Review

Modelling, Measuring, and Visualising Community Resilience: A Systematic Review

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Abstract: The concept of community resilience receives much attention in studies and applications due to its ability to provide preparedness against hazards, to protect our life against risks, and to recover to stable living conditions. Nevertheless, community resilience is complex, contextual, multifaceted, and therefore hard to define, recognise, and operationalise. An essential advantage of having a complete process for community resilience is the capacity to be aware of and respond appropriately in times of adversity. A three-step process constituting of modelling, measurement, and visualisation is crucial to determine components, to assess value, and to represent information of community resilience, respectively. The goal of this review is to offer a general overview of multiple perspectives for modelling, measuring, and visualising community resilience derived from related and emerging studies, projects, and tools. By engaging throughout the entire process, which involves three sequential steps as we mentioned above, communities can discover important components of resilience, optimise available local and natural resources, and mitigate the impact of impairments effectively and efficiently. To this end, we conduct a systematic review of 77 different literature records published from 2000 to 2020, concentrating on five research questions. We believe that researchers, practitioners, and policymakers can utilise this paper as a potential reference and a starting point to surpass current hindrances as well as to sharpen their future research directions.

Keywords: community resilience; systematic overview; resilience modelling; knowledge representation; resilience assessment; information visualisation

1. Introduction

The word resilience originally stems from the Latin term "resiliere" that means to jump back or bounce back. The first careful consideration of the term resilience arose in the field of mechanics in 1858, followed by psychology in the 1950s, human ecology in the 1990s, and ending up with disaster risk reduction and climate change adaptation in the 2000s [1]. Resilience concentrates on improving the capacity of a system in the face of multiple hazards, rather than precluding or diminishing the loss of assets because of specified events. Resilience accepts the condition that a wide range of disruptive events—both stresses and shocks—may take place but are not inevitably foreseeable. This research topic has received significant interest from not only researchers but also practitioners and service-users. Recognising the importance of resilience, many definitions at multiple domains have been offered, as shown in Figure 1, including physical [2,3], social [4,5], ecological [6–8], economic [9], individual [10,11], and community [12,13]. According to mentioned literature, there is no commonly accepted way to define the concept of resilience formally; besides, several definitions are even overlapping with existing concepts [14], some of which are robustness, fault-tolerance, flexibility, survivability, and agility.

As the formal definition given by the United Nations Office for Disaster Risk Reduction (UNDRR), resilience is "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner [15]", in not only pre- but also post-disaster. During pre-disaster, we aim at anticipating vulnerabilities and risks proactively to mitigate harmful effects. On the other hand, the capability of valid and sufficient recovery is an essential objective in the post-disaster period [16]. Studies about resilience can help our societies in reducing disaster risk, adapting to climate changes, and coming up with strategies to develop more sustainably and efficiently.

Figure 1. Multiple domains of resilience.

In this paper, we focus on giving an overview of multiple perspectives regarding community resilience. Community resilience aims at representing the abilities of a local community as a complex system, including actions and interactions of local agencies, natural and built environments, critical infrastructures, and citizens, to reduce, withstand, and even turn back from impacts of hazards, as well as the competence to adapt and thrive themselves to be less vulnerable to future disasters and emergencies. There are more and more studies concentrating on building community resilience across various application domains (e.g., tourism [17], biodiversity management [18], energy [19], and mental health [20]) in either global [21] or regional levels, some of which are Brazil [22], Greece [23], and the United Kingdom [24]. Nonetheless, this research field still needs many efforts from researchers and practitioners to come up with comprehensive methodologies to model, measure, and understand community resilience. These three mandatory phases can support communities in proposing additional activities and new approaches to the comprehension of how to ensure that our communities can be better prepared, more flexible, and have the ability to bounce back promptly from an event, whatever form it may take.

Our motivation is to provide crucial knowledge regarding multiple methods for modelling, measuring, and visualising community resilience in this paper. For coming up with optimal decision-making criteria and strategies to make our communities resilient, we should focus on the entire process—all of these three phases. In particular, we address various components and properties to model community resilience; different qualitative, quantitative, and hybrid approaches for measuring resilience value; and several visualisation methods at the end to show resilience-related information. We believe that this paper can support not only academic researchers but also practitioners in recognising what frameworks are already out there and how we can build on them.

In this section, we introduced the problem and emphasised our motivation for conducting this review. The rest of this paper includes the following structure. In the next section, the necessary background will be given. Section 3 will provide vital information about the materials and methods to conduct this review. Further, Section 4 summarises different methodologies for modelling community resilience. Then, we will describe qualitative, quantitative, and hybrid approaches to

measure community resilience in Section 5. Section 6 will provide various visualisation techniques for representing resilience information. Finally, we will give some discussion, draw essential conclusions, and express future directions in the last section.

2. Background

Community resilience is a complicated concept that cannot be captured and turned into explicit knowledge effortlessly. What is generally accepted among researchers is the fact that community resilience tremendously depends on multiple components that affect and influence the overall resilience of a community [25]. Such elements can be related to particular risks, temporal and spatial contexts, and community features that resilience refers to (e.g., perception, hazards, and capacities). Even more complex, the term community resilience also has diverse meanings between communities by referring to different components of the community, including, but not limited to, the resilience of community infrastructure [26] and the resilience of social relationships [27]. Hence, it is necessary to identify, define, and describe the particular components and properties of community resilience in the process of modelling.

Based on components and properties defined in the modelling step, we can apply qualitative, quantitative, or hybrid methodologies to translate resilience dimensions, indicators, and proxies into tractable and understandable frameworks, expressions, formulations, or values. The target of qualitative methods is to provide detailed descriptions depending on specific contexts. To enable the ability to understand and transfer results, experts account for their viewpoints and perspectives [28] through case studies, grounded theories, interviews, ethnography, phenomenology, and hermeneutics [29]. It is ordinary to represent qualitative results as charts, diagrams, and other graphics by using visualisation methods. On the other hand, we measure quantitative value by paying attention to community resilience at a particular time point or by comparing resilience value before and after an event [30]. Generally, the community resilience value is appropriate for internal use. To compare a community with others, we may use their rank or percentile equivalent of the community resilience value; however, we have to ensure that the measurements should be taken in similar contexts. Our data should be comparable, comprehensible, measurable, and relevant [21] so that it is suitable for quantitative methodologies. Further, hybrid approaches are the integration of quantitative and qualitative methods; therefore, they can estimate both tangible and intangible value of community resilience.

Visualisation is the final puzzle piece to complete a big-picture of community resilience. In emergencies, especially in situations requiring immediate actions, we may face a massive amount of community resilience information. Visualisation is an effective and efficient solution that has the capacity to represent resilience-related information of communities in systematic forms without missing essential details [31]. We can also utilise information visualisation to discover latent patterns, which are arduous to recognise manually [32]. Additionally, emerging digital visualisation tools can involve end-users in many interactions (e.g., zooming in or out, employing dynamic charts, and changing visual appearances such as colours and shapes). With the support of disruptive technologies (e.g., machine learning and artificial intelligence) [33], we can leverage information visualisation to build recommender systems and dashboards for potential use in emergencies, disasters, and catastrophes as well.

3. Methodological Approach

This section describes in detail how we identify relevant and credible literature addressing resilience at different community levels. In the following sections, common themes are determined and summarised to generate insights into community resilience. The interest of this review is to find and evaluate studies, projects, and tools that draw upon new solutions for communities to model, measure, and visualise resilience.

3.1. Research Question

There is a need for a more transparent analytical overview and a selection of the studies, projects, and tools most relevant to what we can focus on in more detail. The results of this review will summarise and discuss the following research questions. Generally, different communities could benefit from this paper's much more comprehensive overview of:

1.　What resilience studies, projects, and tools at community-based levels already exist?
2.　What types of threats, hazards, shocks, disasters, etc. do they face?
3.　What and how many resilience components and properties do they define?
4.　How do they measure community resilience—i.e., using more qualitative evidence, quantitative indicators, or a combination of the two?
5.　What are the appropriate visualisation techniques to express community resilience information?

We conduct this review study to fulfil the information required by communities in both static and dynamic phases. In the static phase, our target is to define what we have and what we suffer from. On the other hand, we aim at understanding whether those variables represent objects or contexts that we can work towards in the dynamic phase.

3.2. Search Strategy

Concerning geographic-based communities and resilience, the concept of community resilience may contain two proxies which are urban and rural resilience [34]. Urban resilience puts more focus on the ability of cities or urban systems to rebound from destruction [35], whereas rural resilience aims to conserve a satisfactory standard of living in rural areas [36]. For the sake of generalisation, we take into account studies, projects, and tools related to not only community resilience but also urban and rural resilience. We started this work by searching the published articles on Google Scholar, Scopus, Web of Science, and ScienceDirect, which are not limited to particular disciplines, using text strings "community resilience", "urban resilience", "rural resilience", "resilience assessment", and "resilience visualisation" and their combinations. Meanwhile, the systematic search of relevant projects and tools is conducted on Google search engine. We also check the reference lists of the selected articles to discover additional related work. Supplementary data sources involve our pre-existing knowledge of the literature.

3.3. Eligibility Criteria and Selection Process

To be included in this review, the inclusion criteria established that the literature must adhere to the following rules. No restrictions are imposed with regards to the time or country of publication.

- Focusing on modelling, measuring, or visualising community, urban, or rural resilience.
- Having full-text publications or descriptions.
- Publishing in the English language.

On the contrary, we define the exclusion criteria used to filter literature that is not relevant for this study as follows.

- The literature is a letter, thesis, dissertation, or conference abstract.
- The literature is not related to defined research questions.

After screening the data, full-text documents are collected to extract necessary study-specific parameters (e.g., type of resilience at community-based levels, number of resilience components, methodologies to assess resilience, and techniques for representing resilience information) for further analysis. Upon our search using the search strategy and inclusion criteria devised, we identify 77 studies, projects, and tools in the last 20 years, from 2000 to 2020, for inclusion in this review, as shown in Table 1.

Table 1. Resilience studies, projects, and tools at community-based levels.

Level	Study/Project/Tool	Focus
Rural	Community Resilience Manual [37]	Community resources
	Insurance for Rural Resilience and Economic Development (INSURED) [38]	Climate risks
	MIME Project [39]	Pre-hospital emergencies
	McManus et al. [40]	Local economy, job, and environment
	Ross and Clay [41]	Capital assets
	Rural Coastal Community Resilience (RCCR) Framework [42]	Sea level rise and saltwater intrusion
	Rural Diversity Index (RDI) [43]	Rural diversity
	Rural Resilience Framework [44]	Climate change
	Rural Social Protection [45]	Risks and threats
	Steiner and Atterton [46]	Private sector enterprises
	Withdrawal Mechanism for Rural Homesteads (WMRH) [47]	Land use policies
	Woolvin [48]	Family estates
Urban	City Resilience Framework [49]	Stresses accumulate and sudden shocks
	City Resilience Roadmap [50]	Acute shocks and long-term stresses
	Coastal Megacity Resilience Simulator (CMRS) [51]	Climate change
	Disaster Resilience Index (DRI) [52]	Urban flood
	Disaster Resilience Indicators [53]	Disasters
	Disaster Resilience Scorecard for Cities [54]	Acute shocks (natural and man-made)
	emBRACE Framework [55]	Disasters
	European Resilience Management Guideline (ERMG) [56]	Climate change and social dynamics
	FEW-Nexus City Index [57]	Food, energy, and water
	Flood Resilience Index (FRI) [58]	Flood
	Foundational Infrastructure Framework (FIF) [59]	Infrastructure sectors
	Grosvenor Research [60]	Shocks and adverse events
	ICLEI ACCCRN Process (IAP) [61]	Climate risks
	Maturity Model (MM) [62]	City stakeholders
	Porębska et al. [63]	Evacuation route planning and design
	RESCCUE Project [64]	Multihazard threats and climate change
	Resilience City Planning Framework (RCPF) [65]	Climate change and environmental risk
	Resilience Diagnostic Tool [66]	Urban planning
	Resiliency Cube [67]	Transportation network in earthquake
	Risk Management Index (RMI) [68]	Urban disasters
	TURaS Project [69]	Urban planning and policy
	Urban Resilience Concept Note [70]	Shocks and stresses
	Urban Resilience Index [71]	Urban social-ecological systems
	Urban Resilience Framework [72]	Heterogeneous risk factors
Community	Analysis of Resilience of Communities to Disasters (ARC-D) Toolkit [73]	Disasters
	Australian Natural Disaster Resilience Index [74]	Hot-spots of high or low disasters
	Baseline Resilience Indicators for Communities (BRIC) [75]	Disasters
	Bay Localize Community Resilience Toolkit [76]	Community assets
	Chandra et al. [77]	National health security
	Climate-related Disaster Community Resilience Framework (CDCRF) [78]	Climate-related disasters
	Community Advancing Resilience Toolkit (CART) [79]	All-hazards environment
	Community And Regional Resilience Initiative (CARRI) Research Report [80]	Natural and human-made disasters
	Community Based Resilience Analysis (CoBRA) [81]	Crises and disasters
	Community Disaster Resilience Index (CDRI) [82,83]	Disasters

Table 1. *Cont.*

Level	Study/Project/Tool	Focus
Community	Community Disaster Resilience Toolkit [84]	Disasters
	Community Resilience Framework (CRDSA) [85,86]	Disasters
	Community Resilience Index [87]	Natural hazards
	Community Resilience System (CRS) [88,89]	Man-made and natural disasters
	Community Self-Assessment [90]	Disasters
	Conjoint Community Resilience Assessment Measurement (CCRAM) [91]	Emergencies
	Costs, Opportunities, Benefits, and Risks Analysis (COBRA) Framework [92]	E-government services
	Disaster Resilience of Place (DROP) Model [93]	Natural disasters
	Flood Resilience Measurement for Communities (FRMC) [94]	Flood
	Framework for Community Resilience (FCR) [95]	Disasters, crises, shocks and stresses
	IMPROVER Project [96]	Critical infrastructure
	Jordan and Javernick-Will [97]	Disasters
	Localized Disaster-Resilience Index [98]	Disasters
	Moreno et al. [99]	Tsunami
	Natural Hazard Resilience Screening Index (NaHRSI) [100]	Natural hazard events
	Pilquimán-Vera et al. [101]	Community based tourism
	PEOPLES Resilience Framework [102]	Extreme events or disasters
	POP-ALERT Project [103]	Crises and cross-border disasters
	Rabinovich et al. [104]	Soil erosion
	Rahman and Kausel [105]	Tsunami
	RELi Resilience Action List & Credit Catalog [106]	Next generation community
	Resilience Matrix (RM) [107]	Disruptive events in coastal areas
	Resilience Modelling Tool [108]	Natural hazards
	School-Community Collaborative Network (SCCN) Conceptual Model [109]	Disaster education
	Sherrieb et al. [110]	Economic development and social capital
	Shesh Kanta Kafle [111]	Disasters
	Tool for Health and Resilience in Vulnerable Environments (THRIVE) [112]	Health, safety, and health equity
	Uddin et al. [113]	Cyclone and storm surge disasters

4. Modelling Community Resilience

Determining and defining community resilience's components and properties is an essential step for further developing clear strategies and undertaking practical activities to attain resilience in our community. This section presents different studies that have been conducted to achieve a better understanding and clarification of the community resilience through modelling step.

4.1. Defining Key Components

Although the importance of modelling resilience is widely recognised and researched, proposing an appropriate number of resilience components is still a significant challenge. Researchers find out that short-term human memory works best when we have fewer elements to remember. People are usually good at remembering no more than seven different components [114]. The community resilience, therefore, almost encompasses from three to seven components. Noting that in most studies, the order of components does not reflect their importance.

Table 2 presents different studies, projects, and tools arranged by the number of components, their focuses, and years of publication. We use the year of publication instead of the year of study as it is relatively more accessible.

Table 2. Summary of community resilience components along with focuses and years of publication.

Number of Components	Focus	Year	Reference
Three components	Acute shocks (natural and man-made)	2017	[54]
	Climate-related disasters	2012	[78]
	Community based tourism	2020	[101]
	Disasters	2017	[55]
	Economic development and social capital	2010	[110]
	Food, energy, and water	2018	[57]
	Health, safety, and health equity	2004	[112]
	Local economy, job, and environment	2012	[40]
	Private sector enterprises	2015	[46]
	Risks and threats	2020	[45]
	Urban planning and policy	2016	[69]
Four components	Acute shocks and long-term stresses	2019	[50]
	All-hazards environment	2013	[79]
	Community resources	2000	[37]
	Disasters	2010	[82]
		2013	[97]
		2014	[84]
	Family estates	2013	[48]
	Land use policies	2018	[47]
	Man-made and natural disasters	2014	[88]
	Natural hazards	2015	[108]
	Next generation community	2014	[106]
	Rural diversity	2014	[43]
	Stresses accumulate and sudden shocks	2015	[49]
Five components	Climate change	2013	[51]
	Disasters	2010	[53]
	Flood	2016	[58]
		2019	[94]
	Sea level rise and saltwater intrusion	2017	[42]
	Soil erosion	2019	[104]
Six components	Community assets	2009	[76]
	Critical infrastructure	2018	[96]
	Disasters	2014	[75]
		2015	[85,86]
		2016	[83]
	Disasters, crises, shocks and stresses	2014	[95]
	Emergencies	2013	[91]
	Natural disasters	2008	[93]
	Urban flood	2019	[52]
Seven components	Disasters	2010	[90]
		2013	[98]
	Extreme events or disasters	2016	[102]

Table 2. *Cont.*

Number of Components	Focus	Year	Reference
More than seven components	Cyclone and storm surge disasters	2020	[113]
	Disasters	2020	[73]
	Hot-spots of high or low disasters	2016	[74]
	Infrastructure sectors	2017	[59]
	Man-made and natural disasters	2013	[89]
	National health security	2011	[77]
	Shocks and adverse events	2014	[60]
	Tsunami	2013	[105]

Figure 2 shows a diagram including nodes and edges, which represent resilience components and their relations based on the literature in Table 2, respectively. A connection exists among two components in case they co-occur in a model. For example, economy and institution are two of five indices defined in [53]; hence, there exists a relationship among these two nodes. Besides, the size of a node depicts the frequency of this component in the literature (i.e., a bigger node points out that this component appears more times than smaller ones). We may recognise from Figure 2 that society, economy, community, physical, resource, and infrastructure are mostly defined in different models.

Figure 2. Community resilience components and their relations.

4.1.1. Less than Five Components

In [55], the emBRACE framework proposes the three community resilience domains, including resource and capacity, action, and learning followed by 17 different resilience indicators. Due to the nonstraightforward allocation property, a defined indicator can fit in not only one but also many dimensions. In addition, focusing on three components for modelling resilience [110], the authors build and verify the correlations of indicators through using the Mississippi county data. The combination of the refined indicators belongs to three community resilience components, which are economic development, social capital, and an additive index of community resilience. Meanwhile, in [112], the THRIVE tool of the Prevention Institute represents community resilience with three interconnected clusters, which are (i) social-cultural environment (people), (ii) physical/built environment (place), and (iii) economic/educational environment (equitable opportunity). This tool guarantees community resilience by increasing the quality of life and handling the biased distribution of health-related resources. Furthermore, social, economic, and environmental components are highly targeted and focused in [40,45,46].

Instead of using three components, the Community Disaster Resilience Framework (CDRF) addresses four different capital assets of a community comprising social, economic, physical, and human capital [82]. Similarly, Jordan and Javernick-Will [97] proposed four recovery indicators that are categorised as social, economic, environmental, and infrastructural. In addition, focusing on social and economic components, together with natural and institutional ones, the RDI [43] provides a better understanding of the connection between diversity in socio-ecological systems and its resilience. In [106], the C3 Living Design Project proposes a comprehensive action list, which can guide actions for a resilience present and future of communities, buildings, homes, and infrastructure, consisting of CV (community cohesion, social, and economic vitality), PH (productivity, health, and diversity), EW (energy, water, and food), and MA (material and artefact). In addition, Huang et al. [47] develop the assessment index system including four components, which are engineering, ecological, economic and social, to assess the changes in rural resilience.

Apart from that, the authors in [79] refer to community capacity and competence-based studies in social psychology and public health to develop the Communities Advancing Resilience Toolkit (CART). The CART describes four overlapping and interrelated domains of community resilience including (i) connection and caring, (ii) resource, (iii) transformative potential, and (iv) disaster management. A community with higher capability in these four defined domains can be more successful in reducing the harmful effects of disasters and other related difficulties. In a different approach [37], the Canadian Centre for Community Renewal (CCCR) focuses on people, organisation, resource, and community process. Among four dimensions, the people and organisation represent attitudes and behaviours of a community; the resource depicts awareness and use; and the community process portrays strategic thinking, participation, and action. These dimensions are further separated into 23 characteristics of resilience. In addition to the studies mentioned above, the authors in [84,115] model the community resilience with community connectedness, risk and vulnerability, available resources, and planning and procedures, which are logically overlapping and able to interact with each other. This demonstrates the equivalence among domains in constructing community resilience towards multiple disasters.

4.1.2. From Five to Seven Components

By applying a five-components approach, the Zurich Flood Resilience Alliance (ZFRA) models community resilience with five capitals comprising human, social, physical, financial, and natural [94]. These five capitals can assist people in their development as well as enhance the ability to cope with and make a response to various flood-related shocks. Following [51], Simonovic and Peck propose the quantitative resilience framework, which combines economic, social, organisational, health and physical impacts, for dealing with climate change on coastal megacities. In [53], the authors propose five indices, which are social, economic, institutional, infrastructure, and community capacities,

to examine community-level resilience. With baseline conditions defined in this study, the authors can not only keep track of changes of resilience at a specific time in a particular place but also compare resilience among locations. The studies in [52,75] are similar; however, the authors extend their model by supplementing one more index that is the environmental capacity.

The similar idea can be found in [95] in which the International Federation of Red Cross and Red Crescent Societies (IFRC) describes six resilience indicators to fortifying community resilience including knowledge and health, society, infrastructure and service, economy, natural asset, and connectivity. These indicators are designed to effectively and efficiently support three critical constituents of the Framework for Community Resilience (FCR) that are (i) assisting communities towards risks promptly and proposing solutions to portray underlying vulnerabilities comprehensively, (ii) placing people and their demands in the centre, and (iii) being retrievable by people at anytime and anywhere. According to [96], The IMPROVER project provides physical, social, human, natural, economic, and institutional capitals as six crucial components along with the IMPROVER Societal Resilience Analysis (ISRA) (for qualitative measuring indicators) to self-assess and guarantee community resilience. In [76], the Bay Localize constructs the community resilience toolkit concentrating on six key components being composed of food, water, energy, transportation and housing, jobs and economy, and civic services. This toolkit is beneficial in helping communities facing risks and hazards in the area of climate change and peak oil. Following Alshehri et al. [85,86], the authors discuss social, economic, physical and environmental, governance, health and well-being, and information and communication dimensions. The featured contribution of these two studies is that the authors discovered the correlation between the six identified dimensions and 62 criteria (i.e., from seven to fourteen criteria connect to every dimension). In [83], Yoon et al. build a set of indicators to measure community disaster resilience index utilising human, social, economic, institutional, physical, and environmental factors that are related to vulnerability and capacity aspects of South Korea.

Concerning seven dimensions depicting community functionality, the PEOPLES framework is constructed in [102] to represent population and demographic, environmental and ecosystem, organised governmental services, physical infrastructure, lifestyle and community competence, economic development, and social-cultural capital. This framework can promote the empowerment of local planners, decision-makers, and stakeholders to evaluate and improve their community resilience in different temporal-spatial contexts.

4.1.3. More than Seven Components

There are not many studies which are conducted in terms of using more than seven components. In [74], the authors leverage the top-down approach to put forward eight different indices for consideration, which are clustered into (i) coping capacity (i.e., social character, economic capital, infrastructure and planning, emergency services, community capital, and information and engagement) and (ii) adaptive capacity (i.e., governance, policy and leadership and community and social engagement). Along with each index is a set of measurable indicators. Hence, we can use either one number or sets of numbers to represent a resilience index in this study. Further, Barkham et al. [60] propose ten key components classified into two distinct themes that are vulnerability and adaptive capacity. The vulnerability includes climate, environment, resource, infrastructure, and community; whereas the adaptive capacity is made up of governance, institution, technical and learning, planning systems, and funding structures. Concerning this approach, a community is resilient in case it possesses low vulnerability and high adaptive capacity. In [89], the Community and Regional Resilience Institute (CARRI) defines Community Service Areas (CSAs) to support communities in realising strengths and shortages of resilience. The CSAs include 18 different aspects, some of which are communications, education, energy, and water, for improving community life and function together.

4.2. Determining Community Resilience Properties

Due to the diversity of definitions of community resilience and their components as we stated in the previous section, the properties of community resilience are therefore divergent as well. In this section, we describe different studies that sought to determine the properties of community resilience in various disciplines. In [94], the authors define four features of a resilient system taking into consideration assets, interactions and interconnections at the community level, including the robustness, redundancy, resourcefulness, and rapidity. These four properties are also determined for both physical and social systems in [30]. In another approach, the Bay Localize mentions the equity, quality, sustainability, and ownership as essential criteria for communities to adapt with resilience requirements related to climate change and peak oil [76].

Besides that, the simplicity, adaptation, dependency (i.e., not stand alone), and (future) orientation are defined as properties to guide the community in modelling resilience regarding a diverse range of philosophies [108]. Similarly, the authors in [88] propose four properties of community resilience involving the attribute, continuity, adaptation, and trajectory. Eventually, community resilience can be considered as a dynamic concept; wherefore, assigning a fixed value for a community over a long-term duration is inappropriate because it may change promptly [9,116]. Table 3 provides properties of community resilience and their descriptions in detail. A community resilience model should satisfy not all but at least some of these properties.

Table 3. Properties of community resilience and their descriptions.

Property	Description
Adaptation	The ability of a community in overcoming regular evaluation and alteration to adjust, update, and acclimate to resilience standards over time
Attribute	The concept of community resilience should be comprehended in not only as an internal resident but also as a general entity
Continuity	The requirement of having inherent, dynamic, and persistent characteristic to guarantee community resilience
Dependency	The interaction and integration with a wide range of related models and frameworks to build community resilience
Dynamic	The effective utilisation and enhancement of resources to repair, reconstruct, and recover from surprising events quickly
Equity	The quality of being fair and impartial for all community members towards basic human needs, no matter who they are, regardless of origin, race, gender, or whatever
Orientation	The utilisations of predicate assumptions to guarantee that the model will follow defined directions strictly
Ownership	The acts, states, and rights of communities in owning resources collectively and securely
Rapidity	The capability of a community to prepare, respond, adapt, and recover from disruptive events promptly
Redundancy	The diversity in giving solutions or strategies in a particular situation
Resourcefulness	The latent qualities or potentiality to mobilise in menacing circumstances
Robustness	The capacity of a community in withstanding the actions or effects of adverse shocks
Simplicity	The ability to transform important and complicated factors into a simple model that allow measuring community resilience easily
Sustainability	The potentiality to maintain resources good enough for producing in the future
Trajectory	The accomplishment of positive outcomes that is relative to "after" state of entities
Quality	The crucial goods and services used to evaluate whether a community achieves good standards, some of which are purified air, healthy food, and safe transportation

5. Measuring Community Resilience

After modelling community resilience, it is indispensable to select appropriate methodologies for aggregating and assessing identified components to come up with general systems [39], comprehensive frameworks [44,65,103], management guidelines [56], innovative models [64,72],

a resilience "value", a feasibility assessment [38], or underlying correlations among components [48]. To measure community resilience, we can apply either qualitative, quantitative, or combine these two methodologies as a hybrid one. Qualitative approaches, which are suitable for processes required professional experience of experts, are used to evaluate community resilience without providing a particular numerical descriptor. Apart from that, quantitative methods leverage numerical data along with statistical models to measure community resilience. From a practical perspective, both qualitative and quantitative approaches have proved beneficial and useful in measuring complex community resilience. Several appropriate methods for use include, for example, in-depth interview [46], semi-structured interview [62], observation [73], and survey [92]. Table 4 shows the summary of qualitative, quantitative, and hybrid approaches to measure community resilience.

5.1. Qualitative Approaches

Qualitative approaches can be applied either at (i) the framework level or at (ii) the component level. At the framework level, qualitative techniques aim at giving understanding into actions, themes, patterns, and overall structures of community resilience, for designing and developing processes, phases, or procedures pragmatically. They are usually designed in a step-by-step format to involve communities in sequences and activities, not only assessment but also engagement, implementation, planning, and others. On the other hand, we concentrate on more detailed and qualitative analyses of community resilience factors and their internal relationships at the component level [117]. Generally, a partial implementation of a framework-based approach can be considered as a component-based one. Qualitative methods are sometimes difficult to conduct due to the diversity of standards, interfaces, and coding.

5.1.1. Framework Level

At the framework level, a completed process including continuous cycle or a sequential series of steps is defined and designed with the ultimate goal aiming at comprehending community resilience for effective development and implementation. Table 5 describes steps, stages, or phases of qualitative approaches at the framework level.

The IAP [61] comes up with six consecutive phases to evaluate climate risk, which are engagement, climate research and impacts assessment, vulnerabilities assessment, city resilience strategy, implementation, and monitoring and review. Along with each phase is the set of tools including objectives, guidance, questionnaires, and exercises. They help cities, local governments, and relevant stakeholders, either with a lot or little experience in climate change planning, to build urban resilience. In a similar manner, the Community Resilience System (CRS) also offers six stages (i.e., engagement, assessment, visioning, planning, implementing, and monitoring and maintaining) to support communities in understanding resilience, defining goals, creating strategies, deciding on tools and processes, and evaluating resilience [89]. To derive robust consequences, the authors describe appropriate steps for each stage in which each stage involves specific actions (together with related and supporting resources) required to accomplish.

In another approach, the CART [79] proposes a process, which encompasses assessment, feedback, planning, and action, to engage stakeholders in addressing community problems through field-tested surveys, key informant interviews, community conversations, and supplemental instruments. This toolkit contributes to empowering communities in leveraging their assets and strengths for overcoming multiple disasters. According to [77], the RAND Corporation aims at providing a roadmap to represent an essential step forward for determining the critical elements of community resilience. Based on eight levers, five core components and their interactions, the literature review, focus groups, and SME meetings are conducted for comprehending and strengthening community resilience. This proposed framework is suitable for various communities in reinforcing resilience concerning health security.

Table 4. Summary of qualitative, quantitative, and hybrid approaches to measure community resilience.

Approach	Focus	Outcome	Reference
Qualitative	All-hazards environment	4-stage process for identifying issues, solving problems, and planning activities	[79]
	Climate risks	6-phase process (4 phases for preparation and 2 phases for implementation and monitoring)	[61]
	Community based tourism	Relationship between tourism experiences with community resilience processes	[101]
	Evacuation route planning and design	Limits of punctual treatments and impacts on dimensions of urban walkability	[63]
	Man-made and natural disasters	6-stage process with detailed guidance, tools, and resources identified for each module	[89]
	National health security	Roadmap used as a starting point to develop local community resilience strategy	[77]
	Soil erosion	Impacts on soil erosion based on social, psychological, and cultural parameters	[104]
	Stresses accumulate and sudden shocks	4 categories, 12 goals, 52 indicators, and 156 variables for city resilience	[49]
	Tsunami	Strength and weakness of tsunami preparedness based on eight resilience elements	[105]
		Analysis of resilience capacities and resources activated to cope with disaster	[99]
Quantitative	Acute shocks (natural and man-made)	Resilience scores for preliminary (from 0 to 30) and detailed assessment (from 0 to 180)	[54]
	Climate change	Space time dynamic resilience measure (ST-DRM)	[51]
	Disasters	Disaster resilience score ranging between 22 and 110	[84]
		Community disaster resilience index for 4 capital indices across 4 management phases	[82]
		A single, scalar measure combined from six multidimensional components	[83]
		Resilience index based on the percentage of check marks and the number of Yes answers	[90]
		Disaster-resilience index score based on process- and outcome-indicator scores	[98]
	Economic development and social capital	Composite scores of economic development, social capital and community resilience	[110]
	Health, safety, and health equity	Top three priorities to increase health and safety and reduce health inequities	[112]
	Natural hazards	Composite resilience index ranging between 0 and 100	[108]
	Rural diversity	Rural diversity index ranging between 0 and 1	[43]
	Shocks and adverse events	Overall rank along with vulnerability, adaptive capacity, and resilience scores	[60]
Hybrid	Community resources	Community portrait involving community perceptions, attitudes, feelings, and others	[37]
	Community assets	Toolkit for specific resources and action ideas in six key sectors	[76]
	Disasters	19 indicators of recovery along with rating of the importance of each indicator	[97]
		Resilience framework involving 7 to 14 criteria in each of six defined dimensions	[85]
	Disaster education	Conceptual model for collaborative network and knowledge management	[109]
	Disruptive events in coastal areas	Resilience Matrix (RM) framework with performance score for each cell ranging from 0 to 1	[107]
	Land use policies	Rural resilience assessment index ranging between 0 and 1	[47]
	Natural and human-made disasters	Resilience baseline and its schematic representation based on GIS methodology	[80]
	Urban disasters	Risk management index ranging between 0 and 100	[68]

Table 5. Summary of steps, stages, or phases of qualitative approaches at the framework level.

Reference	Step/Stage/Phase	Description
[61]	1. Engagement	Determine key stakeholders, set up coordination and reporting structures, and conduct a preliminary measurement of the city's progress to tackle climate change
	2. Climate research and impacts assessment	Analyse climate change data, build a projection of likely climate changes, and evaluate the impact on critical urban systems and resultant risks
	3. Vulnerabilities assessment	Produce maps of high priority climate risks, measure the impact on the most vulnerable groups of people, and inspect the adaptive capability
	4. Resilience strategy	Construct a list of feasible adaptation activities, prioritise interventions, link to existing city plans, and aggregate all the essential information
	5. Implementation	Determine funding options, distribute responsibilities and resources, and put the initiatives into effect
	6. Monitoring and review	Set up performance indicators and reporting systems, monitor and report against defined indicators, and initiate review phase
[77]	1. Wellness and access	Promote pre- and post-incident population health and guarantee access to social services, high-quality and behavioural health
	2. Education	Make certain that information is available to public concerning risks, preparedness, and resources before, during, and after a disaster
	3. Engagement and self-sufficiency	Encourage participatory decision-making in planning, response and recovery activities and support individuals/communities in assuming responsibility for their preparedness
	4. Partnership	Grow evolving, reliable, and strong partnerships within and between government and nongovernmental organisations
	5. Quality and efficiency	Collect, analyse, and make use of data to build community resilience and leverage resources for multiple use and maximal helpfulness
[79]	1. Generation	Create an initial community profile through local demographics, CART survey data, and key informant interviews
	2. Refinement	Determine and analyse assets and needs through CART community conversations, infrastructure mapping, ecological mapping of local relationships, stakeholder analysis, and other group processes
	3. Development	Build a strategic plan to construct targets and objectives by interacting in groups with the involvement of formal and informal community leaders
	4. Implementation	Adopt and implement the strategic plan by spreading the plan among community members, organisations, and leaders
[89]	1. Engagement	Seek for resilience champions, organise them into a logical and consistent leadership team, and build well-established and trusted community networks
	2. Assessment	Derive self awareness by comprehending its interdependencies and vulnerabilities, categorise its accessible resources, and discover which resources are at risk
	3. Visioning	Give a summary of the importance of possessing a resilience-focused vision and explain how community can include resilience into an existing vision or generate a new vision
	4. Planning	Link present state of community and determine a series of activities that are particular, assessable, and supportive of improved daily community function
	5. Implementing	Ensure an organisational home for community resilience program either through establishing a new organisational entity or by integrating into existing public or private organisations
	6. Monitoring and maintenance	Monitor and assess the progress of individual projects and entire community resilience program, making adjustments and alterations as required

5.1.2. Component Level

At the component level, only resilience components are focused on and taken into account. According to [104], the authors first derive experiences from agro-pastoralist stakeholders through semi-structured interviews. In the following step, the theoretical thematic analysis, which is based on community resilience and social dilemmas frameworks, is applied for strengthening community

resilience with respect to the soil erosion reduction concerning five different domains (i.e., economic domain, social domain , cultural domain, governance, and environmental domain). By leveraging in-depth interviews, adding field observation and reading documents, Rahman and Kausel [105] determine planning capacity and social capacity of a community towards a tsunami based on eight essential resilience elements that are governance, society and economy, resource management, land use and structural design, risk knowledge, warning and evacuation, emergency response, and disaster recovery.

Further, the City Resilience Framework supplies a lens through which the cities' complication and the numerous factors that contribute to a city resilience can be acknowledged. To this end, they define 12 indispensable goals, which fit into four categories and seven qualities, as the backbone for the planning of a resilient city [49]. Cities can receive this framework as a compass to guide learning activities from literature, case studies, and other related areas. Equivalently, other authors also apply case study methodology to analyse, understand, and gain insights into community resilience with respect to community-based tourism [101] and evacuation route planning [63].

Referring to [99], this study spends six months to discover relevant and available capacities and resources of a community during a disaster through various resources that are semi-structured interviews, observation, informal conversations, and documentary and social media review. This qualitative research demonstrates the paramount importance of resilience capacities (i.e., local knowledge, sense of community, cooperation, organisation, social capital, and trust) in terms of responding to emergencies.

5.2. Quantitative Approaches

Quantitative approaches aim at measuring community resilience in recognisable ways to reduce the whims and opinions of analysts, experts, or other populations of the study. They can evaluate community resilience through the use of ordinal, interval, and ratio data obtained from surveys, observations, or secondary data. Towards qualitative approaches, the values of resilience components and their relationships need to be validated by discernible outcomes [111]. Based on components determined in the modelling step, a direct approach is to apply the composite index formula [108] as follows.

$$CR = \sum_{j=1}^{|C|} \sum_{k=1}^{|I_{c_j}|} i_k \times w_k, \forall j, k \in \mathbb{N}, j > 0, k > 0 \tag{1}$$

where CR represents community resilience, C is the set of resilience components, I_{c_j} is the set of indicators of component c_j, and i_k, w_k denote for kth indicator and its weight, respectively. According to [54], the UNDRR identifies an ordinal scale in the range of $[0, 3]$ (i.e., preliminary assessment) and the range of $[0, 5]$ (i.e., detailed assessment) to evaluate ten different essentials, which are used to build resilient cities, including (i) three essentials regarding governance and financial capacity, (ii) five essentials related to planning and disaster preparation, and (iii) two essentials considering disaster response and post-event recovery. Local governments then define their weighting for each essential to reflect its importance and to assist the measurement.

As stated in [84], the authors identify a score range from 1 (low degree of resilience, it means the red zone) to 5 (high degree of resilience, it means the green zone) for every question in the scorecards. We obtain the final score by summing all the individual scores. If the overall score is above 99, our community is very resilient to disasters; if it is below 33, we are under the risk of preventing and recovering from disasters. We should especially put the greatest attention to a particular element in case its scores are significantly smaller than the others.

Instead of using an adding function, we can use an unweighted average of based scores [60] or standardised z-scores (due to the diversity of indicators' values) [82,110] on entire indicators. To compare the resilience among cities, the authors in [60] attempt to calculate the average one more time based on cities' scores. The precision of the resilience comparison highly depends

on the context similarity among cities at the time they are examined. As alternatives to explicit numbers, we can also use a priority rating (low/medium/high) [90,112], an effectiveness score range (A–F) [112], a vulnerability/capacity category (V/C), or an effect value (positive/negative) [83] for quantitative approaches.

On the other hand, the Analytic Hierarchy Process (AHP) is put to use in [98] to determine disaster-resilient indicators at the local level. The outcome-indicator score is further calculated based on criterion score and their weights. Besides, a six-point scale, which is extended from [118], is used to rank indicators for measuring process-indicator score. Level 0 represents the "absence of a clear and coherent activity/activities in an overall disaster risk reduction program", while level 5 refers to "a culture of safety exists among all stakeholders". Subsequently, the authors propose the weighted linear average (WLC) to measure composite indices based on these two evaluated scores.

Last but not least, several approaches attempt to capture dynamic resilience directly at the community level. Community resilience value that changes throughout an event due to risk perceptions of citizens or relationships between resilience components. To reflect the dynamic of community resilience, we can measure value at different time points [119] concerning the entirety components. In [51], Simonovic and Peck recognise that community resilience value can be dynamic in both time and space as well.

5.3. Hybrid Approaches

The measurement of community resilience in a variety of situations requires both qualitative and quantitative approaches [40,41] to capture perceptions, vulnerabilities, exposed values, and other resilience-related factors. A hybrid approach is one where both tangible and intangible elements are applicable [120] for enhancing analytical accuracy and deepening the understanding of community resilience. In [37], the authors harvest various information, which is related to characteristics of resilience, involving specific numbers, percentages, yes/no answers, opinions, and perceptions from interviews, organisation inventory, meetings, focus groups, and surveys. Similarly, both qualitative (i.e., literature review, group interview, and discussions) and quantitative (i.e., scales and surveys) data are usable in [42,109]. Nevertheless, we should keep in mind that hybrid approaches may require much effort and may be time-consuming in the data collection process.

The flexible combination of quantitative and qualitative approaches has been demonstrated in different studies. By mixing both methods, we can generally aggregate opinions of experts along multiple dimensions, indicators, and proxies. In [80], Cutter et al. combine the qualitative GIS (Geographic Information System) map and quantitative indicators to generate social vulnerability, built environment/infrastructure, hazard exposure, and hazards mitigation layers. The overlaying of these four layers provides a schematic representation of resilience baseline for communities. In a similar approach, the Bay Localize Community Resilience Toolkit [76] applies a scale from 0–4 to measure community-based resilience indicators. In consonance with rated values, the authors utilise the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, which is an extremely helpful planning and problem-solving technique, to determine and define community's capabilities for overcoming challenges. Strengths and weaknesses are typically internal factors aiming at representing the conditions within our community. On the other hand, opportunities and threats are able to put our community in a clear picture of external influences [121].

In contrast, we can apply a quantitative measurement based on both quantitative and qualitative targets to come up with specific resilience indices [68]. Following this methodology, the following matrix

$$
\begin{array}{c c}
& \begin{array}{cccc} \textit{Prepare} & \textit{Absorb} & \textit{Recover} & \textit{Adapt} \end{array} \\
\begin{array}{r} \textit{Physical} \\ \textit{Information} \\ \textit{Cognitive} \\ \textit{Social} \end{array} &
\left[\begin{array}{cccc}
P-P & Ab-P & R-P & Ad-P \\
P-I & Ab-I & R-I & Ad-I \\
P-C & Ab-C & R-C & Ad-C \\
P-S & Ab-S & R-S & Ad-S
\end{array} \right]
\end{array}
\tag{2}
$$

utilises both qualitative and quantitative data in which qualitative values (obtained through personal communications with stakeholders) are placed at Prepare-Information ($P - I$), Prepare-Social ($P - S$), Recover-Information ($R - I$), and Adapt-Physical ($Ad - P$) positions [107].

According to [97], the authors make use of a three-round Delphi method to determine necessary resilience indicators. The first round begins with a comprehensive literature review to understand and derive a good set of indicators. Experts further evaluate each dimension in the second round in consideration of a five-point Likert type scale that is anchored with 1 (not applicable) and 5 (very important). Besides, the experts are also encouraged to provide their insights into other elements that are crucial for a community to be resilient to change and cope with disasters. All following rounds will continue until we acquire a general agreement of all panel members [85]. Besides, the Delphi method is also used to determine index weights for quantitative calculations [47]. It is noted that a Delphi technique can meet difficulties in case local communities or qualified respondents do not have adequate previous experience.

6. Visualising Community Resilience

This section explores different visualisation techniques to deal with various scales and units of analysis to enhance community resilience. In emergency circumstances, a mass amount of resilience-related information can be generated from diverse data sources. Hence, utilising multiple visualisation techniques to understand and illustrate this information is essential for a more detailed and complete resilience comprehension, community-based resilience planning, and decision-making processes. Besides, employing utilisation technologies can bring us valuable and actionable insights at the application level. Table 6 summarises different visualisation techniques to represent community resilience.

Table 6. Summary of community resilience visualisation techniques.

Type of Visualisation	Technique	Focus	Reference
Geospatial information	Density map	Disasters	[53,75,83]
		Economic development and social capital	[110]
		Flood	[58]
		Hot-spots of high or low disasters	[74]
		Natural hazards	[87,108]
		Urban social-ecological systems	[71]
Multidimensional information	Stacked bar chart	Crises and disasters	[81]
		Shocks and adverse events	[60]
	Spider chart	Crises and disasters	[81]
		Disasters	[73]
		Soil erosion	[104]
		Tsunami	[105]
		Urban planning	[66]
	Radial stacked bar chart	Natural hazard events	[100]
		Stresses accumulate and sudden shocks	[49]
		Urban planning and policy	[69]
	Hypercube	Cyclone and storm surge disasters	[113]
		Transportation network in earthquake	[67]
Others	Bar chart	Food, energy, and water	[57]
		Urban flood	[52]

6.1. Geospatial Information Visualisation

In case geospatial information of community resilience is available, we can use a density map to highlight and demarcate critical locations [74] through different colour codes in which dark and cold colours usually indicate high resilience. In contrast, light and warm colours stand for low resilience. To show colours in a map, we are able to use either qualitative, sequential, or diverging scheme. The density map is advantageous in case many data points (or data lines) exist in a small geographic area. According to [71], the authors combine both numbers and colours to represent urban resilience indices and rankings for 50 Spanish province capitals following the standard deviation classification methodology of ArcGIS. However, the selection of red colour for high resilience areas may mislead readers because this colour is often associated with emergencies. With reference to [53], the authors depict the spatial distribution of disaster resilience and its components (i.e., social, economic, institutional, and infrastructure resilience) for 736 counties in the FEMA Region IV. The disaster resilience scores are expressed as standard deviations in order to emphasise high or low resilient counties extraordinarily. The authors further portray high and low resilient areas as dark blue and red, respectively.

In a similar approach, the authors in [75] visualise disaster resilience as well as six components based on a diverging scheme, from low (standard deviation < -1.5) to high resilience (standard deviation > 1.5). Furthermore, leveraging standard deviations [58,87], other studies create the density map to represent community resilience indices of Mississippi counties [110], disaster resilience indices of 11 local government areas (e.g., Greater Brisbane Area, Sunshine Coast, and others) [108], and community disaster resilience indices of 229 local municipalities in South Korea [83]. Despite the ability to present a holistic perspective of the resilience of a community and its neighbours, the density map shows the disadvantage if we want to represent all dimensions because each dimension will require a separate diagram.

Without tangible geospatial information, a bar chart can be the right selection [52,57] to visualise an overall value of resilience for various communities.

6.2. Multidimensional Information Visualisation

Stacked bar charts, spider charts (which is also known as radar charts), and radial stacked bar charts are beneficial for displaying multiple dimensions of community resilience. Among these three types, stacked bar charts are designed to concurrently compare the overall resilience between communities and recognise essential dimensions within a community. In [60], the authors use a stacked bar chart to display five aspects of vulnerability, five key themes of adaptive capacity, and overall resilience of 50 cities that have significant influence in the world. In another work, stacked bar charts are used to indicate top-ranking resilience dimensions by gender/age group, livelihood group, and level of intervention [81]. Despite that, one major disadvantage of a stacked bar chart is that we find it hard to compare a particular dimension of a community with others since they are not aligned with a common baseline.

On the other hand, spider charts help us to compare (i) resilience dimensions of a community over time or between communities by placing multiple polygons over or upon each other in a single diagram [105] and (ii) resilience dimensions with a defined standard [73]. Generally, spider charts can enable a better understanding of the strengths and weaknesses of resilience dimensions [104] and therefore very useful for high-level presentation of assessments. In [81], the CoBRA framework describes community attainment of resilience by illustrating five sustainable livelihood framework categories that are financial, human, natural, physical, and social by the current and crisis years. Likewise, Wardekker et al. [66] draw spider charts to elucidate the baseline and adaptation plans for flood-related resilience of Rotterdam based on ten resilience components (e.g., anticipation, robustness, flatness, and others). If measuring scales of axes are different, it would not seem helpful to compare resilience dimension across these axes. Besides, we should avoid concentrating too much on the polygons because the area and the shape of polygons can change depending on how we organise

the axes. We may use parallel coordinate charts as an alternative to spider charts. By extending the radial stacked bar chart, the authors in [49,69,100] express multiple indicators associated with defined dimensions required for a resilient community dexterously.

Furthermore, a hypercube has the advantage of providing a direct view of the relationships and correlations among resilient dimensions. Focusing on infrastructure resilience, Jovanović et al. employ a three-dimensional space to visualise three resilience components including matrix-based indicators, complexity (level of detail), and smartness (big data analytics) [122] for healthcare infrastructure exposed to COVID-19 [123]. In another work, a resiliency cube is plotted to manifest the resilience of an urban road network in the time of earthquake [67]. Nevertheless, a hypercube may lose its clarity if there are so many resilient dimensions that need to be represented. A co-occurrence network [113] can be a suitable substitute in this condition.

6.3. Dashboard

A dashboard is a single screen summary of the analysis of different information. The use of dashboard holds great potential in the circumstance that we require multiple visualisations, which influence each other, to offer a comprehensive and engaging view of community resilience. Dashboards are also specialised in their dynamic and interactive capabilities. Infrastructure facility managers [124], local planning for resilience [56], or emergency managers [125] can utilise dashboards to derive critical insights for at-a-glance decision making and comprehensive strategies during a crisis.

To create a successful and helpful dashboard to represent community resilience, whether as an independent element or as a component of a specific framework, we should put our efforts in understanding our data, dealing with outliers, displaying meaningful results, and increasing semantic transparency. On the opposite, it is necessary to minimise response time, futile decorations, and redundant information.

7. Discussion and Conclusions

Acknowledging the importance of community resilience, researchers and practitioners have made significant attempts in not only studies but also practical matters. In particular, the objective of this paper is to provide an investigation and a more comprehensive picture into the state-of-the-art, accessible, and emerging works that are subjected to a three-step sequential process (i.e., modelling, measurement, and visualisation) to build community resilience. The modelling represents what is likely to be components and properties that communities should focus on to guarantee their resilience. Further, the measuring step assists communities in recognising where they are standing. Eventually, the visualisation aims at supporting communities in deriving insights into essential information promptly and precisely with minimum efforts. Based on this skeleton, communities can select most relevant approaches, which we mentioned in this review, to embed into their processes. For a successful resilience plan, communities should consider and follow all these three steps comprehensively. In addition to that, we want to mention critical points that were distilled herein for both research and practical uses.

- The number of components defined in the modelling step is diverse depending on a particular community at a specific time point for certain risks/targets. Nevertheless, we should not define too many components since they can be overlapping and difficult to break down into lower-level elements. Besides, end-users and stakeholders may find it difficult to understand and monitor a large number of components for giving precise actions, especially in the time of adversity.
- Various terminologies are available for modelling community resilience, some of which are, but not limited to, index, dimension, capital, capacity, and domain. The selection of the term highly relies on our practical use. For example, the resilience index, which is usually a combination of indicators, is appropriate for a quantitative assessment. On the other hand, resilience dimension/domain is

more descriptive and suitable for qualitative approaches. In addition, resilience capital/capacity well expresses the potential and abilities of a community to achieve something.

- To measure community resilience, we can leverage not only static (e.g., vulnerabilities, hazards, and exposed values) but also dynamic information (e.g., dynamic risk perception extracted by analysing social media data) at different scales. Information collected at the community level regularly tends to be more informal, undocumented, and implicitly understood than higher scales. It is necessary for us first to determine the goals of our community, target potential end-users, and then stick into them before deciding on any particular approaches to measure resilience.

- This paper presented many studies that aimed at visualising correlation, hierarchy, and geospatial information; however, we should pay more attention to understanding and representing temporal information. Temporal information visualisation can capture common patterns and search for specific sequences, such as the dynamic of community resilience value by time. Area chart and polar area diagram are practical and efficient techniques [126] to portray temporal information of community resilience.

We are living in the fourth industrial revolution with the explosion of disruptive technologies that are essential and valuable for decision-making processes. In the next study, a comprehensive comparative analysis of how to utilise social networking services [127–129] and crowdsourced data for community resilience [130,131] will be taken into account. Besides, we will examine the interrelation and discuss open issues between cutting-edge technologies (e.g., machine learning, Internet of Things, and artificial intelligence) and community resilience. For example, the intelligent and adaptive use of machine learning methodologies to measure community resilience [132] can provide us with excellent opportunities for further development.

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