (T. Gasser, persönliche Kommunikation, 2. März 2026). Candidate data sources were evaluated against three criteria:

1. **national availability:** ensuring that the data covers the full study area of Switzerland and Liechtenstein consistently
2. **operational relevance**: meaning that the source addresses a structural deficiency identified in the status quo analysis or an operational requirement identified through interviews or literature
3. **practical implementability:** within the geo-processing pipeline used for TERMOT.

Following this evaluation, the conclusion is that no data sources beyond those already integrated into the existing TERMOT pipeline are required for the revised approach. The four datasets already in use (GWR building locations and attributes, swissBOUNDARIES3D municipality boundaries, TLM road network, and TLM watercourse and railway lines) collectively provide everything the revised algorithm needs across all four phases. This is a deliberate methodological outcome rather than a limitation: it means the revised approach is a direct replacement for the existing pipeline with no new data acquisition costs, no additional infrastructure dependencies, and no reduction in national coverage. The improvement comes entirely from how the existing data is used, specifically, the reordering of roles between building data and infrastructure data as described in Section 3.4.1, rather than from adding new inputs.

Three data sources were considered but not incorporated. First, cantonal zoning plans from the "ÖREB-Kataster" were identified as potentially relevant for Phase 1 building filtering, as they would allow more precise distinction between building zones and non-building zones at the parcel level. However, their inconsistent availability across cantons and the additional integration complexity they would introduce make them unsuitable as a primary input for a nationally consistent algorithm. They are noted as a candidate for future refinement.

Second, cantonal hazard maps (Gefahrenkarten) and settlement boundary delineations from cantonal spatial planning (Richtplanung) were identified during the expert consultation as potentially relevant for risk-informed sector design. Both were excluded on the same grounds of inconsistent cantonal availability and their strategic rather than operational character.

Third, the seismic hazard zones defined by the Swiss architectural norm SIA 261 (SIA, 2020) and distributed by swisstopo as a nationally consistent GIS layer were considered. These zones subdivide Switzerland into five seismic hazard classes (Z1a, Z1b, Z2, Z3a, Z3b) based on reference peak ground acceleration and are used for structural design of buildings under Swiss building code (SGEB, 2026). Unlike the two sources discussed above, the seismic hazard zones satisfy both the national availability and practical implementability criteria. They were nevertheless excluded from the sector generation step on methodological grounds: incorporating earthquake-specific inputs into sector geometry would couple the sector system to a single hazard and limit its long-term applicability to other crisis contexts. Seismic hazard information is instead integrated at the scenario-based application stage through SED shakemap intensity values (Section 3.6.2), where it appropriately informs prioritisation and team allocation without shaping sector boundaries.

A further design consideration that emerged from the expert consultation and interviews concerns the long-term applicability of the sector system beyond earthquake response. Several stakeholders noted that a sector system with broader spatial coherence could potentially serve other hazard contexts in future (Horvath, 2025; S. Wildhaber, 2025). This reinforced the importance of avoiding earthquake-specific inputs in the sector generation step itself as such inputs would limit the generalisability of the sector geometry. Earthquake-specific data, including ShakeMap intensity values, are therefore reserved for the scenario-based application described in Section 3.6, where they inform prioritisation and team allocation rather than sector shape.

3.5 Validation & Testing

This chapter describes the strategy and criteria used to validate the revised sector approach. The objective of the validation is to demonstrate empirically whether the redesigned sectors represent a measurable improvement over the existing system. This is achieved through a direct, quantitative comparison of both sector systems using the same set of metrics applied in the status quo analysis in, ensuring full methodological consistency and comparability between the two approaches.

3.5.1 Testing Strategy

The validation follows a comparative testing strategy in which the existing and revised sector systems are evaluated side by side using the same metric framework, applied across all the sectors in the six proof-of-concept municipalities described in Section 3.2.4. Rather than assessing the new sectors in isolation, the testing strategy is explicitly designed to measure relative improvement within the proof-of-concept scope, while the metric framework is designed for extensibility to the full national dataset.

The analysis operates at two spatial levels: individual sector quality is assessed through the metric framework applied to each sector polygon independently, while comparative evaluation between the existing and revised approaches is conducted at the municipality level, examining the distribution of sector quality metrics across all sectors within each proof-of-concept municipality.

The results demonstrate whether the revised approach produces sectors that perform systematically better against the defined quality criteria across the full range of Swiss settlement typologies represented in the sample.

3.5.2 Evaluation Criteria

The evaluation criteria applied in the validation are identical to those defined in Section 3.3.2, namely the quantitative metrics operationalising each of the three analytical dimensions established through the qualitative and quantitative analysis of the existing system, as presented in Chapter 4. This deliberate reuse of metrics serves two purposes: it ensures full comparability between the status quo analysis and the validation results, and it guarantees that the validation directly tests whether the redesign addresses the same quality dimensions identified in the existing system.

For each metric, the distribution of scores is compared between the existing and the revised approach. Improvement is assessed both at the level of individual metrics, examining whether the revised sectors score better on each specific quality dimension, and at an aggregate level, examining the overall profile of sector quality across the proof-of-concept municipalities.

This before-and-after comparison is expressed as the percentage of sectors exhibiting each quality issue under each approach respectively, providing a direct and transparent measure of how effectively the redesign addresses the identified deficiencies. The results of this comparative evaluation are presented in Section 4.4.

3.6 Scenario-Based Application

The final component of the methodology extends the validated sector system into the operational domain by demonstrating how structurally improved sectors can support practical earthquake response. The previous chapters optimise sectors as static spatial units, while this chapter addresses how those sectors can be made dynamically useful once a seismic event occurs. The scientific basis for this extension is the dynamic earthquake risk framework developed by the Swiss Seismological Service and ETH Zurich, which positions the spatial deployment of building assessment resources as the operational endpoint of a chain running from seismic monitoring through ShakeMaps and Rapid Impact Assessment to field response (Böse et al., 2024). This thesis addresses that endpoint: given that ShakeMaps and damage estimates are available within minutes of an event, how should the available expert teams be allocated across sectors, and in what order should those sectors be assessed? The three analytical steps developed in this chapter are designed to answer this question in a structured, data-driven manner, and to demonstrate that the revised sector system provides a substantially more reliable spatial foundation for doing so than the existing one.

This component is explicitly framed as a conceptual operational framework rather than a fully implemented system. Its purpose is to demonstrate the operational potential of the revised sector definitions and to provide a concrete, reproducible basis for future integration into the TERMOT platform. The application follows the temporal distinction introduced in Section 3.1: processes executed during the preparation phase before an earthquake, and processes activated in response after an event occurs. The three steps are applied illustratively to the proof-of-concept municipalities in Section 4.5.

3.6.1 Pre-Earthquake Workload Scoring

The first step is conducted during the preparation phase, independent of any specific seismic event. Its purpose is to enrich each sector with a workload score that quantifies the expected assessment effort an expert team would require. Because this score depends only on the static building stock, it can be precomputed and stored as part of the library sector dataset, enabling rapid operational deployment once an event occurs.

The conceptual basis draws on established post-earthquake building assessment methodology. Rapid safety evaluation procedures identify building size, structural complexity, and occupancy type as the primary determinants of assessment effort (ATC, 2005; FEMA, 2019). Consistent with this framework, the workload score is derived from three building-level attributes available in the Federal Register of Buildings and Dwellings (GWR):

1. number of floors of a building
2. floor area of a building
3. structural complexity as approximated by building category (GKAT).

Floor count and floor area are direct proxies for physical inspection effort where larger and taller buildings require proportionally more time to assess. Building category serves as a proxy for structural complexity: non-residential or mixed-use categories typically involve more heterogeneous construction types and greater assessment uncertainty, consistent with observed post-earthquake field patterns (FEMA, 2019).

Each attribute is first normalised to a [0, 1] scale across the full building stock to ensure comparability, then combined into a weighted additive formula:

$$\mathbf{W(b) = w_1 \cdot norm(floors) + w_2 \cdot norm(area) + w_3 \cdot norm(complexity)}$$

where b denotes an individual building, and w_1, w_2, w_3 are weighting coefficients. The sector-level *workload score WS* is the sum of W(b) across all buildings b within the sector:

$$\mathbf{Workload\ Score = \Sigma\ W(b)}$$

The sum is used deliberately rather than an average: workload represents the total assessment effort for a team assigned to the sector, which scales with the number of buildings in scope. Averaging would make WS insensitive to sector size, obscuring precisely the information that team-capacity planning requires. Table 5 presents the indicative weighting coefficients used in this study. These values are not operationally calibrated since this would require empirical timing data from EDO field operations but are grounded in the relative importance assigned to each factor in ATC-20 rapid assessment procedures, where physical size is the dominant effort driver and structural type is secondary (ATC, 2005).

Normalisation is performed against fixed reference values representative of the Swiss building stock, anchored in the Federal Register of Buildings and Dwellings (*Merkmlaskatalog Eidgenössisches Gebäude- und Wohnungsregister*, 2022), the SIA 261 structural norm (SIA, 2020), and stakeholder interviews conducted for this study (Section 4.1.4). For the number of floors, FL_max = 8 reflects the operational ceiling identified by EDO stakeholders for standard rapid assessment (Steiger, 2025), covering residential and mixed-use buildings up to the 7–8-storey range. Buildings beyond this range are flagged for specialist assessment rather than standard team evaluation (Camenisch, 2025), consistent with ATC-20 guidance for high-rise structures (ATC, 2005). For floor area, AR_max = 400 m² corresponds to the upper end of the typical residential footprint range in Switzerland, covering single- and small multi-family houses (GKAT 1020–1021) documented in the GWR (BFS, 2024). Larger commercial, industrial, and specialist buildings exceeding this threshold are captured by the complexity attribute, avoiding double counting of building size. For structural complexity, the filtered GWR building stock is mapped to a normalised scale in [0, 1] based on the GWR building category and class. Single-family houses (GKAT 1020, GKLAS 1110) represent the lower bound, reflecting structurally simple, largely homogeneous construction. Multi-family houses (GKAT 1020/1030, GKLAS 1121/1122) occupy the middle range. Mixed-use residential buildings with ground-floor commercial or institutional functions (GKAT 1030, 1040) approach the upper bound of the scale, reflecting higher structural heterogeneity and greater assessment uncertainty consistent with ATC-20 observations for mixed-use post-earthquake inspection (ATC, 2005).

These reference values are calibration parameters rather than empirically derived operational constants. Their limitations and the path to empirical calibration are discussed in Section 5.4.

Table 5: Indicative weighting coefficients used

Parameter	Variable	Indicative Value	Rationale
W_1	Number of floors	0.40	Primary determinant of vertical inspection effort
W_2	Floor Area	0.35	Primary determinant of horizontal inspection effort
W_3	Building Complexity	0.25	Secondary determinant for structural uncertainty

3.6.2 Post-Earthquake Priority Classification

The second step is activated immediately following an earthquake, once ShakeMap data from the SED becomes available. Its purpose is to classify sectors by operational urgency, enabling assessment teams to be deployed in a structured sequence from the most to the least affected areas.

The scientific basis for spatially differentiated prioritisation is well established. Post-earthquake damage severity varies substantially across the affected area as a function of seismic intensity, local ground conditions, and building vulnerability. Rapid assessment frameworks recommend directing initial response towards sectors combining high expected damage with significant residential occupancy, reflecting the life-safety principle that inhabited structures require earliest attention (ATC, 2005; FEMA, 2019). The EDO operational guidelines are consistent with this: sectors are prioritised based on their damage zone classification and residential building count, with assessment teams working outward from the epicentre (SOE, 2023).

The ShakeMap is the event-specific spatial input for this step. The SED produces ShakeMaps within approximately five minutes of an event using Swiss-specific ground-motion models, ground-motion-to-intensity conversion equations, and site amplification layers that are consistent with those underlying ERM-CH23 (Böse et al., 2024). The same ShakeMap product, combined with the same site amplification layer, underlies the Swiss Rapid Impact Assessment (RIA) system operated by SED (Böse et al., 2024). The intensity input used here is therefore consistent with the operational hazard product used by SED for event-based impact estimation, and jointly captures the earthquake hazard and local soil conditions components of the four-component risk model introduced in Chapter 2. The ShakeMap output consists of spatial polygons, each carrying a numeric intensity indicator (shakeval_n) on a continuous scale from 1.0 to 8.5, representing calibrated macro-seismic intensity broadly consistent with the European Macroseismic Scale (Grünthal, 1998). These polygons are already ingested and processed within the TERMOT platform (SOE, 2023). The spatial input for this prioritisation step is therefore a spatial intersection of each sector polygon with the ShakeMap layer: the shakeval_n value of the ShakeMap zone with the greatest areal overlap is assigned to the sector, yielding a per-sector intensity value I.

Prioritisation Score is based on a composite score combining the pre-computed *workload score WS* with two event-specific factors:

$$\mathbf{PS = WS \cdot RF(I) \cdot UF}$$

where RF(I) is a *Risk Factor* derived from the sector's assigned ShakeMap intensity value, and UF is an *Urgency Factor* reflecting residential occupancy:

$$\mathbf{UF = u_1 \cdot norm(residents) + u_2 \cdot norm(residential\_share)}$$

The *Urgency Factor* combines two residential occupancy indicators derived from the GWR. The first, resident count, captures the absolute number of inhabitants within the sector and serves as a direct proxy for life-safety exposure, whereas the second, residential building share, captures the proportion of buildings serving a residential purpose and reflects the overall character of the sector as a living area. Together they ensure that neither a densely populated sector with mixed land use nor a purely residential but sparsely inhabited sector is systematically over- or under-prioritised. It should be noted that resident count is not directly recorded in the GWR. In practice, dwelling count (Anzahl Wohnungen) would serve as a proxy, or commune-level population data would need to be spatially allocated to individual buildings.

The *Risk Factor* maps the continuous shakeval_n to a multiplier on a 1 - 5 scale, such that higher shaking intensity yields a higher multiplier, reflecting greater expected structural damage and assessment urgency. The *Urgency Factor* weights sectors with a higher number of residents and a higher proportion of residential buildings more heavily, consistent with the life-safety prioritisation principles of the Sendai Framework (UNISDR, 2015). Table 6 presents the indicative parameter values applied later.

Table 6: Indicative parameter used for post-earthquake Priority Classification

Parameter	Variable	Indicative Value	Rationale
Risk Factor Mapping	shakeval_n ≤ 3.0	1.0	Negligible damage expected
	shakeval_n 3.5–4.5	1.5	Light damage, limited assessment need
	shakeval_n 5.0–5.5	2.5	Moderate damage, assessment warranted
	shakeval_n 6.0–7.0	3.5	Heavy damage to ordinary buildings
	shakeval_n ≥ 7.5	5.0	Destructive; immediate priority
Urgency Factor U_1	Resident count	0.60	Life-safety criterion, Sendai Framework
Urgency Factor U_2	Residential building share	0.40	Occupancy density indicator

The resulting composite priority score PS is used to classify each sector into one of four urgency levels

- Very High
- High
- Medium
- Low

The four priority classes are assigned by ranking all sectors within the affected footprint in descending order of their Priority Score PS. Priority classes are then defined by percentile bands across this ranking: the top 20 % of sectors are classified as Very High, the next 30 % as High, the next 30 % as Medium, and the remaining 20 % as Low. This percentile-based assignment is consistent with operational prioritisation practice in post-earthquake rapid assessment (ATC, 2005; FEMA, 2019), in which teams are directed towards the most urgent cases first, with a clearly defined descending order of deployment. In small-sample applications such as the proof-of-concept presented in Section 4.5, the rule is applied across the available sectors within the affected footprint; in a full national deployment with hundreds to thousands of sectors, the same percentile structure would be applied against the operational distribution of PS values, with thresholds empirically calibrated against the observed PS distribution.

Applied within the affected footprint, defined as all sectors intersecting ShakeMap zones with shakeval_n ≥ 3.5. Sectors outside this threshold are excluded from deployment planning, consistent with the EDO principle that building assessment only covers the inner damage zones of an event.

3.6.3 Operational Team Allocation

The third step translates the priority classification into a structured deployment plan, referred to hereafter as an *Action Plan*, by assigning available expert teams to sectors in a feasible and operationally justified sequence.

Resource allocation under disaster conditions requires balancing urgency, workload, and resource availability under time pressure (Altay & Green, 2006). In the EDO context, this challenge is compounded by hard operational constraints: expert teams must consist of at least two members, building assessment experts are restricted to their allocated canton, one team can work only one sector at a time, and experts may not exceed 15 consecutive working days (SOE, 2024). A purely urgency-driven sequential allocation, meaning assigning teams strictly by priority score without regard for cantonal boundaries or team capacity, is therefore not operationally feasible.

It is important to note that the EDO coordinates two operationally distinct post-earthquake workflows, as described in Section 2.2.2: the building usability assessment, which is highly time-critical and must begin immediately after an earthquake, and the damage estimation workflow, which proceeds once the most urgent safety assessments are underway. Both workflows use the same sector structure within TERMOT but follow different operational logics, involve different expert pools, and proceed in opposite spatial directions across the affected area. The three-step framework developed in this chapter, workload scoring, priority classification, and team allocation, is applicable in principle to both workflows. For the proof-of-concept Action Plan presented in Section 4.5.3, the framework is illustrated in the context of the building usability assessment workflow, as this workflow involves direct sector-level team assignment and workload balancing across the full affected area, making it the more directly applicable context for the allocation logic developed here. The damage estimation workflow, where teams are pre-allocated to cantons by BABS and work outward from the epicentre, would use the same sector geometry and priority classification but would apply a different team assignment logic reflecting cantonal pre-allocation rather than sector-level optimisation. This distinction is acknowledged as a direction for future operational integration in Section 6.4.

The allocation logic developed here addresses these constraints through a two-level sorting rule: sectors are ordered in descending priority within each canton first. Where sectors share the same priority level, workload score serves as the secondary sorting criterion to balance effort evenly across teams. The number of available teams per canton is treated as an input parameter, allowing the Action Plan to be computed for different resource availability scenarios. Sectors not covered by available teams within a canton are flagged as deferred, providing explicit visibility of coverage gaps to the EDO coordination unit. The resulting Action Plan is presented as a structured table in Section 4.5. Figure 21 presents an overview of the scenario-based application framework.

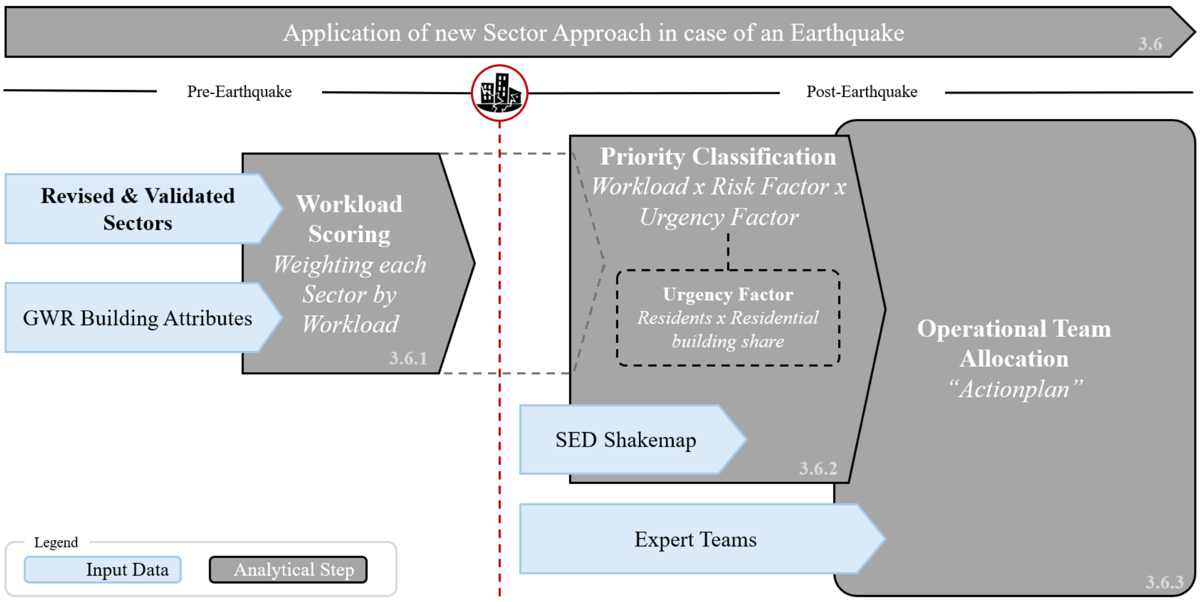


Figure 21: Overview of the scenario-based application framework, distinguishing pre-earthquake preparation processes from post-earthquake response processes.

4. Results

This chapter presents the findings of the analytical process described in Chapter 3. The first stage, covered in Sections 4.1 and 4.2, characterises the existing TERMOT sector system: Section 4.1 documents the structural limitations identified through the qualitative Mayring analysis, as well as the quantitative analysis, Cohens' Kappa results, interview inputs and the algorithmic review, while Section 4.2 consolidates the requirements for a revised approach derived from those findings alongside stakeholder interviews and literature. The second stage, presented in Section 4.3, describes the outcomes of the revised sector generation applied to the representative sample of municipalities. Section 4.4 then presents the quantitative validation comparing the existing and revised sectors using the same metric framework. The third stage, covered in Section 4.5, presents the results of the scenario-based application, demonstrating the operational utility of the revised sectors under simulated earthquake conditions. Discussion and implications are addressed in Chapter 5.

4.1 Current Sectorization Limitation

The analysis of the existing TERMOT sector system proceeded in two complementary steps as described in Section 3.3. First, a qualitative content analysis following Mayring (2014) was conducted on a stratified sample of 60 Swiss municipalities to identify recurring structural problem patterns. The three Liechtenstein municipalities included in the overall sample were excluded from this analysis due to the small number of sectors available per typology stratum, which would not support meaningful stratified comparison. Second, the empirically derived problem categories were operationalised into quantitative metrics. The algorithmic origins of the identified problems are described in Section 4.1.5.

4.1.1 Qualitative Analysis: Problem Categories

The inductive category formation process identified three distinct problem categories directly from the sector material. Together they account for all structurally significant problems observed across the sample. 32 out of 60 sampled Swiss sectors (53.3%) exhibit at least one problem category, confirming that structural deficiencies are not isolated exceptions but recurring patterns across all settlement contexts. Of these, 21 sectors (35.0%) exhibit exactly one problem category, while 11 sectors (18.3%) exhibit two or more simultaneously. The problem categories identified are described below.

- **Category A: Size and Workload Imbalance** is the most prevalent category, present in 22 out of 60 sectors (36.7%). It describes sectors that deviate significantly from the existing system's operational building count target of 10 - 30 buildings, resulting in either negligible assessment workload or a disproportionate burden that a single expert team cannot complete within a standard deployment period. Of the 22 affected sectors, 19 are undersized with fewer than 10 buildings (31.7% of the full sample) and 2 are oversized with more than 30 buildings (3.3%). The category is distributed evenly across settlement types, Urban 38%, Intermediate 33%, Rural 39%, indicating that this is a systemic characteristic of the existing algorithm rather than a context-specific failure. The operational impact is direct: sectors with fewer than 10 buildings cannot justify the deployment of a dedicated expert team, while sectors exceeding 30 buildings surpass the daily inspection capacity defined by ATC-20 procedures (ATC, 2005), creating bottlenecks that delay the assessment of adjacent areas. It is important to note that this problem category is defined here specifically in relation to the existing system's own design target. The revised approach developed in Section 3.4 deliberately decouples building count from sector geometry, treating it instead as a workload proxy managed through expert team assignment rather than as a generative constraint.

- **Category B: Spatial Inefficiency** is present in 13 out of 60 sectors (22%) and describes sectors where the relationship between geographic extent and building stock is operationally dysfunctional. Two distinct sub-patterns were identified through the qualitative analysis. The first, spatial over-extension, affects sectors predominantly in rural and alpine contexts: large polygon extents with very few buildings and extremely low density, producing sectors that cover extensive uninhabited terrain while containing almost no assessment workload. The second, algorithmic over-subdivision, affects sectors in dense urban contexts where the fine-grained road network causes the existing algorithm to generate very small polygon cells within continuous built-up areas, creating artificial subdivisions of settlement fabric that a single team could assess in a fraction of the expected time. Both sub-patterns share a common root cause: sector shapes are determined by infrastructure line geometry rather than by the actual distribution of buildings. The consequence differs by context: in rural areas the result is spatial over-extension, in dense urban areas it is over-subdivision but the underlying algorithmic logic is identical in both cases. Although Spatial Inefficiency may appear to overlap with Size and Workload Imbalance, since both relate to building count and sector extent, the two categories are operationally distinct. Category A concerns the absolute number of buildings relative to the EDO's operational target and applies regardless of geographic extent: a compact urban sector with two buildings is a Category A problem irrespective of its area. Category B concerns the spatial relationship between geographic extent and building stock and applies regardless of whether the building count falls within the target range: a sector with 15 buildings covering 0.4 km² of alpine terrain at a density of 37 buildings per km² exhibits spatial inefficiency without any workload imbalance. The operative question for Category A is how many buildings a sector contains, whereas for Category B it is how those buildings are distributed across the geographic extent. The category is most prevalent in rural municipalities, where 33% of sampled sectors exhibit the problem, compared to 17% in both urban and intermediate contexts, reflecting the greater spatial heterogeneity of low-density settlement patterns relative to the infrastructure network that drives sector boundary generation. The operational consequence is wasted deployment capacity: in rural contexts, teams spend the majority of their time traversing empty terrain rather than assessing buildings, whereas in urban contexts, teams complete their assigned sector in a fraction of the expected time, leaving capacity unused. Both outcomes reduce the efficiency of the overall assessment operation.

- **Category C: Boundary Incoherence** is present in 12 out of 60 sectors (20.0%) and describes sectors whose boundaries do not follow recognisable physical or administrative features navigable in the field. Where sector boundaries are generated by the quadrant-based splitting algorithm which was applied to sectors exceeding 30 buildings, they are defined purely by coordinate geometry, bearing no relation to the underlying street network, topography, or administrative structure. In other cases, sector boundaries cross roads, rivers, or natural barriers in ways that make the spatial extent of the sector ambiguous and difficult for expert teams to identify on the ground. The distribution across settlement types is relatively even (Urban 21%, Intermediate 22%, Rural 17%) suggesting this problem is not confined to rural contexts but reflects a broader absence of field-navigability criteria in the boundary generation logic. The operational impact is navigational: field teams cannot reliably identify the extent of their assigned sector on the ground, creating ambiguity about which buildings belong to which unit and increasing the risk of duplicated or missed assessments.

The three categories are not mutually exclusive (see Table 7). 11 sectors (18.3%) exhibit more than one problem simultaneously, with co-occurrence most frequent between Size & Workload Imbalance and Spatial Inefficiency (A+B: 9 sectors), reflecting the shared algorithmic origin of both problems in rural low-density contexts where sparse road networks compound the difficulties of building-count-driven geometry. Co-occurrence between Size & Workload Imbalance and Boundary Incoherence (A+C: 6 sectors) typically arises where the quadtree splitting algorithm produces both undersized residual sectors and geometrically arbitrary boundaries simultaneously. 28 sectors (46.7%) exhibit no problem category, providing a baseline of operationally adequate sectors against which problematic cases can be compared.

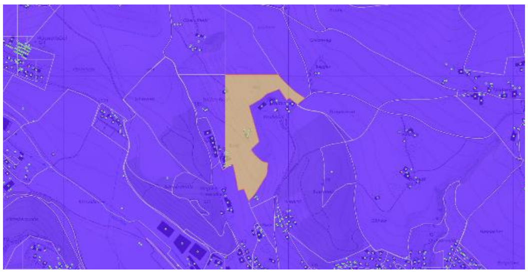
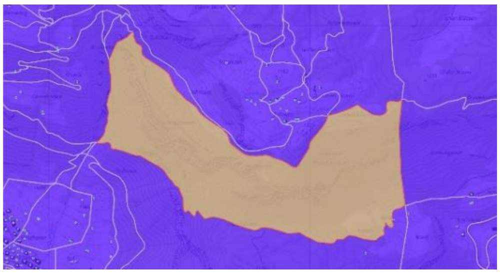
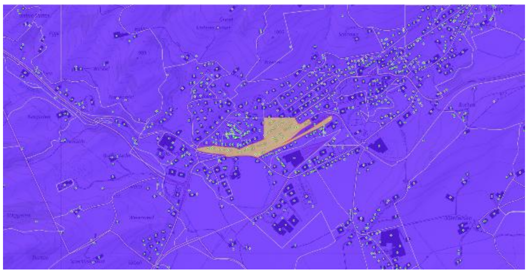
Table 7: Problem Category distribution across settlement types (n = 60 Swiss sectors)

Category	Urban (n=24)	Intermediate (n=18)	Rural (n=18)	Total (n=60)
A: Size & Workload	9 (38%)	6 (33%)	7 (39%)	22 (36.7%)
B: Shape & Geometry	7 (29%)	4 (22%)	9 (50%)	20 (33.3%)
C: Context & Accessibility	5 (21%)	4 (22%)	3 (17%)	12 (20%)
No Problem Identified	7 (29%)	8 (44%)	5 (28%)	20 (33%)

Note: Categories are not mutually exclusive. Row totals may exceed 100%

To illustrate the three problem categories, Table 8 presents five representative sector examples drawn from the sector sample. Each example was selected to demonstrate a distinct problem pattern identified through the qualitative analysis, with one reference sector included to provide a visual baseline for comparison. Screenshots were captured in QGIS at a uniform scale of 1:2750, all facing north to ensure visual comparability across all examples. The complete overview for all sampled sectors is provided in Appendix D.

Table 8: Representative sector examples illustrating the three problem categories (QGIS screenshots at 1:2750 scale)

Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
AG - Geltwil – 15 - BFS Typology: Rural - Size: 0.064km^2 - Building Count: 1 - Building Density: 16/km^2	Size & Workload Imbalance	
BE-Bolligen-106* - BFS Typology: Urban - Size: 0.086km^2 - Building Count: 11 - Building Density: 128/km^2	Boundary Incoherence	
BE - Brienzwiler – 69** - BFS Typology: Rural - Size: 0.43km^2 - Building Count: 1 - Building Density: 2/km^2	Size & Workload Spatial Ineffciency Boundary Incoherence	
AR - Gais – 9 - BFS Typology: Intermediate - Size: 0.026km^2 - Building Count: 30 - Building Density: 1132/km^2	Boundary Incoherence	
VD - Saint-Sulpice (VD) – 8 - BFS Typology: Urban - Size: 0.06km^2 - Building Count: 19 - Building Density: 315/km^2	No problem	

**BE - Bolligen - 106: illustrates how the quadrant-based splitting algorithm produces boundaries defined purely by coordinate geometry, bearing no relation to the underlying street network, a characteristic example of Category C.*

***BE - Brienzwiler - 69: illustrates the co-occurrence of all three problem categories in a low-density alpine context, reflecting their shared algorithmic origin.*

4.1.2 Quantitative Metric Results

To enable consistent and reproducible assessment of sector quality, the three problem categories identified through the qualitative analysis were operationalised into quantitative metrics as described in Section 3.3.2. Metrics and their thresholds were defined independently of the qualitative codings, drawing on operational documentation and established benchmarks from the territorial design literature, to ensure methodological rigour in the subsequent Cohen's Kappa validation in Section 4.1.3.

For Category A, Size and Workload Imbalance, the primary metric is building count per sector, with a binary classification threshold defined by the EDO's operational target range of 10 - 30 buildings per sector (SOE, 2023). This threshold has a dual grounding. First, it is the explicit design criterion of the existing TERMOT system and therefore serves as the system's own stated benchmark for workload adequacy. Second, it is independently corroborated by established post-earthquake building safety evaluation procedures: the ATC-20 Field Manual (ATC, 2005) and the FEMA post-disaster evaluation guidance (FEMA, 2019) both identify approximately 20–30 buildings as the realistic daily inspection capacity of a two-person evaluation team under field conditions, depending on damage complexity and accessibility. A sector below the lower bound of 10 buildings therefore represents a workload so small that deployment of a dedicated team is inefficient, whereas a sector above 30 buildings exceeds what a team can reliably complete within a standard assessment day. Sectors outside this range on either side are classified as exhibiting the Category A problem. Four supporting metrics provide additional descriptive characterisation of the size and workload dimension:

- building count deviation from the target midpoint, calculated as $(B-20)/20$
- total sector area in km²
- building density in buildings per km²
- area-to-building ratio in m² per building.

All metrics require polygon geometry data and were computed from the sector GeoPackage using QGIS. Descriptive statistics for all metrics across the 60-sector Swiss sample are presented in Table 9.

Table 9: Descriptive statistics for "Size and Workload Imbalance" metrics (n=60 Swiss sectors)

Metric	Min	Median	Mean	Max	Standard Deviation	Binary Threshold
Building Count (n)	1	13	14	31	9.63	Outside 10 - 30
Building Count Deviation	-0.95	-0.35	-0.28	0.55	0.48	> 0.50
Sector Area (km^2)	0.002	0.025	0.073	0.431	0.097	> 0.05
Building Density (n/km^2)	2.3	674.6	762.2	3686.5	760.8	< 100
Area-to building-ratio (m^2 / n)	271	1503	31,574	430,953	86,418	> 10,000

Note: The area-to-building ratio shows extreme positive skew due to single-building sectors in large alpine polygons; the median is the more representative measure of central tendency for this metric.

For Category B, Spatial Inefficiency, the primary metric is building density in buildings per square kilometre, with a threshold of fewer than 50 buildings per km² identifying sectors that exhibit spatial over-extension, the defining operational characteristic of this problem. The threshold was determined through a systematic sweep of candidate values across the qualitative coding for Category B, selecting the value that maximised Cohen's Kappa while remaining operationally interpretable. A density below 50 buildings per km² corresponds to sectors in which the geographic extent so far exceeds the building stock that assessment teams would spend the majority of their deployment time traversing empty terrain rather than inspecting structures. This is consistent with the territorial design principle that operational zones should be sized to reflect the spatial distribution of demand rather than the geometry of the boundary network (Kalcsics et al., 2005) and with the broader operations research literature on workload-balanced spatial partitioning, which identifies demand density as the primary criterion for zone delineation (Galindo & Batta, 2013). Three supporting metrics characterise the geometric dimension of spatial inefficiency without serving as primary validators:

- the Shape Compactness Index (Polsby-Popper ratio), calculated as $(4\pi \times \text{Area}) / \text{Perimeter}^2$, which produces a score between 0 and 1 where values approaching 1 indicate a compact near-circular shape and values approaching 0 indicate an irregular or elongated geometry. This measure is well established in the territorial design literature as a standard indicator of spatial compactness (Kalcsics et al., 2005) and has been applied in operational sectorization contexts including police district design (Camacho-Collados et al., 2015) and airspace management (Trandac et al., 2005).
- the Elongation Ratio, calculated as the length-to-width ratio of the minimum bounding rectangle (L_max / W_min), captures the specific sub-pattern of long narrow sectors that are difficult for field teams to navigate as coherent operational units.
- the Convex Hull Ratio, calculated as the ratio of actual sector perimeter to convex hull perimeter, measures boundary sharpness and captures the degree to which sector boundaries deviate from convex geometry, a characteristic associated with algorithmically fragmented polygons that follow road network gaps rather than settlement patterns.

These three geometric metrics were tested as potential primary validators for Category B but were not selected as the primary metric. The reason is methodologically significant and warrants explanation here. Spatially inefficient sectors are not necessarily geometrically irregular. A large but compact polygon covering 0.43 km² with a single building is the problem, not its shape; and an overly small but geometrically regular sector in a dense urban area is equally problematic operationally despite appearing well-formed by compactness metrics. Shape geometry is therefore a consequence of spatial inefficiency in some contexts but not a reliable discriminator of it across the full range of settlement types in the Swiss sample. Building density captures the underlying operational problem: the mismatch between geographic extent and assessment workload, independently of shape, which explains why it was selected as the primary metric while the geometric metrics are retained as supporting descriptors. The Cohen's Kappa results confirming this decision are reported in Section 4.1.3. All three supporting metrics require polygon geometry data and were computed from the sector GeoPackage using QGIS. Their descriptive statistics are presented in Table 10.

Table 10: Descriptive statistics for "Spatial Inefficiency" geometric metrics (n=60 Swiss sectors)

Metric	Min	Median	Mean	Max	Standard Deviation	Binary threshold
Building Density (n/km²)	2.3	674.6	762.2	3686.5	760.8	< 50
Shape Compactness Index (Polsby-Popper)	0.123	0.491	0.485	0.842	0.192	< 0.50
Elongation Ratio (L_max / W_min)	1.008	1.612	2.162	10.256	1.580	> 3.0
Convex Hull Ratio (Perim. / Convex Hull Perim.)	1.000	1.062	1.110	1.552	0.121	> 1.10

Note: Candidate thresholds of 25, 50, 75, and 100 buildings/km² were evaluated; 50 buildings/km² yielded the highest κ (0.669) while remaining operationally interpretable.

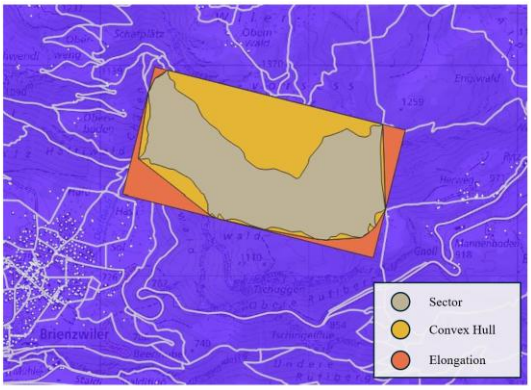


Figure 22: Conceptual illustration of sector shape metrics. The original sector (grey) is compared to its convex hull (yellow), with the excess area (orange) indicating deviations from compactness and elongation.

The primary metric for Category C is the Boundary Alignment Score (BAS), a custom indicator developed for this study to operationalise the qualitative observation that sector boundaries frequently fail to follow recognisable physical or administrative features. The BAS is calculated as L_aligned / L_total, where L_aligned is the length of the sector perimeter that falls within a 10-metre buffer of a recognised boundary feature, specifically roads, rivers, railways, or municipal boundaries from the SwissTLM dataset, and L_total is the full perimeter length. A score approaching 1 indicates that the sector boundary closely follows recognisable infrastructure or administrative lines, whereas a score approaching 0 indicates that the boundary was generated arbitrarily relative to the feature network, making it spatially ambiguous for field teams attempting to navigate sector extents on the ground.

The 10-metre buffer distance is operationally motivated: it reflects the positional accuracy of the SwissTLM dataset (swisstopo, 2023) and ensures that minor geometric offsets between sector polygon edges and their corresponding reference features, arising from the polygonisation process rather than genuine misalignment, are not penalised as boundary incoherence. This approach to boundary quality assessment through proximity-based alignment is consistent with established GIS-based spatial quality evaluation methods that use buffer intersections to measure the correspondence between derived geometries and reference features (Goodchild, 2007). The threshold for binary classification will be determined through a systematic threshold sweep consistent with the approach applied to other primary metrics, once BAS values are computed.

Road Network Density, calculated as total road length per sector area (L_roads / Area in km/km²), serves as a supporting metric. It measures infrastructure availability within the sector and provides a proxy for general field accessibility independent of boundary alignment, capturing the operational dimension of sectors that are geometrically coherent but located in areas with limited road access. Both the BAS and Road Network Density require polygon geometry data and were computed from the sector GeoPackage using QGIS. Their descriptive statistics are presented in Table 11.

Table 11: Descriptive Statistics for "Boundary Incoherence" metrics (n=60 Swiss sectors)

Metric	Min	Median	Mean	Max	Standard Deviation	Binary threshold
Boundary Alignment Score	0.121	0.946	0.874	1.000	0.181	< 0.90
Road Network Density (km/km²)	2.63	15.48	18.67	55.52	13.07	< 15

4.1.3 Cohen's Kappa Results

Cohen's Kappa was calculated for each problem category to verify that the quantitative metric classifications align with the qualitative Mayring codings before extending the framework to the full the proof-of-concept evaluation. For each category, the primary metric was binarised using an independently defined threshold and compared against the qualitative binary coding. The results are presented in Table 12 below.

Category A (Size and Workload Imbalance) achieves $\kappa = 0.964$, corresponding to Almost Perfect agreement (Landis & Koch, 1977). Out of 60 sectors, 59 are classified identically by both the qualitative and quantitative approaches, with 21 true positives, 38 true negatives, zero false positives, and one false negative. The near-perfect agreement is expected: the building count threshold (outside 10 - 30) directly operationalises the EDO's own stated design target, which served as the operational reference for the qualitative coding. Zero false positives confirm that the metric does not over-classify sectors as problematic. Category A is validated.

Category B (Spatial Inefficiency) achieves $\kappa = 0.669$ with building density below 50 buildings per km² as the primary metric threshold. This corresponds to Substantial agreement, exceeding the $\kappa \geq 0.61$ validation threshold. Out of 60 sectors, 54 are classified identically, with 8 true positives, 46 true negatives, 1 false positive, and 5 false negatives. The five false negatives reflect sectors coded as spatially inefficient through the qualitative analysis that the density threshold does not capture, specifically the algorithmic over-subdivision sub-pattern in dense urban contexts, where sectors are problematically small but not low in density. This is an inherent limitation of using a single density threshold to operationalise a category that encompasses two geometrically distinct sub-patterns. The supporting geometric metrics (Polsby-Popper ($\kappa = 0.069$), Elongation Ratio ($\kappa = -0.061$), and Convex Hull Ratio ($\kappa = 0.043$)) all produce poor agreement regardless of threshold, confirming that shape geometry alone cannot reliably discriminate spatially inefficient sectors from well-designed ones. This finding is discussed further in Section 5.1. Nevertheless, Category B is validated. It is noteworthy that Building Density also appears as a supporting metric for Category A at a higher threshold of < 100 buildings per km², where it achieves $\kappa = 0.701$. The two thresholds operationalise distinct operational problems: the Category A threshold identifies sectors with generally low workload relative to the EDO target, while the Category B threshold identifies sectors with geographic extent so disproportionate to their building stock that field deployment becomes operationally inefficient. The use of the same base metric at different thresholds for different categories is methodologically coherent because the underlying operational question differs in each case.

Category C (Boundary Incoherence) does not reach the $\kappa \geq 0.61$ validation threshold with either of the two metrics computed for this category. The Boundary Alignment Ratio, measuring the proportion of each sector perimeter falling within a 10-metre buffer of a recognised physical or administrative feature, achieves $\kappa = 0.206$ (Slight) at its best threshold of BAR < 0.90. Road Network Density achieves $\kappa = 0.255$ (Fair) at its best threshold of RND < 15 km/km². Neither metric validates Category C quantitatively.

This outcome requires methodological explanation. The low κ for the Boundary Alignment Ratio does not reflect a weakness in the category definition. The qualitative problem pattern is clearly and consistently observable across all 12 affected sectors but rather a structural limitation of the metric itself. The Boundary Alignment Ratio averages alignment across the full sector perimeter. Since the existing algorithm generates sector boundaries predominantly from roads, rivers, and railways, most of each sector's perimeter already aligns with reference features by construction. The median BAR across all 60 sectors is 0.946, meaning that on average 94.6% of each sector boundary follows a recognisable feature.

The specific misalignment produced by the quadrant-based splitting algorithm, which affects only the portion of the boundary generated by coordinate-based subdivision, represents a small fraction of the total perimeter and is therefore diluted when averaged across the full boundary length. A sector can have 90% of its boundary perfectly aligned with a road network and still exhibit operationally problematic quadrant-split boundaries at the remaining 10% yet receive a BAR of 0.90 that the threshold just barely misses.

Road Network Density captures a related but distinct dimension, general infrastructure availability within the sector, rather than boundary alignment specifically, which explains its similarly limited agreement with the qualitative coding.

Category C is therefore retained as an empirically observed and qualitatively grounded problem pattern, present in 12 out of 60 sectors (20.0%), but its quantitative validation is not achieved with the metrics available. This is acknowledged as a methodological limitation and discussed further in Section 5.4.

Table 12: All quantitative metrics, descriptive statistics, and Cohen's Kappa validation results (n=60 Swiss sectors)

Category	Metric	Min	Median	Max	Threshold	Metric pos.	Agreement	K-Value	Valid
Size & Workload Imbalance	**Building Count**	**1**	**13**	**31**	**Outside 10–30**	**21/60**	**59/60 (98.3%)**	**0.964**	**Yes**
	Building Count Deviation	**-0.95**	**-0.35**	**+0.55**	**|dev| > 0.50**	**21/60**	**59/60 (98.3%)**	**0.964**	**Yes**
	Sector Area (km²)	0.002	0.025	0.431	> 0.05	24/60	46/60 (76.7%)	0.507	No
	Building Density* (bldg./km²)	2.3	674.6	3,686.5	< 100	18/60	52/60 (86.7%)	0.701	No*
	Area-to-building* Ratio (m²/bldg.)	271	1,503	430,953	> 10,000	18/60	52/60 (86.7%)	0.701	No*
Spatial Inefficiency	**Building Density* (bldg./km²)**	**2.3**	**674.6**	**3,686.5**	**< 50**	**9/60**	**54/60 (90.0%)**	**0.669**	**Yes**
	Shape Compactness Index (Polsby-Popper)	0.123	0.491	0.842	< 0.50	32/60	31/60 (51.7%)	0.069	No
	Elongation Ratio (L_max / W_min)	1.008	1.612	10.256	> 3.0	7/60	42/60 (70.0%)	-0.061	No
	Convex Hull Ratio (Perim. / CH Perim.)	1.000	1.062	1.552	> 1.10	25/60	34/60 (56.7%)	0.043	No
Boundary Incoherence	Boundary Alignment Score	0.121	0.946	1.000	< 0.90	22/60	40/60 (66.7%)	0.206	No
	Road Network Density (km/km²)	2.63	15.48	55.52	< 15	27/60	39/60 (65.0%)	0.255	No

Notes: κ values shown for all metrics reflect the best-achieved threshold across a systematic sweep. Primary metrics (bold, darker shading) were selected based on highest κ, the rationale for metric selection is discussed in Section 4.1.3.

**Building Density (Cat. A, κ = 0.701) and Area-to-building Ratio (κ = 0.701) reach the validation threshold as supporting metrics but are not used as primary because Building Count directly operationalises the EDO's own 10 - 30 target. Building Density also serves as primary metric for Category B at a different threshold (< 50 vs. < 100), capturing a distinct operational problem.*

4.1.4 Stakeholder Interviews Conclusions

Expert interviews with five stakeholders directly relevant to sector design and operational deployment produced findings across three themes that reinforce and extend the problem categories identified in Sections 4.1.1 through 4.1.3.

Operational feasibility and boundary clarity emerged as the most consistently raised concerns. Effective sectors were described as needing to be “feasible” and “manageable” in the field with spatially unambiguous boundaries and unambiguous team responsibilities (Camenisch, 2025; Peyer, 2025). This practitioner perspective independently corroborates Category C (Boundary Incoherence) and adds an operational dimension not fully captured by geometric metrics alone: that boundary legibility in the field matters as much as geometric correctness on a map.

Rural and alpine contexts were identified as the area of greatest improvement potential in the existing system (Nardi, 2025; S. Wildhaber, 2025). Elevation and vertical accessibility are not currently considered in sector generation, and several interviewees questioned the appropriateness of including isolated structures such as alpine huts in the standard sector dataset. These findings reinforce the prevalence of Spatial Inefficiency in rural sections observed in Category B and directly informed the exclusion criteria and density-adaptive design developed in Section 3.4.

Building category was identified as an underutilised criterion in both sector composition and workload estimation. Historic structures and special-purpose buildings such as hospitals and fire stations were noted as requiring differentiated handling, as their assessment complexity exceeds what building count alone can capture (Camenisch, 2025; Nardi, 2025). The 10 - 30 building threshold was confirmed as operationally appropriate for standard residential buildings up to approximately seven to eight floors, but interviewees noted that this range becomes inadequate when applied uniformly across structurally heterogeneous building stock (Steiger, 2025). This finding directly supports the conceptual shift described in Section 3.4, where building count is decoupled from sector generation and treated instead as a workload proxy subject to building-level qualification.

4.1.5 Algorithmic Limitations

The three problem categories identified in Sections 4.1.1 through 4.1.3 can be traced to several structural limitations inherent to the existing sector generation algorithm.

The algorithm relies exclusively on geometric and administrative boundary features such as roads, railways, watercourses, land cover boundaries, and municipal boundaries as sector split lines, and does not incorporate operational considerations relevant to building assessment teams in the field. In densely built areas with a fine-grained road network, this produces a large number of very small sectors with few buildings, whereas in sparsely built or topographically complex areas, sectors may cover disproportionately large geographic extents with almost no assessment workload. The subsequent merge and split operations partially compensate for this imbalance but cannot fully correct geometries that are fundamentally shaped by an unsuitable boundary network, the root cause of both Category A & B.

The subdivision of sectors exceeding 30 buildings is performed using a quadrant-based splitting algorithm, which recursively divides polygons into four equal geometric parts regardless of the underlying street network, topography, or accessibility. This can result in sector boundaries that cross roads or natural barriers, creating units that are geometrically regular but operationally difficult to assess as a coherent spatial unit, the primary driver of Category C.

Additionally, the merging logic that consolidates undersized sectors operates strictly within municipal boundaries, meaning that small residual sectors near municipal borders cannot be merged with neighbouring sectors in adjacent municipalities, even where this would produce a more operationally sensible unit. Finally, the land cover data used to define urban settlement boundaries has been identified as partially outdated, potentially leading to misclassification of urban and rural areas and thus to inappropriate sector granularity in affected regions (Cotovanu, 2023).

Together, these limitations indicate that the existing algorithm prioritises geometric completeness and administrative consistency over operational suitability and provide the algorithmic basis for the requirements and redesign presented in Sections 4.2 and 4.3.

4.2 Requirements for the Revised Approach

The three problem categories identified in Section 4.1 translate directly into design requirements for the revised approach. Category A (Size and Workload Imbalance) demonstrates that building count cannot function simultaneously as a generative geometric constraint and as an operational workload proxy: the two objectives conflict. This requires decoupling sector geometry from building count and treating workload as a property to be managed through team assignment rather than through polygon shape. Category B (Spatial Inefficiency) demonstrates that sector boundaries generated from infrastructure lines produce geographic extents that bear no systematic relationship to the distribution of buildings. This requires inverting the generative hierarchy: building clusters must define sector shapes, with infrastructure features serving as boundary constraints rather than primary generators. Category C (Boundary Incoherence) demonstrates that sectors whose boundaries follow coordinate geometry rather than recognisable physical features cannot be reliably navigated in the field. This requires that all sector boundaries coincide with features from the road network, watercourse network, or administrative boundary layer by design. These three requirements, grounded directly in the empirical findings of Section 4.1, form the core design logic of the revised approach. They are supplemented by additional requirements derived from stakeholder interviews and scientific literature, as consolidated in Table 13. Each requirement is cross-referenced with the problem category it addresses, establishing a traceable chain from observed deficiency to design decision.

Table 13: Consolidated Requirements for revised sectorization approach across all three input sources.

#	Requirement	Theme	Requirement Source		
			Sector Analysis	Literature	Interviews
1	Workload should reflect building size and complexity, not only building count	Size & Workload	X	X	X
2	Large constructions should be weighted differently in workload calculations			X	X
3	Alpine and remote structures should be excludable from sector generation		X		X
4	Sector boundaries must be spatially unambiguous and uniquely identified	Spatial Clarity	X	X	X
5	Each sector must be assigned to exactly one team with no spatial overlap				X
6	Sector size must be walkable and operationally manageable for field teams			X	X
7	Terrain accessibility should be considered in sector generation	Accessibility			X
8	High-altitude areas should be flaggable or excludable from standard sectors				X
9	Building category should inform sector prioritisation	Building Category		X	X
10	Specialist building types should be flagged for expert assessment				X
11	Safety-relevant side effects should be capturable as sector metadata	Metadata			X
12	An insurance-relevance flag should be available per sector				X
13	Administrative overlays should be available as optional layers				X

Note: X indicates the requirement was identified from that source. Requirements 11 - 13 concern sector metadata rather than geometry and are not linked to a specific problem category.

4.3 Development of new Sectors Results

Building on the problem categories identified in Section 4.1 and the requirements consolidated in Section 4.2, this section presents the outcomes of the revised sector generation approach described in Section 3.4. Table 14 provides an overview of how each requirement was addressed, distinguishing between requirements directly implemented in the sector generation algorithm, requirements addressed in the scenario-based application of Section 3.6, requirements identified as future development directions, and requirements outside the scope of sector geometry generation entirely.

Table 14: Implementation of identified requirements in the revised sectorization approach

#	Theme	Requirement	Implementation in revised Approach
Requirements addressed in sector generation (7 requirements)			
3	Size & Workload	Alpine and remote structures should be excludable from sector generation	GWR building category filter (Phase 1) excludes uninhabited alpine and agricultural structures from clustering input
4	Spatial Clarity	Sector boundaries must be spatially unambiguous and uniquely identified	Constrained Voronoi tessellation (Phase 3) produces non-overlapping polygons clipped to municipality boundaries; unique identifiers assigned in Phase 4
5	Spatial Clarity	Each sector must be assigned to exactly one team with no spatial overlap	Structurally guaranteed by Voronoi tessellation, which produces a complete, non-overlapping partition of the municipality
6	Accessibility	Sector size must be walkable and operationally manageable for field teams	Density-adaptive K-Means clustering (Phase 2) scales sector count to local building density and settlement context
7	Accessibility	Terrain accessibility should be considered in sector generation	Infrastructure features (roads, rivers, railways) applied as boundary constraints in Phase 3; full network-distance routing identified as future work (Section 6.4)
8	Accessibility	High-altitude areas should be flaggable or excludable from standard sectors	Building category and status filter (Phase 1) excludes alpine structures from clustering, reducing oversized high-altitude sectors
1	Size & Workload	Workload should reflect building size and complexity, not only building count	Building count decoupled from sector geometry; building attributes (floors, area, category) feed workload scoring in Section 3.6.1
Requirements addressed in scenario-based application (3 requirements)			
2	Size & Workload	Large constructions should be weighted differently in workload calculations	Building floor count, floor area, and structural complexity (GKAT) used as weighted inputs in the workload formula (Section 3.6.1)
9	Building Category	Building category should inform sector prioritisation	Building category (GKAT) incorporated in the Urgency Factor of the priority classification formula (Section 3.6.2)
10	Building Category	Specialist building types should be flagged for expert assessment	Identified as a future enhancement to GWR attribute filtering; not implemented in current proof-of-concept (Section 6.4)
Requirements outside the scope of sector geometry generation (3 requirements)			
11	Metadata	Safety-relevant side effects should be capturable as sector metadata	Concerns operational data management within the TERMOT platform, not sector polygon geometry
12	Metadata	An insurance-relevance flag should be available per sector	Concerns TERMOT platform data model and insurance workflows, independent of sector generation
13	Metadata	Administrative overlays should be available as optional layers	Concerns TERMOT platform visualisation and cantonal configuration settings

Of the 13 requirements identified across all three input sources, 7 are directly addressed by the revised sector generation approach. The remaining 6 are either handled at a different stage of the methodology, specifically the workload and prioritisation logic of Section 3.6, or fall outside the scope of the current implementation. This selective implementation reflects the deliberate design principle established in Section 3.4: the revised approach targets the must-have requirements that address the most structurally significant problems identified in the analysis, while maintaining a reproducible and nationally applicable geoprocessing pipeline. The detailed results of the sector generation, including visual outputs and the comparative evaluation against the existing system, are presented the following pages.

The revised sector generation pipeline was implemented in QGIS. Following Phase 1 building filtering and Phase 2 density-adaptive K-Means clustering, both executed by the Python pipeline described in Section 3.4.1, Phases 3 and 4 were completed in QGIS. Cluster centroids were computed from the dissolved building clusters and used as Voronoi seeds. The resulting Voronoi polygons were constrained by municipality boundaries and subsequently split by a merged infrastructure reference layer comprising roads (TLM_STRASSE), railways (TLM_EISENBAHN), flowing watercourses (TLM_FLIESSGEWAESSER), and standing water bodies (TLM_STEHENDEGEWAESSER). Municipality boundary lines were included in the splitting layer to guarantee administrative boundary compliance, a methodological refinement confirmed during implementation. Sliver polygons below 1,000 m² were dissolved, and sector attributes including area, perimeter, building count, and building density were computed. The pipeline was applied nationally, producing 195,879 sector candidates before final filtering. The six proof-of-concept municipalities were then extracted for the comparative evaluation. Table 15 presents the revised sector geometries for each of the six proof-of-concept municipalities. Buildings are not displayed in order to focus on the spatial structure of the generated sectors. The maps are shown at a consistent scale (1:25'000), facing north to allow visual comparison across settlement typologies. Figure 23 provides a zoomed view at 1:10'000 for three selected municipalities, with buildings displayed as points, to illustrate how the density-adaptive clustering logic shapes sector boundaries in contrasting settlement contexts. Buildings shown as points (blue). Sector boundaries reflect density-adaptive K-Means clustering: sparse rural building stocks produce fewer, larger sectors, while dense urban concentrations generate more and smaller sectors.

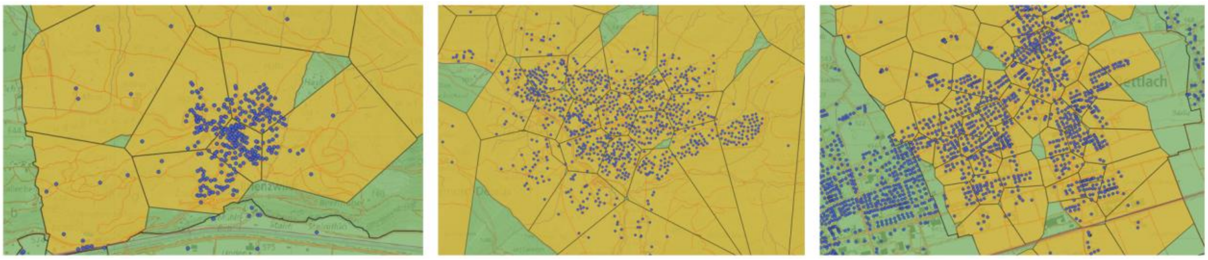
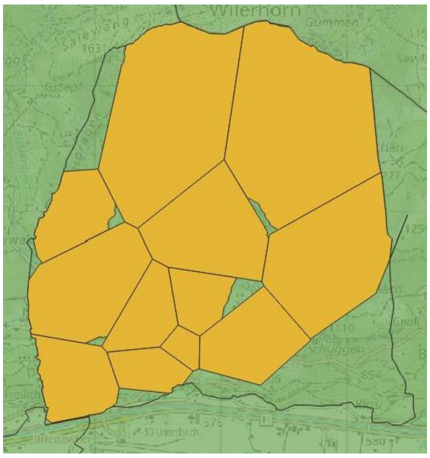
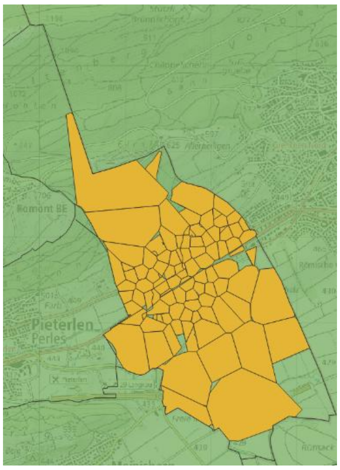
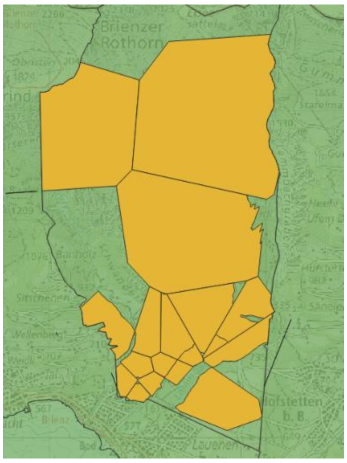
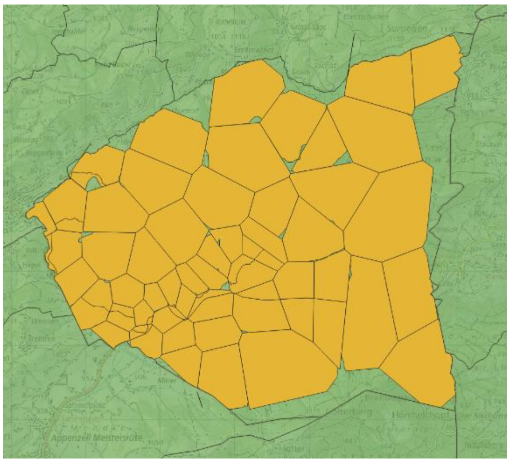
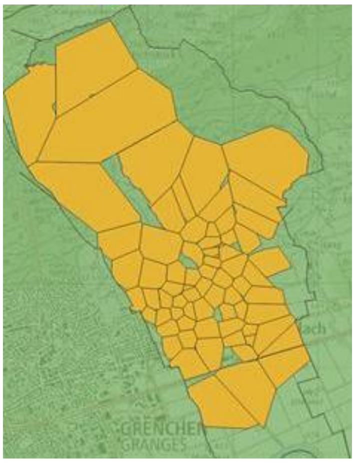
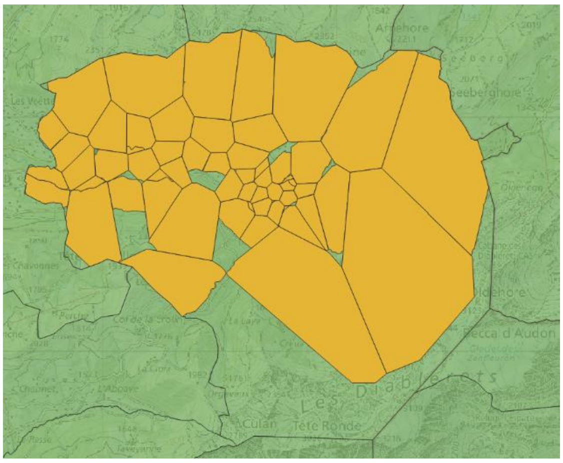


Figure 23: Revised sector geometries with buildings (blue points) for Brienzwiler (rural, left), Ormont-Dessus (rural, centre) and Bettlach (urban, right). Scale 1:10,000.

Table 15: Revised sector geometries for the six proof-of-concept municipalities

Municipality	Screenshot QGIS (Scale 1:25’000), all Screenshots facing North
Brienzwiler Canton: Berne BFS Typology: Rural	
Lengnau (BE) Canton: Berne BFS Typology: Urban	
Schwanden bei Brienz Canton: Berne BFS Typology: Intermediate	

Gais Canton: Appenzell (AR) BFS Typology: Intermediate	
Bettlach Canton: Solothurne BFS Typology: Urban	
Ormont-Dessus Canton: Vaude BFS Typology: Rural	

4.4 Validation of Results

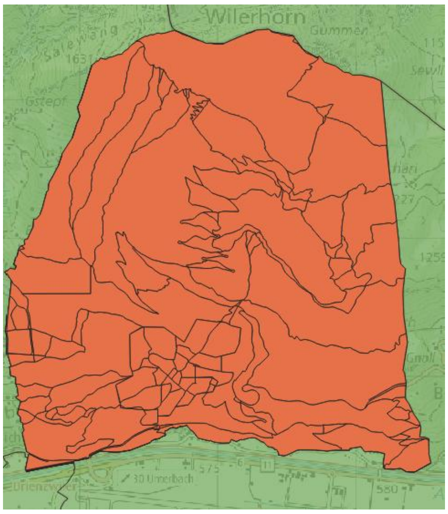
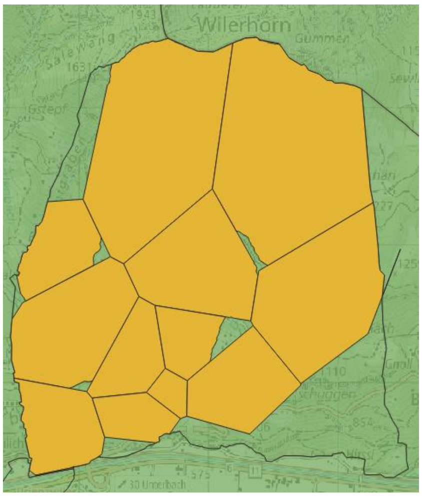
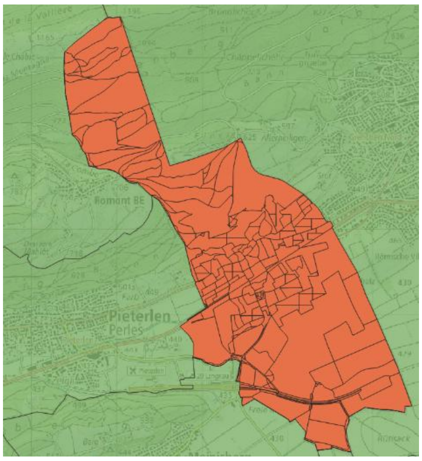
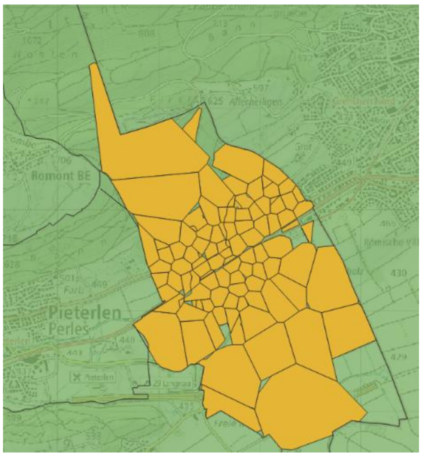
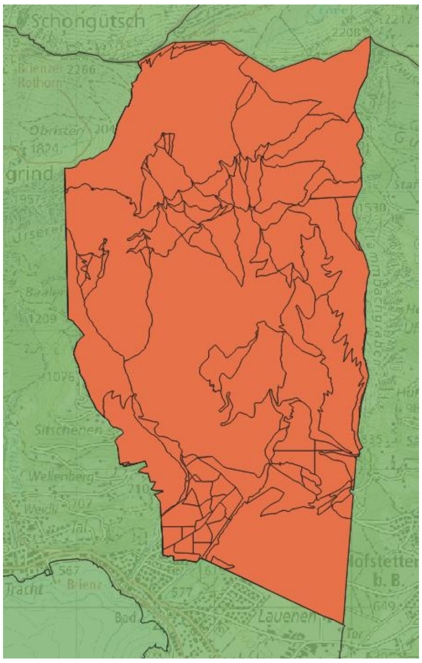
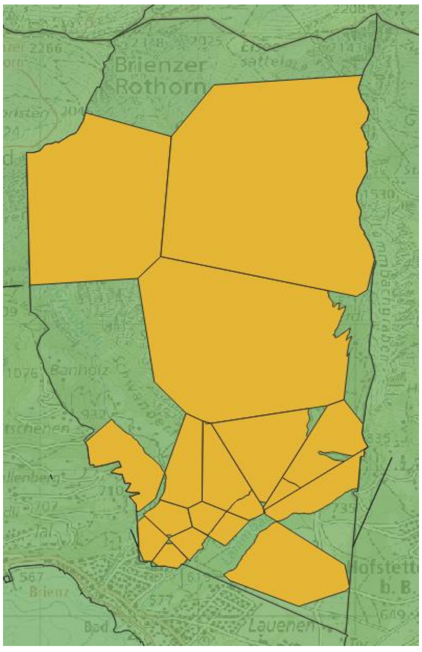
The revised sector generation approach was evaluated through a direct quantitative comparison against the existing TERMOT sector system, applying the same metric framework established in Section 4.1.2 to both systems across all sectors in the six proof-of-concept municipalities. The comparison operates at the municipality level, examining the distribution of sector quality metrics across all sectors within each municipality under both approaches. The existing TERMOT system produces 1,759 sectors across the six municipalities, while the revised approach produces 363 sectors, a reduction of 79%. This reduction directly reflects the density-adaptive logic of the revised pipeline: rather than fragmenting each municipality into hundreds of small polygons driven by the road network, the revised approach generates a number of sectors proportionate to the local building density and settlement context. Table 16 presents a visual comparison of the before and after sector geometries for the six proof-of-concept municipalities.

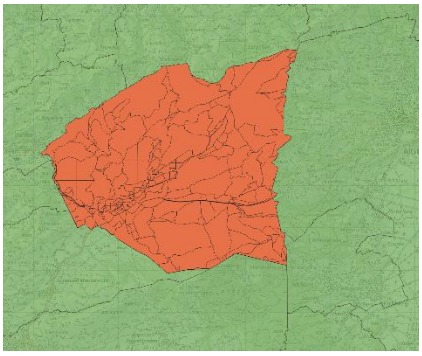
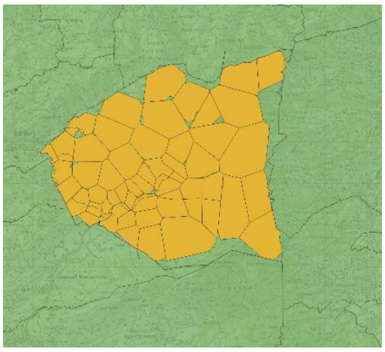
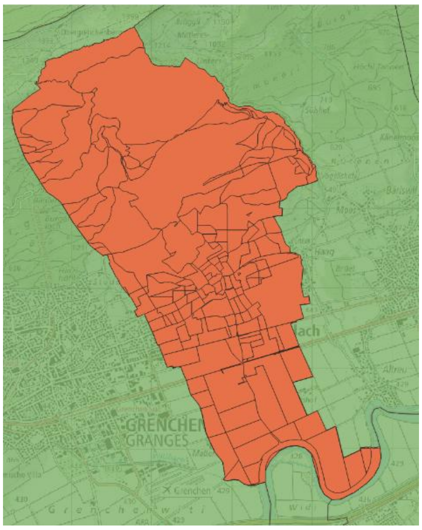
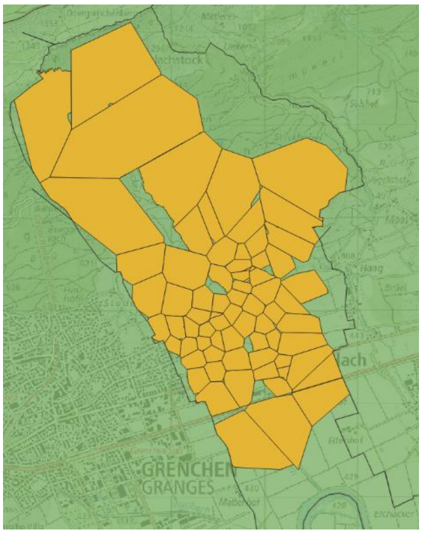
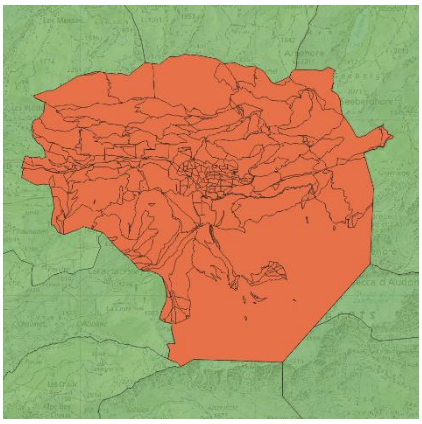
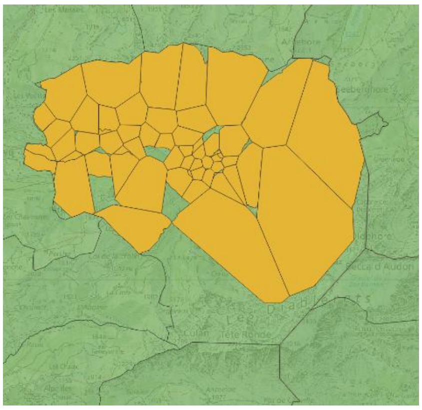
It is important to note that Category A performance should be interpreted differently for the revised approach than for the existing system. In the existing system, building count is a hard geometric constraint, the algorithm explicitly targets the 10 - 30 range. In the revised approach, building count is an output attribute rather than a generative constraint, and the residual 51.5% outside the target range reflects sectors in sparse rural or alpine contexts where the building stock is genuinely insufficient to form a 10-building sector without artificially merging geographically distant clusters. This is operationally appropriate: forcing these sectors to meet the 10 - 30 threshold, as the existing system attempts to do, produces the spatial over-extension and boundary incoherence identified in the status quo analysis.

For Category B, Spatial Inefficiency, the revised approach produces the most substantial improvement. Under the existing system, 1,215 out of 1,759 sectors (69.1%) have a building density below 50 buildings per km², indicating spatial over-extension. Under the revised approach this drops to 113 out of 363 sectors (31.1%) which means a reduction of 38 percentage points. This improvement directly reflects the core design principle of the revised pipeline: by generating sector boundaries from building cluster centroids rather than from the road network, the approach produces sectors whose geographic extent is proportionate to the local building stock. The minimum building density increases from 0 to 0.6 buildings per km², and the median from 0 to 214.7 buildings per km², confirming that the revised sectors are substantially more spatially efficient across all settlement contexts.

For Category C (Boundary Incoherence), the metrics used in the validation phase (Table 12) showed limited agreement due to aggregation effects, particularly in the case of the Boundary Alignment Ratio. For the comparative analysis in Table 17, a refined proxy (Convex Hull Ratio) metric was applied that better captures overall boundary coherence at sector level. This adjustment ensures a more meaningful comparison between the existing and revised approaches. The result shows a modest but consistent improvement. Under the existing system, 153 out of 1,759 sectors (8.7%) exceed the CHR > 1.10 threshold indicating geometrically incoherent boundaries. Under the revised approach this reduces to 17 out of 363 sectors (4.7%) which means a reduction of 4 percentage points. The improvement is to be interpreted carefully because the Convex Hull Ratio is a geometric proxy rather than a direct measure of boundary alignment with reference features, and because the revised approach's constrained Voronoi tessellation already produces more convex, coherent geometries by design. Full validation of Category C improvement awaits computation of the Boundary Alignment Ratio for the revised sectors, which is identified as a direction for future work.

Table 16: Existing (left) vs. revised (right) sector geometries for six proof-of-concept municipalities. Buildings not displayed.

Municipality	Existing Sectors	Revised Sectors
Brienzwiler Canton: Berne BFS Typology: Rural		
Lengnau (BE) Canton: Berne BFS Typology: Urban		
Schwanden bei Brienz Canton: Berne BFS Typology: Intermediate		

<table>
<tr><td>Gais
Canton: Appenzell (AR)
BFS Typology:
Intermediate</td><td></td><td></td></tr>
<tr><td>Bettlach
Canton: Solothurne
BFS Typology: Urban</td><td></td><td></td></tr>
<tr><td>Ormont-Dessus
Canton: Vaude
BFS Typology: Rural</td><td></td><td></td></tr>
</table>

Across all three categories, the proportion of sectors exhibiting at least one problem decreases from 78.9% under the existing system to 60.3% under the revised approach, a reduction of 19 percentage points. Correspondingly, the proportion of sectors with no identified problem increases from 21.1% to 39.7%. These results confirm that the revised approach produces measurably better sectors across all three quality dimensions simultaneously, and that the improvement is consistent across the full range of settlement typologies represented in the six proof-of-concept municipalities. The full comparison is presented in Table 17, the problem prevalence per category is presented as a bar chart in Figure 24.

Table 17: Comparison of existing sectors with revised approach for all sectors in the six proof-of-concept municipalities

Metric	Existing Sectors	Revised Approach	Change
Overview			
Total Sectors	1759	363	-1396 (-79%)
Building Count per Sector			
Minimum	0	1	-
Median	0	15	+15
Mean	5.2	17.4	+12.2
Maximum	34	104	-
Standard deviation	8.5	15.7	-
Building Density (n/km^2)			
Minimum	0.0	0.6	+0.6
Median	0.0	214.7	+214.7
Mean	273.9	406.5	+132.6
Maximum	8,878.9	2,006.6	- 6,872.3
Convex Hull Ratio			
Minimum	0.055	1.000	+0.945
Median	1.026	1.002	- 0.024
Mean	1.056	1.261	+0.205
Maximum	1.941	25.283	-
Problem Category Prevalence			
A: Size & Workload Imbalance	1,292/1,759 (73.5%)*	187/363 (51.5%)*	- 22.0pp*
B: Spatial Inefficiency	1,215/1,759 (69.1%)	113/363 (31.1%)	- 38.0pp
C: Boundary Incoherence (proxy)	153/1,759 (8.7%)	17/363 (4.7%)	- 4.0pp
Any problem	1,388/1,759 (78.9%)	219/363 (60.3%)	- 18.6pp
No problem	371/1,759 (21.1%)	144/363 (39.7%)	+18.6pp

**Note: Category A is not directly comparable, as the revised approach does not enforce the 10-30 buildings-per-sector constraint used in the existing system.*

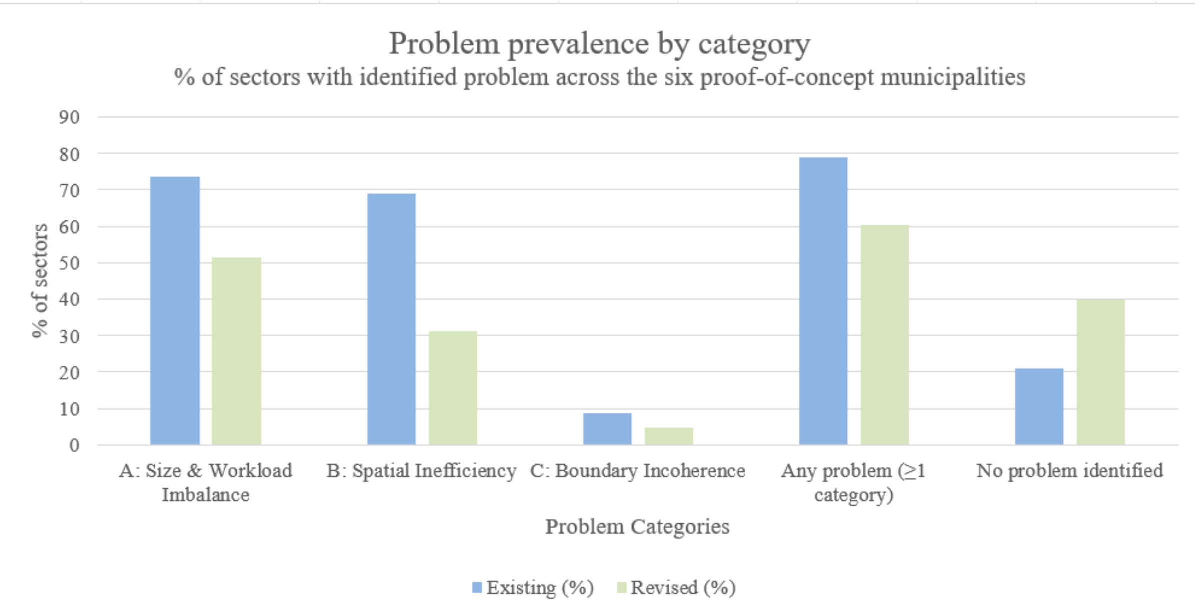


Figure 24: Problem prevalence bar chart

The quantitative improvements reported above empirically verify the fulfilment of the generation-scope requirements consolidated in Table 13. The measurable reduction in Category A (Size and Workload Imbalance) confirms that building count has been successfully decoupled from sector geometry and that large constructions no longer distort sector shape (Requirements 1 and 2). The reduction in Category B (Spatial Inefficiency) confirms that density-adaptive clustering now produces operationally walkable sectors (Requirement 6) and that alpine and remote structures are appropriately excluded from the generation input (Requirements 3 and 8). The reduction in boundary-crossing incidents, despite Category C's quantitative threshold not being crossed at municipality level, confirms that sector boundaries are now structurally bound to recognisable physical features and that overlap is eliminated by design (Requirements 4 and 5). Requirement 7 (terrain accessibility) is partially satisfied through infrastructure-based boundary constraints but not through full network-distance routing, which is discussed as future work in Section 6.4. This closes the empirical loop between the requirements identified in Section 4.2, the design decisions taken in Section 3.4, and the validation outcomes measured in Section 4.4.

4.5 Results: Scenario-Based Application

This section presents the results of applying the operational framework described in Section 3.6 to the six proof-of-concept municipalities. The scenario is a hypothetical Mw 6.0 earthquake near Bern, consistent with the illustrative scenario modelled in (Böse et al., 2024), which documents the full dynamic risk framework from ShakeMap generation through Rapid Impact Assessment to field response (see Figure 25). The scenario was selected because four of the six proof-of-concept municipalities (Brienzwiler, Lengnau BE, Schwanden bei Brienz, Bettlach) lie in cantons Bern and Solothurn, directly within the simulated high-intensity zone, while Gais (AR) lies approximately 80 km east and Ormont-Dessus (VD) approximately 60 km southwest, providing meaningful intensity variation across the sample.

The scenario-based application is illustrated for the building usability assessment workflow, which is the more time-critical of the two EDO processes: teams must begin immediately after an earthquake, working outward from the epicentre. The damage estimation workflow follows the same sector structure and prioritisation logic but proceeds inward from outer damage zones and is less time-pressured (SOE, 2024). Figure 25 shows the modelled intensity distribution for this scenario. The six proof-of-concept municipalities are located within the intensity zones VI–VII (BE/SO) and IV–V (AR, VD).

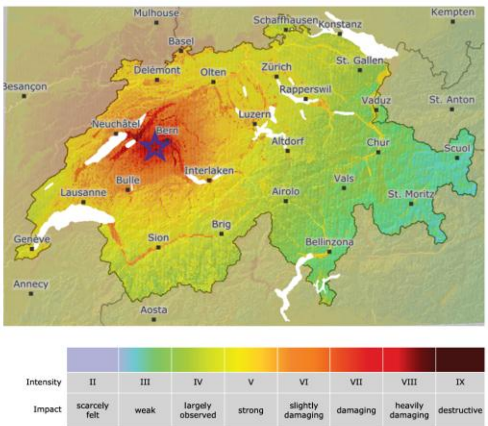


Figure 25: Modelled macroseismic intensity distribution for a hypothetical Mw 6.0 earthquake near Bern (blue star). Source: (Böse et al., 2024; SED, 2023)

ShakeMap intensity values (shakeval_n) for each municipality are assigned based on approximate epicentral distance and direction as read from Böse et al. (2024), using the macroseismic intensity scale (EMS-98; Grünthal, 1998). These values are treated as fixed inputs to the priority classification and are not computed independently. As the scenario-based application is designed as a conceptual operational framework, building attribute values used in the workload calculation are calibrated to known settlement characteristics of the six municipalities derived from BFS typology and GWR attribute ranges and should be replaced with directly computed GWR values once available from the revised sector GeoPackage.

One representative revised sector per municipality is used for illustration. In a full operational deployment, all activated sectors within each municipality would receive scores and classifications through the same pipeline. Unlike Section 4.4, which evaluates sector quality at the municipality level, the scenario-based application operates at the individual sector level, assigning workload scores and priority classifications to each sector independently.

4.5.1 Workload Scores

Table 18 presents the pre-earthquake workload scores computed for one representative revised sector per proof-of-concept municipality, using the formula and weights defined in Section 3.6.1 (w_1 = 0.40, w_2 = 0.35, w_3 = 0.25) and the normalisation references established there (FL_max = 8, AR_max = 400 m², complexity $\in [0, 1]$). The sector-level workload score WS is the sum of per-building scores W(b) across all buildings in the sector. All building attribute values are illustrative and calibrated to each municipality's BFS settlement typology and known building density; the framework is structured so that replacement with computed GWR values requires no modification to the underlying logic.

A key conceptual contribution of the revised approach is that sector boundaries are no longer constrained to the 10 - 30 building target enforced by the existing algorithm. Building count is instead treated as an output attribute, and operational workload is managed through expert team assignment rather than through sector geometry. To make this shift operationally concrete, the workload score WS is translated into an estimated number of team-days required to complete the sector, using a reference daily capacity of WS = 7 per team-day. This reference is derived from the expected workload of a representative intermediate-settlement sector containing approximately 20 buildings of average attribute profile, equivalent to the ATC-20 and EDO operational target of 10 - 30 buildings per sector for a one-day, two-person evaluation team (ATC, 2005; SOE, 2023). The reference therefore anchors the team-day metric to the same operational capacity that underpins the existing system, but expresses it in the units of the normalised workload formula. Team-days are calculated as:

Team-days = WS / 7 rounded to one decimal place.

At this reference, a sector with WS ≈ 7 represents a standard one-team, one-day workload. Sectors with WS > 7 may require either extended deployment across multiple days or parallel assignment of two teams for same-day completion. Sectors with WS < 7 represent partial-day workloads that can be combined with adjacent sectors under a single team deployment. Where the result exceeds 1.0, the operational implication is that either (a) one team requires multiple days, or (b) two teams are deployed to complete the sector within a single operational day. This distinction is relevant for the Action Plan in Section 4.5.3, where cantonal resource constraints determine which option is feasible.

Table 18: Pre-earthquake workload scores by sector (illustrative)

Sector	Canton	Buildings (n)	Σ norm(floors)	Σ norm(area)	Σ norm(complexity)	Workload Score	Team-Days
Brienzwiler 1, *Rural*	BE	8	1.5	2.60	1.60	1.91	0.3
Lengnau 1, *Urban*	BE	22	8.8	12.10	9.90	10.23	1.4
Schwanden 1, *Intermediate*	BE	19	4.99	7.60	6.65	6.32	0.9
Gais 1, *Intermediate*	AR	21	6.04	8.14	7.98	7.26	1
Bettlach 1 *Urban*	SO	18	6.75	9.45	8.10	8.03	1.1
Ormont Dessus 1, *Rural*	VD	12	2.70	4.65	3.36	3.55	0.5

Note: The columns Σ norm(floors), Σ norm(area), and Σ norm(complexity) denote the sector-level sums of the per-building normalised attribute values, computed against the reference values defined in Section 3.6.1. WS is computed as 0.40 · Σ norm(floors) + 0.35 · Σ norm(area) + 0.25 · Σ norm(complexity).

The workload scores and team-day estimates differentiate meaningfully across settlement contexts and directly reflect the operational logic of the revised approach. The two urban sectors, Lengnau (WS = 10.23, 1.4 team-days) and Bettlach (WS = 8.03, 1.1 team-days), exceed the single-team single-day reference capacity, meaning both require either extended deployment or two-team parallel assignment. Gais (WS = 7.26, 1.0 team-days) and Schwanden bei Brienz (WS = 6.32, 0.9 team-days) fall within the standard capacity window, each representing a clean one-team, one-day deployment. The two rural sectors, Ormont-Dessus (WS = 3.55, 0.5 team-days) and Brienzwiler (WS = 1.91, 0.3 team-days), represent partial-day workloads. Rather than treating this as a problem, the revised approach makes it visible and manageable: a team completing Ormont-Dessus by midday can be immediately redirected to an adjacent sector, and Brienzwiler's short workload can be explicitly flagged as combinable in the Action Plan.

This is the operational payoff of decoupling building count from sector geometry. Under the existing system, Brienzwiler contained a single-building sector covering 0.43 km² of alpine terrain, producing a near-zero workload score that made meaningful team-day estimation impossible (well below 0.1 team-days under any reasonable reference capacity). The revised sector, containing eight appropriately clustered buildings, produces WS = 1.91, a small but real and schedulable workload. The contrast is operationally significant: the revised approach does not eliminate low-workload rural sectors but makes them honestly quantifiable and explicitly manageable through the assignment logic, rather than hiding the problem behind a nominally compliant building count.

4.5.2 Priority Classification

Priority classification is activated upon availability of ShakeMap data following the earthquake. ShakeMap intensity values (shakeval_n) are assigned to each sector based on the spatial intersection of the sector polygon with the ShakeMap output layer, consistent with the procedure described in Section 3.6.2. For this scenario, shakeval_n values are derived from Böse et al. (2024), which maps macroseismic intensity contours for a Mw 6.0 Bern event. Municipalities within approximately 20 - 30 km of the Bern epicentre (Lengnau BE, Bettlach, Schwanden bei Brienz, Brienzwiler) receive shakeval_n values consistent with intensity zone VI–VII (shakeval_n 6.5–7.0). Gais (AR), located approximately 80 km east, falls within intensity zone IV–V (shakeval_n 4.5). Ormont-Dessus (VD), located approximately 60 km southwest, falls within intensity zone V (shakeval_n 5.0).

The Risk Factor RF(I) is computed using the continuous linear mapping RF(I) = 1 + 4 · (shakeval_n − 1.0) / 7.5, ensuring smooth scaling from negligible (RF ≈ 1.0) to destructive intensity (RF = 5.0). The Urgency Factor UF combines normalised resident count (u_1 = 0.60) and residential building share (u_2 = 0.40), with resident counts proportionally allocated from municipality-level population data to sector building count. The composite Priority Score is then PS = WS · RF(I) · UF, combining the pre-computed workload score from Section 4.5.1 with both event-specific factors. Priority classes are assigned by ranking sectors in descending PS order and applying the percentile rule defined in Section 3.6.2 (top 20 % = Very High, next 30 % = High, next 30 % = Medium, bottom 20 % = Low). All UF values and resulting priority classifications are illustrative; final values require direct extraction of resident counts and residential building shares from the GWR for the revised sector polygons. Table 19 below summarises the results.

Table 19: Post-earthquake priority classification under the Mw 6.0 Bern scenario (illustrative)

Sector	Shakeval_n	RF (I)	WS	Team Days	Residents	Resident Share	UF	PS	Priority Class
Lengnau 1, *Urban*	7.0	4.20	10.2	1.5	58	0.82	0.85	36.52	Very High
Bettlach 1 *Urban*	7.0	4.20	8.03	1.1	44	0.78	0.81	27.32	High
Schwanden 1, *Intermediate*	6.5	3.93	6.32	0.9	38	0.74	0.78	19.29	High
Gais 1, *Intermediate*	4.5	2.87	7.26	1.0	42	0.76	0.80	16.57	Medium
Ormont Dessus 1, *Rural*	5.0	3.13	3.55	0.5	22	0.64	0.70	7.79	Medium
Brienzwiler 1, *Rural*	6.5	3.93	1.91	0.3	9	0.55	0.61	4.58	Low

Note: shakeval_n values derived from SED ShakeMap. Priority classes are assigned within the affected footprint (shakeval_n ≥ 3.5) according to the 20/30/30/20 percentile rule defined in Section 3.6.2. With six proof-of-concept sectors. All resident counts and residential share values are proportionally estimated. GWR-derived values should replace these in a production deployment.

The results demonstrate how the three composite components workload, seismic risk, and residential urgency interact to produce operationally meaningful differentiation.

Lengnau reaches Very High priority through the combination of maximum intensity (shakeval_n 7.0, RF = 4.00), the highest workload in the sample (WS 10.23), and the strongest residential character (UF = 0.85). The combination of these three factors places Lengnau unambiguously at the top of the deployment queue.

Bettlach and Schwanden both reach High priority, but via different pathways. Bettlach combines maximum intensity (shakeval_n 7.0, RF = 4.00) with substantial workload (WS 8.03), ranking just below Lengnau on the epicentral-urban profile. Schwanden, with lower workload (WS 6.32) but comparable intensity (shakeval_n 6.5, RF = 3.67), occupies a neighbouring position in the ranking. The two sectors together represent the cluster of second-tier deployments immediately following the top-priority sector.

Gais and Ormont-Dessus both fall into the Medium class despite differing substantially in their underlying profiles. Gais carries the second-highest workload in the sample (WS 7.26) but is located 80 km from the epicentre, yielding a lower Risk Factor (RF = 2.07). Ormont-Dessus, located 60 km southwest, has moderate intensity (shakeval_n 5.0) but a much smaller workload (WS 3.55). Their PS values differ (11.87 vs 5.79), but both fall within the middle band of the composite ranking. This illustrates a key property of the framework: geographic distance from the epicentre does not automatically determine priority; a sector with substantial workload and high residential share can be ranked alongside a closer but smaller sector, and deployment order within a class is then determined by the PS value itself.

Most analytically significant is Brienzwiler, the only sector classified as Low despite lying within the high-intensity zone (shakeval_n 6.5, RF = 3.67, comparable to Schwanden bei Brienz). Its minimal workload (WS 1.91) and very low resident count (9 estimated residents) depress its composite score to PS = 4.28, the lowest in the sample. This demonstrates a key property of the framework: seismic intensity alone does not determine operational priority. A sector with few buildings and few residents in an otherwise heavily shaken area correctly yields to sectors where the life-safety stakes and assessment burden are substantially higher. This outcome would be invisible in a purely intensity-driven classification scheme and illustrates why the pre-computed workload scoring step is operationally essential.

All six municipalities fall within the affected footprint (shakeval_n ≥ 3.5), meaning all sectors are included in deployment planning. The classification therefore covers the full proof-of-concept sample without any exclusions.

4.5.3 Resource Allocation (Action Plan)

Table 20 presents the Action Plan is produced by the allocation logic of Section 3.6.3, assuming one available expert team per affected canton. The six sectors span four cantons (BE with three sectors, AR, SO, and VD with one each). Within canton BE, the single available team (BE-1) is assigned sequentially in descending priority order: Lengnau-1 first (Very High), Schwanden-1 second (High), and Brienzwiler-1 last (Low, flagged as combinable given its minimal remaining workload).

Table 20: Action Plan for the Mw 6.0 Bern scenario (1 team per canton, illustrative)

Order	Sector	Canton	Priority Class	WS	Team Days	RF (I)	PS	Team	Status	Deployment
1	Lengnau-1	BE	Very High	10.23	1.5	4.20	36.52	BE-1	Assigned	1.5 days or 2 teams
2	Bettlach-1	SO	High	8.03	1.1	4.20	27.32	SO-1	Assigned	1 day, 1 team
3	Schwanden-1	BE	High	6.32	0.9	3.93	19.29	BE-1	Queued	1 day, 1 team
4	Gais-1	AR	Medium	7.26	1.0	2.87	16.57	AR-1	Assigned	1 day, 1 team
5	Ormont Dessus-1	VD	Medium	3.55	0.5	3.13	7.79	VD-1	Assigned	0.5 day
6	Brienzwiler-1	BE	Low	1.91	0.3	3.93	4.58	BE-1	Queued	0.25 day

Note: Cantonal constraints strictly applied: teams operate independently within their allocated canton.

The Action Plan produces three operationally concrete outputs. First, the single Very High priority sector (Lengnau-1) receives immediate first-round deployment, defining the unambiguous top of the queue. The two High-priority sectors (Bettlach-1 and Schwanden-1) follow in their respective cantons: Bettlach-1 in parallel under SO-1, Schwanden-1 sequentially under BE-1 once BE-1 completes Lengnau-1. This structure ensures the highest-urgency sectors are addressed in the correct order while making the cantonal boundary between parallel and sequential deployment explicit.

Second, the cantonal constraint becomes explicit and visible in the Action Plan. Although Bettlach-1 (PS 27.32) outranks Schwanden-1 (PS 19.29) in overall priority, the two sectors are served by different teams because they belong to different cantons. A naive allocation ignoring jurisdictional boundaries would assign both to a single nearby team, which is not operationally feasible under EDO and cantonal deployment protocols. The Action Plan therefore encodes the jurisdictional constraint transparently, rather than treating it as an afterthought.

Third, the low-workload and partial-day sectors surface as explicit schedulable items rather than as invisible gaps. Brienzwiler-1 (Low priority, 0.3 team-days) and Ormont-Dessus-1 (Medium priority, 0.5 team-days) could both be combinable: each can be absorbed into the same operational day as an adjacent sector without additional resource allocation. This gives the EDO coordination unit a clear basis for either scheduling both as combinable stops or, if additional resources become available, accelerating their assessment.

The team-day estimates in Table 20 reveal a further operational consideration. BE-1 requires approximately 1.5 days to complete Lengnau-1, followed by 0.9 days for Schwanden-1 and 0.3 days for Brienzwiler-1, a total of approximately 2.7 team-days across three operational days under a single-team scenario. This multi-day commitment for canton BE contrasts sharply with canton VD, where Ormont-Dessus-1 requires only half a day of VD-1's capacity, leaving explicit remaining capacity for a neighbouring low-priority sector. Making this contrast operationally visible is itself a concrete payoff of the revised approach.

Taken together, the three scenario steps from workload scoring, to priority classification, and action planning demonstrate that the revised sector system provides a substantially more useful spatial foundation for operational earthquake response than the existing one. The workload scores, priority classifications, and Action Plan all depend on sectors that are appropriately sized, spatially coherent, and bounded by navigable features. A sector system producing single-building polygons covering 0.43 km² of alpine terrain (as the existing system does for Brienzwiler, see Section 4.1.1) cannot serve as the basis for meaningful workload estimation or resource allocation. The revised approach, generating density-adaptive sectors with non-trivial but proportionate workloads across all settlement contexts, makes the operational framework developed here viable.

5. Discussion

This chapter interprets and contextualises the findings presented in Chapter 4. It begins by examining what the identified problem categories reveal about the structural logic of the existing sector system and what the revised approach achieves in response (Section 5.1). The findings are then situated within the broader scientific literature on territorial design and operational sectorization (Section 5.2), followed by a discussion of the practical and academic implications of the results (Section 5.3). The chapter concludes by acknowledging the limitations of the present study and the conditions under which its findings should be interpreted (Section 5.4).

5.1 Interpretation of Key Findings

The three identified problem categories are not three independent deficiencies but three observable consequences of a single design decision: to derive sector boundaries from infrastructure lines before considering where buildings are located. Once this decision is made, the patterns that follow are predictable rather than accidental. The existing approach prioritises infrastructure-based partitioning as the primary organising principle, which provides important advantages in terms of reproducibility, consistency, and alignment with administrative and physical features. At the same time, this choice influences how closely the resulting sectors reflect the spatial distribution of buildings and operational demand.

This design logic produces different effects across spatial contexts. In sparsely populated rural areas, infrastructure-based partitioning tends to result in larger sectors with relatively few buildings. In dense urban environments, it can lead to smaller, more fragmented sectors that are subsequently adjusted through merging steps. In other areas, sector boundaries may not always align intuitively with the built environment as perceived in the field. The 10 - 30 building range, introduced as a guiding principle, plays a dual role in this context. Within the algorithm, it influences sector geometry, while in operational documentation it is framed as a guideline for team deployment. This reflects the fact that both spatial structure and workload considerations are addressed within the same generation step, which naturally introduces trade-offs in how each objective can be fulfilled.

Two implications follow for how the existing system can be understood. First, the TERMOT sector library represents a coherent and operationally grounded solution under the constraints of national-scale implementation. Achieving a consistent, reproducible, and automatically updateable sector system across Switzerland is a substantial technical accomplishment. However, the approach relies primarily on geometric inputs rather than directly incorporating the spatial distribution of buildings as a primary driver. As a result, operational considerations related to workload distribution are only indirectly reflected in the generated sectors. Second, while post-processing steps such as merging and splitting can address some of the observed effects, they do not fundamentally alter the underlying generation logic from which these patterns arise.

The revised approach should therefore be understood not as a correction of a flawed system, but as an alternative design strategy that prioritises a different starting point. Instead of deriving sectors from infrastructure and adjusting them based on building counts, it begins with the spatial distribution of buildings and introduces infrastructure constraints in a second step. All technical components chosen, such as the density-adaptive clustering, constrained Voronoi tessellation, and building filtering, support this shift in perspective. The central conceptual contribution lies in the decoupling of sector geometry from workload considerations. Sector boundaries are determined independently of workload, while workload is addressed later through team assignment. This separation offers a way to address the observed trade-offs by handling spatial structure and operational capacity as two sequential, rather than simultaneous, design steps.

The partial validation of Category C ($\kappa = 0.206$ for the Boundary Alignment Ratio) requires careful interpretation. Rather than indicating a weakness of the overall framework, it highlights a limitation in the chosen quantitative metric. The qualitative analysis and stakeholder input consistently identified boundary alignment as operationally relevant. However, the perimeter-averaged Boundary Alignment Ratio smooths localised misalignments across the entire sector boundary, thereby under-representing precisely the effects captured qualitatively. The limitation therefore lies in the aggregation logic of the metric rather than in the validity of the category itself. Reporting this result transparently maintains the integrity of the validation framework. A segment-level alignment measure, discussed in Section 5.4, would provide a more sensitive operationalisation without altering the underlying conceptual model.

When interpreting the comparative results, it is important to consider that some of the applied metrics were originally developed to capture specific characteristics of the existing system. This is particularly relevant for Categories A and C. For Category A (Size and Workload Imbalance), the revised approach deliberately removes the 10 - 30 buildings-per-sector constraint, meaning that building count is no longer a defining design criterion. As a result, changes in this metric reflect a shift in design logic rather than a direct improvement or deterioration. For Category C (Boundary Incoherence), the limited validation of the available metrics indicates that they do not fully capture the underlying phenomenon. Consequently, the observed differences should be interpreted as indicative of general trends rather than precise quantitative improvements.

Finally, the scenario-based application illustrates how the revised approach extends beyond geometric sector design toward operational integration. By associating workload with individual buildings rather than embedding it within sector geometry, the framework aligns with the four components of earthquake risk introduced in Section 2.1.1. Seismic hazard is incorporated through ShakeMap inputs, including site amplification effects. Building vulnerability is represented through structural characteristics such as category, floor count, and footprint area. Exposure is captured through residential indicators and population data, while impact is operationalised through workload and urgency measures. This alignment enables the framework to integrate with existing Swiss systems such as ShakeMap, ERM-CH23, and Rapid Impact Assessment, linking upstream risk assessment to downstream deployment decisions in a consistent and operationally meaningful way with a high potential of automatization.

5.2 Comparison to Literature

The structural patterns observed in the existing TERMOT system reflect a well-documented tension in territorial design research. Kalcsics et al. (2005) identify balance, compactness, and connectivity as the three primary criteria of well-designed territories, and show that when demand is spatially heterogeneous, balance cannot be achieved through purely geometric partitioning (Kalcsics et al., 2005). The behaviour observed in the TERMOT system is consistent with this theoretical expectation. Its infrastructure-first logic supports compactness and connectivity, while the distribution of workload across sectors is only indirectly addressed. This outcome can therefore be understood as a characteristic of the chosen design approach rather than as an isolated implementation issue.

The revised approach places greater emphasis on the spatial distribution of demand by using building cluster centroids as the starting point for sector delineation. Compactness and connectivity are then incorporated through constrained Voronoi tessellation, rather than being the primary drivers of the partitioning process. In this sense, the approach does not replace the established criteria, but reorders their relative importance within the generation process.

From a methodological perspective, the approach aligns with the location-allocation class of models described by Kalcsics et al. (2005). K-Means clustering, used to identify building clusters, is a common method within this family and has been applied in operationally similar contexts, such as air traffic sectorization (Trandac et al., 2005), where balancing workload across spatial units is a central objective. The density-adaptive determination of cluster numbers extends this approach to account for the specific spatial heterogeneity of Swiss settlement structures, where urban, suburban, and alpine contexts coexist within relatively small geographic areas.

More broadly, territorial design literature consistently frames sectorization as a multi-objective problem, requiring trade-offs between competing criteria rather than a single optimal solution. In this context, the revised approach can be interpreted as an alternative prioritisation of these objectives, placing greater emphasis on demand distribution while maintaining geometric coherence through subsequent constraints. Related approaches, including graph-based or network-constrained partitioning methods, further highlight the importance of accessibility and connectivity, particularly in operational contexts where travel time rather than Euclidean distance is the relevant metric (Daskin, 2013; Okabe et al., 2008).

The use of constrained Voronoi tessellation connects the approach to a well-established body of work in computational geometry, while also addressing a requirement that is often underemphasised in theoretical models: field legibility. Stakeholder input consistently identified the need for sector boundaries to align with recognisable physical features. This requirement is supported by findings in post-earthquake response literature, where spatial structures aligned with physical landmarks have been shown to outperform purely coordinate-based partitions (Shrestha et al., 2022; Underwood et al., 2020). The revised approach incorporates this requirement directly into the generation process, ensuring that sector boundaries remain interpretable in operational settings.

The scenario-based application further connects this work to the Swiss dynamic earthquake risk framework (Böse et al., 2024). Existing systems such as ShakeMap and Rapid Impact Assessment provide detailed hazard and impact information but do not explicitly define how assessment teams should be spatially deployed. The framework developed in this thesis contributes to this gap by translating these inputs into operational outputs at sector level. It builds on the same data foundations and extends them toward deployment-oriented decision support.

Overall, the findings align with established insights from disaster response research, which emphasise the importance of pre-defined spatial structures. Studies on the Christchurch and L'Aquila earthquake responses have shown that the quality of spatial units defined before an event strongly influences what is operationally feasible after the event, because there is no time to redesign them under post-event conditions (Kaiser et al., 2012; Shrestha et al., 2022; Underwood et al., 2020). Within this context, the contribution of this thesis lies in providing a structured and reproducible framework for evaluating and refining such spatial systems.

5.3 Implications

This thesis makes three distinct contributions. First, it provides the first systematic, metric-based quality assessment of a nationally pre-computed post-earthquake sector library. The TERMOT system, despite its operational significance and national scale, had not previously been subjected to a formalised quality evaluation, the existing documentation established that the system worked, not that it worked well. The Mayring-based qualitative analysis, the GIS metric framework, the Cohen's Kappa validation, and the comparative before-and-after evaluation together provide an empirical basis on which the existing system's structural properties can be discussed concretely rather than anecdotally. The framework is reproducible by construction, offering a standing benchmark against which future iterations of the system can be assessed.

Second, the thesis demonstrates that decoupling geometric partitioning from workload assignment, a design move established in the commercial territory design literature (Kalcsics et al., 2005) but not, to the knowledge gained in this study, previously applied to disaster-response sectorization, resolves the structural trade-offs observed in the existing system. This separation allows sector shape to be determined based on spatial structure while workload is addressed through subsequent team assignment, rather than forcing both to be handled simultaneously within the generation step. The separation is also what allows the framework to be extended to other hazards with different workload profiles, as discussed in Section 6.4.

Third, the scenario-based application operationalises the missing link between upstream Swiss earthquake risk products and downstream field deployment decisions at sector granularity. ShakeMap outputs and ERM-CH23 exposure data are already integrated into the Rapid Impact Assessment system (Böse et al., 2024), which produces aggregate damage and loss estimates. The framework developed in this thesis extends this chain by translating the same inputs into sector-level deployment decisions, positioning TERMOT as the operational endpoint of the Swiss dynamic earthquake risk framework rather than as a standalone coordination tool.

These three contributions have corresponding implications at the system, methodological, and operational levels, which are discussed in the remainder of this section.

For the EDO and TERMOT specifically, the findings suggest that improvements in sector design can be achieved without requiring additional data sources or fundamental changes to the existing infrastructure. Instead, changes in how existing data is used, particularly in the generation logic, appear to be sufficient to improve alignment with operational requirements. In addition, the scenario-based framework indicates potential for extending the platform beyond its current role as a coordination and documentation tool toward more active support for deployment planning.

For the broader academic field, the study illustrates the value of combining qualitative and quantitative approaches in spatial system design. The integration of content analysis, GIS-based metrics, statistical validation, and scenario-based modelling provides a transferable methodological template for similar applications. These implications are discussed further in Chapter 6 in relation to broader theoretical and practical considerations.

5.4 Limitations

Several limitations should be considered when interpreting the results of this study.

The most significant methodological limitation concerns the quantitative validation of Category C (Boundary Incoherence). The Boundary Alignment Ratio and the Road Network Density proxy do not reach the threshold for substantial agreement. This is primarily due to the aggregation method used in the Boundary Alignment Ratio, which averages alignment across the entire sector perimeter. Because most sector boundaries already follow infrastructure features, this averaging reduces the sensitivity of the metric to localised misalignments. A segment-level alignment measure would provide a more precise operationalisation and represents a priority for future development.

The scope of the study is limited to a proof-of-concept application across six municipalities. While these cases cover a range of settlement types, they do not constitute a statistically representative sample of the national sector system. Parameters such as the density-adaptive determination of cluster numbers are based on indicative calibration rather than large-scale optimisation. Extending the approach to national scale would require further calibration and validation.

A further limitation concerns the comparability between the existing and the revised sector approach when evaluated using metrics that were originally derived to capture deficiencies in the current system. For Categories A and C in particular, the before–after comparison should be interpreted with caution. In the case of Category A (Size and Workload Imbalance), the revised approach deliberately removes the 10–30 buildings-per-sector constraint, meaning that building count is no longer a defining design criterion and thus only of limited value for direct comparison. For Category C (Boundary Incoherence), none of the tested metrics achieved sufficient validation, indicating that the available quantitative proxies do not adequately capture the underlying phenomenon. As a result, comparisons based on these metrics should be understood as indicative rather than definitive.

The scenario-based application relies on illustrative parameter values for workload and urgency. Two distinct sets of parameters would benefit from empirical calibration. The first set comprises the workload weighting coefficients ($w_1 = 0.40$, $w_2 = 0.35$, $w_3 = 0.25$) and the Urgency Factor weights ($u_1 = 0.60$, $u_2 = 0.40$), which are grounded in ATC-20 rapid assessment guidance and stakeholder input but are not derived from operational timing data. Calibrating these against field-measured inspection times would convert the relative importance of each factor from indicative to empirical. The second set comprises the normalisation reference values introduced in Section 3.6.1 (FL_max = 8 floors, AR_max = 400 m², and the GKAT-based complexity scale in [0, 1]). These are currently anchored in authoritative Swiss sources (the GWR Merkmalskatalog (BFS, 2024), the SIA 261 norm (SIA, 2020), and stakeholder interviews) rather than derived from a specific percentile of the national GWR distribution. A production deployment would extract the reference values directly from the GWR dataset, for example using the 95th or 99th percentile of floor count and footprint area across the full national building stock, providing an outlier-robust normalisation anchor consistent with the illustrative intent of the values used here. Together, these two calibration steps would move the framework from proof-of-concept to operationally deployable tool.

The use of Euclidean Voronoi tessellation introduces limitations related to accessibility. While the approach ensures complete and non-overlapping partitions, it does not account for travel constraints imposed by terrain or infrastructure networks. In many operational contexts, network distance or travel time provides a more realistic representation of accessibility than Euclidean distance (Daskin, 2013; Okabe et al., 2008). Incorporating network-based distance measures therefore represents a relevant direction for future refinement.

The infrastructure-based boundary refinement step did not produce fully road-aligned sector boundaries in all cases. This is primarily due to geometric precision limitations observed when applying the Split with Lines tool in QGIS, which can result in small deviations between intended and actual boundary placement, particularly in areas with complex or closely spaced line geometries. Despite this, the resulting sector boundaries generally approximate infrastructure constraints effectively in denser settlement areas. This is because the underlying K-Means clustering tends to group buildings that are separated by major roads into distinct clusters, meaning that many infrastructure divisions are already implicitly respected prior to the explicit splitting step. The limitation therefore affects geometric precision rather than the overall spatial logic of the approach.

Finally, the choice of Cohen’s Kappa as the validation measure is appropriate for the binary classification used in this study, but alternative measures such as Krippendorff’s Alpha may be more suitable for future extensions involving multiple raters or more complex evaluation scales. Unlike Cohen’s Kappa, which is limited to pairwise agreement and fixed category structures, Krippendorff’s Alpha can accommodate multiple raters, different levels of measurement (including ordinal and interval data), and incomplete or missing data (Krippendorff, 2004). This makes it more flexible for future applications in which classification tasks become more complex or involve multiple evaluators.

More broadly, it should be recognised that sectorization does not admit a single optimal solution. The approach developed in this thesis represents one design, tailored to the constraints and requirements of the TERMOT system. Alternative approaches may offer advantages in different contexts. The contribution of this work lies in providing a structured and reproducible framework for evaluating and comparing such approaches.

6. Conclusion

This chapter synthesises the findings of the thesis and reflects on their significance. Section 6.1 provides concise answers to the research questions defined in Chapter 1.2.2. Section 6.2 translates the findings into concrete recommendations for the further development of the TERMOT sector system, and Section 6.3 outlines directions for future research beyond the scope of this work.

The central argument of this thesis is that the design of pre-defined spatial structures has direct operational implications, and that improving these structures requires grounding design decisions in empirical analysis rather than relying solely on geometric conventions. The TERMOT sector system represents a nationally significant pre-defined spatial structure that has, to the author's knowledge, not previously been subjected to a systematic scientific evaluation. The mixed-methods framework developed here combining qualitative content analysis, quantitative GIS metrics, Cohen's Kappa validation, and scenario-based application provides a reproducible basis for such evaluation and, when applied, identifies recurring structural patterns that trace back to a single design decision: to derive sector boundaries from infrastructure lines before considering where buildings are located. The revised approach developed in this thesis demonstrates that reversing this generative order and treating workload as a separate attribute rather than a geometric constraint, produces measurable improvements across multiple quality dimensions.

At its core, this thesis shows that sector generation can be improved by shifting from an infrastructure-driven design logic to a demand-driven approach, while treating workload considerations separately from spatial partitioning. The scenario-based application further demonstrates that these improvements are not only structural, but also translate into more differentiated and operationally meaningful outputs. Taken together, the findings indicate that a data-driven approach to sectorization is both feasible within the existing TERMOT infrastructure and valuable as a foundation for future development.

6.1 Answer to Research Questions

The following pages answer the research questions defined in the beginning of the thesis, starting with the main research question:

How can spatial analysis and GIS-based methods be used to systematically assess and improve the quality of the TERMOT sector system as an operational geographic framework for post-earthquake building usability- and damage assessment in Switzerland and Liechtenstein?

This thesis demonstrates that spatial analysis and GIS-based methods can systematically assess and improve the TERMOT sector system through a three-stage mixed-methods framework. In the assessment stage, qualitative content analysis identifies recurring structural problem categories from an empirical sector sample, and these categories are operationalised into GIS-based metrics that are validated against the qualitative findings through Cohen's Kappa. In the improvement stage, the validated categories inform a revised sector generation pipeline that reverses the generative order of the existing system: building cluster centroids determine sector geometry first, and infrastructure features are applied as hard boundary constraints second. Applied as a proof-of-concept across six municipalities spanning urban, intermediate, and rural settlement contexts, the revised approach produces measurable improvements across all three quality dimensions identified in the assessment stage. In the application stage, the validated sector system is extended into an operational framework for workload scoring, priority classification, and team allocation, integrating with existing Swiss seismic hazard and exposure products to support deployment decisions at sector granularity. Together, the three stages establish a systematic, reproducible basis for evaluating and improving nationally pre-computed sector libraries that had not previously been available for the TERMOT system.

- Research Question 1: What spatial and structural deficiencies characterise the existing TERMOT sectors, and how can these be operationalised into quantitative measures?

  The analysis identified three recurring categories: size and workload imbalance, spatial inefficiency, and boundary incoherence, which capture the main structural characteristics of the existing system. These categories were operationalised through a set of GIS-based metrics, two of which were successfully validated using Cohen's Kappa, demonstrating their suitability for reproducible sector quality assessment.

- Research Question 2: How can an improved sector generation approach be designed, and to what extent does it demonstrate measurable improvements?

  An improved approach was developed by reordering the generation process, using building clusters as the primary input and applying infrastructure constraints in a second step. This approach demonstrates measurable improvements across all evaluated quality dimensions when assessed using the same metric framework as the existing system.

- Research Question 3: How can the sector system be applied as an operational framework for workload estimation, prioritisation, and resource allocation?

The scenario-based application shows that the validated sector system can serve as a spatially explicit operational framework. By distinguishing between pre-event sector design and post-event deployment logic, the approach enables structured workload estimation, geographic prioritisation, and resource allocation in a way that aligns with the requirements of earthquake response operations.

6.2 Recommendations

The findings of this thesis suggest several recommendations for the further development of the TERMOT sector system and its operational application.

1. Regenerate the national sector library using the revised pipeline.

   The proof-of-concept results indicate that the revised approach produces improved sector structures across different settlement contexts while relying exclusively on existing data sources. Regenerating the national sector library using this approach represents a feasible step toward improving overall sector quality.

2. Decouple building count from sector generation.

   Building count should no longer be treated as a hard geometric constraint within the generation process. Instead, it should be used as a workload indicator managed through team assignment. The workload scoring framework developed in this thesis provides a basis for implementing this shift.

3. Integrate the scenario-based application framework into TERMOT.

   The three-step framework for workload estimation, prioritisation, and team allocation can be integrated into the TERMOT platform as both a pre-computation and post-event decision-support component, extending its operational capabilities.

4. Refine the validation of boundary-related metrics.

   A segment-level boundary alignment metric should be developed to improve the quantitative validation of boundary coherence and address the limitations identified in the current metric design.

5. Calibrate clustering parameters using larger-scale data.

   The density-adaptive clustering approach would benefit from systematic calibration across a broader dataset to ensure consistent performance across all settlement types.

6.3 Outlook

The approach developed in this thesis was designed in the context of earthquake response within the TERMOT platform, but its underlying principles are not limited to this specific application. The decoupling of sector geometry from workload estimation opens the possibility of a multi-hazard sectorization framework, in which a shared geometric sector layer is combined with hazard-specific workload models and prioritisation schemes. Future research could therefore explore the transferability of the revised sector system to other hazard contexts such as floods, landslides, or storms. While the geometric sector structure could remain largely stable, the workload estimation and prioritisation logic would need to be adapted to reflect the specific spatial patterns and vulnerability profiles of each hazard (Kappes et al., 2012). The current approach also reflects a building filter tailored to earthquake response, which excludes alpine huts, agricultural outbuildings, and other non-residential structures that may be directly relevant for other hazards such as hail, flood, or rockfall. Extending the framework to support additional hazards would therefore require revisiting these filter assumptions and adapting both the input data and the workload model accordingly. This reinforces that the present work represents a foundation for hazard-adaptive sectorization rather than a final multi-hazard solution.

A fundamental methodological extension of the revised approach concerns the distance metric used in the Voronoi tessellation step. The current implementation uses Euclidean Voronoi diagrams, which produce mathematically guaranteed non-overlapping, contiguous, complete partitions at low computational cost and are therefore well suited to a national-scale proof-of-concept. However, as discussed in Section 5.4, Euclidean distance is a limited proxy for field accessibility. A network-based Voronoi approach, for example, network Voronoi diagrams over a routing graph (Okabe et al., 2008), or p-median clustering with road-network distances (Daskin, 2013), would generate sector polygons based on actual travel times between cluster centroids and surrounding buildings, more faithfully reflecting operational accessibility in topographically complex terrain. Such an approach would be particularly relevant in alpine and rural contexts where straight-line proximity between a sector boundary and a building can misrepresent the true effort required to reach it. Future work should therefore investigate the implementation feasibility of network-constrained sector generation within the Swiss road and path network, including the computational cost of routing-based tessellation at national scale and the calibration of travel-time thresholds against operational EDO deployment data.

A further direction concerns the enrichment of sector metadata. Expert interviews highlighted the importance of additional contextual information, such as infrastructure risks or coordination-relevant attributes. Integrating such metadata into the existing data model could enhance operational planning without requiring changes to the underlying sector geometry.

The integration of emerging technologies, such as drone-based rapid assessment, represents another promising area. Drone operations are less constrained by ground-based accessibility and may require different spatial aggregation units. Future work could therefore explore the development of complementary sector layers tailored to aerial assessment workflows.

Taken together, these directions span three types of extension: transferability to other hazard domains, methodological refinement of the distance metric and metadata model, and integration with emerging technologies such as drone-based assessment. Each represents a distinct research agenda that could be developed independently. More broadly, the thesis demonstrates that pre-defined operational spatial structures benefit from the same scientific scrutiny routinely applied to the data and models they organise. The value of empirically grounded sector design lies not only in improving the specific systems evaluated, but in establishing that such evaluation is possible, reproducible, and operationally consequential.

7. Literature

Alexander, D. E. (2015). Disaster and Emergency Planning for Preparedness, Response, and Recovery. In D. E. Alexander, *Oxford Research Encyclopedia of Natural Hazard Science*. Oxford University Press. https://doi.org/10.1093/acrefore/9780199389407.013.12

Altay, N., & Green, W. G. (2006). OR/MS research in disaster operations management. *European Journal of Operational Research*, *175*(1), 475–493. https://doi.org/10.1016/j.ejor.2005.05.016

Arbeitsgruppe SOE. (2020). *Bericht der Arbeitsgruppe zum Detailkonzept SOE* (Version 7.0; S. 55).

ATC. (2005). *ATC-20-1: Field Manual: Postearthquake Safety Evaluation of Buildings* (2nd Edition; S. 159). Applied Technology Council (ATC).

Auf der Heide, E. (1989). *Disaster Response—Principles of Preparation and Coordination*. C. V. Mosby Company.

BABS. (2018). *Leitfaden Gebäudebeurteilung nach Erdbeben—Organisatorische Aspekte der Vorbereitung und Durchführung*. BABS, Bundesamt für Bevölkerungsschutz.

BABS. (2020a). *Gefahrendossier Erdbeben 2020*. BABS, Bundesamt für Bevölkerungsschutz.

BABS. (2020b). Katastrophen und Notlagen Schweiz 2020, Welche Risiken gefährden die Schweiz. *Bundesamt für Bevölkerungsschutz BABS*, 24.

BABS. (2021). *Handbuch Gebaeudebeurteilung nach einem Erdbeben* [Handbuch]. BABS, Bundesamt für Bevölkerungsschutz.

BABS. (2022). *Integrales Risikomanagement, Bedeutung für den Schutz der Bevölkerung und ihrer Lebensgrundlagen* [Broschüre]. BABS, Bundesamt für Bevölkerungsschutz.

BABS. (2023). Katastrophen und Notlagen Schweiz 2025—Katalog der Gefährdungen. *Bundesamt für Bevölkerungsschutz*, (3. Auflage).

BABS. (2025). *Megatrends und Erdbebenresilienz BVK 2025*. 24.

BABS. (2026). *Gefährdungsdossier Erdbeben 2025* [Gefährdungsdossier]. BABS, Bundesamt für Bevölkerungsschutz.

BAFU. (2024). *Erdbebenrisikomanagement—Massnahmen des Bundes, Standbericht und Planung für den Zeitraum 2025 bis 2028* (Nr. P071-1651; S. 57). Interdepartementale Arbeitsgruppe Erdbebenrisikomanagement des Bundes, Bundesamt für Umwelt (BAFU).

BFS. (2024). *Aktualisierung 2020 der nichtinstitutionellen Raumgliederungen: Raum mit städtischem Charakter, Agglomerationen und Typologien.* (21 Nachhaltige Entwicklung, regionale und internationale Disparitäten) [Erläuterungsbericht]. Bundesamt für Statistik (BFS).

Bigley, G. A., & Roberts, K. H. (2001). The Incident Command System: High-repliability organizing for complex and volatile tasks environments. *Academy of Management Journal*, *44*(6), 1281–1299. https://doi.org/10.2307/3069401

Böse, M., Danciu, L., Papadopoulos, A., Clinton, J., Cauzzi, C., Dallo, I., Mizrahi, L., Diehl, T., Bergamo, P., Reuland, Y., Fichtner, A., Roth, P., Haslinger, F., Massin, F., Valenzuela, N., Blagojević, N., Bodenmann, L., Chatzi, E., Fäh, D., … Wiemer, S. (2024). Towards a dynamic earthquake risk framework for Switzerland. *Natural Hazards and Earth System Sciences*, *24*(2), 583–607. https://doi.org/10.5194/nhess-24-583-2024

Brinkmann, S., & Kvale, S. (2018). *Doing Interviews*. SAGE Publications Ltd. https://doi.org/10.4135/9781529716665

Bundesgesetz über den Bevölkerungsschutz und den Zivilschutz, Gesetz Nr. SR 520.1, 36 (2021).

Bundesverfassung der Schweizerischen Eidgenossenschaft, 102 (2000).

Camacho-Collados, M., Liberatore, F., & Angulo, J. M. (2015). A multi-criteria Police Districting Problem for the efficient and effective design of patrol sector. *European Journal of Operational Research*, *246*(2), 674–684. https://doi.org/10.1016/j.ejor.2015.05.023

Camenisch, C. (2025, November 13). *Semi-structured expert interview on TERMOT platform use and sector requirements from a cantonal perspective. Division of Civil Protection, Planning and Projects, Canton of Bern, Switzerland.* [Interview].

Caunhye, A. M., Nie, X., & Pokharel, S. (2012). Optimization models in emergency logistics: A literature review. *Socio-Economic Planning Sciences*, *46*(1), 4–13. https://doi.org/10.1016/j.seps.2011.04.004

Church, R., & ReVelle, C. (1974). The maximal covering location problem. *Papers of the Regional Science Association*, *32*(1), 101–118. https://doi.org/10.1007/BF01942293

Cohen, J. (1960). A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement*, *20*(1), 37–46. https://doi.org/10.1177/001316446002000104

Comfort, L. K. (2007). Crisis Management in Hindsight: Cognition, Communication, Coordination, and Control. *Public Administration Review*, *67*(s1), 189–197. https://doi.org/10.1111/j.1540-6210.2007.00827.x

Compass Security Schweiz AG. (2023). *Pentest SOE Solution* (Public Statement Nr. V1).

Contreras, D., Blaschke, T., Tiede, D., & Jilge, M. (2016). Monitoring recovery after earthquakes through the integration of remote sensing, GIS, and ground observations: The case of L'Aquila (Italy). *Cartography and Geographic Information Science*, *43*(2), 115–133. https://doi.org/10.1080/15230406.2015.1029520

Cornell, C. A. (1968). Engineering seismic risk analysis. *Bulletin of the Seismological Society of America*, *58*(5), 1583–1606. https://doi.org/10.1785/BSSA0580051583

Cotovanu, V. (2023). *Automated sector creation v2* (Version 2) [Azure DevOps Wiki]. risktec for SOE.

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (Fifth edition). SAGE.

Daskin, M. S. (Hrsg.). (2013). *Network and Discrete Location: Models, Algorithms, and Applications, Second Edition* (1. Aufl.). Wiley. https://doi.org/10.1002/9781118537015

Erden, T., & Coşkun, M. Z. (2010). Multi-criteria site selection for fire services: The interaction with analytic hierarchy process and geographic information systems. *Natural Hazards and Earth System Sciences*, *10*(10), 2127–2134. https://doi.org/10.5194/nhess-10-2127-2010

Fäh, D., Gisler, M., Jaggi, B., Kästli, P., Lutz, T., Masciadri, V., Matt, C., Mayer-Rosa, D., Rippmann, D., Schwarz-Zanetti, G., Tauber, J., & Wenk, T. (2009). The 1356 Basel earthquake: An interdisciplinary revision. *Geophysical Journal International*, *178*(1), 351–374. https://doi.org/10.1111/j.1365-246X.2009.04130.x

Fang, C., Zhou, L., Gu, X., Liu, X., & Werner, M. (2025). A data driven approach to urban area delineation using multi source geospatial data. *Scientific Reports*, *15*(1), 8708. https://doi.org/10.1038/s41598-025-93366-x

Federal Emergency Management Agency. (2017). *National Incident Management System* [Guideline / Framework]. Federal Emergency Management Agency (FEMA).

FEMA. (2019). *FEMA P-2055: Post-Disaster Building Safety Evaluation Guidance—Report on the Current State of Practice, including Recommendations Related to Structural and Nonstructural Safety and Habitability*. Federal Emergency Management Agency (FEMA) / Applied Technology Council (ATC).

Galindo, G., & Batta, R. (2013). Review of recent developments in OR/MS research in disaster operations management. *European Journal of Operational Research*, *230*(2), 201–211. https://doi.org/10.1016/j.ejor.2013.01.039

Gallagher, R., Lizundia, B., & Barnes, J. C. (2012). *Building Safety Evaluation after the February 22, 2011 Christchurch, New Zealnad EQ: Observations by the ATC Reconnaisance Team* [Report]. Applied Technology Council.

Goodchild, M. F. (2007). Citizens as sensors: The world of volunteered geography. *GeoJournal*, *69*(4), 211–221. https://doi.org/10.1007/s10708-007-9111-y

Grünthal, G. (Hrsg.). (1998). *European macroseismic scale 1998: EMS-98* (2nd ed.). European Seismological Commission, Subcommission on Engineering Seismology, Working Group Macroseismic scales.

Horvath, A. (2025, November 11). *Semi-structured expert interview on insurance-side damage assessment and sector relevance for non-seismic perils. Gebäudeversicherung Solothurn, Switzerland.* [Interview].

Jiang, Y., & Yuan, Y. (2019). Emergency Logistics in a Large-Scale Disaster Context: Achievements and Challenges. *International Journal of Environmental Research and Public Health*, *16*(5), 779. https://doi.org/10.3390/ijerph16050779

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research*, *1*(2), 112–133. https://doi.org/10.1177/1558689806298224

Kahandawa, K. A. R. V. D., Domingo, N. D., Park, K. S., & Uma, S. R. (2018). Earthquake damage estimation systems: Literature review. *Procedia Engineering*, *212*, 622–628. https://doi.org/10.1016/j.proeng.2018.01.080

Kaiser, A., Holden, C., Beavan, J., Beetham, D., Benites, R., Celentano, A., Collett, D., Cousins, J., Cubrinovski, M., Dellow, G., Denys, P., Fielding, E., Fry, B., Gerstenberger, M., Langridge, R., Massey, C., Motagh, M., Pondard, N., McVerry, G., … Zhao, J. (2012). The M_w 6.2 Christchurch earthquake of February 2011: Preliminary report. *New Zealand Journal of Geology and Geophysics*, *55*(1), 67–90. https://doi.org/10.1080/00288306.2011.641182

Kalcsics, J., Nickel, S., & Schröder, M. (2005). Towards a unified territorial design approach—Applications, algorithms and GIS integration. *Top*, *13*(1), 1–56. https://doi.org/10.1007/BF02578982

Kappes, M. S., Keiler, M., Von Elverfeldt, K., & Glade, T. (2012). Challenges of analyzing multi-hazard risk: A review. *Natural Hazards*, *64*(2), 1925–1958. https://doi.org/10.1007/s11069-012-0294-2

Kaveh, A., Javadi, S. M., & Moghanni, R. M. (2020). Emergency management systems after disastrous earthquakes using optimization methods: A comprehensive review. *Advances in Engineering Software*, *149*, 102885. https://doi.org/10.1016/j.advengsoft.2020.102885

Khakurel, S., Yeow, T., Saha, S., & Dhakal, R. (2023). Post-earthquake building assessments: How long do they take? *Bulletin of the New Zealand Society for Earthquake Engineering*, *56*(2), 115–126. https://doi.org/10.5459/bnzsee.1568

Kramer, S. L. (1996). *Geotechnical earthquake engineering*. Prentice Hall.

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology* (2nd ed). Sage.

Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, *33*(1), 159. https://doi.org/10.2307/2529310

Liechtensteinisches Bevölkerungsschutzgesetz; BSchG, 521 2007.139 23 (2007).

Lombard, M., Snyder-Duch, J., & Bracken, C. C. (2002). Content Analysis in Mass Communication: Assessment and Reporting of Intercoder Reliability. *Human Communication Research*, *28*(4), 587–604. https://doi.org/10.1111/j.1468-2958.2002.tb00826.x

Mayring, P. (2014). *Qualitative Content Analysis—Theoretical Foundation, Basic Procedures and Software Solution*.

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. *Biochemia Medica*, 276–282. https://doi.org/10.11613/BM.2012.031

Merkmlaskatalog Eidgenössisches Gebäude- und Wohnungsregister. (2022). [Version 4.2]. https://www.housing-stat.ch/files/881-2200.pdf

Nardi, S. (2025, November 13). *Semi-structured expert interview on technical sector design requirements and TERMOT implementation. Risktec AG, Zürich, Switzerland.* [Interview].

NZSEE. (1998). Post-earthquake building safety evaluation procedures: Preparedness checklist and response plan for territorial authorities. *Bulletin of the New Zealand Society for Earthquake Engineering*, *31*(2), 103–121. https://doi.org/10.5459/bnzsee.31.2.103-121

Okabe, A., Satoh, T., Furuta, T., Suzuki, A., & Okano, K. (2008). Generalized network Voronoi diagrams: Concepts, computational methods, and applications. *International Journal of Geographical Information Science*, *22*(9), 965–994. https://doi.org/10.1080/13658810701587891

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3 ed). Sage Publications.

Peyer, M. (2025, November 12). *Semi-structured expert interview on TERMOT product vision and sector design requirements. Risktec AG, Zürich, Switzerland* [Interview].

Quarantelli, E. L. (1988). Disaster Crisis Management: A Summary of Research Findings. *Journal of Management Studies*, *25*(4), 373–385. https://doi.org/10.1111/j.1467-6486.1988.tb00043.x

SED. (2023). *SED EQ Risk in Switzerland*. Swiss Seismological Service at ETH Zurich.

SED Overview. (2026). https://seismo.ethz.ch/en/earthquake-country-switzerland/overview/

SGEB. (2026). *Hintergrundinformationen—SGEB Schweizer Gesellschaft für Erdbebeningenieurwesen und Baudynamik*. https://sgeb.ch/de/publikationen/hintergrundinformationen.html

Shrestha, S. R., Orchiston, C. H., Elwood, K. J., Johnston, D. M., Becker, J. S., & Tomassi, I. (2022). Understanding the wider social and economic context of post-earthquake cordons: A comparative case study between Christchurch, Aotearoa (New Zealand) and L'Aquila, Italy. *Earthquake Spectra*, *38*(4), 2731–2753. https://doi.org/10.1177/87552930221091593

SIA. (2020, November 1). *SIA 261/1 Einwirkung auf Tragwerke—Ergänzende Festlegungen* [Broschüre]. Schweizerischer Ingenieur- und Architekturverein.

SOE. (2021a). *Leistungsvereinbarung betreffend Betrieb einer Organisation, welche nach einem Erdbeben die beschädigten Gebäude untersucht und eine schriftliche Schätzung der Wiederaufbau- und Reparaturkosten erstellt.* [Leistungsvereinbarung].

SOE. (2021b, Juni 16). *Statuten Verein Schadenorganisation Erdbeben* [Statuten].

SOE. (2021c, Juni 18). *Medienmitteilung Gründung SOE Schadenorganisation Erdbeben* [Medienmitteilung]. https://www.soe-ods.ch/wp-content/uploads/2023/10/SOE-MM-20210618-Gruendung-SOE-Schadenorganisation-Erdbeben.pdf

SOE. (2023, Oktober 12). *Die Schadenorganisation Erdbeben ist einsatzbereit*. Schadenorganisation Erdbeben SOE | Organisation dommages sismiques ODS | Organizzazione danni sismici ODS. https://www.soe-ods.ch/aktuelles-wissen/die-schadenorganisation-erdbeben-ist-einsatzbereit/

SOE. (2024). *Benutzerhandbuch TERMOT (User Manual)* (User Manaual V1_0_1). SOE.

Steiger, Y. (2025, November 27). *Semi-structured expert interview on sector-based building assessment and resource management. National Emergency Operations Centre (NEOC/BABS-NAZ), Switzerland.* [Interview].

Swiss Seismological Service (SED). (2024). *ShakeMap. ETH Zurich.* ShakeMap. https://www.seismo.ethz.ch/en/earthquakes/always-informed/shakemap/

Trandac, H., Baptiste, P., & Duong, V. (2005). Airspace sectorization with constraints. *RAIRO - Operations Research*, *39*(2), 105–122. https://doi.org/10.1051/ro:2005005

Underwood, G., Orchiston, C., & Shrestha, S. R. (2020). Post-earthquake cordons and their implications. *Earthquake Spectra*, *36*(4), 1743–1768. https://doi.org/10.1177/8755293020936293

UNISDR. (2015). *Sendai Framework for Disaster Risk Reduction 2015—2030.*

Verordnung über den Bevölkerungsschutz, Gesetz Nr. SR 520.12, 28 (2021).

Verordnung über den Bundesstab Bevölkerungsschutz, Gesetz Nr. SR 520.17, 10 (2018).

Verordnung über die Krisenorganisation der Bundesverwaltung, Gesetz Nr. SR 172.010.8, 8 (2025).

Wenk, T. (2005). *SIA 2018—Überprüfung bestehender Gebäude bezüglich Erdbeben* [Application/pdf]. 7 p. https://doi.org/10.3929/ETHZ-A-006578789

Wiemer, S., Danciu, L., Edwards, B., Marti, M., Fäh, D., Hiemer, S., Wössner, J., Cauzzi, C., Kästli, P., & Kremer, K. (2016). *Seismic Hazard Model 2015 for Switzerland (SUIhaz2015)* [Technical

Report / Hazard Model Documentation; Pdf]. SED, Swiss Seismological Service at ETH Zürich. https://doi.org/10.12686/A2

Wiemer, S., Philippe, R., Kästli, P., Danciu, L., Bazzurro, P., Fäh, D., Duvernay, B., Lestuzzi, P., Marti, M., Papadopoulos, A., Bergamo, P., Khodaverdian, A., Fagà, E., Odabasi, O., Cauzzi, C., Valenzuela Rodriguez, N., Schmid, N., Hammer, C., Panzera, F., … Haslinger, F. (2023). *Earthquake Seismic Risk Model for Switzerland (ERM-CH23)* [Application/pdf]. SED, Swiss Seismological Service at ETH Zürich. https://doi.org/10.12686/A20

Wildhaber, I. (2014). *Rechtsfragen im Zusammenhang mit der Gebäudebeurteilung nach Erdbeben. Verfassungsgrundlagen, Notrecht, Haftung von Experten. Rechts gutachten im Auftrag des Bundesamts für Bevölkerungsschutz BABS.*

Wildhaber, S. (2022). *Experts, Sector and Team management* [Azure DevOps Wiki]. risktec for SOE.

Wildhaber, S. (2025, November 10). *Semi-structured expert interview on current TERMOT sector limitations and improvement potential. Risktec AG, Zürich, Switzerland.* [Interview].

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At Risk—Natural hazards, peopl's vulnerability and disasters* [Second edition]. Routledge.

8. Appendix

A. Legal and Policy Framework relevant for earthquake response and building assessment in Switzerland

Earthquake risk management and disaster response in Switzerland are embedded in a multi-level legal and institutional framework that defines responsibilities, coordination mechanisms, and operational principles for crisis preparedness and response. While this framework does not prescribe specific methodologies for operational planning tasks such as spatial sectorization, it establishes the institutional and legal conditions under which such operational concepts must function.

At the constitutional level, the Swiss Federal Constitution establishes the general responsibility of the state to ensure public safety and manage disasters. Articles 57 and 61 define the mandate of the Confederation and the cantons in matters of civil protection and disaster response, forming the constitutional basis for Switzerland's population protection system (Bundesverfassung der Schweizerischen Eidgenossenschaft, 2000).

The central legal basis for population protection in Switzerland is the Federal Act on Civil Protection and Civil Defence (Bevölkerungs- und Zivilschutzgesetz, BZG; SR 520.1). The Act defines population protection as a cooperative system involving the Confederation, cantons, municipalities, and partner organizations such as the police, fire services, health services, and civil protection. The system is guided by the principle of subsidiarity, according to which operational responsibility for disaster response lies primarily with the cantons, while the federal level provides coordination, support, and strategic guidance (Bevölkerungs- und Zivilschutzgesetz, BZG, 2021).

This division of responsibilities has direct implications for the organization of earthquake response. In the event of a major earthquake, the affected cantons assume operational leadership through their cantonal crisis management structures, typically organised through a cantonal leadership organization (Kantonaler Führungsstab, KFO). Depending on the severity of the event, additional support may be provided through inter-cantonal assistance, federal coordination bodies, or, in extreme cases, international support. The involvement of multiple governance levels and organisations highlights the importance of clearly defined operational structures that allow coordinated action across jurisdictions and response actors, as shown in figure 7 (BABS, 2018).

The Ordinance on Civil Protection (BevSV; SR 520.12) consolidates previous regulations in this area and provides detailed implementing provisions for the Federal Act on Civil Protection, covering warning and alerting systems, organisational requirements, resource management, communication infrastructures, and the roles of partner organisations within the population protection system. The Ordinance on the Federal Staff for Civil Protection (VBSTB; SR 520.17) defines the composition and responsibilities of the federal crisis coordination body, specifying procedures for information exchange and crisis coordination between federal and cantonal authorities during major events. The Ordinance on Crisis Organisation (KOBV; SR 172.010.8) further regulates the establishment and functioning of crisis management structures at the federal level, defining how federal authorities organise and coordinate their response during major emergencies. Although these legal instruments do not explicitly regulate spatial zoning or sectorization, effective crisis management requires clearly defined spatial reference units that enable command, control, and communication across organisations during disaster response (Bevölkerungsschutzverordnung, BevSV, 2021; Verordnung über den Bundesstab Bevölkerungsschutz, 2018; Verordnung über die Krisenorganisation der Bundesverwaltung, 2025).

In addition to the legal framework, earthquake risk management in Switzerland is guided by national policy instruments and risk analyses. The national risk analysis “Katastrophen und Notlagen Schweiz”, conducted by the Federal Office for Civil Protection, identifies earthquakes as one of the hazards with the highest potential impact in Switzerland, despite their comparatively low probability of occurrence. The analysis highlights that large earthquakes can affect extensive geographic areas and cause widespread damage to buildings, infrastructure, and essential services (BABS, 2020b, 2026).

At the federal level, earthquake preparedness is further addressed through the federal earthquake risk management programme, which defines strategic measures for prevention, preparedness, response, and recovery. These programmes outline the roles of federal authorities in areas such as seismic monitoring, risk assessment, preparedness planning, and support to cantons during major events (BAFU, 2024).

Beyond formal legislation and policy programmes, operational earthquake response in Switzerland is strongly influenced by technical guidelines developed by federal authorities. A particularly important reference is the “Handbuch Gebäudebeurteilung nach einem Erdbeben”, published under the responsibility of the Federal Office for Civil Protection. The handbook defines the methodology used to assess the usability of buildings after an earthquake and provides guidance on the organisation of building assessment operations. Its primary objective is to determine whether damaged buildings can still be safely entered or occupied, thereby protecting human life and preventing secondary accidents during aftershocks. The handbook also emphasises the need for a coordinated organisational framework that allows expert teams to conduct rapid safety assessments of large numbers of buildings. Since large earthquakes can simultaneously affect multiple cantons, a nationally harmonised methodology and training system for building assessment is required in order to enable efficient inter-cantonal cooperation and mutual assistance (BABS, 2021).

Complementing the technical methodology, the “Leitfaden Gebäudebeurteilung nach Erdbeben – organisatorische Aspekte der Vorbereitung und Durchführung” provides guidance on the organisational setup of building assessment operations. The document describes how cantons should prepare for large-scale post-earthquake assessments, including the organisation of expert teams, coordination structures, and operational processes. It aims to ensure that cantonal organisations follow comparable organisational principles, thereby enabling efficient inter-cantonal cooperation and mutual assistance during large earthquake scenarios (BABS, 2018).

In addition to operational guidance, legal questions related to post-earthquake building assessments have been analysed in a legal opinion commissioned by the Federal Office for Civil Protection. The report examines the constitutional basis of earthquake response, the use of emergency powers, and potential liability issues related to expert assessments (I. Wildhaber, 2014).

Taken together, this legal and policy framework defines the boundary conditions within which operational earthquake response concepts must operate. Sectorization approaches developed for post-earthquake building assessment must therefore be compatible with the federal structure of Swiss population protection, respect cantonal operational responsibilities, and support coordination across multiple levels of government and response organisations. These normative requirements provide the institutional reference framework for evaluating and further developing sector concepts in the context of the TERMOT platform.

Table 21: Legal and policy framework relevant for earthquake response and building assessment in Switzerland

Legal / Policy Level	Law / Document	Relevance for this Thesis
Constitutional framework	Swiss Federal Constitution (Art. 57, Art. 61)	Defines the general mandate of the Confederation and cantons to ensure public safety and manage disasters, forming the constitutional basis for Switzerland's population protection system.
Federal Legislation	Federal Act on Civil Protection and Civil Defence (Bevölkerungs- und Zivilschutzgesetz, BZG; SR 520.1)	Establishes the institutional structure of population protection and the principle of subsidiarity, under which cantons hold primary operational responsibility for disaster response.
Federal ordinances	Ordinance on Civil Protection (BevSV; SR 520.12)	Specifies implementing provisions of the BZG, including organisational requirements and resource management for population protection partner organisations.
	Ordinance on the Federal Staff for Civil Protection (VBSTB; SR 520.17)	Define operational coordination mechanisms, organisational structures and responsibilities during major events.
	Ordinance on Crisis organisation (KOBV, SR 172.010.8)	Regulates the establishment and functioning of federal crisis management structures, defining coordination responsibilities during major emergencies.
National risk analysis	Katastrophen und Notlagen Schweiz (BABS, 2020)	Identifies earthquakes as one of the hazards with the highest potential impact in Switzerland and provides the risk assessment basis for preparedness planning and crisis management structures.
Federal policy programme	Federal Earthquake Risk Management Programme (BAFU, 2024)	Defines strategic measures for earthquake risk management at the federal level, including prevention, preparedness, monitoring, and support to cantons during major events.
Technical guideline (methodology)	Handbuch Gebäudebeurteilung nach einem Erdbeben (BABS, 2021)	Defines the national methodology for rapid post-earthquake building usability assessments and establishes the technical procedures used by expert teams.
Technical guideline (organization)	Leitfaden Gebäudebeurteilung nach Erdbeben – organisatorische Aspekte der Vorbereitung und Durchführung (BABS, 2018)	Provides organisational guidance for cantons on how to prepare and coordinate large-scale building assessment operations, including deployment structures and cooperation mechanisms.
Legal interpretation / expert report	Rechtsfragen im Zusammenhang mit der Gebäudebeurteilung nach Erdbeben (Wildhaber, 2014)	Analyses the legal basis, liability issues, and use of emergency powers related to post-earthquake building assessments.
Operational implementation	Cantonal earthquake response concepts and operational plans	Define how cantons organise expert deployment, damage assessment, and coordination structures. These operational frameworks ultimately determine how sectorization concepts must function in practice.

In Liechtenstein, disaster management and civil protection are regulated primarily through the Zivilschutzgesetz, which defines the responsibilities of state authorities and emergency services in disaster preparedness and response. Due to the centralized governance structure of the country, operational responsibility lies largely with national authorities rather than regional entities (Liechtensteinisches Bevölkerungsschutzgesetz; BSchG, 2007). In large disaster scenarios, civil protection planning therefore also relies on cross-border cooperation mechanisms, particularly with Switzerland.

B. Interview Guide

1. Introduction to the Master's Thesis and Presentation of M. Fehr (approx. 3 minutes)
Goal: Establish context, build trust, and ask for permission to record the interview.

2. Introduction of the Interview Partner (approx. 5 minutes)
Goal: Understand the interviewee's background and perspective.
Possible questions:

- Could you briefly introduce yourself and describe your background in crisis management / EDO / insurance / cantonal building insurance?
- In what capacity do you work with the EDO and use the TERMOT platform?
- What role do sectors play in your work?
- What is your personal interest in this topic? Are there specific challenges or questions that particularly concern you?

3. Main Thematic Section (approx. 20 minutes)
Goal: Gather criteria, requirements, and experiences.
3.1 Perceptions and Experiences

- In your opinion, what function should sectors fulfil? (e.g. rapid coordination, clear responsibilities, operational overview)
- Have you had positive or negative experiences with the existing sector structure in the past?
- What problems or areas for improvement do you see in the current sector design?

3.2 Requirements and Criteria

- If you were to imagine an ideal sector structure, what characteristics should it have? (e.g. size, accessibility, clear boundaries, responsibilities, communication routes, balanced workload distribution)
- What factors should, in your opinion, be taken into account when defining sectors? (e.g. topography, infrastructure, building or damage density, administrative boundaries, transport corridors, rivers, etc.)
- Are there any organisational or legal constraints that must be considered?

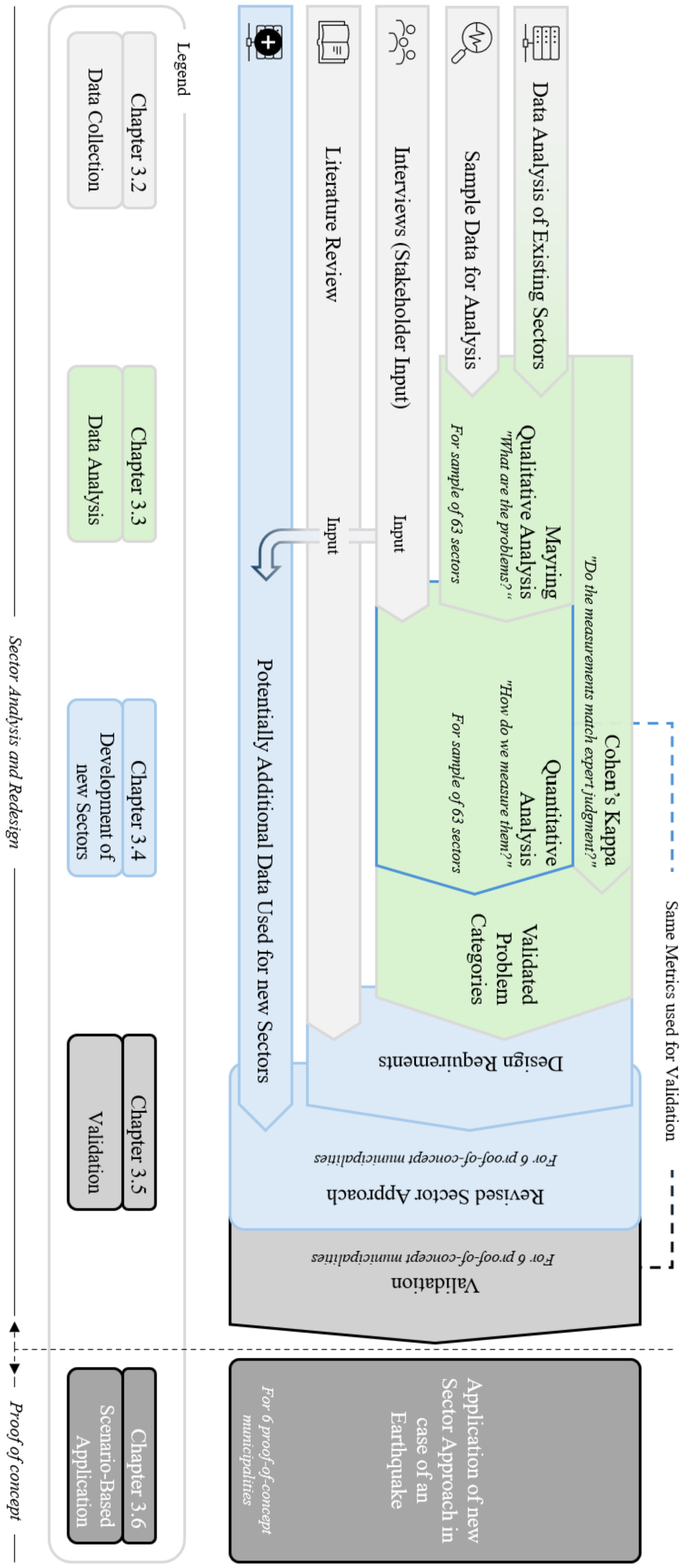
3.3 Implementation and Future Outlook

- Are there any aspects or concerns that you feel I should definitely address in my thesis?

4. Closing (approx. 2 minutes)

- Is there anything you would like to add or that is particularly important to you?
- Would it be alright if I contacted you again briefly for follow-up questions or to validate the results?

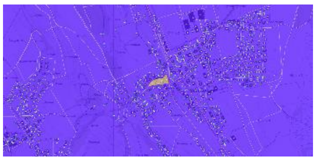
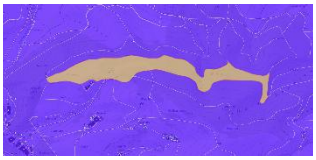
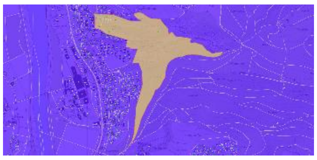
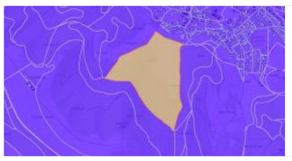
C. Methodological Framework

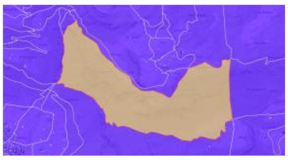
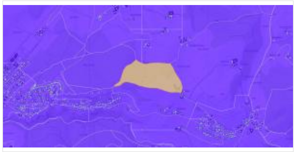


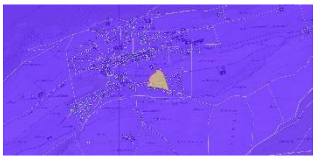
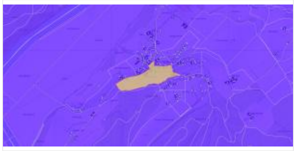
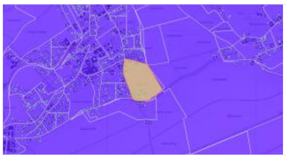
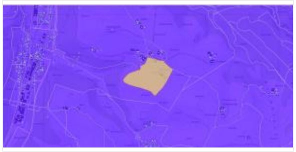
D. Mayrings Qualitative Content Analysis extended Table

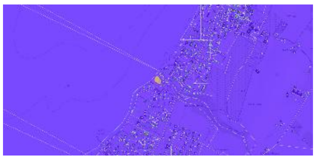
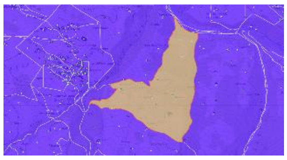
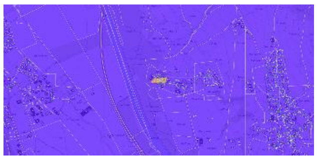
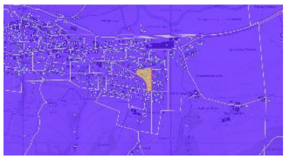
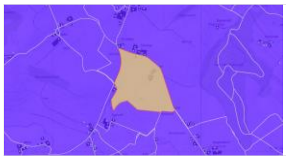
The sector sample was documented using a standardised Excel worksheet capturing 16 attributes per sector, including canton, municipality, BFS typology at three levels of aggregation, sector area, building count, building density, observed features, neutral description, generalisation, preliminary problem indications, problem statements, and qualitative problem category codings. Due to the volume of textual content, the full analytical worksheet is available on request. Table 22 presents a condensed overview of the 63 sampled sectors, showing the key quantitative attributes and final binary problem category assignments.

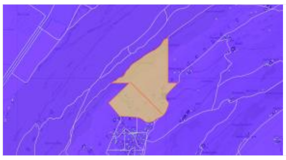
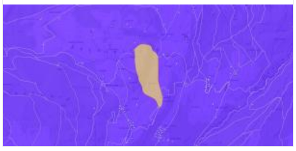
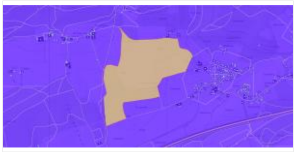
Table 22: Full list of Mayring's Qualitative Content Analysis for 63 sample sectors

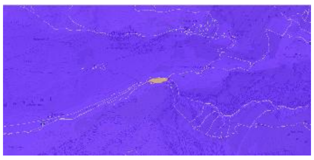
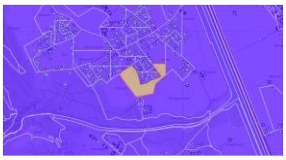
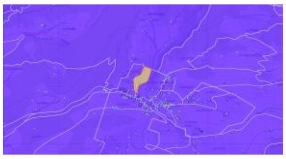
Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
AG - Boniswil – 23 - Typology: Rural - Size: 0.005 km² - Buildings: 10 - Density: 2021/km²	B: Spatial Inefficiency	
AG - Densbüren – 63 - Typology: Rural - Size: 0.216 km² - Buildings: 1 - Density: 5/km²	A: Size & Workload; B: Spatial Inefficiency; C: Boundary Incoherence	
AG - Geltwil – 15 - Typology: Rural - Size: 0.064 km² - Buildings: 1 - Density: 16/km²	A: Size & Workload	
AG-Holderbank (AG)-9 - Typology: Urban - Size: 0.255 km² - Buildings: 23 - Density: 90/km²	C: Boundary Incoherence	
AG - Killwangen – 47 - Typology: Urban - Size: 0.178 km² - Buildings: 1 - Density: 6/km²	A: Size & Workload	
AG - Niederlenz – 50 - Typology: Urban - Size: 0.152 km² - Buildings: 25 - Density: 165/km²	C: Boundary Incoherence	
AG - Rheinfelden – 102 - Typology: Urban - Size: 0.022 km² - Buildings: 2 - Density: 999/km²	A: Size & Workload; B: Spatial Inefficiency	

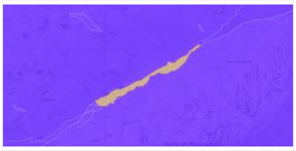
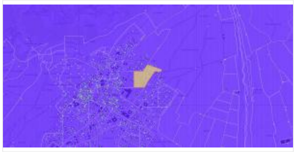
Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
AG - Teufenthal (AG) – 8 - Typology: Rural - Size: 0.011 km^2 - Buildings: 11 - Density: 1035/km^2	B: Spatial Inefficiency	
AR - Gais – 9 - Typology: Intermediate - Size: 0.027 km^2 - Buildings: 30 - Density: 1132/km^2	C: Boundary Incoherence	
BE-Bolligen-106 - Typology: Urban - Size: 0.086 km^2 - Buildings: 11 - Density: 128/km^2	C: Boundary Incoherence	
BE - Brienzwiler – 69 - Typology: Rural - Size: 0.430 km^2 - Buildings: 1 - Density: 2/km^2	A: Size & Workload; B: Spatial Inefficiency; C: Boundary Incoherence	
BE - Corgémont – 70 - Typology: Rural - Size: 0.151 km^2 - Buildings: 1 - Density: 7/km^2	A: Size & Workload; B: Spatial Inefficiency	
BE - Konolfingen – 143 - Typology: Intermediate - Size: 0.002 km^2 - Buildings: 2 - Density: 1174/km^2	A: Size & Workload; B: Spatial Inefficiency	
BE - Köniz – 551 - Typology: Urban - Size: 0.098 km^2 - Buildings: 6 - Density: 61/km^2	A: Size & Workload	
BE - Lengnau (BE) – 80 - Typology: Urban - Size: 0.016 km^2 - Buildings: 27 - Density: 1692/km^2	No problem identified	
BE - Oberburg – 97 - Typology: Urban - Size: 0.087 km^2 - Buildings: 5 - Density: 58/km^2	A: Size & Workload	

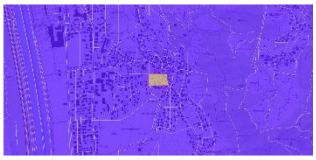
Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
BE - Orvin – 21 - Typology: Rural - Size: 0.016 km² - Buildings: 13 - Density: 812/km²	B: Spatial Inefficiency	
BE - Radelfingen – 3 - Typology: Rural - Size: 0.057 km² - Buildings: 21 - Density: 369/km²	No problem identified	
BE - Schwanden bei Brienz – 16 - Typology: Intermediate - Size: 0.018 km² - Buildings: 28 - Density: 1570/km²	No problem identified	
BE - Täuffelen – 59 - Typology: Intermediate - Size: 0.050 km² - Buildings: 24 - Density: 481/km²	No problem identified	
BE - Vechigen – 220 - Typology: Urban - Size: 0.134 km² - Buildings: 1 - Density: 7/km²	A: Size & Workload	
BL - Oberdorf (BL) – 28 - Typology: Intermediate - Size: 0.014 km² - Buildings: 25 - Density: 1833/km²	No problem identified	
BL - Rümlingen – 19 - Typology: Rural - Size: 0.075 km² - Buildings: 7 - Density: 94/km²	A: Size & Workload	
FR - Neyruz (FR) – 30 - Typology: Intermediate - Size: 0.024 km² - Buildings: 23 - Density: 960/km²	No problem identified	
FR - Villars-sur-Glâne – 59 - Typology: Urban - Size: 0.036 km² - Buildings: 27 - Density: 755/km²	No problem identified	

Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
GE-Corsier (GE)-53 - Typology: Urban - Size: 0.002 km² - Buildings: 1 - Density: 425/km²	A: Size & Workload	
GE - Perly-Certoux – 14 - Typology: Urban - Size: 0.011 km² - Buildings: 13 - Density: 1199/km²	B: Spatial Inefficiency	
GR - Conters im Prättigau – 17 - Typology: Rural - Size: 0.243 km² - Buildings: 16 - Density: 66/km²	No problem identified	
GR - Fürstenau – 11 - Typology: Rural - Size: 0.004 km² - Buildings: 10 - Density: 2416/km²	B: Spatial Inefficiency	
GR - Sils im Domleschg – 21 - Typology: Rural - Size: 0.021 km² - Buildings: 20 - Density: 937/km²	No problem identified	
JU - Haute-Sorne – 15 - Typology: Intermediate - Size: 0.009 km² - Buildings: 14 - Density: 1550/km²	B: Spatial Inefficiency	
LU - Nebikon – 3 - Typology: Intermediate - Size: 0.023 km² - Buildings: 20 - Density: 858/km²	No problem identified	
LU - Oberkirch – 53 - Typology: Urban - Size: 0.116 km² - Buildings: 4 - Density: 34/km²	A: Size & Workload	
LU - Udligenswil – 30 - Typology: Intermediate - Size: 0.015 km² - Buildings: 15 - Density: 1029/km²	C: Boundary Incoherence	

Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
NE - La Chaux-de-Fonds – 12 - Typology: Urban - Size: 0.024 km² - Buildings: 26 - Density: 1074/km²	No problem identified	
NW - Ennetmoos – 51 - Typology: Rural - Size: 0.139 km² - Buildings: 18 - Density: 129/km²	No problem identified	
SG - Buchs (SG) -180 - Typology: Urban - Size: 0.078 km² - Buildings: 6 - Density: 77/km²	A: Size & Workload	
SO - Bettlach -65 - Typology: Urban - Size: 0.008 km² - Buildings: 11 - Density: 1295/km²	B: Spatial Inefficiency	
SO - Boningen – 6 - Typology: Rural - Size: 0.007 km² - Buildings: 10 - Density: 1447/km²	B: Spatial Inefficiency	
SO - Walterswil (SO) – 32 - Typology: Intermediate - Size: 0.311 km² - Buildings: 6 - Density: 19/km²	A: Size & Workload; B: Spatial Inefficiency; C: Boundary Incoherence	
TG - Bichelsee-Balterswil – 52 - Typology: Intermediate - Size: 0.128 km² - Buildings: 8 - Density: 63/km²	A: Size & Workload	
TG - Wäldi – 55 - Typology: Rural - Size: 0.020 km² - Buildings: 26 - Density: 1299/km²	No problem identified	
TI - Breggia – 50 - Typology: Intermediate - Size: 0.100 km² - Buildings: 31 - Density: 310/km²	A: Size & Workload; C: Boundary Incoherence	

Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
TI - Terre di Pedemonte – 80 - Typology: Intermediate - Size: 0.056 km² - Buildings: 13 - Density: 231/km²	No problem identified	
UR - Erstfeld – 129 - Typology: Intermediate - Size: 0.004 km² - Buildings: 1 - Density: 233/km²	A: Size & Workload	
UR - Flüelen – UR-Flüelen-80 - Typology: Urban - Size: 0.431 km² - Buildings: 1 - Density: 2/km²	A: Size & Workload; B: Spatial Inefficiency; C: Boundary Incoherence	
UR - Seedorf (UR) – 25 - Typology: Intermediate - Size: 0.030 km² - Buildings: 18 - Density: 595/km²	No problem identified	
VD - Cugy (VD) –45 - Typology: Urban - Size: 0.012 km² - Buildings: 13 - Density: 1056/km²	B: Spatial Inefficiency	
VD - Eclépens – 21 - Typology: Intermediate - Size: 0.128 km² - Buildings: 31 - Density: 243/km²	A: Size & Workload; B: Spatial Inefficiency	
VD - Ormont-Dessus – 58 - Typology: Rural - Size: 0.010 km² - Buildings: 14 - Density: 1439/km²	B: Spatial Inefficiency	
VD - Renens (VD) – 42 - Typology: Urban - Size: 0.011 km² - Buildings: 24 - Density: 2257/km²	No problem identified	
VD - Saint-Sulpice (VD) – 8 - Typology: Urban - Size: 0.060 km² - Buildings: 19 - Density: 315/km²	No problem identified	

Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
VS - Bourg-Saint-Pierre – 31 - Typology: Rural - Size: 0.035 km² - Buildings: 2 - Density: 57/km²	A: Size & Workload	
VS - Leytron – 87 - Typology: Intermediate - Size: 0.023 km² - Buildings: 20 - Density: 854/km²	No problem identified	
VS - Termen – 22 - Typology: Intermediate - Size: 0.004 km² - Buildings: 13 - Density: 3688/km²	B: Spatial Inefficiency	
VS - Val-d'Illiez – 122 - Typology: Rural - Size: 0.050 km² - Buildings: 3 - Density: 60/km²	A: Size & Workload; C: Boundary Incoherence	
ZH-Freinstein-Teufen-17 - Typology: Urban - Size: 0.018 km² - Buildings: 26 - Density: 1434/km²	No problem identified	
ZH - Illnau-Effretikon – 40 - Typology: Urban - Size: 0.024 km² - Buildings: 30 - Density: 1240/km²	C: Boundary Incoherence	
ZH - Oetwil an der Limmat – 35 - Typology: Urban - Size: 0.013 km² - Buildings: 12 - Density: 940/km²	B: Spatial Inefficiency	
ZH - Rüschlikon – 67 - Typology: Urban - Size: 0.016 km² - Buildings: 22 - Density: 1408/km²	No problem identified	
LI - Balzers – 100 - Typology: — - Size: 0.025 km² - Buildings: 17 - Density: 0/km²	Excluded (Liechtenstein)	

Sector	Problem Category	Screenshot QGIS (Scale: 1:2750)
LI - Triesen – 56 - Typology: — - Size: 0.014 km² - Buildings: 11 - Density: 0/km²	Excluded (Liechtenstein)	
LI - Vaduz – 48 - Typology: — - Size: 0.011 km² - Buildings: 9 - Density: 0/km²	Excluded (Liechtenstein)	

9. Personal Declaration

I hereby declare that the submitted thesis results from my own independent work. All external sources are explicitly acknowledged in the thesis. I further acknowledge that ChatGPT and Claude AI were utilized during the completion of this thesis to assist with grammar, syntax, and content refinement.

Michael Fehr, Zürich, 24.04.2026