Article

A Framework for Scaling Urban Transformative Resilience through Utilizing Volunteered Geographic Information

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Abstract: Resilience in the urban context can be described as a continuum of absorptive, adaptive, and transformative capacities. The need to move toward a sustainable future and bounce forward after any disruption has led recent urban resilience initiatives to engage with the concept of transformative resilience when and where conventional and top-down resilience initiatives are less likely to deliver effective strategies, plans, and implementable actions. Transformative resilience pathways emphasize the importance of reflexive governance, inclusive co-creation of knowledge, innovative and collaborative learning, and self-organizing processes. To support these transformative pathways, considering techno-social co-evolution and digital transformation, using new data sources such as Volunteered Geographic Information (VGI) and crowdsourcing are being promoted. However, a literature review on VGI and transformative resilience reveals that a comprehensive understanding of the complexities and capacities of utilizing VGI for transformative resilience is lacking. Therefore, based on a qualitative content analysis of available resources, this paper explores the key aspects of using VGI for transformative resilience and proposes a comprehensive framework structured around the identified legal, institutional, social, economic, and technical aspects to formalize the process of adopting VGI in transformative resilience initiatives.

1. Introduction

Global development agendas such as the 2030 Agenda for Sustainable Development (SDGs), the Sendai Framework, and the New Urban Agenda (NUA), as well as academic circles, have emphasized the importance of strengthening cities' resilience to disasters in light of the growing spectrum of risks stemming from climate change, natural hazards, and, more recently, pandemics [1–5]. However, a greater emphasis on disaster resilience requires a shift in focus from a command-and-control model to a more strategic, participatory, and dialogic model by promoting new and innovative technical and scientific methods through community and stakeholder collaboration processes [6,7].

The importance of building urban resilience by considering the important role of governance, people, and technology to tackle challenges and create solutions in a place-based, integrated, inclusive, risk-aware, and forward-looking manner has compelled recent urban resilience initiatives to focus on the concept of transformative resilience, especially when incremental adaptation and conventional resilience planning are insufficient [5,8–10]. Transformational approaches stress the role of citizen participation, techno-social co-evolution, and reflexive governance processes at supranational, national, and local levels [11–14].

To guide transformations and strengthen community resilience, not only should long-term guiding visions and strategies be outlined to improve qualities such as transparency, self-organization, flexibility, and the active role of citizens [15,16], but also, based on today's problems, the development of policies based on the open exchange and multi-level collaboration using digital technologies and data innovations such as Big Data and citizen-generated data should be promoted [4,17]. It is recommended that in the era of digital and data transformation, countries explore the added value of using other data, such as social sensing, crowdsourcing, and Volunteered Geographic Information (VGI), to improve their data capabilities through near-real-time access to geospatial information, leading to better-informed decisions to enable innovation in geospatial technology, improve the quality and applicability of disaster-related data, overcome institutional barriers, and increase community resilience by connecting people to geospatial information services [4,18–20].

It has been more than a decade since the author of [21] defined VGI as 'the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals'. Since then, VGI activities ranging from contributions to online crowdsourced mapping to location-related posts on social media contributions, along with digital transformation, have transformed the process of acquiring or providing geospatial data, largely influencing traditional authoritative systems and creating new forms of public engagement based on voluntary contributions [12,22–25]. VGI attributes, such as its timeliness-reflecting spatial dynamics [26], facilitating multidirectional communication, increasing situational awareness, and enabling collective intelligence, may outperform traditional geospatial datasets [22,27].

Thus, utilizing VGI in disaster resilience initiatives can not only help fill the gap in disaster-related geospatial data by engaging volunteers to co-create, curate, and disseminate free, up-to-date, and near-real-time geospatial information [22,28,29], but also create an opportunity for self-organization within the digital volunteer network and enabling remote citizens and volunteers to effectively and actively contribute to disaster resilience initiatives using their technical, local, and on-site knowledge [30–32]. Moreover, the use of such collaborative data ecosystems can play an important role either in improving the accessibility of geospatial information and related techno-social tools for all or in developing innovative, customized tools that lead to disaster risk reduction and community resilience [18,33].

Against this backdrop, while previous studies have discussed the opportunities and challenges associated with using VGI for disaster resilience, they have notably lacked conceptual framework underpinnings, leaving the overall picture of VGI for urban resilience unclear. Accordingly, this paper aims to address this gap and explore the various aspects of using VGI to facilitate and support transformative resilience. It also proposes a comprehensive framework that structures identified aspects to formalize the process of adopting VGI for transformative disaster resilience. In the remainder of this paper, Section 2 manifests the research background on transformative resilience. Section 3 presents the research methodology used in this study. Sections 4 and 5 discuss in detail the various aspects of using VGI for transformative resilience. Section 6 presents a comprehensive framework for leveraging VGI to facilitate transformative resilience. Finally, the key challenges and limitations associated with VGI-based initiatives, as well as the agenda for future research directions and conclusions, are drawn in Sections 7 and 8, respectively.

2. Transformative Urban Resilience

Resilience in the urban context can be seen as the continuum of (1) the capability of cities and regions to withstand change and bounce back to a previous state (absorptive capacity—short-term), (2) adapt to change and reorganize without altering existing structures (adaptive capacity—medium-term), and (3) transform through learning, self-organization, and exploring new ways along with flexibility and considerable changes in existing structure (transformative capacity—long-term) [9,34–37].

Although embedding a resilience narrative is context-dependent, recent literature on urban resilience questions the effectiveness of existing resilience practices and emphasizes the importance of transformative capacity, rather than relying solely on incremental and absorptive coping capacities [8–10,35]. As new crises of unforeseeable nature, e.g., extreme floods and pandemics, are likely to emerge more frequently, transformation measures can strengthen people and mobilize the creativity and devotion needed for dealing with the crisis [38].

Transformation requires cross-scale awareness and incentives for change and can also improve absorptive and adaptive capacity [39]. Thus, collaborative urban experiments are needed to guide transition pathways by establishing reflexive governance approaches and flexible institutional settings, in which a given problem is jointly perceived and collective visions and missions are developed. In such a setting, resilience strategies are goal-oriented and interactive, policies are legitimized based on collective rationalities, foresight exercises and transdisciplinary research are conducted, and hybrid decision making and planning are employed [9,11,18,34,40,41]. This can lead to enabling collaborative learning and being dynamic to absorb, adapt, transform, and evolve in the face of changes and uncertainties [42–44].

Furthermore, transformative resilience is characterized by system-wide, fundamental, and long-term changes that challenge conventional approaches and aim to deliver innovative, forward-looking, and multiscale approaches based on a common purpose and ensuring new paradigms in thinking, acting, and self-organizing to evolve toward new norms, forms, and functions to achieve sustainability and resilience [9,12,13,34,36,45–47].

The availability and redundancy of resources and services through the use of new data sources (crowdsourcing, open data science, etc.) and the mobilization of cutting-edge technologies, such as the Internet of Things (IoT), Machine Learning (ML), and Digital Twins, to name a few, ensures the creation of backups and the diversification of services and processes through the creation of alternatives based on a system-wide or cross-system perspective, which ultimately contributes to a better urban analysis and informed decision making to improve resilience in the urban context [18,48,49].

Transformative resilience emphasizes the importance of the co-creation of knowledge and collaboration among stakeholders (actors, communities, and citizens), urban systems (housing, transportation, infrastructure, etc.), and institutions before, during, and after a disaster by considering socio-technological acceptability and socioeconomic affordability [10,11]. To scale transformation in resilience governance, planning, and practice, collaboration needs transparency and openness among public institutions, the private sector, and academia. Moreover, to enable meaningful participation, multidirectional communication, and sharing of resilience knowledge, citizen-centric initiatives that include individuals, civic organizations, and relevant communities are required [48,50–54]. These key characteristics of urban resilience that contribute to scaling transformation are detailed in Figure 1.
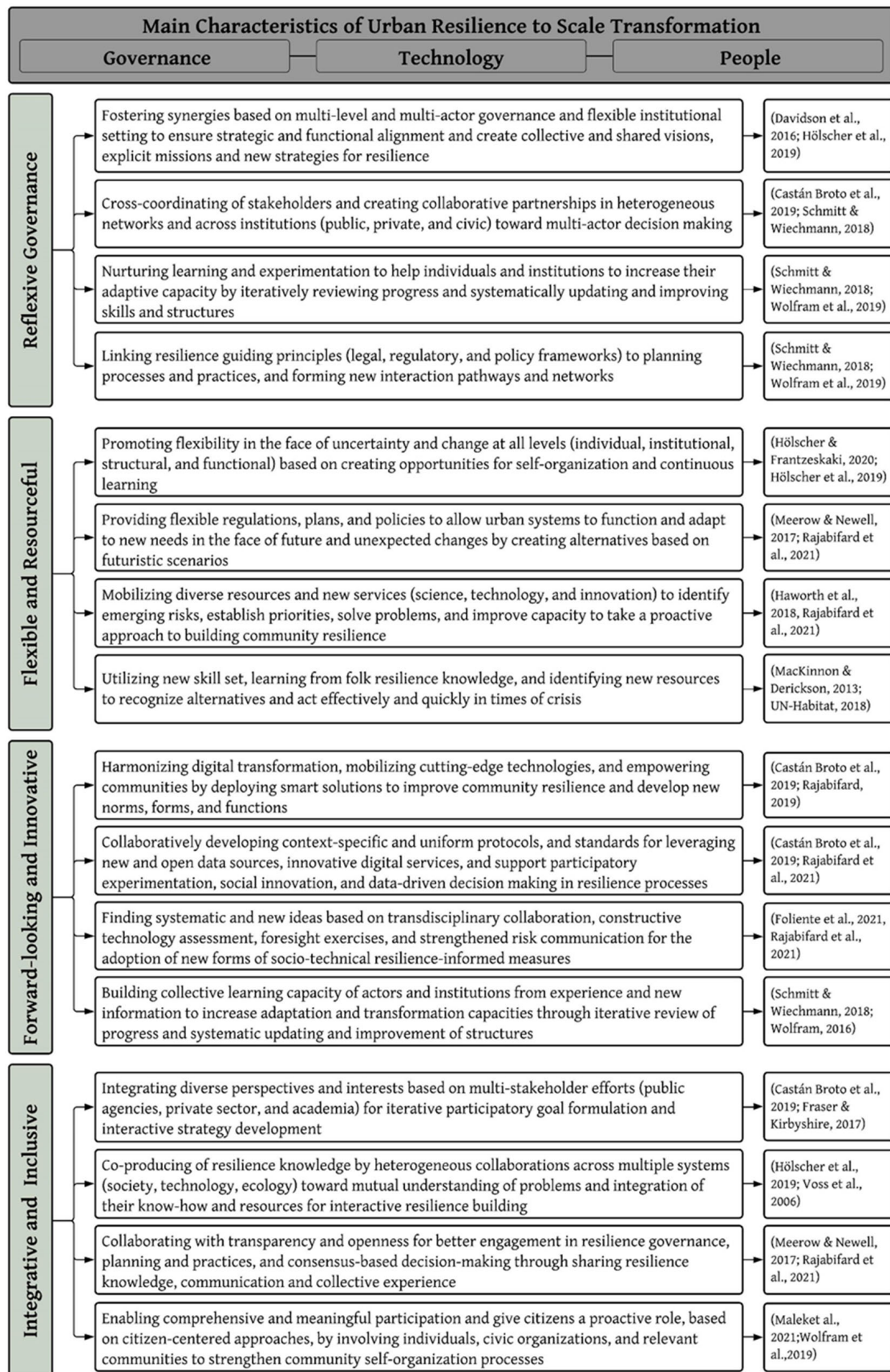
Main Characteristics of Urban Resilience to Scale Transformation

Governance	Technology	People

Reflexive Governance

Characteristic	Reference
Fostering synergies based on multi-level and multi-actor governance and flexible institutional setting to ensure strategic and functional alignment and create collective and shared visions, explicit missions and new strategies for resilience	(Davidson et al., 2016; Hölscher et al., 2019)
Cross-coordinating of stakeholders and creating collaborative partnerships in heterogeneous networks and across institutions (public, private, and civic) toward multi-actor decision making	(Castán Broto et al., 2019; Schmitt & Wiechmann, 2018)
Nurturing learning and experimentation to help individuals and institutions to increase their adaptive capacity by iteratively reviewing progress and systematically updating and improving skills and structures	(Schmitt & Wiechmann, 2018; Wolfram et al., 2019)
Linking resilience guiding principles (legal, regulatory, and policy frameworks) to planning processes and practices, and forming new interaction pathways and networks	(Schmitt & Wiechmann, 2018; Wolfram et al., 2019)

Flexible and Resourceful

Characteristic	Reference
Promoting flexibility in the face of uncertainty and change at all levels (individual, institutional, structural, and functional) based on creating opportunities for self-organization and continuous learning	(Hölscher & Frantzeskaki, 2020; Hölscher et al., 2019)
Providing flexible regulations, plans, and policies to allow urban systems to function and adapt to new needs in the face of future and unexpected changes by creating alternatives based on futuristic scenarios	(Meerow & Newell, 2017; Rajabifard et al., 2021)
Mobilizing diverse resources and new services (science, technology, and innovation) to identify emerging risks, establish priorities, solve problems, and improve capacity to take a proactive approach to building community resilience	(Haworth et al., 2018, Rajabifard et al., 2021)
Utilizing new skill set, learning from folk resilience knowledge, and identifying new resources to recognize alternatives and act effectively and quickly in times of crisis	(MacKinnon & Derickson, 2013; UN-Habitat, 2018)

Forward-looking and Innovative

Characteristic	Reference
Harmonizing digital transformation, mobilizing cutting-edge technologies, and empowering communities by deploying smart solutions to improve community resilience and develop new norms, forms, and functions	(Castán Broto et al., 2019; Rajabifard, 2019)
Collaboratively developing context-specific and uniform protocols, and standards for leveraging new and open data sources, innovative digital services, and support participatory experimentation, social innovation, and data-driven decision making in resilience processes	(Castán Broto et al., 2019; Rajabifard et al., 2021)
Finding systematic and new ideas based on transdisciplinary collaboration, constructive technology assessment, foresight exercises, and strengthened risk communication for the adoption of new forms of socio-technical resilience-informed measures	(Foliente et al., 2021, Rajabifard et al., 2021)
Building collective learning capacity of actors and institutions from experience and new information to increase adaptation and transformation capacities through iterative review of progress and systematic updating and improvement of structures	(Schmitt & Wiechmann, 2018; Wolfram, 2016)

Integrative and Inclusive

Characteristic	Reference
Integrating diverse perspectives and interests based on multi-stakeholder efforts (public agencies, private sector, and academia) for iterative participatory goal formulation and interactive strategy development	(Castán Broto et al., 2019; Fraser & Kirbyshire, 2017)
Co-producing of resilience knowledge by heterogeneous collaborations across multiple systems (society, technology, ecology) toward mutual understanding of problems and integration of their know-how and resources for interactive resilience building	(Hölscher et al., 2019; Voss et al., 2006)
Collaborating with transparency and openness for better engagement in resilience governance, planning and practices, and consensus-based decision-making through sharing resilience knowledge, communication and collective experience	(Meerow & Newell, 2017; Rajabifard et al., 2021)
Enabling comprehensive and meaningful participation and give citizens a proactive role, based on citizen-centered approaches, by involving individuals, civic organizations, and relevant communities to strengthen community self-organization processes	(Malek et al., 2021; Wolfram et al., 2019)

Figure 1. Key characteristics of urban resilience that scale transformation.

3. Research Methodology

As mentioned earlier, the use of VGI for transformative resilience encompasses multiple aspects and involves multidisciplinary bodies of knowledge. Therefore, any attempt to employ VGI toward transformative resilience requires a basic understanding of the VGI aspects in line with the characteristics of transformative resilience. The following main steps were thus taken to establish a conceptual framework. In the first phase, to select our primary studies, we applied the search string ('Volunteered Geographic Information and 'disaster resilience' and 'transformation') to Google Scholar, Web of Science, and Scopus) to search for studies published since 2010, when [55] discussed the topic of VGI for disaster resilience as a frontier area for research, to May 2021. The choice of the search strings was due to our goal of obtaining studies in the field of disaster resilience, and not in other fields applying VGI, such as location-based services for routing and navigating. Studies were selected based on three inclusion criteria: (i) the article matches the keywords, (ii) the article discusses a type of transformation that VGI and crowdsourcing have caused, and (iii) the article discusses the added value and constraints of VGI in disaster resilience. As exclusion criteria, we discarded articles that only mentioned the VGI itself used for the study (e.g., OSM or Tweeter) but did not refer to any aspect of VGI that contributes to the transformative processes in disaster resilience. Excluding conference papers, a total of 82 relevant studies were selected from 414 hits for review. The publications were generally included or excluded by reading the titles and then the abstracts when more detailed decisions had to be made.

The second phase was to identify and extract concepts in the review of previous studies. Therefore, the 'Concept Matrix' method was used as a systematic concept-centric technique for the qualitative and content analysis of available resources to synthesize the literature [56,57]. The concept matrix helps identify opportunities for synthesis that can provide a comprehensive understanding of a topic revealed by overlapping statements in individual sources [58]. To develop the concept matrix, the references were listed in the left column of the matrix, while the title of each column represents the identified concepts in the literature. The identified concepts were coded (first cycle coding) using the inductive coding method, which develops progressively during analyzing the dataset without having the prior coding system and is usually influenced by the research questions [59]. Whenever a new concept was found, another column was added to the matrix. In this case, the discussed concepts in prior studies were recorded in a concept matrix, which then enabled all studies to be comparatively analyzed [60]. This technique is generally appropriate for identifying the themes and underlying concepts in previous relevant research [61].

The third phase consisted of organizing and grouping the concepts and their relationships by pattern coding (second cycle coding) according to their characteristics, assumptions, and highlighted themes based on the authors' scientific and conceptual reasoning [58,59]. Conceptualization is an iterative process, and a well-designed concept matrix can facilitate the process of coding the concepts and classifying them. To this end, another dimension was added to the concept matrix to handle the unit of analysis by grouping the concepts under major aspects and to enable schematic higher-order themes for building the synthesis framework [57,61]. This helps summarize the material from the first cycle coding into meaningful and manageable units of analysis and create a cognitive map, an evolving, integrated scheme for understanding interactions [59].

As [62] articulated, 'a conceptual framework explains, either graphically or in narrative form, the main things to be studied—the key factors, concepts, or variables—and the presumed relationships among them' (p. 18). The fourth phase, therefore, was to conceptualize the role of VGI in transformative resilience by synthesizing the identified concepts and their relationships and proposing a synthesis framework. Figure 2 shows the research process overview.
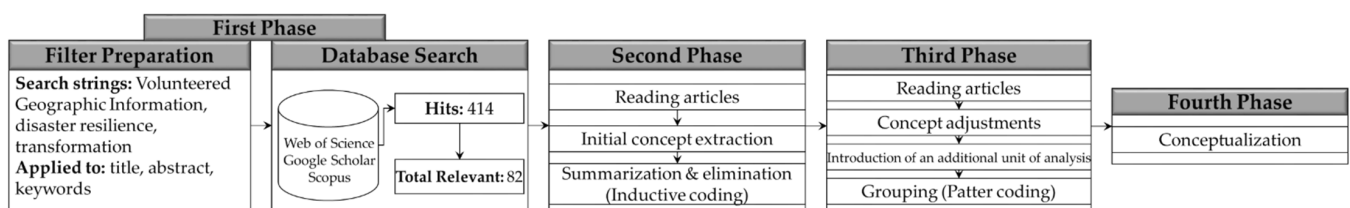
Figure 2. Research process overview.

4. VGI for Urban Transformative Resilience

Transformative approaches to urban resilience advocate creating and embedding innovations and novelties in governance, planning performance, and techno-social and technical exercises [18]. The logic is to endorse forward-looking decision making and predispose decision makers to adopt new ways of doing, thinking, and organizing [9]. Therefore, as promoted in international development agendas, measures need to be developed based on the open exchange and collaboration at multiple levels that leverage rapid communication, sustainable geospatial information systems, and geospatial technology innovations with near real-time access to geospatial information to improve the overall resilience of communities to disasters [1,2,4,19].

Profound transformations related to extensions of geospatial technologies based on new data sources through Digital Twins (a real-time digital representation of the physical world), Web 2.0, advances in G5 and mobile communications, blockchain, Big Data, volunteer crowdsourcing, digital volunteering, IoT, georeferencing, and geotagging have forced urban resilience processes to rethink several core concepts and methods they have relied on and to effectively use technological capabilities to proactively reshape crisis management, planning, and practices [12,17,18,21,63,64].

Data-enabled transformation pathways (data usage, data circulation, and data generation) of information, open and efficient exchange of geospatial information with advanced tools, and better urban analytics and simulations can greatly improve decision-making capabilities based on near-real-time information, reduce disaster impact, and enhance community resilience in the short, medium, and long term [17,48,65,66]. In this context, VGI offers alternatives and complementary opportunities to collect, share, and use geospatial data across different geographic and administrative scales that are otherwise extremely difficult and costly to collect [67] and provides near real-time, affordable, up-to-date, flexible, and fit-for-purpose geospatial information and supports the limited geospatial data infrastructures [22,68].

Transformative urban resilience promotes mechanisms with better and open access to spatial and risk-related information that enables better communication, knowledge sharing, and collaboration in decision-making processes across scales, actors, and citizens to foster synergies and minimize conflict [9,50]. The VGI process involves the use of modern information technologies and tools to create, organize, and disseminate geographic data, particularly in map-making, and are voluntarily developed and made available on the Web by individuals and non-formal institutions [69–72]. Figure 3 provides a schematic representation of the drivers and outcomes of transformative resilience regarding the capacities associated with VGI.
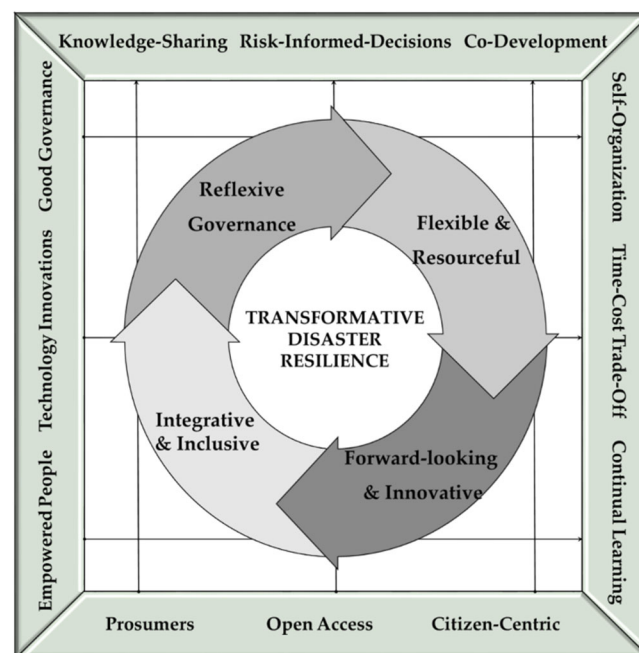
Figure 3. Drivers and outcomes of transformative resilience regarding VGI capacities.

The most successful example of VGI to date is OpenStreetMap (OSM), a citizen-driven initiative to create an open digital map of the world by digital and on-site volunteers that rivals many authoritative datasets in its richness and timeliness [73,74]. OSM has more than 6.2 million registered users and more than 6.4 billion features stored on the OSM platform [23]. Another example is Humanitarian OpenStreetMap (HOT), a volunteer-based group that applies the principles of open source and open data sharing to humanitarian aid and community development based on VGI and OSM, activates OSM mappers for crisis response or crisis mapping, and facilitates volunteer efforts by providing a tasking function; the HOT Tasking Manager [29]. Nevertheless, there is an emerged potential entry point for transformation, and that is through the integration of a collective community conscience via citizen-generated crowdsourced data to authoritative data [14,75]. Smarter management (collecting, sharing, updating, and using) of information, open and efficient exchanging of geospatial information with advanced tools, and better urban analytics and simulation to improve the ability to make real-time decisions, reducing the impact of disasters and enhance community resilience in the short, medium, and long term [48,66,76,77]. Since VGI is a multifaceted phenomenon, the next section explains the various factors or concepts that are critical to a deeper understanding of the extent to which VGI contributes to transformative resilience.

5. Toward Transformative Resilience—Main Aspects of Utilizing VGI

Based on the Concept Matrix developed (Section 4), 18 core VGI concepts related to urban resilience were identified (Figure 4). These concepts were presented in at least one of the resources, albeit in varying degrees of comprehensiveness and emphasis. To enable conceptual scaffolding, five main categories—social, economic, technical, institutional, and legal—were exploited to reflect the dimensions of utilizing VGI toward transformative urban resilience. The following subsections discuss each of these aspects and their contribution to transformative urban resilience.

Aspects of Volunteered Geographic Information

Social Aspects
- Inclusion and engaging mechanism
- Crowds' characteristics, motivations & contribution patterns
- Capacity to self-organization and self-assessment
- Information & communication

Economic Aspects
- Prosumers
- Open up data
- Collaborative Commons & Co-management
- Time-cost trade-offs

Legal Aspects
- Liability & licensing
- Standards & policies
- Non-sensitive data catalog

Institutional Aspects
- Systems, agents, and institutions interactions
- Culture of collaboration and collective actions
- Contributors' roles and devolution of power

Technical Aspects
- Data architecture
- Data principles
- Hybrid epistemologies and data conflation
- Tools, platforms and procedures

Figure 4. Core identified aspects of VGI.

5.1. Social Aspects

VGI introduces new social practices, projects, and processes whose success is driven by citizen contributions. Unlike conventionally produced forms of geographic information, volunteer efforts have added several different axes to structuring and representing geographic knowledge, producing and validating knowledge, and changing power relations [21,69]. Therefore, in this subsection, we intend to foreground the social aspects of VGI.

5.1.1. Inclusion and Engagement Mechanism

The bottom-up potential of VGI processes and practices raises questions about who is included or excluded in VGI practices (creating, using, or sharing information), why, and the extent to which they can reflect their knowledge [69]. Therefore, a participatory mechanism that is compatible with local characteristics, norms, and cultures can promote public participation and citizen engagement and help express local experiential knowledge [22]. Mapathons (community mapping events) are an example of how an engaging mechanism with a flexible structure through public calls can engage participants (e.g., citizens, youth mappers, or students) in mapping exercises and bring together a group of interested and motivated volunteers to collaboratively create, curate, and disseminate free and up-to-date spatial information, e.g., in disaster response activities [28,33,78]. This engagement mechanism not only provides volunteers with the opportunity to contribute to society based on collective action but also to learn new technologies through the use of web-based mapping [79,80].

5.1.2. Crowds Characteristics, Motivations, and Contribution Patterns

VGI is part of a profound shift in the way geospatial data are produced and disseminated by changing the roles associated with the creation and use of digital geospatial data [81]. VGI can be operated by a range of participants with different levels of expertise, experience and activeness, numbers, and responsibilities [72,82]. Motivations for contributing also vary from constructive and altruistic motivations (social reward, personal reputation, professional interest, making money, sense of community, instrumentality,

and skill development) [21,69] to harmful contributions (massive or partial deletions and misinformation) [72,83]. Understanding crowd characteristics and formulating motivational strategies would therefore influence the outcomes of the VGI-based initiative [84–86]. Because the crowd is a relative term, contribution patterns, types, and roles of the crowd involved in the task may vary concerning the goals and roadmap of the initiative and need to be determined at an early stage [87–89].

5.1.3. Capacity to Self-Organization and Self-Assessment

The proactive role of citizens, community-led organizations, and e-participation intervention through digital technologies can illuminate the rise of self-organizing capacity in VGI-based communities [51,69]. Self-organization is a capability in which reorganization is endogenous, not forced by external factors, and enables novel self-assessment and reflexivity to facilitate innovative problem solving based on collective intelligence [90–92]. VGI, through collective technologies, actions, and tasks, empowers volunteers to self-organize and share information and resources to respond to disasters in a timely, responsive, and effective manner [22,93,94]. Through self-organizing community platforms (e.g., OSM, HOT, Missing Maps, etc., local communities, remote and distant volunteer networks can facilitate mutual self-organizing activities by collecting, validating, analyzing, and disseminating information before, during, and after a disaster, catalyzing a people-centered humanitarian approach that was long overdue [29,33,90].

5.1.4. Information and Communication

According to [95], disaster resilience initiatives typically have two types of communication paradigms for disseminating information: one-to-many and many-to-many. The former uses a top-down approach from one sender to a multitude of receivers (radio, television, and the Internet), while the latter uses a decentralized architecture to disseminate information among a multitude of transmitters and receivers by using services such as social media platforms, collaborative disaster mapping based on crowdsourcing, and social sensing. Therefore, innovative technologies based on new data sources, including VGI, are needed for integrated and flexible communication and an information system that enables multidirectional dialog among agencies, communities, and affected people [27,96]. VGI can make disaster-related information available to all in the cloud in near real-time for early warning of adverse events, within hours during and after a disaster, and for the early organization of spontaneous digital and non-digital volunteers after a disaster [27,55].

5.2. Economic Aspects

VGI and its mode of production provide open, timely, and freely accessible geospatial data that can be used in proactive disaster resilience initiatives to reduce disaster-related costs through better analysis, preparedness, effective risk communication, and economic value creation for the community [97]. This subsection examines the related economic aspect of VGI.

5.2.1. Prosumers

'Prosumers' (a portmanteau of provider and consumer) are consumers who have become their own producers through commons-based peer production in which large numbers of people work cooperatively over the Internet [98]. VGI and its associated processes, therefore, enable citizens or remote volunteers to actively contribute as prosumers to the production of geospatial content based on their individual or community needs and to use the produced data for their advantage [99]. This can be seen as an important innovation that combines sociotechnical practices and power relations supported by the so-called 'sharing economy' as a socioeconomic system based on sharing goods, skills, and services [30]. This brings prosumers together to collaboratively produce and use geospatial data in general and disaster-related geospatial data in particular. This enables better access to and use

of information in near real-time and minimizes waste of resources due to duplication of effort [87].

5.2.2. Open Up Data

Creating an open data ecosystem for cities and resilience initiatives can facilitate innovation and data-driven disaster risk management [49]. The open-source data movement in principle enables any prosumer to educate, learn, and engage in information communities by exchanging know-how and expertise via Web 2.0 tools and platforms with varying levels of education, knowledge, and skills [30,100]. Unlike authoritative data, VGI can be collected, shared, used, and reused under an open-access license without technical limitations. This enables innovative and unrestricted reuse of data across sectors, leading to prosperity and better analysis at lower data-related costs [28,101,102]. The use of VGI-based platforms (e.g., OSM, OSMWiki, etc.), software and applications (e.g., InaSAFE, GeoNode, Open Data for Resilience Index, etc.), and open dashboards (e.g., Building Information Platform Against Disaster for Decision Making in Federal Nepal) that bring together a variety of data for disaster risk management can increase the prosperity of the scholars and citizens cooperating with the local government dealing with disaster risk management in a timely and efficient manner [76,103,104].

5.2.3. Collaborative Commons and Co-Management

A new economic paradigm—Collaborative Commons—is transforming the way humanity lives based on IoT, which facilitates collaboration to drive the social economy, optimize lateral peer production, promote universal access to information, and innovative and inclusive approaches by fostering the culture of sharing [98]. VGI as peer production of geospatial data can therefore increase productivity and connectivity through better access to timely data through the way it is produced and shared, based on user needs, backgrounds, and goals through collaborative engagement [105,106]. Co-management and co-production of knowledge (sharing power and responsibility between government and local resource users) [107] in VGI-based practices for disaster resilience can also bridge the data-related divide between different sectors and individuals from the local to the international level to generate and mobilize jointly produced geospatial data and knowledge and enable learning through uncertainty using a collaborative platform [30,97,108,109].

5.2.4. Time–cost Trade-Offs

Harnessing the power of today's communication technologies, prosumers share their location-based knowledge, goods, and services at lower marginal costs [98]. In the context of disaster resilience, VGI enables the faster sharing of diverse disaster-related geographic information at a fraction of the cost associated with traditional data collection and dissemination [63]. Internet facilitation enables agencies and citizens to collaborate, collect, and disseminate large amounts of geospatial data in near real-time through digital and on-site volunteers by reducing the limitations associated with traditional approaches, such as high costs and slow access to near real-time data [68,109]. In addition, new data and technologies (crowdsourcing, digital volunteering, mobile communications, etc.) that enable real-time dynamic monitoring, multidirectional communication, and situational awareness can advance urban disaster resilience initiatives and overcome traditional, outdated, and costly methods. [27].

5.3. Technical Aspects

Decision makers and citizens increasingly require high-resolution data, both temporal and spatial, for successful disaster resilience initiatives. The large-scale and timely observations are, therefore, unique advantages that can be provided by VGI [63,74]. This subsection examines the technical aspects of VGI to highlight the opportunities and challenges associated with utilizing such data.

5.3.1. Data Principles

Access to open, free, and high-quality datasets (e.g., accurate, relevant, complete, reliable, and timely data) is necessary for efficient, inclusive, and innovative resilience planning [20,102,110,111]. In the field of VGI, the issue of quality is challenging because the method of data collection deviates from the strict official data collection frameworks [112]. Several research studies assess the quality of VGI based on the aforementioned elements (see, [33,110,112–116]. However, VGI provides inherent quality assurance due to the 'power of crowd' principle known as Linus's Law and can provide accurate and trustworthy information [117]. Ensuring data accuracy (e.g., positional, thematic, semantic accuracy, and topological consistency) in VGI-based resilience initiatives is critical and should reflect a real-world situation considering time-critical situations [84,118].

Data relevance comes into play when irrelevant data collection should be avoided and a fit-for-purpose approach to data collection and integration should be considered [68]. Data completeness is an essential component of data quality and is closely related to validity and accuracy. For example, in map-based VGI, statistics on the number of objects, attributes, and values can be tracked to measure the degree of completeness or the percentage of missing data in a region [84,119]. Reliability also means that the user has access to the maximum amount of information with the best possible timeliness [120]. Data timeliness shows how accessible and up-to-date the information is, leading to better analysis and decision making without wasting time in time-critical situations. The experience of OSM Haiti showed that volunteers who collaborated around OSM could quickly create accurate and trusted information when institutional data were lacking in time-sensitive situations [65,121]. Moreover, VGI has the potential to be a timely source for disaster preparedness and early warning [31,84,122]. An example is the Open Cities project by OpenDRI in Sri Lanka, in which crowdsourced VGI data and tools were adopted to collect useful data for risk preparedness and exposure mapping [100].

5.3.2. Data Architecture

Data architecture is the process that governs and standardizes how organizations collect, assess, create, validate, consolidate, distribute, and use data by conceptualizing, contextualizing, and modeling data [70]. Therefore, a systematic approach to creating, curating, analyzing, and using VGI to improve urban resilience must be employed by relative institutions or foundations guiding contributors to completing the tasks [123]. Since VGI often lacks standard metadata due to a lack of quality control in data-collection processes [87], establishing a practical and consistent guideline for data architecture based on project goals can be instrumental in developing a common operating picture for all stakeholders and contributors [113].

5.3.3. Hybrid Epistemologies and Data Conflation

The authors of [124] discussed that VGI is itself a socially constructed epistemology based on the embedding of a labor relationship (volunteers as free laborers), a reference relationship (experts versus amateurs), and a governance relationship (volunteers as citizens) and must be treated independently. In addition to traditional authoritative data, which are typically associated with high costs, outdated data, and restrictive licensing terms for urban resilience initiatives, VGI can be considered a complementary and important source that can be integrated with authoritative datasets [112,125]. Although there are fundamental epistemological differences between VGI and authoritative data (existing levels of expert oversight, standards, and the inherent heterogeneity of VGI), organizations can leverage VGI based on their goals within a formalized process for data collection and multi-level collaboration when they have clear requirements, such as a faster update cycle, capturing additional or real-time attribute information, engaging the community, or reducing the cost of geospatial data acquiring [20,81]. A shift toward hybrid epistemologies and data conflation processes based on situating and adopting VGI by governments may provide an opportunity for data-driven decision making [23,87,126].

5.3.4. Tools, Platforms, and Procedures

Location-based and GPS-based services (e.g., maps, social media applications, tracking, and information services) for disaster information and resilience, as well as open-source tools for realistic natural hazard impact scenario building for better planning, preparedness, and response, can collect information from users and then provide them with actionable information, often through a map interface [74]. Several methods support the collection and dissemination of geospatial data by volunteers, e.g., OSM, WikiMapia, Geo-Wiki, documentation websites (e.g., Siteleaf), HOT's Tasking Manager (campaigning, data creation, and validation), scanning by drone and 3D laser, and smartphones (e.g., MapSwipe app) (e.g., MapSwipe App) [18,63,68,111,127]. Crisis or resilience dashboards and urban digital twin platforms can also serve as platforms to aggregate multiple data from different data sources (e.g., social sensing, weather, road traffic, pollution, etc.) to provide real-time information to citizens and improve transparency, efficiency, and resilience [103,128]. Required practices, such as managing a Mapathon (open digital community mapping) using the Missing Maps planning checklist, and developing workflows, roadmaps, frameworks, and catalogs for fit-for-purpose data collection, will ensure the contextualizing process of resilience improvement based on goals, local values, facts, and needs [29,101,129].

5.4. Institutional Aspects

The institutional structure has a direct impact on the availability and accessibility of geospatial data and can significantly hinder or facilitate the process of geospatial data collection, usage, and sharing [130]. Institutional arrangements as a link between agents and systems can determine the extent of collaboration in decision making and collective learning [131]. Since the VGI paradigm may create a new relationship between governments and citizens and motivate citizens to actively contribute to disaster resilience initiatives [22], the corresponding components of the institutional aspects of VGI are discussed in the following subsections.

5.4.1. Systems, Agents and Institutions Interactions

Urban resilience functionality is characterized by dynamic interactions among urban systems (e.g., built environment, critical infrastructure, and essential services), agents (people and organizations), and institutions (e.g., policies, laws, social norms, etc.) that connect systems and actors and mediate their interactions [35,132]. The use of VGI can be adopted based on the definition of an institution with specific rules and regulations compatible with desired structures or formalities [32]. However, the VGI structure can influence institutional mechanisms that have evolved across spatial, temporal, and sectoral boundaries, strengthening collaboration among different stakeholders and creating a new relationship between systems and actors through the provision and application of new geospatial knowledge [22,69,88,125].

5.4.2. Culture of Collaboration and Collective Actions

Collaborative disaster resilience planning requires collective efforts from multiple government agencies, nongovernmental organizations, the private sector, communities, and civil society [22,125]. Therefore, sufficient information flow with transparency, accountability, and responsiveness plays an important role. VGI and related technologies can be used to engage relevant institutions and citizens to disseminate and use collective geographic data toward collaborative resilience building. Collective action requires time and resources. Institutions and agencies must be prepared to strategically engage and manage dynamic information flow and ideas from citizens and other institutions [74,133].

5.4.3. Contributors' Roles and Devolution of Power

Urban resilience governance and planning in many countries is top-down and sector-based. However, governance systems (i.e., the process of decision making) are likely to be collaborative, participatory, and inclusive to enhance community resilience [134].

The emergence of VGI potentially challenges traditional institutional forms of disaster management. Crowdsourcing processes are defined by [135] defined as 'the process by which the power of the many can be leveraged to accomplish feats that were once the province of a specialized few' (p. 56). VGI not only enabled the active contributions of individuals but also offered new norms and forms in information conditions as well as power relations at all levels that can lead to integrating authoritative epistemologies with a more open and local representation through an appropriate collaboration mode [69,125,136]. However, there is an ongoing debate about the level of authorities' involvement and enforcement of regulations, the scope, structure, and outcomes of VGI projects that are mainly citizen-led initiatives [67,81].

5.5. Legal Aspects

The legal aspects of VGI are complex, as legislation typically lags behind technological advances and often varies across countries and between citizens, national mapping agencies, and commercial companies [74]. Legal concerns are likely when using VGI in official systems. The compilation methods of VGI are very different from those of structured datasets, and although there may be restrictions on their integration in official databases, VGI can contribute to the enhancement of place-based knowledge without incurring legal consequences [68]. In this sense, platform operators, users, and contributors of VGI must all be attentive to the legal issues that may be triggered by their activities [137]. In this subsection, we highlight some of the key issues related to VGI in the context of urban resilience.

5.5.1. Liability and Licensing

The main problem related to liability is who is responsible and under what conditions when socioeconomic losses occur or wrong decisions are made. However, under the VGI model, VGI contributors cannot be held legally responsible for their contributions [24]. Therefore, disclaimers or data quality notices are necessary to limit potential liability [137]. In addition, VGI initiatives should establish procedures and develop protocols to deal with insufficient quality when providing information about legal disclaimers or licensing agreements [68].

Part of the motivation for developing VGI was to provide data that were voluntarily generated and could be used relatively free of licensing restrictions due to the lack of access to costly authoritative datasets [24]. Since different forms of licensing and terms of use may limit the ability to use such information in the case of the need to merge datasets with different licensing strategies, possible integration scenarios can be defined by stakeholders [74]. Moreover, VGI does not have legal status in many countries. Therefore, the legal implications for volunteers and project developers should be clarified, as the data-collection process for VGI is different from formal datasets [68].

5.5.2. Standards and Policies

Open source and user-generated geospatial content and its foundations (such as the Open Source Geospatial Foundation) are expected to grow at both the national and international levels (the Open Geospatial Consortium and the International Organization for Standardization) [70,138]. In this sense, the creation and development of new legal frameworks, guidelines, and open standards for different VGI platforms or tools seems necessary. This will not only lead to the facilitation of interoperability and data exchange but also to the protection of the integrity and objectivity of these data to prevent the emergence of data-related risks and mitigate existing ones [138]. Standard models for linking administrative datasets to other datasets or for data exchange on the Web to integrate VGI into spatial data infrastructures based on paradigms such as the Linked Data paradigm [139] also need to be developed [23,25].

Furthermore, the necessary policies should be defined at different governance levels, such as an Open Data policy and an integrated data and service sharing policy, to increase

the chance of a functioning system for resilience initiatives that build on technology, community engagement, and a smart governance structure while reducing the potential impact of using VGI in decision making [20,25,74].

5.5.3. Non-Sensitive Data Catalog

According to the Sendai Framework, it is important to make non-sensitive disaster-related information publicly usable and freely available based on open exchange for successful disaster risk communication, mitigation, and prevention following national laws. The sensitivity of the information, whether it is commercially, socially, culturally, or technically sensitive, is a legal issue for governments [77]. Therefore, data collection in VGI-based initiatives requires operational strategies or protocols for the intended purpose, formulation of the plan, and implementation of a project according to a country's national policy [32,68]. The critical step is to define a fit-for-purpose approach to geospatial data collection that is flexible, inclusive, participatory, affordable, reliable, achievable, and extensible [140,141]. The design of the data catalog also requires close collaboration among working groups to define its architecture based on a low-risk, high-benefit approach in an iterative process that requires upfront legal, ethical, and technical research at the local level to capture non-sensitive information and preserve the privacy and security of disaster-prone communities [22,65].

5.6. Main Lessons Learned from VGI Practices

Some of the key lessons learned from VGI-based disaster risk management initiatives include the following: Coordination among participating organizations and volunteers is essential to take full advantage of human resources and technical innovations and to avoid duplication of data and waste of resources; government and community cultural conditions must be known to choose an appropriate approach; the process is best kept at the community and local levels to ensure sustainable curation; it is crucial to have a transparent and flexible stakeholder mapping and data model that can be easily adapted to community needs, available tools, and resources; consensus building among those who need and control data and appropriate development of open data policies can address legal and regulatory issues; concerns about the quality of datasets generated can be addressed through quality control and a progressive process of data improvement [18,30,49].

6. A Framework to Leverage VGI toward Transformative Urban Resilience

This section proposes a synthesis framework (Figure 5) developed based on the key aspects outlined in Section 5. The framework was designed using a combination of current literature and resources obtained from previous studies. A conceptual framework is a tool that contains a set of logical building blocks and their interconnections [62]. Thus, the proposed conceptual framework is not just a collection of aspects but rather a construct in which each aspect has an integral effect on utilizing VGI, as described below. Likely, clarifying the various aspects in the form of a conceptual framework could support the potential process of employing VGI in transformative disaster-resilience initiatives within three main phases (columns), namely resourceful planning and creative data collection, cooperative design and forward-looking analysis, and generation of added value and collective learning. Legal, institutional, technical, and socioeconomic aspects of VGI are shown in different colors (rows).
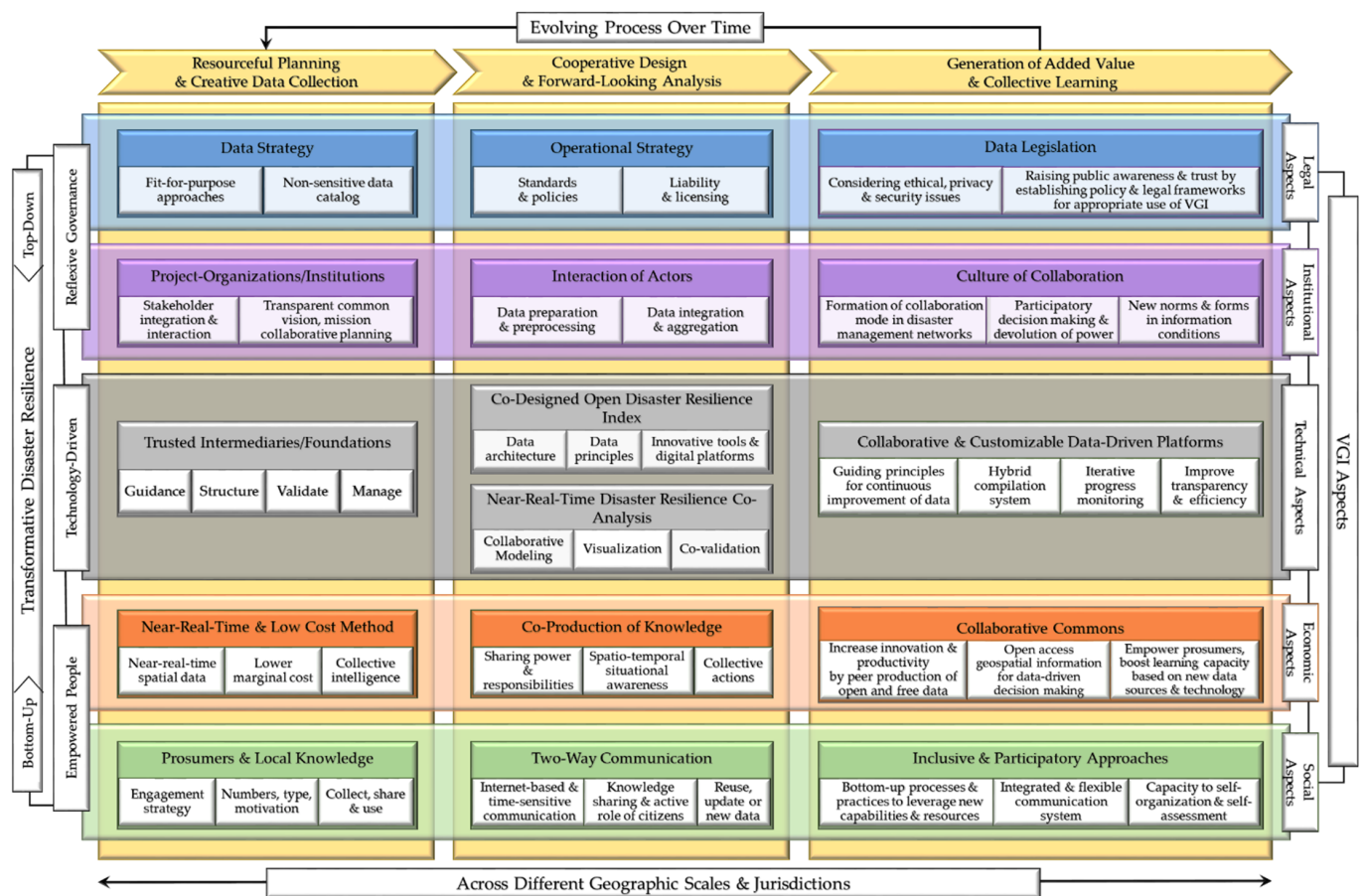
Figure 5. A framework for leveraging VGI toward urban transformative resilience.

From a bottom-up perspective, legal and institutional issues can enable or hinder a VGI-based project. Therefore, as part of a reflexive governance approach, project organizations or institutions in the planning and data collection phases should consider developing operational protocols based on a fit-for-purpose approach to collecting non-sensitive data while considering the data policies and regulations of the relevant jurisdiction. This requires an interactive, inclusive, and multiscale process of establishing shared visions, missions, and practices about what they want to achieve and how. The co-design and co-analysis phase should consider legal obligations for managing VGI, linking or integrating that into administrative datasets for liability and licensing arrangements, and revising them as needed by adopting open-source data policies, standards, and licensing strategies considering privacy, security, and ethical issues. Developing new data legislation and increasing public awareness and trust for the appropriate use of VGI can be achieved through collective and cumulative learning processes.

Since building community resilience depends on empowering people and considering bottom-up approaches, it is important to develop a mechanism that encourages citizen participation. Prosumers' and citizens' contribution is the most important part of any VGI initiative because of its bottom-up structure and socioeconomic aspects. The engagement mechanism in any VGI initiative depends on the goals of the project and should focus on encouraging the type of crowd that is more likely to make effective contributions (collecting, sharing, updating, and reporting the required geospatial data). However, in general, this enables leveraging new capacities and resources and developing their self-organization capacities through collaborative learning and work within a flexible communication system over open Web-based platforms across all sectors. By facilitating the Internet, agencies and citizens can collaborate and disseminate large amounts of geospatial data in near real-time and at a lower cost. This enables rapid access to location-based data, time-sensitive two-

way communication, co-production of location-based knowledge, situational awareness, collective action, and collaborative coordination in the context of transformative resilience. Thus, value is added by enabling prosumers and citizens to increase their learning capacities based on new data and technologies and digitalization for productivity and growth.

Reflexive governance cannot be achieved without empowered people, and technology-enabled approaches can act as facilitators in this regard. Technology and data innovations contribute to transformative resilience in the face of uncertainties associated with disasters. Trusted intermediaries or foundations (e.g., OSM, HOT, etc.) provide guidance (e.g., learning guides and community events such as Mapathons) and structure (mapping, tagging, labeling, etc.) to volunteers, and validate and manage collected data through systematic approaches on existing or newly developed platforms and have better overall quality control. Efficient, inclusive, and innovative resilience planning requires access to high-quality and timely data sets (e.g., accurate, relevant, complete, reliable, and timely data). Therefore, defining a practical and unified data architecture and catalog based on the project goals for co-designing an open resilience index is necessary to develop a common operating picture for creating, curating, analyzing, using, and sharing information among stakeholders and systems. Innovative tools and methodologies (e.g., IoT, ML, Digital Twin, etc.) can be applied to VGI to enable collaborative modeling, real-time analysis, co-validation, and better visualizations. This facilitates innovative problem solving based on collective intelligence and may overcome the potential spatial and temporal limitations of traditional approaches. The added value of such an approach could be a collaborative and adaptive hybrid data-driven ecosystem that enables continuous improvement of geospatial data (leveraging the power of traditional knowledge systems and citizen science), iterative progress monitoring of disaster resilience dynamics, and improved transparency and efficiency among institutions, agencies, and the public, as well as informed decision making.

The framework proposed in this study should therefore be considered as a guide for researchers and practitioners on how VGI can be implemented in disaster resilience initiatives, taking into account a comprehensive understanding of the complexities and interconnections of legal, institutional, technical, economic, and social aspects within each jurisdiction. Indeed, a shared understanding of the benefits of emerging trends in geospatial data, smart technologies, and spatial analytics using new data and tools can bring government, industry, and communities together to effectively build sustainable and resilient communities.

7. Key Challenges and Limitations

VGI-based initiatives may offer many opportunities to contribute to transformative pathways to disaster resilience, but they also present a number of challenges. In this study, the concerns and challenges associated with using VGI for transformative resilience are structured around the five thematic aspects discussed in Section 5.

With legislation typically lagging behind technological developments, VGI presents numerous challenges to existing legal and policy structures related to spatial data, information, and maps. There are limitations on its adoption in official databases in various jurisdictions. Therefore, the formation and development of new legal frameworks, policies, and open standards for open-source and user-generated spatial data content and foundations must be considered at all governance levels and researched further to ensure the integrity and objectivity of this data and prevent the emergence of risks or mitigate existing risks.

The institutional structure has a direct impact on the availability and accessibility of geospatial data and can significantly hinder or facilitate the process of collecting, using, and sharing geospatial data. In most jurisdictions, governments play a central role in urban resilience practices, and professionals within organizations have primary responsibility for geospatial data collection and maintenance. However, a VGI paradigm would suggest a new relationship between governments and citizens that may be challenging for national institutional structures that are not linked to local and community processes. Therefore,

the level of interest and active participation of government agencies, as well as regulatory enforcement, may affect the progress and outcome of VGI-based initiatives and may slow down the creativity and innovation of VGI projects.

From a technical perspective, the emergence of VGI as Big Data has exponentially increased the volume, velocity, and variety of geospatial data generated, and the coupling with geosocial applications has led to a fundamental shift in how these data are maintained, stored, processed, and used [142,143]. This includes the search for appropriate synthesis methods, the integration and use of these data along with government-managed geospatial data for urban disaster resilience, and the need for new tools for data management, curation, and analysis [143,144]. In addition, VGI may also present obstacles in terms of reliability, validity, and intrinsic and extrinsic quality of data and metadata [143]. Therefore, based on the project goals, it is necessary to develop a data protocol between the involved actors and systems to overcome these limitations.

On the socioeconomic side, issues such as local differences, the extent of community acceptance of technology, the digital divide, marginalization of certain groups, openness to digitization, reliance on digital data collection devices, privacy concerns, and ethical issues in collecting and publishing VGI in practice need to be considered and should be further explored in future studies. Other important concerns include capacity building and resource allocation, increased trust in data and transparency, and collaborative decision making and coordination at the local level that need to be addressed in VGI-based practices.

Although the comprehensive framework proposed in this study attempts to provide an overall picture of VGI capacity for transformative resilience while addressing the complex issues that are considered missing knowledge in the field of urban resilience, the rapid advances in technology, society, and digital innovation as influential drivers may influence the direction of future research and provide opportunities to refine and expand the framework. In addition, we recognize that the application of the framework will also be an opportunity for further study and is a limitation of this study, as it is beyond the scope of a single study.

8. Conclusions

Transformative resilience aims to achieve reflexive governance with empowered people, using technology-enabled approaches as facilitators. This article, therefore, considers the key characteristics of transformative resilience to explore the various aspects of VGI for strengthening community resilience in the face of disasters and to fill the knowledge gap in the two areas. Qualitative analysis of available resources led to the identification of 18 key VGI concepts in the categories of legal, institutional, social, economic, and technical, providing a multifaceted view of VGI adaptation for transformative resilience. To develop a deeper understanding of how VGI can be considered in research and practice, the framework was proposed to provide a comprehensive foundation as a guide for VGI-based initiatives with a broader consideration of socioeconomic, techno-social, legal, and institutional issues. Indeed, building upon our framework with its flexibility, future research can explore new aspects of VGI in light of new insights and learning through resilience processes while addressing the relevant challenges.

VGI-based models can be considered either as stand-alone or complementary mechanisms when and where conventional approaches are less suited to foster collective community resilience or culture of collaboration, and administrative datasets are less appropriate for providing open, accessible, and timely geospatial information to both the community and decision makers. Given the increasing access to VGI and related technologies, it is timely to assess their opportunities, challenges, and effectiveness through comprehensive empirical studies at multiple scales and contexts in future research and practical projects to effectively incorporate VGI into resilience transformation processes.

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