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The Resilience of Complex Sociotechnical Systems: A Meta-Review of Conceptualisations

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Abstract

This meta-review systematically examines 88 review papers from the scientific literature, focusing on the diverse ways scholars define and conceptualise the resilience of complex sociotechnical systems (STS). Among the 484 different conceptualisations identified in the reviews, we observe recurring patterns based on their semantics. In particular, four constructs are predominant: some positive elements, some negative events, specific actions, and some constraints on these actions. Our analysis involves a meticulous categorisation and synthesis of these findings, revealing underlying convergences in the academic discourse on STS resilience. Despite what seemed to be apparent disagreements among scholars in the last decade, our study shows that many differing viewpoints are actually complementary, representing varied expressions of similar underlying principles converging towards a large consensus. This comprehensive synthesis offers a unique perspective on the field of STS resilience, demonstrating the feasibility of moving from diverse meta-theoretical paradigms towards a more unified paradigmatic approach.

Keywords: meta-analysis; resilience; adaptation; disruption; terminology; semantics; ontology

1. Introduction

Over the past several decades, resilience has generated a substantial and interdisciplinary body of research spanning fields such as psychology, ecology, veterinary sciences, energy studies, and the social sciences [1]. Narrowing the focus only to sociotechnical systems (STS), the growing interest and importance of resilience as a concept can be primarily attributed to its critical role in managing uncertainties, unforeseen events, and disasters, which have become increasingly prevalent in an interconnected and rapidly evolving global landscape. The escalating frequency and intensity of unforeseen events, ranging from natural disasters to technological failures and societal upheavals, necessitate an integrative framework for anticipation, response, and adaptation [2]. Resilience provides a paradigm for understanding and navigating these uncertainties, offering strategies to not only withstand shocks but also to adapt and thrive in the face of such challenges. Moreover, the modern world is characterised by a high degree of complexity, arising from global interconnectedness, technological advancements, and multifaceted societal dynamics. This complexity often results in unpredictable scenarios, making traditional linear approaches to problem-solving inadequate. Resilience offers a more holistic and flexible approach, acknowledging and embracing complexity as a fundamental characteristic of modern systems. In addition, large, complex systems such as STS inherently possess a level of complexity

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that leads to unpredictable functioning. These systems are marked by numerous non-linear interactions, where small changes can have disproportionate effects [3]. Resilience in this context becomes essential, as it focuses on enhancing the system's ability to anticipate, absorb, and recover from disruptions, irrespective of their source or nature.

The concept of resilience of sociotechnical systems remains a subject of ongoing academic debate, with no clear consensus emerging on its precise nature. This lack of agreement is evident in the literature, as numerous scholars have pointed out the diverse and sometimes conflicting interpretations of resilience.

Refs. [4,5] explicitly acknowledge the absence of unanimity on what the concept entails. Similarly, ref. [6] notes that no consensus has been reached, reflecting the ongoing discourse and differing viewpoints in this field. Refs. [7,8] reiterate the absence of a broad consensus regarding the definition of resilience, further emphasising the fragmented understanding within the academic community. Ref. [9] discusses the implications of this lack of consensus, particularly how it impedes the implementation of resilience assessment and strategies. Moreover, ref. [1] acknowledges that discussions on resilience can often lead to confusion due to the lack of a universally accepted definition. Ref. [10] points out the continued disagreement among researchers regarding the definition of resilience. Ref. [11] extends this observation to add that a unified definition of resilience remains elusive. However, ref. [12], while noting the lack of collective agreement, suggests that the essence of resilience understandings sometimes aligns, indicating a possible common ground despite the varied interpretations.

Despite this extensive and growing body of work, no meta-review has yet synthesised how resilience is conceptualised specifically within sociotechnical systems. Existing reviews typically focus on individual sectors or adopt a general, cross-disciplinary perspective that does not account for the distinctive properties of STS as large-scale, interconnected, and human–technology–organisation systems. As a result, the field lacks a systematic consolidation of the conceptual patterns, shared elements, and underlying principles that define resilience in STS. A dedicated meta-review is therefore both necessary and timely: necessary because the fragmented landscape of definitions impedes conceptual clarity and practical application, and timely because the increasing complexity and societal relevance of STS demand a more unified understanding of their resilience.

The aim of this paper is to show that many differing viewpoints are actually complementary, representing varied expressions of similar underlying principles converging towards a large consensus. This study offers a unique perspective on the field of STS resilience, demonstrating the feasibility of moving from diverse meta-theoretical paradigms towards a more unified paradigmatic approach.

1.1. Sociotechnical Systems

To study the resilience of real-world sociotechnical systems, we first need to understand what sociotechnical systems are and how they function. The term *sociotechnical systems* is not universally used among scholars nor practitioners. Complex sociotechnical systems are dynamic, open systems in which human and technological components are interconnected and interact within organisational and infrastructural settings. These systems are embedded in broader societal and environmental contexts, where both social and technical elements co-evolve to achieve specific goals. The interactions between people, technology, and the environment shape the system's behaviour, performance, and adaptability [13].

Complex sociotechnical systems (STS) underpin the functioning of modern societies, performing diverse and critical functions. They extract natural resources (e.g., mines, offshore oil and gas platforms), transform materials and energy (e.g., nuclear plants, chemical

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industries, vehicle factories), and transport goods, people, or energy (e.g., road, rail, air, maritime transport, and distribution networks). STS are also central to healthcare, scientific research, and space exploration (e.g., hospitals, particle accelerators, tokamaks, the International Space Station, Tiangong Space Station, lunar and upcoming Mars missions). These systems provide the foundation for daily life. Every individual interacts with STS directly or indirectly—the food we consume, the products we use, the transport we rely on, and the services we access all depend on their seamless operation, which is often only noticed when disrupted. In this sense, complex STS are indispensable pillars of societal functioning. Their continuous and reliable operation supports economic activity and safeguards well-being. Understanding, managing, and maintaining these systems is therefore essential for the resilience and advancement of modern societies. Although STS have long been recognised and studied, their evolving complexity and critical role in modern societies call for renewed and structured attention. Emphasising this ongoing focus underscores the importance of systematically analysing, managing, and enhancing the resilience of these systems.

1.1.1. Characteristics of Complex STS

Complex STS display intricate characteristics. As identified in the comprehensive review by [3], in which complex STS such as power plants, aviation, healthcare, and petrochemical industries were under consideration, these systems are marked by a multitude of dynamically interacting elements. The complexity is further enhanced by numerous control parameters that interact in unforeseen ways. In such systems, each element not only influences, but is also influenced by, multiple others, creating a network of interconnectedness and interdependencies:

1. The interactions within STS are non-linear, where minor changes can lead to disproportionately large effects due to the system's sensitivity to internal and external conditions. This is compounded by tight couplings among components that are not necessarily sequential in the system's functioning.
2. Unanticipated variability and unpredictability are hallmark features of such systems. Moreover, the systems exhibit desirable emergent phenomena, such as safety, but sometimes catastrophic phenomena, such as accidents.
3. The intractability of sociotechnical systems means that performance conditions are often underspecified, leading to low system transparency. The relationship between cause and effect in STS becomes clear only in retrospect and does not necessarily repeat. These systems are open, interacting continuously with their environment, and exhibit adaptation through the behaviour of agents.
4. Self-organisation is a critical aspect, especially as operating conditions are typically underspecified and dynamic, necessitating local adjustments for system functioning. Performance variability can be both an asset and an obstacle, depending on its alignment with the system's needs. Agents in STS possess some degree of behavioural autonomy and intelligence.

More specifically, ref. [14] lists the elements of real-world STS identified in eight different models: agents, equipment, formal/informal rules, hardware, knowledge, management, managers, operations, operators, organisational conditions, personnel, physical environment, physical layout, plans, policies, procedures, resources, roles, skills, social elements, software, staff, structure, tasks, team, technologies, tools, workers, and workload. Similar terms are present since the terminologies come from different STS models. These elements, in addition to interacting with each other, interact as well with the system's environment. In particular, ref. [14] lists the following: legal environment, economic environment, supply chain, political environment, other companies, regulators, associations, government, and society. These attributes collectively underscore the complexity and multifaceted nature of STS.

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1.1.2. STS Modelling and Representation

In scientific research, finding the appropriate level of abstraction is a crucial yet challenging process, as explained by [15], and the representation of STS depends on the purpose of modelling. STS can be conceptualised and represented through various lenses or frameworks, each providing a distinct vantage point. These include, but are not limited to, viewing STS as networks, cyber-physical infrastructures [16], information flow, and energy consumption/transmission. Further dimensions extend to economic, financial or business, organisational, safety, functional, operational, cognitive, social, legal, shareholder, technical or technological, user, and performance levels. This multiplicity of perspectives underscores the diversity in approaches to understanding STS. However, it is crucial to acknowledge that each of these angles offers only a fragmentary glimpse into the functioning of STS. Given their inherent complexity, as previously discussed, no single perspective can fully encapsulate the entirety of an STS's dynamics. In a recent systematic review conducted by [17], this notion is further detailed. The review identified 106 methods developed for investigating STS, each contributing a piece to the intricate puzzle of these large and complex systems. This vast array of methodologies highlights not only the richness and depth of research in this field but also the inherent challenges in achieving a comprehensive understanding of STS. Individually, these methods provide valuable insights, but together they offer a more holistic, though still partial, understanding of STS due to their intrinsic complexity. Consequently, if understanding the overall functioning of STS is challenging, comprehending their resilience without predefined assumptions is equally difficult. The concept of STS resilience, deeply intertwined with the diverse and interdependent aspects of STS, requires an equally nuanced and comprehensive approach to fully understand its manifestation and influence within these complex systems.

1.1.3. Integrated Perspectives on Sociotechnical Systems

To complement the diverse representations of STS, several systems-based approaches aim to offer more integrated perspectives on system structure, organisation, and long-term functioning under changing conditions. Within the family of systems-based approaches, the viable system model (VSM) [18] provides a cybernetic framework explicitly concerned with the conditions under which systems remain viable under environmental change. Originating from management cybernetics, the VSM represents sociotechnical systems as recursively organised control structures composed of interacting regulatory functions responsible for operational execution, coordination, control, environmental scanning, and policy formulation. Central to the model is the regulation of complexity through feedback, attenuation and amplification of variety, and the dynamic balance between internal stability and external adaptability. These regulatory mechanisms correspond closely to core control-theoretic notions underpinning many interpretations of resilience, such as disturbance absorption, adaptive reconfiguration, and maintenance of essential system functions.

The VSM has been operationalised as a diagnostic and design framework in empirical studies of real-world sociotechnical systems, providing concrete mechanisms for embedding resilience within organisational and infrastructural control architectures. Ref. [19], for example, demonstrates how the explicit allocation of regulatory functions and feedback channels prescribed by the VSM can enhance organisational resilience in the presence of uncertainty. Similarly, applied studies in critical infrastructure contexts illustrate how the VSM supports the design of decentralised yet coherent control structures capable of responding to climate-induced disturbances, as shown in oil refinery operations [20] and in municipal waste management systems facing evolving environmental and operational demands [21]. These applications exemplify how resilience can be conceptualised as an emergent property of effective regulation, recursive control, and environment–system

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coupling. While the VSM represents only one of several systems-theoretic approaches to modelling sociotechnical systems, it illustrates how cybernetic principles provide a rigorous bridge between abstract resilience constructs and their practical implementation in complex, adaptive systems.

1.2. Literature Gap and Aim of the Meta-Review

Although there is no consensus on *what is STS resilience*, there is a clear consensus on *the need for resilience* across various STS systems: ref. [22] highlights the growing number of publications on resilience, indicating a widespread agreement on the importance of designing resilient infrastructures vital for societal functioning. Ref. [23] acknowledges a strong consensus regarding the need to apply resilience at an industrial level, emphasising its practical utility in this sector. Despite this necessity, there has not yet been a meta-review specifically on STS resilience, although there exists a plethora of reviews, each of which considers certain aspects of STS or certain aspects of resilience. This situation is compounded by the extensive and diverse vocabulary used in resilience studies, making it challenging at times to draw connections between different research works in this field.

Given the lack of consensus on the conceptualisation of STS resilience, it logically follows that there is also no consensus on how to operationalise, measure, and enhance it. This ambiguity in defining resilience fundamentally hinders the development of coherent methodologies and strategies for resilience improvement, which is the ultimate goal of resilience science. Consequently, this absence of a shared understanding of resilience poses a significant obstacle to advancing research focused on effectively enhancing the resilience of STS.

The aim of this paper is to identify patterns of meaning within the vast body of literature on STS resilience and to distil the essence of what constitutes the core of STS resilience. It seeks to identify a potentially unacknowledged consensus among scholars regarding this concept. Finally, it aims to harmonise the terminology and semantics used across various studies, thereby fostering a more cohesive and clear understanding of STS resilience, allowing scholars to investigate and communicate on STS resilience in a more seamless way.

Moreover, this study contributes to organising and advancing the discussion on STS resilience by synthesising existing definitions, structuring the terminology, providing an extensive index, and highlighting the conceptual elements shared across the literature. It provides a common ground for researchers, facilitating clearer comparison and alignment across future formal studies. Without such a foundation, it becomes difficult to determine how to measure, improve, or operationalise resilience. Beyond providing a conceptual foundation, this study offers practical value by clarifying terminology and conceptual relationships in STS resilience. This clarity can help practitioners and policymakers interpret research consistently, design more coherent resilience strategies, and align operational practices with scholarly understanding. By establishing a shared language and framework, the study supports more informed decision-making and fosters better integration of resilience principles into the management of complex sociotechnical systems. Finally, this study is also an effort to provide a shared language that may help to move the field beyond the endless debate on "what resilience is."

1.3. Methodology

To conduct the meta-review, we followed the preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology [24]. This approach was designed to help systematic reviewers transparently report why the review was conducted, what the authors did, and their findings. It was recently successfully applied to perform a meta-review on supply chain resilience [25]. The methodology consists of the following 5 main steps: (1) the formulation of the research questions, (2) sourcing relevant literature, (3) literature screening, (4) analysis and synthesis, and (5) reporting of research findings.

Step 1: Formulation of the research questions

The meta-review is conducted to answer the following research questions. RQ1: How do scholars define and conceptualise the resilience of sociotechnical systems? RQ2: Among the identified definitions and conceptualisations, what are the different patterns of meanings? RQ3: How do we restructure the patterns of meaning into a synthetic, coherent, more abstracted view?

Step 2: Sourcing relevant literature

The goal is to establish search criteria related to the topic, which will help in pinpointing pertinent literature. Accurate keywords need to be identified according to the research questions. Keywords to search in the scientific literature and keywords related to the topic are first (group A keywords), and keywords related to our specific interest in the chosen topic are second (group B keywords). Diversifying the search terms used is usually crucial for identifying studies that use different terminology. However, we make the assumption that we do not know anything *a priori* about resilience. If we use what we believed to be close synonyms of resilience, for instance, "adaptation", "robustness", "coping strategies", "recovery strategies", "disruption management", "stability", "antifragility", and "uncertainty management", we would introduce bias in the later analysis. Since there is no consensus yet on *what is resilience*, there is no consensus either on *what are the synonyms of resilience*. Consequently, only *resilien** is used in the search engines for the topic, which captures *resilience*, *resilient*, and *resiliency*. Regarding the Group B keywords, we used "review", "comprehensive analysis", "systematic analysis", "meta-review", "meta-analysis", "secondary study", "overview", and "tertiary study". The associated query to the two groups A and B is (TI = (resilien*)) AND TI = (review OR comprehensive OR systematic OR meta-review OR meta-analysis OR secondary OR overview OR tertiary study). The literature search was performed by applying the query to the titles, keywords, and abstracts of the publications.

Since *sociotechnical systems* is not a term universally used, we did not include it as a keyword in the search. Many terms describe different aspects of such systems, parts of these systems, or the domains of study of these systems, for example, cyber–physical systems, human–machine systems, system engineering, engineered systems, high-reliability organisations, human factors and ergonomics, human safety systems, critical infrastructures, interconnected systems, joint cognitive systems, cognitive engineering, cognitive systems engineering, organisational systems, safety management systems, Safety systems, safety-critical sociotechnical systems, systems engineering, and systems-of-systems. Consequently, we did not include keywords about any systems or topics, and we later excluded irrelevant reviews in the literature screening step. We searched Web of Science and ScienceDirect to access peer-reviewed journals and conference papers. The search included papers up to July 2023.

Step 3: Literature screening

The title and abstract of papers are initially read to assess their appropriateness regarding content relative to the considered three dimensions: resilience, review, and sociotechnical systems. Should the abstract not provide a conclusive determination, the full article is then examined. The process of the literature search is detailed in Figure 1. Regarding the selection criteria, we excluded papers that were not published in English. As well, we excluded papers that addressed supply chains. Supply chains can sometimes be modelled as part of sociotechnical systems, in particular when humans are explicitly integrated in the decision-making process to deal with a disruption, but since there are already meta-reviews in the scientific literature (e.g., [26]), they do not constitute a literature gap. We also excluded papers where the human part of STS was not explicitly present, i.e., the STS system is viewed as a pure technical level, for instance, studies of the resilience of certain infrastructures such as bridges and electricity networks. Reviews on resilient cities have been excluded too, as cities are more an aggregation of multiple interconnected systems with different stakeholders, which can have different objectives, rather than a single, coherent, sociotechnical system. Moreover, papers where STS are viewed as purely organisational or social have been excluded too, such as looking at the resilience of some transportation systems as business models, or studying the resilience of health care systems only at the level of patients' well-being. The total number of review papers included in our meta-review is 88. The details about the reviews' titles, authors, journal/conference, year of publication, and considered systems of study can be found in Appendix A Table A1.

Step 4: Analysis and synthesis

The selected review papers have been read, and the data relevant to the research questions have been extracted (see Appendix A Table A2). The following data have been systematically analysed: a typology and different categorisations have been designed to look at the data through a new lens. This step is detailed in Sections 2 and 3.

Step 5: Reporting of research findings.

After the analysis, the evaluation of the relevance and consequences of the meta-review is discussed. This step is presented in Section 4.

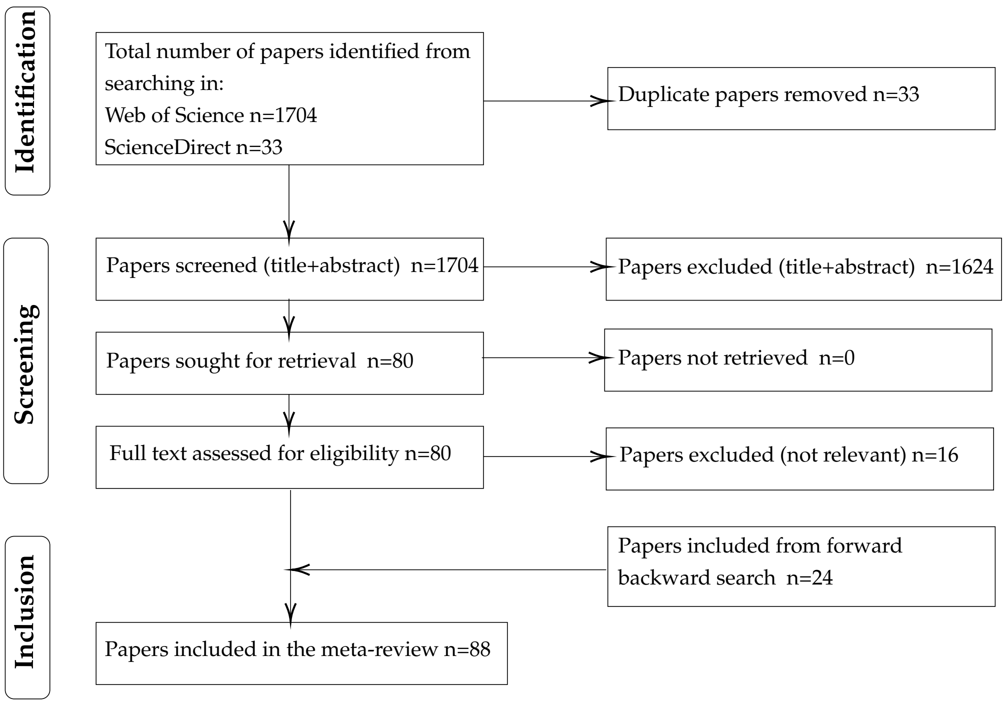

Figure 1. PRISMA process of the review paper selection process.

2. Data Extraction

Resilience, as a concept, exhibits significant polysemy and polyonymy: it has multiple meanings and is represented by different terms across various domains. Apart from its metaphorical interpretation, the resilience of fundamentally different systems—like an ecological system (e.g., a forest) and a sociotechnical system (e.g., an airport), or a social system (e.g., a family) and a computer system (e.g., software)—has very distinct meanings. This divergence stems from the unique characteristics, functions, and objectives inherent to each type of system. For instance, resilience in an ecological system focuses on the capacity to maintain ecological balance and biodiversity; resilience in a social system, like a family, may pertain to emotional and social stability; in a computer system, resilience involves robustness against failures or attacks. Therefore, while the term "resilience" is applied broadly, its specific implications and applications vary considerably, reflecting the unique contexts and requirements of different systems. Consequently, we have specifically concentrated on extracting data from review papers that solely address STS resilience. This targeted approach means that our analysis excludes mention of other types of systems in the reviews, or alternate conceptions of resilience that do not directly pertain to STS. For instance, broader analyses of resilience, such as those found in ecological systems (focusing on stability), physical systems (concerning elasticity), or psychological contexts (emphasising trauma recovery), like the ones explored in [27], have been deliberately omitted. This exclusion is strategic, ensuring a focused and coherent examination of resilience strictly within the realm of STS. By narrowing our scope in this manner, our meta-analysis remains tightly aligned with the specific interest in STS, thus providing a more precise and relevant understanding of resilience in this particular context.

All data extraction and categorisation in this study were performed manually by the authors. Each of the 88 review papers was systematically and thoroughly read to identify the different conceptualisations of STS resilience. The subsequent categorisation of these conceptualisations was also conducted manually, following a rigorous and transparent process. This approach allowed us to focus on the meaning of each conceptualisation, ensuring a nuanced and accurate synthesis, rather than relying on algorithmic or automated methods.

The careful reading of the 88 review papers led to the identification of 484 definitions and conceptualisations. They are presented in Appendix A Table A2. A number from #1 to #484 was associated with each of them. The 484 definitions and conceptualisations were sorted by alphabetical order of the name of the first author of the review paper. For instance, three definitions were identified in the first review [4], so they are definitions #1, #2, and #3. In the last review [28], eight definitions were found and thus have numbers from #477 to #484.

The distinction between a definition and a conceptualisation is subtle, especially for complex concepts such as resilience. A definition provides a precise and often concise description of a concept, often presenting the core characteristics. It serves as a foundational tool for both understanding and communicating the essential nature of a concept. A conceptualisation extends beyond definition to encompass a broader interpretation and theoretical framing of the concept. It integrates the concept within a wider theoretical context, offering insights into relationships with other close or similar concepts. An example of a definition of STS resilience is #364: *"Resilience is maintaining performance above the critical threshold, recovering within the time threshold, or remaining within both thresholds"*. An example of a conceptualisation of STS resilience is #365: *Four dimensions of the concept of resilience: "(1) resilience as rebound from trauma and return to equilibrium; (2) resilience as a synonym for robustness; (3) resilience as the opposite of brittleness, i.e., as graceful extensibility when surprise challenges boundaries; (4) resilience as network architectures that can sustain the ability to adapt to future surprises as conditions evolve*. Here, the difference between #364 and #365 is obvious, but sometimes it is subtle, so the different definitions and conceptualisations range from very concise to very explanatory. Consequently, we integrated the full spectrum of definitions and conceptualisations in this meta-review.

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During the data extraction process, it was observed that identical definitions occasionally recurred across multiple review papers. In instances where the same definition appeared in two different review articles authored by the same author(s), only one instance of the definition has been incorporated into the meta-review. This approach was taken to avoid over-representation of a single scholar's perspective. Conversely, if identical definitions were found in works by different authors, both instances were included in the meta-review. For instance, *"Resilience is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions"* is presented by both [29,30] in [11]. They have both been included in the meta-review (#209 and #213). Moreover, several definitions that are different from only one or two words were all included. For instance, #170 "Ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" and #268 "Ability to prepare and plan for, absorb, recover from, and successfully adapt to disruptive events", even though very similar, have both been included in the meta-review. These inclusions serve to underscore the consensus or common understanding among different scholars in the field, thereby highlighting the widespread acceptance and validation of certain definitions within the academic community.

Certain papers presented definitions or conceptual frameworks without explicitly attributing them to any particular authors. In such cases, where no specific authorial citation was provided for a given definition or conceptualisation, the convention adopted was to ascribe the attribution to the authors of the review paper in which these elements were found. In this case, the authors' names in the 3rd and 4th column of the table in the Appendix A Table A1 are identical.

To ensure that the information extracted remained aligned with the overarching focus of our study—complex STS—rather than being narrowly confined to specific system types, we homogenised parts of the data. For example, in instances where an author's definition explicitly referred to a particular system, such as the maritime infrastructure system, we generalised the term to "system." This adaptation was implemented to maintain consistency across the meta-review, given that all definitions under consideration pertained to some form of STS. Similarly, specific references in the original text, such as "to continue to provide electricity to consumers," were broadened to more general terms such as "to continue to provide services." Such modifications are needed to abstract and harmonise the diverse inputs to fit the meta-review's scope, thereby ensuring that the resultant analysis is applicable to a broad range of STS rather than being limited to specific examples or sectors.

3. Analysis

It is unequivocally agreed, based on the extensive corpus of interdisciplinary research and theoretical analyses, that resilience is a concept of substantial complexity. Resilience is described as follows:

- multi-dimensional [4,31,32];
- multi-level [31,33];
- multi-factorial [31,34];
- multi-faceted [4,27];
- multi-disciplinary [9,27];
- multi-attribute [33,35];
- multi-functional [36];
- multi-aspect [2].

When addressing complex concepts, the task of providing a clear, delimited conceptualisation is a difficult exercise due to the existence of multiple theoretical approaches, lenses, frameworks, and paradigms through which these concepts can be explored. These conceptualisations often transcend rigid disciplinary boundaries, interacting dynamically with various fields of knowledge and levels of representation. Therefore, attempting to confine them within strict definitional limits results in an incomplete or skewed understanding. Concentrating on the core aspects of the concept, rather than its peripheral or boundary definitions, allows for a more profound exploration of its intrinsic nature and underlying principles, acknowledging the rich diversity of perspectives that contribute to its complexity. Consequently, our approach prioritises the identification of recurring patterns of meaning within the array of definitions and conceptualisations, rather than emphasising the differences among them. This approach is adopted with the intent to discern the core constructs and underlying structures in the used semantics. By focusing on these commonalities, it is possible to uncover the fundamental elements that consistently emerge across various interpretations.

All 484 definitions were read in full and manually analysed by the authors. Their constituent elements were identified and separated without relying on any predefined or labelled categories. It appears that the different definitions and conceptualisations can be grouped into three main categories: those where resilience is understood as a process or consequences of a process (97%), see Section 3.1; those where resilience is described as a measure of a certain quantity/quality (2%), and those (1%) where resilience corresponds to a set of properties (for both see Section 3.2)

3.1. Resilience as a Process and Consequences of Actions

In most of the definitions and conceptualisations of STS resilience, which is viewed as a process and consequences of actions, certain core components—called *Fundamental constructs*—are systematically present. Four have been identified: first, negative situations that can happen; second, some elements regarded as valuable or worthy of preservation; third, a necessity to do something, to perform some actions; fourth, some constraints in which the actions should be taken. Another construct, although less fundamental, is sometimes present: the execution time of these actions. The detailed lists of these fundamental constructs are provided in the Supplementary Materials: Table S1 (actions related to negatives), Table S2 (actions related to positives), Table S3 (negatives), Table S4 (positives), Table S5 (constraints on actions), and Table S6 (time of execution of actions).

3.1.1. Fundamental Constructs

Negatives

Among the 484 different definitions and conceptualisations, 93% (451/484) of them explicitly refer to some undesirable events or situations. Undesirable events are events that interrupt normal processes or activities of a system, leading to a change in the established order or the way things typically function. Such events are detrimental to the normal function of a system because they create an unwanted state of disorder, potentially preventing the system from achieving its goals as efficiently, effectively, or reliably as it would under normal circumstances.

A multitude of terminologies are employed to characterise these events. The most used terms are “disruption”, which occurs 77 times, then “disturbance” (53 occurrences), “disruptive event” (44 occurrences), and “changes” (30 occurrences). Anecdotally, the term “perturbance” in #187 is an interesting portmanteau neologism, very likely made from “perturbation” and “disturbance”. Each term, while nuanced in its connotation, essentially converges on the representation of negative occurrences. In this meta-review, the term “negative” is used as an encompassing descriptor. “Negative” denotes a negative connotation or valence. This choice is made to avoid contextual limitations inherent in the aforementioned terminologies, and to encapsulate a broad spectrum of unfavourable events without

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anchoring our analysis to the system-specific implications that terms such as "adversity", "disruptions", or "disturbances" might carry.

It should be noted that not all terms deemed undesirable in the various reviews carry an equivalently strong negative connotation. For instance, while the term "disaster" unequivocally conveys a profound negative implication, words such as "change", "situation", and "condition" are relatively neutral and do not intrinsically embody a similarly intense negative sentiment. This distinction between varying degrees of negative valence in terminologies is crucial because the concept of resilience covers a wide spectrum of adversities characterised by different amplitudes, durations, and intensities. This distinction is especially significant in distinguishing between incidents ranging from minor, local, anticipated transient failures to catastrophic, unpredictable, systemic events. The consideration of a large spectrum of adverse events is explicitly mentioned in several definitions and conceptualisations, for instance, "in the most diverse situations" (#95), "expected and unexpected situations" (#136), "under varying conditions" (#188), "all kind of hazards" (#284), and "any changes" (#321).

The lexicon encompassing negatives is notably expansive, incorporating a plethora of terms ranging from "Abnormal situations" and "Alterations" to "Catastrophic changes" and "Continuous significant stresses". This extensive vocabulary further extends to "Destabilising perturbations", "Exceptional events", "Future crises", "Hazard effects", "Major disasters", "Potentially damaging events", "Short-term stressors", "Unanticipated dangers", "Unfavourable conditions", and "Unusual events". In total, reviews' authors use 281 different ways to refer to negatives (see Supplementary Materials Table S3). Despite this linguistic diversity, a structured typology can be effectively developed to categorise the myriad terms. This proposed typology systematically classifies terms into nine distinct categories: six corresponding to specific characteristics of adverse events and three corresponding to the knowledge of these six specific characteristics.

1. **Origin of the Event**: Terms in this category refer to where the events come from, their source. For instance, "Internal errors" (#26), "Natural hazards" (#286), and "Environmental stressors" (#347) mean the event originates from inside or outside the system.
2. **Effects or Consequences**: This category focuses on what the impacted elements are. For instance, "Operations cessations" (#368), "Performance loss" (#158), and "Negative economic impacts" (#265). It can also have more general meanings, such as "Failure consequences" (#269), "Hazard effects" (#41), and "Extreme events impacts" (#208).
3. **Amplitude of the Event**: This encompasses the intensity scale of the event, including its temporal extent, impact magnitude, and resultant consequences.
    - **Amplitude in time (i.e., duration**: "Sudden shocks" (#450) and "Long-term changes" (#243).
    - **Amplitude in consequences**: "Severe disruptions" (#225) and "Fatal crashes" (#5).
    - **Amplitude in size**: "Major events (#360)".
4. **Quantity/Types of Considered Events**: This addresses the dynamics and complexity of events, including scenarios such as ripple effects or interconnected disruptions. For instance, "Multiple possible hazards" (#228), "Simultaneous failures" (#281), "Cascading failures" (#260), "Different stresses scenarios" (#468), and "Impact propagation" (#233).
5. **Time of Consideration of the Event**: It emphasises the temporal aspect of the considered event, such as "Previous disasters" (#254), "Future threats" (#453), and "Ongoing pressures" (#350).

6. **Frequency/Probability of Occurrence**: This category assesses the regularity of the event, ranging from low-probability occurrences to those commonly encountered in everyday scenarios. Examples are "Rare disastrous events" (#239) and "Day-to-day fluctuations" (#243).

Since sociotechnical systems are complex systems, the inherent intricacy of these occurrences often results in a partial or incomplete understanding among the system's agents that are required to deal with these events. This limitation in agents' knowledge and awareness is a critical factor influencing the terminological diversity employed by scholars in this domain. Specifically, these terms can be broadly categorised into three distinct dimensions based on the characteristics of the events and the agents' capacity to reason and interact with them. These dimensions are: knowability, predictability, and anticipability/avoidability.

A. **Knowability**: This dimension pertains to the extent to which the adverse event is understood by agents/stakeholders or can be comprehended within the existing knowledge framework. It reflects the degree of informational accessibility about the event's nature, characteristics, and potential consequences. Examples are "Uncertain environment" (#144), and "Normal situations" (#393), which refer to unknown and known conditions, respectively.
B. **Predictability**: This aspect revolves around the ability to foresee an event before its occurrence. Predictability is contingent upon the availability and analysis of relevant data, patterns, and historical precedents that can signal the likelihood of such events. Examples are "Unpredicted situations" (#361) and "Unpredictable events" (#230).
C. **Anticipability/Avoidability**: This is closely related to predictability, where anticipability refers to the capability to prepare for an event in advance, such as "Unanticipated disturbances" (#317).

Such a typology not only aids in navigating the extensive terminological landscape, but also provides a comprehensive framework for understanding and analysing the multifaceted nature of adverse events within various contexts. A complete list of negatives mentioned in the 484 definitions and conceptualisations is presented in Table S3 in the Supplementary Materials.

Positives

In 54% (262/484) of definitions and conceptualisations, another recurring element is the explicit reference to an entity of value inherently associated with the system under consideration. This valuable entity may encompass the system in its entirety or specific components thereof, such as its functions, infrastructures, services, operations, or performances. These aspects represent critical attributes or characteristics of the system that are vulnerable to adverse events. These events pose significant threats to these valuable elements, potentially compromising their integrity, quality, or effectiveness. These elements are collectively referred to as "positives." This nomenclature is adopted to underscore their intrinsic value and critical importance to the overall integrity and efficiency of sociotechnical systems. In addition to "system", the most used terms are "function\functionality\functioning" (114 occurrences), "performance" (65 occurrences), and "operation\operational" (64 occurrences). Here, we explain their importance.

Function: an STS is designed to perform a specific set of tasks, all contributing to a larger goal or purpose. This implies that the components within the system are organised and interact in a way that enables it to achieve this intended outcome, often through a coordinated process or a series of interrelated actions. The function of a system defines its role, utility, and the reason for its existence within a broader context. For instance, the function of an airport is to facilitate air transportation. This includes ensuring safety and efficiency of operations for the landing, takeoff, and parking of aircraft, as well as the handling of passengers and cargo. The function of a nuclear power plant is to generate electricity through the controlled use of nuclear reactions, which is then distributed for residential, commercial, and industrial use.

Performance: performance is the ability of a system to achieve specific outcomes or results, often measured against predefined standards or objectives. Performance can encompass various aspects such as efficiency, effectiveness, reliability, and productivity. It implies how well the system operates under different conditions, how it handles demand, and its capability to meet its intended goals. For an airport, examples of performances include the following: efficiency in handling flights (the number of flights an airport can handle within a certain time frame, turnaround times for aircraft, and cumulative delays), passenger throughput (the number of passengers entering or leaving the airport per unit of time), customer satisfaction (level of service provided to passengers, including amenities, cleanliness, and overall passenger experience), and environmental impact (efforts to minimize noise pollution or air pollution). For a nuclear plant, performance is represented by power generation (the amount of electricity produced), operational reliability (the ability to operate continuously without unscheduled shutdowns), safety record (maintaining safety standards to prevent accidents, manage radioactive materials, and protect workers), and cost-effectiveness (the economic efficiency of producing electricity, including operational and maintenance costs).

Operation: an operation is a series of actions, tasks, or activities, systematically organised and executed to achieve a specific goal. It involves planning, resource allocation, management, and continuous improvement to ensure efficiency and effectiveness. For instance, in airports operations can be: ground handling (baggage handling, aircraft towing, refuelling, and servicing the aircraft), air traffic control (controllers manage the movement of aircraft on the ground and in the airspace around the airport, ensuring safe takeoffs and landings), passenger services (check-in, boarding, security checks, customer service, handling passenger inquiries), and maintenance and repairs (regular maintenance of airport facilities and equipment, including runways, terminals, and other infrastructure). In a nuclear plant, operations are as follows: the control of the fission process, maintaining the reactor's cooling system, handling and disposing of radioactive waste products, scheduled inspections, and radiation monitoring.

Other examples of positives are as follows: "services", "objectives", "processes", "safety level", and "working conditions". A complete list of positives mentioned in the 484 definitions and conceptualisations is presented in Table S4 in the Supplementary Materials.

Actions

The definition #221 states that resilience is the "ability of a system to cope with disturbance and to recover its functionality". The phrase outlines two components: "to cope with" and "to recover", which shows an explicit implication of some required action or activities in order for a system to be resilient. "To cope with" refers to the system's immediate and effective response to disturbances. "To recover" extends beyond immediate response, emphasising a longer process of restoring and repairing the system to its original state. Recovery may encompass the physical reconstruction or the re-establishment of operational functionality. In 97% (468/484) of definitions and conceptualisations, a similar necessity of actions or activities is mentioned. Examples of other actions are: "to adjust" (#345), "to anticipate" (#103), "to change" (#24), "to identify" (#402), "to regulate" (#361), "to repair" (#464), and "to respond" (#86). While our analysis categorises these imperatives broadly under the umbrella term "actions," it should be noted that they encompass a spectrum of dynamics that could be described as activities, tasks, behaviours, or processes.

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Essentially, these terms signify proactive endeavours—a range of deliberate and strategic "doings" or interventions—needed for a system to exhibit resilience.

It should be noted as well that several verbs such as "to absorb," "to overcome," and "to achieve," would be more accurately characterised as the outcomes or consequences of actions (i.e., the system's state) rather than the actions themselves. For instance, "to absorb" may denote the capacity to mitigate impacts, a consequence of certain proactive measures rather than a direct action. Similarly, "to overcome" and "to achieve" refer to the end-states or goals of a series of actions or activities. Moreover, the four terms "adaptive capacity" (#235), "capacity to adapt", "adaptation" (#52), and "to adapt" (#48) essentially refer to the same core idea and have all been considered as actions (or potential for actions).

The actions used within conceptualisations (such as "to adjust", "to anticipate", "to change", and "to identify"), are invariably contextualised in relation to either a negative aspect (such as "disruptions", "disturbances", or "adverse events") or a positive element (such as "system", "level of service", "objectives", and "operations"). These actions are not perceived in isolation; rather, they are understood as responses to specific challenges (the negatives) or as efforts to preserve or enhance certain valued aspects (the positives) of a system. For instance, in the conceptualisation #139: "System's capacity to recover from a disruptive event and resume its normal operation", the action "to recover" is directly associated with the negative "a disruptive event" and aimed at resuming a positive element, the "normal operations." This linkage between actions and their contextual factors—either as responses to negatives or as measures to uphold positives—seems to be a fundamental factor in understanding the dynamic interplay of resilience within systems, as they are often present in the diverse definitions and conceptualisations.

The most used actions related to a negative are: "to recover from" (121 occurrences), "to absorb" (94 occurrences), "to adapt to" (93 occurrences), and "to withstand" (48 occurrences). The most used actions linked to a positive are: "to maintain" (69 occurrences), "to recover" (59 occurrences) and "to return to" (31 occurrences). The complete list is presented in the Table S1 in the Supplementary Materials (for actions related to negatives) and Table S2 (actions related to positives).

Constraints on Actions

In 32% (157/484) of the definitions and conceptualisations of resilience, actions (or consequences of actions) are delineated with accompanying constraints. These constraints, exemplified by terms such as "as fast as possible," "at a rational cost," "effectively", and "in a timely manner" serve to qualify and define the parameters within which these actions should be executed. For instance, constraints such as "as quickly as possible" (#98) or "in the shortest time possible" (#189) emphasise the urgency and time sensitivity associated with the resilience actions. This underscores the need for rapid response and recovery to minimise the duration and extent of disruption impact. Similarly, constraints such as "at a rational cost" (#310) and "efficiently" (#224) imply that actions should not only be effective but also resource-efficient, balancing efficacy with economic and operational feasibility. Phrases such as "comprehensively considering the response time, operation costs, and possibility" (#71) and "in an efficient manner" (#41) further articulate the multi-dimensional nature of the constraints, incorporating factors such as time, cost, feasibility, and overall system impact. The most frequent terms are the following: "quickly" (40 occurrences), "rapidly" (27 occurrences), and "acceptable levels" (12 occurrences). The complete list is presented in Table S5 in the Supplementary Materials.

Building upon the previous analysis of constraints in resilience actions, it is evident that systems, when confronted with various types of disruptions, inherently strive to

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minimise key negative impacts. Specifically, systems aim to reduce costs, time, and losses to the lowest feasible extent.

- Minimising Cost: Cost efficiency is a crucial consideration. Systems seek to manage disruptions in ways that are economically viable, ensuring that the financial burden of response and recovery is as low as possible. This includes direct costs, such as repairs, and indirect costs, such as lost revenue or productivity.
- Minimising Time: Time is of the essence in managing disruptions. Systems endeavour to restore normal operations swiftly, minimising the duration of impact. This rapid response is essential not only to reduce operational downtime but also to mitigate the cascading effects of the disruption.
- Minimising Losses: Beyond financial aspects, minimising losses encompasses a broader scope, including preventing loss of service, operational capacity, customer trust, or even loss of lives in critical systems. The goal is to limit the extent of damage and quickly return to pre-disruption performance levels.

These constraints can be understood as benchmarks for satisfactory resilient behaviour. These constraints are not arbitrary but are instead informed by an estimation of what constitutes an effective and efficient resilience response within the context of a given system. The determination of what is satisfactory in the context of resilience is a complex assessment that takes into account the specificities of the system, the nature of a considered disruption, and the realistic capabilities of the system to respond. It involves evaluating trade-offs between different constraints, such as how quickly a system can respond versus the cost implications of such a response. These constraints also serve as operational benchmarks or targets for the system to achieve in its resilience efforts. For example, a system may aim to restore operations within a certain, predefined, time frame (time constraint) while keeping costs below a predetermined level (cost constraint) and minimising the extent of operational disruption or damage (loss constraint).

The consequence of these constraints is that they introduce additional layers of complexity and requirements into the resilience process. They necessitate a careful balancing act between various factors—speed, cost, effectiveness, and efficiency—thus shaping the strategic approach to resilience. Constraints also define the standards and expectations for what constitutes successful adaptations, ensuring that actions are not just reactionary but also aligned with broader systemic goals and practical realities. The presence of these constraints in the definitions highlights the recognition that resilience is not only about absorption or recovery but involves doing so within specified, often challenging, requirements.

Time of Execution of Actions

A recurring theme, explicitly mentioned in 30% (143/484) of the definitions and conceptualisations, is the temporal aspect associated with the actions required to effectively address disruptions. This emphasis on timing is crucial in understanding when specific resilience actions should be initiated and executed. For instance, definition #6—"A resilient system can adjust its functioning prior to, during, and following changes and disturbances, so that it can continue to perform as required after a disruption or a major mishap, and in the presence of continuous stresses," explicitly delineates the temporal stages—"prior to", "during", and "following"—which indicate the periods for action execution.

Further exemplifying this temporal dimension, other definitions incorporate phrases such as "after facing" (#239), "after the occurrence" (#238), and "afterwards" (#425), which pinpoint the post-event phase as a critical time for resilience actions. Similarly, terms such as "as soon as possible" (#75) and "at an early stage" (#119) emphasise the importance of prompt and proactive responses. "At the time of occurrence" (#238), "in the presence of"

(#151) and "during" (#449) underscore the need for pre-emptive and concurrent actions in response to potential or ongoing disturbances. The complete list of the terminology is presented in Table S6 in the Supplementary Materials.

These temporal qualifiers in resilience definitions serve a dual purpose: they not only specify the timing of actions but also highlight the continuous and dynamic nature of resilience. By categorising actions within these temporal frames, the definitions implicitly advocate for a comprehensive approach to resilience, encompassing anticipatory measures, immediate responses, and post-event recovery processes. This temporal framing reinforces the concept of resilience as an ongoing, adaptive process, rather than a static state, necessitating actions that are aligned with the specific phases of disruption and stress a system encounters.

The prevalence of the temporal prepositions "after" (63 occurrences) and "during" (25 occurrences) in the context of resilience discussions aligns coherently with the fundamental essence of resilience, which centrally involves addressing unexpected events. This linguistic pattern reflects the reactive nature of many resilience strategies and actions. First, the frequent use of "after" suggests a strong focus on the post-event phase in resilience planning and response. It indicates that a significant aspect of resilience involves actions taken in the aftermath of an unexpected event. This encompasses recovery and rebuilding processes, learning from the event, and improving future preparedness. The high occurrence of "after" underlines the importance placed on the ability of systems to bounce back and restore functionality following disruptions. Second, the use of "during" emphasises the importance of actions taken in the midst of an unexpected event. This aligns with the need for systems to have effective mechanisms for immediate response and management of crises as they unfold. It reflects the criticality of real-time decision-making, resource allocation, and operational adjustments to mitigate the impact of the event while it is occurring. The predominance of these temporal prepositions underscores the fact that awareness and identification of many unexpected, unknown events often occur only when they are already unfolding or have already happened. Therefore, it appears that resilience is fundamentally conceptualised as systems respond to, manage, and recover from these unexpected, unknown events. The emphasis on "after" and "during" in resilience discourse highlights this reactive dimension of resilience, where the focus is on dealing with events that are either currently happening or have already occurred, rather than only on preventative measures, even though they are important as well for the system.

It is noteworthy that many action-oriented verbs inherently carry an implicit temporal connotation. The following verbs implicitly signal the timing of actions relative to a disruptive event, even in the absence of explicit temporal markers:

- Pre-Disruption Actions: Verbs such as "to anticipate" (#325), "to avoid" (#28), "to plan for" (#420), and "to prepare for" (#183), inherently suggest actions taken prior to a potential disruption. These terms imply a forward-looking, proactive approach, focusing on measures that pre-emptively address potential risks or challenges. The underlying temporal aspect in these actions is one of foresight and preparation, highlighting the pre-emptive phase of resilience.
- Actions During Disruption: Conversely, verbs such as "to cope with" (#332), "to deal with" (#122), "to detect" (#411), and "to respond to" (#361) imply actions that occur simultaneously with a disruption. These terms denote immediate reaction and management strategies employed as the event unfolds. The embedded temporal implication here is one of real-time, in-the-moment response, underscoring the importance of adaptability and immediate problem-solving in resilience.
- Post-Disruption Actions: Lastly, verbs such as "to bounce back" (#67) and "to learn from" (#22) are indicative of actions undertaken after a disruption has occurred. These

terms reflect the post-event phase of resilience, focusing on recovery and learning from past experiences to enhance future preparedness and response. The implicit timing in these actions is retrospective and restorative, emphasising the importance of reflection, learning, and improvement following an adverse event.

3.1.2. Categorisation

Following the previous analysis, it is possible to categorise definitions and conceptualisations of STS resilience into categories made of a combination of the four fundamental constructs: negatives, positives, actions, and constraints on actions. In this section, we have deliberately chosen to omit the hypernyms commonly associated with definitions and conceptualisations of resilience—phrases such as "Resilience is the capacity to...", "Resilience is the system's ability to...", "is the capability of a sociotechnical system to...", and "is the situation where...". Instead, the focus has been narrowed to concentrate exclusively on four theoretical constructs. For each of the categories, one illustrating example from Appendix A Table A2 is provided in the Tables 1–4.

Table 1. Categorisation with 2 constructs.

	Constructs	Examples
1	$Action + negative$	#27—To absorb unexpected events
2	$\sum Action + negative$	#23—To absorb, adapt, and transform in the face of challenges
3	$Action + \sum negative$	#321—To absorb any changes or disturbances
4	$\sum Action + \sum negative$	#387—To adapt or absorb disturbance, disruption and change
5	$\sum(Action + negative)$	#198—To withstand stresses and cope with failures
6	$Action + positive$	#222—To restore the system to its original level of service
7	$\sum Action + \sum positive$	#140—To preserve, improve, or return to the system's original performance and functions

Table 2. Categorisation with 3 constructs.

	Constructs	Examples
8	$Action + positive + negative$	#29—To regain a previous state following a disturbance
9	$Action + positive + constraint$	#315—To maintain the services in acceptable levels
10	$Action + negative + constraint$	#442—To absorb shocks while maintaining function
11	$Action + positive + \sum negative$	#430—To maintain the system' services under stress and in turbulent conditions
12	$Action + negative + \sum constraint$	#320—To recover safely and efficiently from adverse events
13	$\sum Action + negative + constraint$	#250—To anticipate, absorb, adapt to, and recover quickly from a troublesome occasion
14	$Action + \sum negative + constraint$	#55—To accommodate variable and unexpected conditions without catastrophic failure
15	$Action + \sum positive + constraint$	#211—To sustain a level of functionality or performance over a given period range
16	$\sum Action + \sum negative + constraint$	#87—To withstand, to adapt, and to quickly recover from stresses and shocks
17	$\sum Action + negative + \sum constraint$	#257—To anticipate, absorb and recover from the serious occasions in a convenient and successful way
18	$\sum Action + positive + \sum constraint$	#251– To continually change and adapt the system yet stay within critical thresholds
19	$Action + \sum positive + \sum negative$	#133—To adapt existing resources and skills to new systems and operating conditions

Table 2. *Cont.*

	Constructs	Examples
20	$\sum Action + positive + \sum negative$	#196—To maintain and adapt its operational performance in the face of failures and other adverse conditions
21	$\sum(Action + negative) + constraint$	#194—To reduce the chances of shock, to absorb such a shock if it occurs, and to recovery quickly after a shock
22	$\sum(Action + positive) + constraint$	#467—To maintain the system's demonstrated level of service or to restore the system to that level of service in a specified time frame
23	$\sum(Action + positive) + negative$	#261—To maintain a steady state or recover from a disruptive event to be able to operate as normal
24	$\sum(Action + positive) + \sum negative$	#85—To adapt the system's behavior to maintain continuity of the operations in the presence of disruptions or distress
25	$\sum(\sum Action + negative) + constraint$	#183—To prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions

Table 3. Categorisation with 4 constructs.

	Constructs	Examples
26	$Action + negative + action + positive$	#139—To recover from a disruptive event and resume normal operations
27	$Action + positive + negative + constraint$	#279—To recover the system's desired level from disruption event within an acceptable time
28	$Action + negative + action + constraint$	#371—To avoid disruptions, and if unsuccessful recover quickly
29	$Action + \sum negative + action + positive$	#148—To absorb continuous and unpredictable change and still maintain vital functions
30	$Action + positive + \sum action + negative$	#370—To maintain the organisation's operations, adapt, and recover from a disaster
31	$\sum(Action + negative) + action + positive$	#9—To absorb the impact of disruptions, to adapt to disruptions, and to recover to a normal regime
32	$Action + negative + action + \sum positive$	#445—To absorb disturbances and still retain the system's basic function and structure
33	$Action + positive + negative + \sum constraint$	#367—To return quickly to the functional acceptable state from disruptions
34	$Action + positive + \sum(action + negative)$	#476—To monitor the system's operations, anticipate potential-failures, response to failure, and learn from failures
35	$Action + negative + \sum(action + positive)$	#50—To survive uncertain extreme events outside traditional design boundaries, achieve a safe-to-fail state and recover functionality
36	$\sum Action + negative + \sum action + positive$	#220—To adapt by resisting or changing when exposed to hazards in order to reach and maintain an acceptable level of functioning
37	$\sum Action + positive + negative + constraint$	#446—To withstand and stay operational at the required level of safety during the impact of a given disruptive event
38	$\sum Action + \sum positive + negative + constraint$	#230—To restore or adapt as quickly as possible functions and infrastructures when encountering unpredictable events
39	$\sum Action + positive + \sum negative + constraint$	#309—To maintain or quickly recover the system's function after a disruption or a disaster
40	$\sum(Action + positive) + negative + constraint$	#265—To maintain expected level of service or to regain that level of service within a specified time interval after the disturbance

Table 4. Categorisation with 5 constructs.

	Constructs	Examples
41	$Action + negative + action + positive + constraint$	#307—To experience a negative, potentially damaging event and return to a healthy state of operations in a reasonable amount of time after that event
42	$Action + negative + action + positive + \sum constraint$	#481—To absorb disruptive events gracefully and restore the pre-disruption level of service in a specified time frame
43	$\sum(Action + positive) + action + negative + constraint$	#434—To maintain function and to recover rapidly from a severe shock to achieve a desired state
44	$\sum(Action + negative) + action + positive + constraint$	#284—To resist all kind of hazards, withstand the consequences of initial incident, and quickly restore back to normal operation
45	$Action + negative + \sum(action + positive) + \sum constraint$	#313—To absorb disruptive events gracefully, to maintain a demonstrated level of service, or to return to a level of service equal or greater than the pre-disruption level of service within a reasonable time frame
46	$Action + negative + \sum action + \sum positive + \sum constraint$	#303—To subsist to an unpredictable event by planning, absorbing, recovering and adapting efficiently and quickly all system's elementary functions and structures
47	$Action + \sum negative + action + positive + constraint$	#26—To adapt to internal and external errors bychanging the system's mode of operations, without losing its ability to function
48	$Action + negative + \sum action + positive + constraint$	#189—To reduce impacts by maintaining or restoring a regular level of activities in the shortest time possible
49	$\sum Action + negative + \sum positive + action + constraint$	#103—To anticipate, circumvent threats to the system's existence and primary goals, and rapidly recover
50	$Action + \sum negative + action + positive + \sum constraint$	#317—To respond to an unanticipated disturbancethat can lead to failure and then to resume normal operations quickly and with minimum decrement in their performance

3.1.3. Composition

It is possible to apply the identified schemes to more complex definitions. We illustrate here with 3 examples:

#310—To recover activities, to meet the demand, and to recover and ensure the persistence of the performance level at a rational cost within a limited period, when faced with disruptions to the system caused by unconventional emergency events, $Action + positive + action + negative + \Sigma action + positive + \Sigma constraint + \Sigma negative$

#457—To return to some normal condition or state of functioning after a disruptive event, to cope with pressure and problems by being flexible without compromising system performance, and to adapt to a new normal state, where system functioning is reorganised or enhanced in some way in response to the disruption they face, $Action + \Sigma positive + negative + action + \Sigma negative + action + constraint + action + positive + \Sigma action + positive + action + negative$

#257—To anticipate, absorb, and recover from the serious occasions in a convenient and successful way, it alludes to the system's capability to recover rapidly after a disaster, or, in general, the ability to anticipate the exceptionally and HILP events, the rapid recovery from troublesome occasions, and absorbing experiences to adjust its infrastructure and operations and prevent or alleviate the effect of same future events, $\Sigma action + negative +$

$\Sigma constraint + action + negative + constraint + action + \Sigma negative + action + negative + constraint + action + negative + action + \Sigma positive + \Sigma action + negative$

3.2. Resilience as a Measure or as a Set of Properties

Among the different conceptualisations of STS resilience, around 3% of them (16/484) do not explicitly reference specific actions to be undertaken. Instead, some conceptualisations opt to characterise resilience in terms of quantifiable measures or assessments. This approach reflects an analytical perspective, focusing on resilience as a measurable attribute of a system rather than a process or a capacity. For example, #44 describes resilience as "remaining system's performance during a disruption," emphasising the evaluation of system performance under adverse conditions. Similarly, #177 defines resilience as "a function of the system functionality loss and the failure event duration," suggesting a quantitative relationship between resilience, the extent of functionality loss, and the duration of the disruptive event. The conceptualisation #270, "The degree of a passive survival rate plus a proactive survival rate," implies a composite measure combining both reactive and anticipatory aspects of system survival. In contrast, #480 frames resilience as "A measure of maximum agitation a system can take in before getting displaced from one state to another," focusing on the threshold of system tolerance to disturbances. Finally, #482 views resilience as "A time-dependent ratio of recovery to loss suffered by the system at some previous point," introducing a temporal dimension to the assessment of resilience, quantifying recovery in relation to past losses. These examples illustrate an alternative approach to understanding resilience, one that prioritises the measurement and quantification of system attributes and responses, rather than detailing specific actions or strategies. This perspective provides a more objective, metric-based understanding of resilience, facilitating comparative analysis and benchmarking across different STS and scenarios.

Other conceptualisations emphasise some properties or qualities a system should possess to be resilient instead of focusing on some actions or measures. For instance, #351 identifies key indicators of a resilient system, including "top-level commitment, awareness, learning culture, just culture, flexibility, and preparedness." Similarly, #390 describes resilience as a combination of "risk management, vulnerability, reliability, robustness, flexibility, and survivability". In #479 and #200, resilience is defined in terms of four properties: "robustness, redundancy, resourcefulness, and rapidity".

The list of conceptualisations that do not explicitly refer to some actions (or capacity/necessity for actions) is #34, #44, #54, #177, #200, #206, #244, #270, #272, #336, #351, #390, #447, #479, #480, and #482.

4. Discussion

It appears that STS resilience is largely conceptualised as a dynamical process or outcome shaped by the actions of agents within these systems. Central to this perspective is the recognition that the "socio" aspect of sociotechnical systems—encompassing the human actors and their interactions—is fundamental in mediating the system's response to adversity. These agents, through their decision-making, problem-solving, and adaptive capacities, actively contribute to the system's resilience. Their actions, ranging from preventative strategies to real-time responses to adverse events, are pivotal in maintaining or restoring system functionality. Consequently, the resilience of a sociotechnical system can be understood as emergent from the collective and individual actions of its social components. This consideration underscores the importance of human agency in shaping resilience, positioning it at the core of how these complex systems withstand, adapt to, and recover from a large range of situations. Moreover, certain aspects of the analysis

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warrant further commentary and need to be contextualised in relation to one another. In this section, we will discuss several key points regarding what constitutes STS resilience.

4.1. Positives vs. Negatives

The conceptualisation of positives, encompassing elements such as function, infrastructure, state, level of service, performance, objectives, and operations, forms one facet of a dichotomous lens, with adverse events constituting the other. This dichotomy can be compared to the two opposing faces of a coin, wherein the positives represent the valued components of a system, while adverse events symbolise potential threats to these elements. The intrinsic interrelation between these two facets is foundational to our understanding of STS resilience. Adverse events are defined as such, not in isolation, but because of their detrimental impact on these positives. It is the potential or actual impairment of an operation, the compromise of a structure, or the undermining of an objective that characterises an event as adverse. In essence, the concept of adversity gains meaning and significance only in the context of something valued within the system. Therefore, the duality of positives and negatives is not merely a classification but a reflection of the fundamental interconnectedness within systems. The identification and preservation of these positives are crucial, as they are the elements against which the impact of adversity is measured and understood. This interplay underscores the importance of a holistic approach in system analysis, recognising that the resilience of a system is as much about safeguarding the ’positives’ as it is about mitigating the adverse events.

4.2. Known or Unknown Events

The distinction of events as “known” or “unknown” is actually not an intrinsic property of the events themselves but rather a reflection of a system’s prior experiences and learning. Whether an event is considered known or unknown hinges on the system’s historical encounters with similar events and the resultant accumulation of knowledge, procedures, and preparedness strategies. An event is “known” if the system has previously encountered it and has developed specific responses, such as established procedures or plans. Conversely, an event is “unknown” if it falls outside the system’s experiential learning and preparedness, presenting novel challenges that require adaptive responses. Moreover, despite the presence of plans and procedures developed from past experiences, the effectiveness of a system’s response to disruptions critically depends on the agents involved. These agents—individuals or groups responsible for managing the disruption—must understand and make sense of the unfolding event. Their ability to interpret, adapt, and make decisions in real-time is crucial for the system to be resilient. In situations where agents encounter disruptions that are not adequately addressed by existing plans, the event effectively becomes ’unknown’ in a practical sense. The process of dealing with such events necessitates on-the-spot decision-making based on the agents’ understanding of the situation. This scenario underscores the dynamic nature of adaptive capacity, where situation awareness and sense-making are paramount. Finally, it should be noted that there actually exists a continuum spectrum regarding the extent of knowledge about these events, ranging from “known event” to “unknown event”. This spectrum encapsulates the varying degrees of familiarity and predictability associated with different events. Such a continuum highlights the dynamic nature of knowledge and preparedness in the face of potential adversities, and shifts the problem of dealing with external adversity (what is happening?) to internal knowledge, skills, plans, learning/creative/resourceful capacities (system-wise—how is the current state of the system?).

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4.3. Actions as Forces

Actions can symbolically be understood as forces that separate the positives (desirable attributes or outcomes of a system) from the negatives (adverse events or conditions). These actions function as an opposing force, striving to maintain a buffer between the positive and negative aspects, or to prevent the transformation of positives into negatives. In this context, actions are not mere responses but are proactive and strategic endeavours aimed at safeguarding the integrity, functionality, and objectives of the system—the positives. They serve as a bulwark against the encroachment of negatives, such as disruptions, stresses, or pressures, which can compromise the system's desired state. For instance, actions like "anticipating" or "preparing for" potential disruptions are proactive measures that keep negatives at bay, ensuring that the positives remain unaffected. Similarly, in scenarios where negatives interact with the system, actions like "coping with", "adapting to", and "recovering from" are crucial in mitigating their impact. These actions symbolise a countervailing force that works to restore or maintain the positives, preventing the negatives from causing irreversible damage or turning the system's positive attributes into negative outcomes.

4.4. Resilience and Desirability

The hierarchy of desirability in behaviours and outcomes is an important aspect of STS resilience. Certain responses to adversity are more favourable than others, creating a gradation of desirability based on the efficiency and effectiveness of the system's reaction. For instance, avoiding adverse impacts is inherently more desirable than dealing with them when they occur. Moreover, the concept of constraints on actions (or consequences of actions) can be interpreted as a "desirability envelope" within which the system's performance should ideally be contained. For example, a quick recovery is more desirable than an indeterminate recovery period, and maintaining operational continuity during adversity is preferable to prolonged system degradation. Similarly, reorganising the system at a rational cost is more advantageous than doing so at any cost. When confronted with adverse events exceeding the system's adaptive capacity, a gradual degradation ("degrading gracefully") is more desirable than an abrupt and total collapse. Maintaining control during a failure, even if partial, is better than a complete operational shutdown. In the spectrum of undesirable events, a near-miss is deemed preferable to an actual accident, and an accident without loss of life is more favourable than one with fatalities.

The distinction between a resilient system and a recoverable system lies precisely in these constraints or desirability levels. A system that regains functionality after disruption is a recoverable system, but a system that does so efficiently, optimally, with limited cost and reorganisation, and in a timely manner is a resilient system. Thus, resilience transcends and includes the concepts of absorption, recovery, or adaptation, adding layers of desirability and efficiency to the system's response. Resilience, therefore, is not merely about bouncing back; it is about doing so in a way that aligns with optimal, pre-defined, desirable parameters of system performance and efficiency.

4.5. Core of STS Resilience

In the scientific exploration of complex concepts, the pursuit of establishing precise boundaries often proves to be a futile endeavour. This is because complex concepts are typically characterised by their multifaceted nature, encompassing a wide array of interpretations, applications, and implications that defy rigid categorisation. Consequently, the effort to delineate exact boundaries can lead to oversimplification or misinterpretation of the concept's true scope and significance. Instead, a more fruitful approach is to concentrate on the core aspects of the concept. By focusing on the central elements or fundamental principles that constitute the essence of the concept, researchers can gain a deeper and more

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nuanced understanding. This approach acknowledges the inherent interdisciplinarity and multidisciplinarity of complex concepts, allowing for a more holistic and comprehensive exploration. Focusing on the core rather than the peripheries enables scholars to identify the key characteristics, themes, and patterns that are most critical to the concept. It allows for an examination of how these central elements interact with each other and with other related concepts. This method not only facilitates a clearer understanding of the concept itself but also provides insights into its broader implications and connections within a larger knowledge framework.

It appears that, for STS resilience, the core lies in dealing with unexpected and uncertain situations. There is a rich vocabulary in the 88 reviews to describe these unexpected situations or events. Examples of descriptors of such events are: "ambiguous" [22], "black swans" [6], "deeply uncertain" [37], "inevitable" [32], "irregular" [38], "non-normal" [39], "not-prepare-for" [40], "unanticipated" [41], "unavoidable" [42], "uncommon" [9], "unconventional" [28], "underestimated" [43], "undetected" [33], "unexampled" [44], "unforeseeable" [6], "unimaginable" [45], "unknowable" [39], "unknown" [46], "unobserved" [33], "unprecedented" [2], "unpredictable" [47], "unpreventable" [45], "unspecified" [48], and "unthinkable" [45]. They all reflect the range of different descriptors applied to hard-to-predict and hard-to-avoid events. These terms underscore the inherent unpredictability and complexity of such situations, which are ongoing challenges that systems must actively manage and contend with, given their intrinsic nature of being unavoidable. As a consequence of these unavoidable situations, the role of humans becomes central and paramount. Human agents are key to managing, responding to, and adapting within these unpredictable scenarios. Understanding resilience, therefore, necessitates a deep comprehension of human thinking and behaviour at multiple levels, including cognitive, social, organisational, and both top-down and bottom-up approaches. This human-centric perspective acknowledges that resilience is a reflection of human capabilities, decision-making processes, and collective actions. Attempting to grasp resilience without considering the human element—how people perceive, react to, and handle unexpected events—would be an incomplete endeavour. It is through this human lens that resilience in sociotechnical systems gains its full meaning and relevance, highlighting the intricate interplay between human actors and systemic structures in navigating the uncertain and dynamic landscapes of unforeseen challenges.

4.6. Semantic Gradient and a Hidden Consensus

In the introduction of this meta-review, an initial assertion was posited following the opinions of the different reviews' authors, suggesting an absence of consensus regarding the definitions and conceptualisation of STS resilience. This assertion warrants reevaluation in light of the analytical findings. Contrary to the initial assumption, a closer examination reveals a remarkable coherence among the various conceptualisations of STS resilience, despite the ostensible diversity. This coherence stems from the inherent nuances and semantic flexibility of natural languages, such as English, which permits subtle gradations in meaning—a sort of "semantic gradient" or "connotation continuum". The richness of language, while facilitating diverse expressions, often masks the underlying continuity among concepts. For instance, the nuanced differences between terms such as "disruption" and "disturbance", or "prior to" and "before", "unexpected event" and "surprise event", "to change" and "to modify", "unpredicted" and "unanticipated", "quickly" and "as fast as possible", "normal performance level", and "original functional state", "to resist" and "to withstand", "to minimize" and "to mitigate", and "to limit" and "to circumvent" are emblematic of this phenomenon. These variations, while seemingly distinct, are closely aligned within the semantic spectrum, thereby contributing to the overarching understanding of resilience. This is further elucidated in Section 3.1.2, where the potential for generating a myriad of definitions is explored. Specifically, within the category 41 only, the combinatorial possibilities of selecting one action (related to negatives) from 65 options, one negative from 280, one action (related to positives) from 45, one positive from 128, and one constraint from 84, culminate in the theoretical generation of approximately 8 billion different definitions. If we consider all the possible categorisations that include up to five elements, this number increases to more than 1000 billion. This staggering potential for variability underscores the futility of designating a singular, all-encompassing definition of resilience. Each conceptualisation, though perhaps incomplete in isolation, collectively contributes to a more comprehensive understanding of the term. Consequently, the endeavour to identify the 'best' definition is not only impossible but also overlooks the value inherent in the multiplicity of perspectives and context-dependent considerations.

In synthesising all 484 definitions and conceptualisations, and abstracting from contingent information, a consensus appears. This consensus, distilled to its essence through actions, negatives, positives, and constraints, shows that STS resilience is "moving from an undesirable state to a desirable state in a satisfactory way". The undesirability and satisfactory degrees are context-specific, system-specific, event-specific, and subject to systems' actors (workers, managers, directors, and stakeholders) who can decide on the adequate standards.

4.7. Conceptual Complexity or Systems' Complexity?

The conceptual complexity attributed to resilience, as discussed at the beginning of Section 3, is less a reflection of the inherent intricacy of the resilience concept itself and more an outcome of the profound complexity characterising STS. These systems are distinguished by their multilayered structure, encompassing cognitive, social, technical, organisational, and infrastructural dimensions, all of which are non-linearly intricately interconnected. The multitude of components within these systems, including a diverse array of agents, resources, and processes, further adds to this complexity. Consequently, the difficulty in understanding and operationalising resilience is directly linked to the inherent complexity of STS. The resilience of these systems, therefore, cannot be understood or enhanced without a deep appreciation of their multifaceted and interconnected nature. It is this very complexity that renders the task of ensuring resilience a nuanced and challenging endeavour, requiring a comprehensive and systemic approach that accounts for the various layers and their interdependencies. A pragmatic consequence is that understanding the complexity of resilience as a mirror of the complexity of STS would help scholars in terms of choosing adequate scientific methods for investigating resilience. Researchers may need specific tools and techniques from the science of complexity to study STS resilience.

4.8. From Pre-Paradigmatic Phase to Science

Our findings can also be situated within broader theoretical perspectives on system theory. As outlined by [49], concepts such as adaptation, emergence, self-organisation, and resilience are fundamental to understanding the dynamics of complex adaptive STS. By linking our approach to this theoretical foundation, we argue that it can contribute to ongoing efforts to conceptualise and design STS that are inherently more resilient. In addition, the concept of complex STS resilience currently resides within a pre-paradigmatic phase, underscoring a nascent stage in its academic development and understanding. This phase is characterised by a notable diversity of models, theories, and methodologies, where scholars often operate in isolation or small cohorts, devoid of a unified consensus on foundational principles [50]. This diversity manifests in a broad spectrum of research questions and methodological approaches, each competing for legitimacy and acceptance within the academic community. Such a scenario fosters a vibrant environment of exploration and experimentation, leading to rapid innovations and shifts in research focus as new insights emerge. However, this proliferation of competing ideas also signifies a lack of consensus on what constitutes valid and essential research queries or methodologies, thus hindering the field's progression towards a cohesive, universally accepted scientific paradigm, as explained in the introduction of this meta-review. To transition STS resilience from this pre-paradigmatic state to the paradigmatic phase—wherein a set of common theories, methods, and standards are widely recognised and adopted—the scientific community must endeavour to foster collaborative dialogues and integrative research efforts. Harmonising discussions and aligning research agendas are imperative to establish a coherent science of resilience. Such concerted efforts will not only facilitate the consolidation of a shared scientific foundation but also enhance the applicability of resilience principles to complex real-world STS.

5. Limitations of the Study

This study has several limitations that should be taken into account when interpreting the results. First, the literature search was conducted exclusively through Web of Science and ScienceDirect. Although these databases offer broad multidisciplinary coverage, they do not index all journals or publication venues. Consequently, relevant studies published outside these platforms may not have been captured.

Second, the identification of conceptual patterns and the linguistic analysis were performed manually by the authors rather than through automated or computational techniques. While the process was carried out systematically and collaboratively, subjective interpretation cannot be entirely eliminated.

Third, the dataset consists of 88 review papers on STS resilience. This focus allowed for a coherent and comparable synthesis, but does not encompass the full corpus of primary research on the topic. Additionally, only review papers published in English were included, meaning that relevant reviews available in other languages were not considered. This may introduce linguistic or regional biases.

Fourth, we did not include reviews focusing on cyber–physical systems (CPS). Although CPS can be interpreted as a type of sociotechnical system, they often form a distinct research stream with different conceptual emphases and were thus excluded to preserve the coherence of the dataset.

Finally, the analysis does not incorporate closely related concepts such as robustness, stability, or antifragility—terms that are sometimes treated as synonyms or near-synonyms of resilience by certain scholars. While these concepts are relevant to the broader discourse, they were beyond the scope of this study.

Despite these limitations, the study provides a structured and transparent synthesis of the terminology and conceptual patterns associated with STS resilience, offering a valuable contribution to organising and advancing discussions in the field.

6. Conclusions

In our comprehensive meta-review, we have meticulously examined 88 reviews focusing on the resilience of sociotechnical systems. Each review delves into specific facets of these systems, ranging from the human factor, organisational dynamics to infrastructural aspects, or explores various interpretations of resilience, such as its role in recovery processes, capacity for absorption, or as a paradigm in managing unexpected disruptions.

From this extensive body of work, we have systematically extracted the definitions and conceptualisations of STS resilience, encompassing diverse perspectives and interpretations. Subsequent to this extraction, we semantically analysed each definition and conceptualisation. This analysis was not merely descriptive but involved a comparative approach, aiming to discern patterns of meaning among the varied definitions.

Our analytic endeavour led to the identification of four principal constructs that underpin these definitions: positives, negatives, actions related to positives or negatives, and constraints on actions. These constructs have provided a foundation for categorising the different definitions and conceptualisations and their elements, facilitating a more structured understanding of resilience within sociotechnical systems.

A pivotal insight emerged from recognising the semantic gradient inherent in the terminology employed by scholars across several dimensions. By acknowledging and analysing this gradient, we unveiled a consensus on the concept of resilience. This consensus, previously obscured by the diversity of terms and constructs, reveals a unified underlying comprehension of resilience, demonstrating the coherence in scholarly discourse despite apparent terminological diversity.

The three research questions outlined in the introduction can now be addressed. First, scholars have provided 484 definitions and conceptualisations of sociotechnical system resilience, which are listed in Appendix Table A2. These definitions reveal four primary patterns of meaning: positive, negative, actions related to positive or negative, and constraints on these actions. Finally, a synthesis of these patterns suggests that the resilience of sociotechnical systems is fundamentally understood by scholars as moving from an undesirable state to a desirable state in a satisfactory way.

The future work will be concerned with conducting a meta-review with a focus on "how to enhance the resilience of STS", with the same corpus of review papers. This forthcoming endeavour aims to meticulously review and synthesise the factors that improve the resilience of these systems. Our objective is to distil these factors into discernible patterns, and elevating them to the status of universal principles for resilience enhancement. This approach is not only pivotal for deepening our understanding of STS resilience but also holds the potential to operationalise resilient behaviours across various domains.

Additionally, future research could build on the present findings in several important ways. First, the integration of computational methods—such as natural language processing, clustering techniques, or semantic network analysis—would enable the examination of larger and more diverse corpora, complementing the manual approach adopted in this study. Second, the principles identified here warrant empirical validation through multiple case studies across different types of STS, in order to assess their explanatory power and applicability in real-world contexts. Third, further work could focus on linking these conceptual principles to practical, operational metrics by developing formal approaches that translate abstract definitions of resilience into measurable indicators. Such efforts would advance both theoretical refinement and practical implementation in the study of STS resilience.

Moreover, the methodology employed in this meta-review possesses significant applicability beyond the scope of sociotechnical systems. It could be adeptly adapted to analyse the diverse conceptualisations of resilience in other system types, thereby serving as a valuable tool to elucidate and streamline communications and discussions in those fields. Such an expansion of our methodology's application could contribute to a more coherent and unified understanding of resilience in their respective domains, facilitating internal dialogues and collaborative problem-solving.

Finally, this study aims to take a step towards advancing the discussion on "What is resilience?" and provides a shared language that promotes more structured conversations, communications, and investigations into the resilience of complex sociotechnical systems. This will enable researchers to shift their focus from conceptual analyses to more formal, quantified investigations of STS resilience.

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Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/systems14010071/s1, Table S1: Actions related to negatives; Table S2: Actions related to positives; Table S3: Negatives; Table S4: Positives; Table S5: Constraints on actions; Table S6: Time of execution of actions.

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Data Availability Statement: All the data used in this meta-review is accessible through the 88 review papers listed in the Table A1 of the Appendix A.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Information on the 88 review papers.

#	Title	Authors	Considered Systems	Journal/Conference	Year
1	Fameworks, quantitative indicators, characters, and modeling approaches to analysis of energy system resilience: A review	S. Ahmadi, Y. Saboohi, A. Vakili [4]	Energy systems	Renewable and Sustainable Energy Reviews	2021
2	Resilience modeling concepts in transportation systems: a comprehensive review based on mode, and modeling techniques	S. Ahmed, K. Dey [42]	Transportation systems	Journal of Infrastructure Preservation and Resilience	2020
3	Analysis of quantitative metrics for assessing resilience of human-centered CPPS workstations	T. Aruväli, M. De Marchi, E. Rauch [34]	Industrial human workstations	Nature Scientific Reports	2023
4	What Is Resilience and How Can It Be Nurtured? A Systematic Review of Empirical Literature on Organizational Resilience	E. Barasa, R. Mbau, L. Gilson [48]	Health care systems	Int J Health Policy Manag	2018
5	Organizational resilience in the oil and gas industry: A scoping review	F. Bento, L. Garotti, M. Mercado [5]	Oil and gas industry	Safety Science	2021
6	On the rationale of resilience in the domain of safety: A literature review	J. Bergström, R. van Winsen, E. Henriqson [39]	Safety systems, Aviation	Reliability Engineering and System Safety	2015
7	Resilience in railway transport systems: a literature review and research agenda	N. Bešinović [51]	Railway transport systems	Transport Reviews	2020
8	Resilience: the concept, a literature review and future directions	R. Bhamra, S. Dani, K. Burnard [27]	Organisations and infrastructures	International Journal of Production Research	2011
9	Old wine in new bottles? Understanding infrastructure resilience: Foundations, assessment, and limitations	W. Bi, K. MacAskill, J. Schooling [32]	Critical infrastructures	Transportation Research Part D	2023
10	Reviewing qualitative research approaches in the context of critical infrastructure resilience	R. Cantelmi, G. Di Gravio, R. Patriarca [52]	Critical infrastructures	Environment Systems and Decisions	2021
11	Transportation Resilience: A summative review on Definition and Connotation	M. Cao [53]	Transportation systems	International Conference on Automation, Mechanical Control and Computational Engineering (AMCCE)	2015

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
12	Critical review of existing built environment resilience frameworks: Directions for future research	G. Cerè, Y. Rezgui, W. Zhao [54]	Infrastructure systems	International Journal of Disaster Risk Reduction	2017
13	Resilience assessment and management: A review on contributions on process safety and environmental protection	C. Chen, J. Li, Y. Zhao c, F. Goerlandt, G. Reniers, L. Yiliu [55]	Industrial processes and safety	Process Safety and Environmental Protection	2023
14	Systems resilience assessments: a review, framework and metrics	Y. Cheng, A. Elsayed, Z. Huang [56]	Multiple sociotechnical systems	International Journal of Production Research	2022
15	Resilience of Critical Infrastructures: Review and Analysis of Current Approaches	C. Curt, J.-M. Tacnet [6]	Critical Infrastructures	Risk Analysis	2018
16	Resilience engineering of industrial processes: Principles and contributing factors	L.T.T. Dinh, H. Pasman, X. Gao, M.S. Mannan [33]	Safety-critical industrial systems	Journal of Loss Prevention in the Process Industries	2012
17	Simulation of transportation infrastructures resilience: a comprehensive review	B.-X. Dong, M. Shan, B.-G. Hwang [57]	Transportation systems	Environmental Science and Pollution Research	2022
18	Patterns of resilience: A scoping review and bibliometric analysis of resilient health care	L. A. Ellis, K. Churruca1, R. Clay-Williams, C. Pomare, E. E. Austin, J. C. Long, A. Grødah, J. Braithwaite [58]	Health care systems	Safety Science	2019
19	Resilience(N)—a Multi-Dimensional Challenge for Maritime Infrastructures	E. Engler, D. Göge, S. Brusch [59]	Maritime infrastructures	Naše more	2018
20	Measuring the Performance of Transportation Infrastructure Systems in Disasters: A Comprehensive Review	R. Faturechi, E. Miller-Hooks [60]	Transportation Systems	Journal of Infrastructure Systems	2015
21	Review of disaster resilience assessment methods	M. Feofilovs, A. Gravelsins, F. Romagnoli [61]	Energy systems	IEEE 61st International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON)	2020
22	Resilience Engineering in Healthcare: A Systematic Literature Review	J. Fernandes, P.M. Arezes, M.A. Rodrigues [62]	Healthcare systems	18th International Symposium on Occupational Safety and Hygiene (SHO 2022)	2022
23	Adaptation as a source of safety in complex socio-technical systems: A literature review and model development	C.J. Foster, K. L. Plant, N. A. Stanton [63]	Multiple sociotechnical systems	Safety Science	2019

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
24	A metric and frameworks for resilience analysis of engineered and infrastructure systems	R. Francis, B. Bekera [37]	Engineered and infrastructure systems	Reliability Engineering and System Safety	2014
25	A review of resilience management application tools in the transport sector	E. Gaitanidoua, M. Tsamib, E. Bekiarisc [36]	Transportation systems	3rd Conference on Sustainable Urban Mobility (CSUM2106)	2017
26	A review on resilience assessment of energy systems	P. Gasser, P. Lustenberger, M. Cinelli, W. Kim, M. Spada, P. Burgherr, S. Hirschberg, B. Stojadinovic, T. Y. Sun [22]	Energy systems	Sustainable and Resilient Infrastructure	2021
27	Resilience of civil infrastructure systems: literature review for improved asset management	L. F. Gay, S. K. Sinha [64]	Infrastructure systems	Int. J. Critical Infrastructures	2013
28	Resilience activation in extreme situations: a literature review	C. Geoffroy, E. Rigaud, F. Guarnieri [45]	Nuclear industrial systems	European Safety and Reliability Conference (ESREL)	2016
29	Literature Review on Resilience Engineering in the Health-Care Industry	A. Goel [65]	Heathlcare systems	International Conference on Computer Communication and Informatics (ICCCI2022)	2022
30	A systematic review of resilience in the maritime transport	B. Gu, J. Liu [66]	Maritime transport systems	International Journal of Logistics Research and Applications	2023
31	Resilience Assessment Frameworks of Critical Infrastructures: State-of-the-Art Review	D. Guo, M. Shan, E. Kingsford Owusu [67]	Critical infrastructures	Buildings	2021
32	Enabling and impeding factors for organizational adaptive capacity—a review of the literature	H. Hassel, A. Cedergren [7]	Critical organisational infrastructures	32nd European Safety and Reliability Conference (ESREL 2022)	2022
33	A review of definitions and measures of system resilience	S. Hosseini, K. Barker, J.E.Ramirez-Marquez [68]	Engineering systems	Reliability Engineering and System Safety	2016
34	A Review on the Resilience Assessment of Power Systems under Disasters	C.-L. Huang, Y.-K. Wu, Y.-Y. Li [69]	Power systems	7th International Conference on Applied System Innovation (ICASI)	2021
35	Energy system resilience—A review	J. Jasiūnas, P. D. Lund, J. Mikkola [8]	Energy systems	Renewable and Sustainable Energy Reviews	2021
36	Adapting the theory of resilience to energy systems: a review and outlook	B.-J. Jesse, H. U. Heinrichs, W, Kuckshinrichs [70]	Energy systems	Energy, Sustainability and Society	2019

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
37	Safety Critical Maritime Infrastructure Systems Resilience: A Critical Review	A. John, T. C. Nwaoha [71]	Safety Critical Maritime Systems	International Journal of Maritime Engineering	2016
38	Resilience theory incorporated into urban wastewater systems management. State of the art	P. Juan-García, D. Butler, J. Comas, G. Darch, C. Sweetapple, A. Thornton, Ll. Corominas [9]	Water systems	Water Research	2017
39	Sensemaking in Critical Situations and in Relation to Resilience—A Review	S. S. Kilskar, B.-E. Danielsen, S. O. Johnsen [38]	Safety-critical sociotechnical systems	ASME J. Risk Uncertainty Part B	2020
40	Assessing Urban Transportation Systems Resilience: A Proposal of Indicators	C. M. Leobons, V. B. G. Campos, R. A. de Mello Bandeira [72]	Transportation systems	21st EURO Working Group on Transportation Meeting, EWGT 2018	2018
41	Review of studies on the resilience of urban critical infrastructure networks	W. Liu, Z. Song [11]	Critical infrastructure systems	Reliability Engineering and System Safety	2020
42	Resilience in Infrastructure Systems: A Comprehensive Review	W. Liu, M. Shan, S. Zhang, X. Zhao, Z. Zhai [46]	Infrastructure systems	Buildings	2022
43	The human factor in the disaster resilience modeling of critical infrastructure systems	J. J. Magoua, N. Li [73]	Critical infrastructure systems	Reliability Engineering and System Safety	2023
44	A Review of the Measures to Enhance Power Systems Resilience	M. Mahzarnia, M. P. Moghaddam, P. T. Baboli, P. Siano [74]	Power Systems	IEEE Systems journal	2020
45	Team adaptation and safety in aviation	S. Malakis, T. Kontogiannis [75]	Aviation	Safety Science	2023
46	Vulnerability and resilience of transport systems—A discussion of recent research	L.-G. Mattsson, E. Jenelius [76]	Transportation systems	Transportation Research Part A	2015
47	Resilience and Systems—A Review	K. Mayar, D. G. Carmichael, X. Shen [1]	Dynamical systems, engineering systems	Sustainability	2022
48	Proactive Resilience of Power Systems Against Natural Disasters: A Literature Review	M.A. Mohamed, T. Chen, W. Su, T. Jin [2]	Power systems	IEEE Access	2019

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
49	Cyber-physical-social interdependencies and organizational resilience: A review of water, transportation, and cyber infrastructure systems and processes	S. Mohebbi, Q. Zhang, E. C. Wells, T. Zhao, H. Nguyen, M. Li, N. Abdel-Mottaleb, S. Uddin, Q. Lu, M. J. Wakhungu, Z. Wu, Y. Zhang, A. Tuladhar, X. Ou [77]	Infrastructure systems	Sustainable Cities and Society	2020
50	The Resilience of Critical Infrastructure Systems: A Systematic Literature Review	A. Mottahedi, F. Sereshki, M. Ataei, A. N. Qarahasanlou, A. Barabadi [10]	Critical infrastructure systems	Energies	2021
51	Safety and reliability in aviation—A systematic scoping review of normal accident theory, high reliability theory, and resilience engineering in aviation	N. Muecklich, I. Sikora, A. Paraskevas, A. Padhra [43]	Aviation	Safety Science	2023
52	A Review of Methods to Study Resilience of Complex Engineering and Engineered Systems	N. Naghshbandi, L. Varga, A. Purvis, R. Mcwilliam, E. Minisci, M. Vasile, M. Troffaes, T. Sedighi, W. Guo, Weisi, E. Manley, D. Jones [78]	Engineered systems	IEEE Access	2020
53	Systematic review of critical infrastructure resilience indicators	R. Osei-Kyei, L. M. Almeida, G. Ampratwum, V. Tam [79]	Critical infrastructure systems	Construction innovation	2022
54	Vulnerability and resilience of transportation systems: A recent literature review	S. Pan, H. Yan, J. He, Z. He [80]	Transportation systems	Physica A	2021
55	Resilience engineering: Current status of the research and future challenges	R. Patriarca, J. Bergström, G. Di Gravio, F. Costantino [23]	Multiple sociotechnical systems	Safety Science	2018
56	Applications of resilience engineering principles in different fields with a focus on industrial systems: A literature review	B. Pawar, S. Park, P. Hu, Q. Wang [81]	Industrial systems	Journal of Loss Prevention in the Process Industries	2021
57	A resilience engineering perspective of safety performance measurement systems: A systematic literature review	G. A. Peñaloza, T. A. Saurin, C. T. Formoso, I. A. Herrera [82]	Multiple sociotechnical systems	Safety Science	2020
58	Resilience Engineering: An Integrative Review of Fundamental Concepts and Directions for Future Research in Safety Management	M. Pillay [44]	Multiple sociotechnical systems	Open Journal of Safety Science and Technology	2017

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
59	Measuring Resilience Engineering: An Integrative Review and Framework for Bench-Marking Organisational Safety	M. Pillay, G. Morel [31]	Multiple sociotechnical systems	Safety	2020
60	Infrastructure resilience curves: Performance measures and summary metrics	C. Poulin, M. B. Kane [83]	Infrastructure systems	Reliability Engineering and System Safety	2021
61	Resilience of critical infrastructure to natural hazards: A review focused on drinking water systems	G. Quitana, M. Molinos-Senante, A. Chamorro [84]	Critical infrastructure systems	International Journal of Disaster Risk Reduction	2020
62	Indicators to assess organizational resilience—a review of empirical literature	K. Rahi [85]	Multiple sociotechnical systems	International Journal of Disaster Resilience in the Built Environment	2018
63	Resilience Engineering Indicators and Safety Management: A Systematic Review	U. Ranasinghe, M. Jefferies, P. Davis, M. Pillay [86]	Safety-critical sociotechnical systems	Safety and Health at Work	2020
64	Power Systems Resilience Metrics: A Comprehensive Review of Challenges and Outlook	H. Raoufi, V.Vahidinasab, K. Mehran [87]	Power systems	Sustainability	2020
65	Transport resilience and vulnerability: The role of connectivity	A. Reggiani, P. Nijkamp, D. Lanzi [88]	Transportation systems	Transportation Research Part A	2015
66	A systematic literature review of resilience engineering: Research areas and a research agenda proposal	A.W. Righi, T. A. Saurin, P. Wachs [89]	Safety-critical sociotechnical systems	Reliability Engineering and System Safety	2015
67	Resilience of Critical Infrastructure Systems: A Systematic Literature Review of Measurement Frameworks	M. Sathurshan, A. Saja, J. Thamboo, M. Haraguchi, S. Navaratnam [90]	Critical infrastructure systems	Infrastructures	2022
68	Urban Transportation Networks Resilience: Indicators, Disturbances, and Assessment Methods	M. Z. Serdar, M. Koç, S. G. Al-Ghamdi [91]	Transportation systems	Sustainable Cities and Society	2022
69	Resilience-Based Design of Infrastructure: Review of Models, Methodologies, and Computational Tools	M. Shadab Far, M. Mahsuli, Y. Zhang, Y. Xue, Yadong, B. Ayyub, H. Huang, R. Medina [92]	Infrastructure systems	ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A	2021
70	Enhancing distribution system resilience against extreme weather events: Concept review, algorithm summary, and future vision	Q. Shi, W. Liu, B. Zeng, H. Hui, F. Li [93]	Infrastructure systems	International Journal of Electrical Power and Energy Systems	2022

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
71	Investigating resilience in emergency management: An integrative review of literature	C. Son, F. Sasangohar, T. Neville, S. C. Peres, J. Moon [94]	Multiple sociotechnical systems	Applied Ergonomics	2020
72	Resilience metrics and measurement methods for transportation infrastructure: the state of the art	W. Sun, P. Bocchini, B. D. Davison [95]	Transportation systems	Sustainable and Resilient Infrastructure	2020
73	Structuring a Definition of Resilience for the Freight Transportation System	C. Ta, A. V. Goodchild, K. Pitera [96]	Transportation systems	Transportation Research Record	2009
74	A systematic review of the resilience of transportation infrastructures affected by flooding	S. Tachaudomdach, K. Arunotayanun, A. Upayokin [97]	Transportation systems	International Conference on Transportation and Traffic Engineering	2018
75	Resilience in transportation systems	P. Tamvakis, Y. Xenidis [41]	Transportation systems	Procedia—Social and Behavioral Sciences	2012
76	Contribution of Diversity to the Resilience of Energy Systems—A literature review	P. Thier, C. Pot d'or [98]	Energy systems	30th European Safety and Reliability Conference (ESREL)	2020
77	Resilience in transportation systems: a systematic review and future directions	C. Wan, Z. Yang, D. Zhang, X. Yan, S. Fan [99]	Transportation systems	Transport Reviews	2018
78	Research on Resilience of Power Systems Under Natural Disasters—A Review	Y. Wang, C. Chen, J. Wang, R. Baldick [100]	Power Systems	IEEE Transactions on Power Systems	2016
79	Analysis of the Definitions of Resilience	Z. Wang, M. S. Nistor, S. W. Pickl [101]	Multiple sociotechnical systems	IFAC-PapersOnLine	2017
80	Literature review on modeling and simulation of energy infrastructures from a resilience perspective	J. Wang, W. Zuo, L. Rhode-Barbarigos, X. Lu, J. Wang, Y. Lin [12]	Infrastructure systems	Reliability Engineering and System Safety	2019
81	A Systematic Review: To Increase Transportation Infrastructure Resilience to Flooding Events	G. Watson, J. Eun Ahn [102]	Transportation systems	Applied Sciences	2022
82	Modeling critical infrastructure resilience under compounding threats: A systematic literature review	E.M. Wells, M. Boden, I. Tseytlin, I. Linkov [103]	Critical infrastructure systems	Progress in Disaster Science	2022

Table A1. *Cont.*

#	Title	Authors	Considered Systems	Journal/Conference	Year
83	Defining the boundaries and operational concepts of resilience in the resilience in healthcare research program	S. Wiig, K. Aase, S. Billett, C. Canfield, O. Røise, O. Njå, V. Guise, C. Haraldseid-Driftland, E. Ree, J.E. Anderson, C. Macrae [104]	Healthcare systems	BMC Health Services Research	2020
84	An overview of agility and resilience: From crisis management to aviation	R. Woltjer, B.J. E. Johansson, P. Berggren [105]	Aviation	Resilience Engineering Association	2015
85	Resilience Indicator of Urban Transport Infrastructure: A Review on Current Approaches	Z. Yang, B. Barroca, A. Bony-Dandrieux, H. Dolidon [106]	Transportation systems	Infrastructures	2022
86	Indicator-based resilience assessment for critical infrastructures—A review	Z. Yang, B. Barroca, A. Weppe, A. Bony-Dandrieux, K. Laffrechine, N. Daclin, V. November, K. Omrane, D. Kamissoko, F. Benaben, H. Dolidon, J. Tixier, V. Chapurlat [107]	Critical infrastructures systems	Safety Science	2023
87	Engineering Resilience Quantification and System Design Implications: A Literature Survey	N. Yodo, P. Wang [47]	Engineered systems	ASME–Journal of Mechanical Design	2016
88	Resilience of Transportation Systems: Concepts and Comprehensive Review	Y. Zhou, J. Wang, H. Yang [28]	Transportation Systems	IEEE Transactions on Intelligent Transportation Systems	2019

Table A2. Definitions and conceptualisations of the resilience of sociotechnical systems presented in the 88 review papers.

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
1	Ability of a system to reduce the magnitude and/or the duration of disruptive events. Its effectiveness depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event	NIAC (2009) [108]	Ahmadi (2021) [4]
2	Quality of a system which reduces the vulnerability of a system, absorbs the effects of disruptive events, enhances its ability to respond and recover, and facilitates its adaptation to disruptive events similar to those encountered in the past	Rehak (2019) [109]	Ahmadi (2021) [4]
3	Ability of a system to minimize the impact of a disruption by evading it entirely (resistance capacity) and ability of a system to find a return path to a steady state of functionality (recovery capacity)	Melnyk (2014) [110]	Ahmadi (2021) [4]
4	A resilient system is capable of minimising the disaster impacts with its inherent ability to maintain the reasonable performance of system components and enables the rapid restoration of the system	Ahmed (2020) [42]	Ahmed (2020) [42]
5	The resilience of systems can be defined with ten dimensions: (i) redundancy (i.e., same functionality of multiple components), (ii) diversity (i.e., different functionality), (iii) efficiency (i.e., demand and supply optimization), (iv) components' dependency (i.e., ability to operate independently), (v) strength (i.e., ability to withstand an event), (vi) stakeholders' collaboration (i.e., information and resource sharing among multiple entities of the system), (vii) adaptability (i.e., flexibility in the system elements), (viii) mobility performance (reaching objectives within a reasonable time), (ix) safety performance (i.e., less fatal/injury crashes), and (x) the ability to recover quickly (i.e., rapid restoration with minimal intervention)	Murray-Tuite (2006) [111]	Ahmed (2020) [42]
6	A resilient system can adjust its functioning prior to, during, and following changes and disturbances, so that it can continue to perform as required after a disruption or a major mishap, and in the presences of continuous stresses	Dekker (2008) [112]	Ahmed (2020) [42]
7	Resilience is the expected fraction of demand (before a disaster) the system can accommodate post-disaster (after the recovery works are completed), considering the allocated recovery budget	Chen (2012) [113]	Ahmed (2020) [42]
8	The measure to characterise preparedness against disruptions	Aruvali (2023) [34]	Aruvali (2023) [34]
9	System's ability to absorb the impact of disruptions, to adapt to disruptions, and to recover to its normal regime	Aruvali (2023) [34]	Aruvali (2023) [34]
10	Ability of a system to withstand potentially high-impact disruptions, and is characterised by the capacity of the system to mitigate or absorb the impact of disruptions, and quickly recover to normal conditions	Gu (2015) [114]	Aruvali (2023) [34]
11	Process under which the observed system undergoes in response to a disruption quantified in terms of a measure of a system performance and its evolution over the system response time after an event	Gasser (2021) [22]	Aruvali (2023) [34]
12	Ability of a component or a system to maintain its required functionality by resisting and recovering from adverse events	Yoon (2017) [115]	Aruvali (2023) [34]
13	Resilience is an attribute of the service and is a measure of the insensitivity of the system to disruptions	Song (2020) [116]	Aruvali (2023) [34]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
14	Ability of a system to maintain operations under disruptions	Zhang (2021) [117]	Aruvali (2023) [34]
15	Performance measure representing the system ability to survive disruptive events, and the rapidity in restoring system capacity after the disruptive event has occurred	Caputo (2019) [118]	Aruvali (2023) [34]
16	Ability of the system to perform at an acceptable level when the disturbance occurs	Li (2019) [119]	Aruvali (2023) [34]
17	Ability of a system to withstand potentially high-impact disruptions, and is characterised by the capability of the system to mitigate or absorb the impact of disruptions, and quickly recover to normal conditions	Jin (2016) [120]	Aruvali (2023) [34]
18	System's ability to continue to meet its objectives in the face of challenges	Barasa (2018) [48]	Barasa (2018) [48]
19	Resilience is a function of planning for and preparing for future crisis (planned resilience), and adapting to chronic stresses and acute shocks (adaptive resilience)	Barasa (2018) [48]	Barasa (2018) [48]
20	Adaptation and transformation of systems through the emergence of new structures such as policies, processes and organizational culture that enable organizational systems to continue to perform their functions in the face of challenges	Pike (2010) [121]	Barasa (2018) [48]
21	Maintenance of positive adjustment under challenging conditions such that the organization emerges from those conditions strengthened and more resourceful	Vogus (2007) [122]	Barasa (2018) [48]
22	Capacity of a system to absorb disturbances, while learning from them and reorganising	Folke (2006) [123]	Barasa (2018) [48]
23	Ability of a system to absorb, adapt, and transform in the face of challenges	Bristow (2014) [124]	Barasa (2018) [48]
24	Dynamical capacity to adapt to internal and external perturbations by changing its mode of operation without losing its ability to perform	Bento (2021) [5]	Bento (2021) [5]
25	Capacity of a system to absorb and return to a stable state after a disruption	Folke (2006) [123]	Bento (2021) [5]
26	Capacity to adapt to internal and external errors by changing the system's mode of operations, without losing its ability to function	Barabasi (2013) [125]	Bento (2021) [126]
27	Qualitative capacity to absorb unexpected events	Bento (2021) [5]	Bento (2021) [5]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
28	Ability of a system in difficult situations to stay within the safe envelope and avoid accidents	Hale (2006) [127]	Bergstrom (2015) [39]
29	Ability of a system to regain a previous state following a disturbance	Bergstrom (2015) [39]	Bergstrom (2015) [39]
30	Capability of a system to compensate for risky variability	De Carvalho (2011) [128]	Bergstrom (2015) [39]
31	Ability of a system to adapt to or absorb disturbing conditions	Lundberg (2014) [129]	Bergstrom (2015) [39]
32	Ability of a system to keep the system within its functional limits	Gomes (2009) [130]	Bergstrom (2015) [39]
33	Strategy for how to help people to cope with complexity under pressure to obtain success	Shirali (2012) [131]	Bergstrom (2015) [39]
34	Desired key to success despite risky complexity and variability	Bergstrom (2015) [39]	Bergstrom (2015) [39]
35	Ability of a system to maintain normal operations even during stress and disturbances	Ross (2014) [132]	Bergstrom (2015) [39]
36	Ability of a system to recover and avoid accidents in poor circumstances	Furniss (2011) [133]	Bergstrom (2015) [39]
37	Ability of a system to continue functioning when there is stress and disturbances, but more importantly, the ability to adjust how people and system's function	Saurin (2011) [134]	Bergstrom (2015) [39]
38	Strategy in the risk assessment of the system to improve safety, security, and quality of service	Johnsen (2013) [135]	Bergstrom (2015) [39]
39	Capacity of a system to rebound from adversity strengthened and more resourceful	Carmeli (2013) [136]	Bergstrom (2015) [39]
40	Characteristic that a system needs to possess in order to stay within functional limits	Bergstrom (2015) [39]	Bergstrom (2015) [39]
41	Ability of a system exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions	UNISDR (2009) [137]	Besinovic (2020) [51]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
42	Ability of a system to provide effective services in normal conditions, as well as to resist, absorb, accommodate and recover quickly from disruptions or disasters	Besinovic (2020) [51]	Besinovic (2020) [51]
43	Ability of a system to recover quickly from a disruption	Bababeik (2018) [138]	Besinovic (2020) [51]
44	Remaining system's performance during a disruption	Khaled (2015) [139]	Besinovic (2020) [51]
45	A function of system's vulnerability against potential disruption, and its adaptive capacity in recovering to an acceptable level of service within a reasonable timeframe after being affected	Zhang (2018) [140]	Besinovic (2020) [51]
46	Capability and ability of an element to return to a stable state after a disruption	Bhamra (2011) [27]	Bhamra (2011) [27]
47	Ability of a system to adapt to the requirements of the environment and to manage the environments variability	McDonald (2006) [141]	Bhamra (2011) [27]
48	Ability of a system to sense, recognise, adapt, and absorb variations, changes, disturbances, disruptions, and surprises	Hollnagel (2006) [25]	Bhamra 2011 [27]
49	Capacity of a system to recover from disturbances	Gallopins (2006) [142]	Bhamra (2011) [27]
50	Ability of a system to survive uncertain extreme events outside traditional design boundaries, achieve a safe-to-fail state and recover functionality	Bi (2023) [32]	Bi (2023) [32]
51	Inherent system property that emphasises the multi-faceted capacities of CI systems to (a) withstand the impact of disruptions and continue to operate with acceptable function degradation, (b) restore the normal system performance level in a timely manner, and (c) adapt to future disruptions	Davis (2018) [143]	Bi (2023) [32]
52	To achieve a "safe-to-fail" state and emphasises prompt recovery and adaptation to cope with disruptions	Ganin (2016) [144]	Bi (2023) [32]
53	Ability of the system to reduce the chances of shock, to absorb a shock if it occurs and to recover quickly after a shock (re-establish normal performance)	Bruneau (2003) [145]	Cantelmi (2021) [52]
54	Ability of a system to become healthy and strong again after a disruptive event	Cao (2015) [53]	Cao (2015) [53]
55	Ability of a system to accommodate variable and unexpected conditions without catastrophic failure	Foster (1993) [146]	Cao (2015) [53]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
56	Capacity of a system to absorb shocks gracefully	Foster (1993) [146]	Cao (2015) [53]
57	The ability of the system to absorb shock as well as to recover from a disruption so that it can return back to its original service delivery levels or close to it	Omer (2012) [147]	Cao (2015) [53]
58	A function of system's vulnerability against potential disruption, and its adaptive capacity in recovering to an acceptable level of service within a reasonable time frame after being affected by disruption	Mansouri (2009) [148]	Cao (2015) [53]
59	Capability of a system to provide and maintain an acceptable level of service in the face of major changes or disruptions to the environment	Mansouri (2010) [149]	Cao (2015) [53]
60	System's ability to maintain its demonstrated level of service or to restore itself to that level of service in specified time frame	Serulle (2011) [150]	Cao (2015) [53]
61	Ability of a system to absorb disruptive events gracefully and return to a level of service equal to or greater than the pre-disruption level of service within a reasonable time frame	Freckleton (2012) [151]	Cao (2015) [53]
62	Inherent ability of a system to cope with disruption via topological and operational attributes and potential actions that can be taken in the immediate aftermath of a disruption or disaster event	Miller-Hooks (2012) [152]	Cao (2015) [53]
63	Capability of a system to resist and recover from a disruption or disaster	Chen (2012) [113]	Cao (2015) [53]
64	Ability of a system to return to a stable state following a strong perturbation caused by failure, disaster or attack	Ip (2011) [153]	Cao (2015) [53]
65	A characteristic that indicates system performance under unusual conditions, recovery speed, and the amount of outside assistance required for restoration to its original functional state	Murray-Tuite (2006) [111]	Cao (2015) [53]
66	Capacity of a system to absorb the effects of a disruption and to quickly return to normal operating levels	Adams (2012) [154]	Cao (2015) [53]
67	Ability of a system to maintain function and to bounce back quickly from a disturbance	Cox (2011) [155]	Cao (2015) [53]
68	Capacity of a system to proactively adapt to external disturbances and recover from them	Cerè (2017) [54]	Cerè (2017) [54]
69	Ability of a system to absorb changes or disturbances	Pawar (2021) [81]	Chen (2023) [55]
70	Ability of a system to adapt to future surprises as conditions evolve	Woods (2015) [156]	Chen (2023) [55]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
71	Capacity of a system to prevent the negative impact while suffering from the external disruption and to recover comprehensively considering the response time, operation costs, and possibility	Chen (2023) [55]	Chen (2023) [55]
72	Ability of a system to prepare for and resist the unexpected hazards, absorb their effects, maintain desired functionality and rapidly recover	Cheng (2022) [56]	Cheng (2022) [56]
73	Capacity of a system to plan and prepare for the adverse events (planification), to reduce the impact of events (absorption or resistance), to minimize the time to recovery (recovery), and to evolve through the development of specific processes (adaptability)	Curt (2018) [6]	Curt (2018) [6]
74	Resilience is the degree of recovery, time to recovery, or extent of damage avoided	Gilbert (2010) [157]	Curt (2018) [6]
75	Ability of a system to recover as soon as possible after an unexpected situation	Dinh (2012) [33]	Dinh (2012) [33]
76	Ability of a system to recover quickly after an upset	Dinh (2012) [33]	Dinh (2012) [33]
77	Ability of a system to bounce back when hit with unexpected demands	Dinh (2012) [33]	Dinh (2012) [33]
78	Ability of a system to minimize damages and get operations back to normal from adverse events rapidly	Dinh (2012) [33]	Dinh (2012) [33]
79	Ability of a system to control the situation by minimising probability of failure, consequences, and restoration and recovery time	Dinh (2012) [33]	Dinh (2012) [33]
80	Ability of a system to resist and recover from damage or disaster	Chen (2012) [113]	Dong (2022) [57]
81	Ability of a system to absorb the effects of damages and quickly return to a level of service equal to or greater than the pre-disruption level of service	Adams (2012) [154]	Dong (2022) [57]
82	Ability of a system to withstand disruptions within acceptable reduction in service performance	Jin (2014) [158]	Dong (2022) [57]
83	Ability of a system to withstand and recover from disruptions under extreme conditions, such as public events, terrorist attacks, and natural disasters	Zhu (2017) [159]	Dong (2022) [57]
84	Recovery or the self-healing capacity to become fully or partially operational after disruption due to natural or human-made impacts that arise from physical or cyber threats	Aydin (2018) [160]	Dong (2022) [57]
85	Capacity to adapt the system's behavior to maintain continuity of the operations in the presence of disruptions or distress	Morshed (2021) [161]	Dong (2022) [57]
86	Capacity of a system for flexibility, robustness, and adaptability in response to changing circumstances so that performance, including safety, is maintained	Woods (2015) [156]	Ellis (2019) [58]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
87	Ability of a system to withstand, to adapt, and to quickly recover from stresses and shocks	EC (2012) [162]	Engler (2018) [59]
88	To succeed under varying conditions, so that the number of intended and acceptable outcomes is as high as possible	Hollnagel (2013) [163]	Engler (2018) [59]
89	Ability to resist, absorb and adapt to disruptions and return to normal functionality	Faturechi (2015) [60]	Faturechi (2015) [60]
90	System's ability to cope with disaster impact and post-disaster adaptive actions that aim to restore functionality	Faturechi (2015) [60]	Faturechi (2015) [60]
91	System's ability to resist and absorb the impact of disruptions	Bruneau (2003) [145]	Faturechi (2015) [60]
92	Ability of a system to bounce back from a certain impact after disruptive event to previous functionality level or equilibrium state in which the system is stable	Feofilovs (2020) [61]	Feofilovs (2020) [61]
93	Dynamic metric of system performance over the disaster event with the response and recovery, preparedness and mitigation as one function	Cimellaro (2010) [164]	Feofilovs (2020) [61]
94	Ability of the systems to be successful in different situations, requiring performance adjustments and adaptations to respond	Hollnagel (2013) [163]	Fernandes (2023) [163]
95	Ability of a system to function in the most diverse situations	Hollnagel (2017) [165]	Fernandes (2023) [62]
96	Ability to bounce-back from adversity and to learn from the past and from other industries. The resilience of systems to disturbances is largely based upon the human ability to absorb, adapt and restore in the event of surprise	Foster (2019) [63]	Foster (2019) [63]
97	Endowed or enriched property of a system that is capable of effectively combating (absorbing, adapting to or rapidly recovery from) disruptive events	Francis (2014) [37]	Francis (2014) [37]
98	Ability to anticipate and absorb potential disruptions; develop adaptive means to accommodate changes within or around the system; and establish response behaviors aimed at either building the capacity to withstand the disruption or recover as quickly as possible after an impact	Francis (2014) [37]	Francis (2014) [37]
99	Ability of to flexibly accommodate potential shocks without irreversible or unacceptable declines in performance, structure, and function	Francis (2014) [37]	Francis (2014) [37]
100	Ability to reduce the magnitude and/or duration of disruptive events, which depends upon the ability to anticipate, absorb, adapt to,and/or rapidly recover from a potentially disruptive event	NIAC (2009) [108]	Francis (2014) [37]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
101	Coordinated planning across sectors and networks; responsive, flexible, and timely recovery measures; and the development of an organizational culture that has the ability to provide a minimum level of service during interruptions, emergencies, and disasters, and return to full operations quickly	Aust. Gov. (2010) [166]	Francis (2014) [37]
102	Ability of a system to recover from adversity, either back to its original state or an adjusted state based on new requirements	McCarthy (2007) [167]	Francis (2014) [37]
103	Ability of an organization to anticipate, circumvent threats to its existence and primary goals, and rapidly recover	Hale (2006) [127]	Francis (2014) [37]
104	Ability to recognise and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of process, strategies, and coordination	Fujita (2006) [168]	Francis (2014) [37]
105	Balance of stability and flexibility that allows for adaptations in the face of uncertainties without losing control	Grote (2006) [169]	Francis (2014) [37]
106	Ability of a system to efficiently adjust to harmful influences	Woods (2006) [170]	Francis (2014)
107	Capacity of a system to recognise threats and hazards and make adjustments that will improve future protection efforts and risk reduction measures	DHSRSC (2008) [171]	Francis (2014) [37]
108	Ability of a system to sustain a shock without completely deteriorating which involve some idea of adapting to and bouncing back from a disruption	Kendra (2003) [172]	Francis (204) [37]
109	Capability of a system to maintain its functions and structure in the face of internal and external change, and to degrade gracefully when it must	Allenby (2005) [173]	Francis (2014) [37]
110	Ability of a system to resist, absorb, recover from, or successfully adapt to adversity or a change in conditions	DHSRSC (2008) [171]	Francis (2014) [37]
111	Ability of a system to withstand a major disruption within acceptable degradation parameters and to recover within acceptable time, composite costs, and risks	Haimes (2009) [174]	Francis (2014) [37]
112	Capacity of the system to tolerate disturbances while retaining its structure and function	Fiksel (2006) [175]	Francis (2014) [37]
113	How well the system adapts and to what range or source of variation	Woods (2006) [176]	Francis (2014) [37]
114	Time of return to a global equilibrium following a disturbance	Gunderson (2002) [177]	Francis (2014) [37]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
115	Ability of the system to reduce the chances of a shock, to absorb a shock if it occurs (abrupt reduction of performance), and to recover quickly after a shock (re-establish normal performance)	Bruneau (2003) [145]	Francis (2014) [37]
116	Ability of a system to continuously adapt in order to respond to its operational goals; its resilience depends of the level and time of recovering from disruptive events and/or shocks to its initial state	Gaitanidou (2017) [36]	Gaitanidou (2017) [36]
117	Level of adaptability of the risks, externalities and shocks in order for the system to remain sustain and/or stable	Gaitanidou (2017) [36]	Gaitanidou (2017) [36]
118	Capacity to adapt resources and skills to face new situations and operational targets	Comfort (1999) [178]	Gaitanidou (2017) [36]
119	Intrinsic ability of a system to react to and recover from disturbances at an early stage, with minimal effect on its dynamic stability and to adjust its functioning prior to, during or following changes and disturbances, under both expected and unexpected conditions	Hollnagel (2011) [179]	Gaitanidou (2017) [36]
120	Processes, disciplines and infrastructures that need to be in place to make sure that undesired event do not happen or that systems may survive such events and maintain operation	Jackson (2010) [180]	Gaitanidou (2017) [36]
121	Ability to keep or recover quickly to a stable state, allowing it to continue operations during and after a major mishap, or in the presence of continuous significant stresses	Wreathall (2006) [181]	Gaitanidou (2017) [36]
122	Key property to adequately deal with disruptions	Jackson (2015) [182]	Gasser (2021) [22]
123	Process that the observed system undergoes in response to a disruption quantified in terms of a measure of system performance and its evolution during the system response time after an event	Gasser (2021) [22]	Gasser (2021) [22]
124	Ability to withstand within acceptable degradation parameters and to recover within an acceptable time and costs	Haimes (2008) [183]	Gasser (2021) [22]
125	Ability to maintain desired levels of system performance by adapting in response to expected and unexpected events over time	Gillespie-Marthaler (2018) [184]	Gasser (2021) [22]
126	Ability of a system to 'bounce back' from disruption	Gay (2013) [64]	Gay (2013) [64]
127	To recover pre-disruption performance level after disruption	Gay (2013) [64]	Gay (2013) [64]
128	Ability of a system to return to non-failure state after a failure has occurred	Kjeldsen (2004) [185]	Gay (2013) [64]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
129	Capacity of a system to minimize performance loss due to disruption, and to recover a specified performance level within acceptable predefined time and cost limits	Gay (2013) [64]	Gay (2013) [64]
130	Successful adaptations of a system to an event	Geoffroy (2016) [45]	Geoffroy (2016) [45]
131	Capacity of a system to react to a shock, in order to maintain or restore its essential functions and adapt itself to environmental transformations	Geoffroy (2016) [45]	Geoffroy (2016) [45]
132	Capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back	Wildavsky (1991) [186]	Geoffroy (2016) [45]
133	Capacity to adapt existing resources and skills to new system's and operating conditions	Comfort (1999) [178]	Geoffroy (2016) [45]
134	Capability to bounce back and to use physical and economic resources effectively to aid recovery following exposure to hazards	Paton (2001) [187]	Geoffroy (2016) [45]
135	Ability to recognise and adapt to handle unanticipated perturbations that call into question the model of competence, and demand a shift of processes, strategies and coordination	Woods (2006) [188]	Geoffroy (2016) [45]
136	Intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected situations	Hollnagel (2010) [189]	Geoffroy (2016) [45]
137	Emergent property resulting from three capacities: absorption, adaptation and transformation	Béné (2012) [126]	Geoffroy (2016) [45]
138	Capability to anticipate, cope with, recover, and learn from unexpected activities and resources at the same time they struggle to handle demands	Nemeth (2008) [190]	Goel (2022) [65]
139	System's capacity to recover from a disruptive event and resume its normal operation	Gu (2023) [66]	Gu (2023) [66]
140	Capacity to preserve, improve, or return to its original performance and functions	Notteboom (2021) [191]	Gu (2023) [66]
141	Ability to withstand disruption and return to a desirable performance level following disruptive events	Gu (2023) [66]	Gu (2023) [66]
142	Ability to deliver a certain service level even after the occurrence of a disruptive event, and to recover the desired functionality as fast as possible	Bocchini (2014) [192]	Guo (2021) [67]
143	Maintaining a minimum level of service and recovering after a disruptive event quickly	Petersen (2020) [193]	Guo (2021) [67]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
144	Capacity to plan and adapt to an emergency for survival and development in an uncertain environment	Brown (2017) [194]	Guo (2021) [67]
145	Capacity of a system to maintain its function in the face of destruction	Guo (2021) [67]	Guo (2021) [67]
146	Capacity of a system to cope with unanticipated dangers after they have become manifest	Wildavsky (1991) [186]	Hassel (2022) [7]
147	Ability of an entity or system to return to normal condition after the occurrence of an event that disrupts its state	Hosseini (2015) [195]	Hosseini (2016) [68]
148	Measure of a system's ability to absorb continuous and unpredictable change and still maintain its vital functions	Pregenzer (2011) [196]	Hosseini (2016) [68]
149	Ability of a system to withstand a major disruption within acceptable degradation parameters and to recover within a suitable time and with reasonable costs and risks	Haimes (2009) [174]	Hosseini (2016) [68]
150	Given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is that system's ability to efficiently reduce both the magnitude and duration of deviation from targeted system performance levels	Vugrin (2010) [197]	Hosseini (2016) [68]
151	Inherent ability to keep or recover a steady state, thereby allowing it to continue normal operations after a disruptive event or in the presence of continuous stress	Sheffi (2007) [198]	Hosseini (2016) [68]
152	Ability of an organization to absorb strain and improve functioning despite the presence of adversity	Vogus (2007) [122]	Hosseini (2016) [68]
153	Systems' ability to, and the speed at which they can, return to their normal performance level following a disruptive event	McDonald (2006) [141]	Hosseini [68] (2016)
154	The sum of the passive survival rate (reliability) and proactive survival rate (restoration) of a system	Youn (2011) [199]	Hosseini (2016) [68]
155	Intrinsic ability of a system to adjust its functionality in the presence of a disturbance and unpredicted changes	Hollnagel (2006) [25]	Hosseini (2016) [68]
156	Ability of a system to sustain external and internal disruptions without discontinuity of performing the system's function or, if the function is disconnected, to fully recover the function rapidly	ASME (2009) [200]	Hosseini (2016) [68]
157	Ability of a system to maintain system functionality when a disruption occurs	Rose (2007) [201]	Hosseini (2016) [68]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
158	Probability of the initial system performance loss after a disruption being less than the maximum acceptable performance loss, and the time to full recovery being less than the maximum acceptable disruption time	Chang (2004) [202]	Hosseini (2016) [68]
159	To recover normal operating conditions after an accident	Huang (2021) [69]	Hosseini (2016) [68]
160	Ability to survive and quickly recover from extreme and unexpected disruptions	Jasiunas (2021) [8]	Jasiunas (2021) [8]
161	Ability of the system to survive strong and unexpected disruptions and to recover quickly afterward	Sharifi (2016) [203]	Jasiunas (2021) [8]
162	Capacity of a system and its components to cope with a hazardous event or trend, to respond in ways that maintain its essential functions, identity and structure as well as its capacity for adaptation, learning and transformation which encompasses robustness, resourcefulness, recovery	IEA (2015) [204]	Jasiunas (2021) [8]
163	Ability of a system to recover from adversity	Roege (2014) [205]	Jasiunas (2021) [8]
164	To be able to withstand the unexpected	Cascio (2009) [206]	Jesse (2019) [70]
165	Ability of a system to provide and maintain an accepted level of service even in the event of failure	Afgan (2012) [207]	Jesse (2019) [70]
166	Intrinsic ability of a system to adjust its functioning prior to or following changes and disturbances so that it can sustain operations even after a major mishap or in the face of continuous stress	Hollnagel (2006) [25]	John (2016) [71]
167	Ability to anticipate unexpected and uncertain events that may disrupt the system, to adjust operations in the face of adverse operational scenarios in order to maintain functionality	Johnsen (2012) [208]	John (2016) [71]
168	Ability to make appropriate adjustments to the current system operations in such a way to anticipate adverse events and act in a proactive manner	John (2016) [71]	John (2016) [71]
169	Resilient systems possess several properties that allow them to withstand, respond to, and adapt more readily to stressors, for example: robustness, redundancy, resourcefulness and flexibility	Yazdani (2011) [209]	Juan-Garcia (2017) [9]
170	Ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events	Juan-Garcia (2017) [9]	Juan-Garcia (2017) [9]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
171	Ability to gracefully degrade and subsequently recover from a potentially catastrophic disturbance that is internal or external in origin	Scott (2012) [210]	Juan-Garcia (2017) [9]
172	Degree to which the system minimises level of service failure magnitude and duration over its design live when subject to exceptional conditions	Butler (2017) [211]	Juan-Garcia (2017) [9]
173	Reduced failure probabilities, reduced consequences, reduced time to recover	Cuppens (2012) [212]	Juan-Garcia (2017) [9]
174	Degree to which the asset base can perform and maintain its desired function under both, routine and unexpected circumstances	Currie (2014) [213]	Juan-Garcia (2017) [9]
175	Ability to reduce the magnitude and/or duration of disruptive events	Francis (2014) [37]	Juan-Garcia (2017) [9]
176	Degree to which the process can handle short-term stressors that affect the dynamics of the process	Hopkins (2001) [214]	Juan-Garcia (2017) [9]
177	Resilience is a function of the system functionality loss and the failure event duration	Hwang (2014) [215]	Juan-Garcia (2017) [9]
178	Speed with which the system recovers following a perturbation	Mabrouk (2010) [216]	Juan-Garcia (2017) [9]
179	Ability of the system to minimize the magnitude and duration of consequences resulting from extreme events	Mugume (2014) [217]	Juan-Garcia (2017) [9]
180	Ability of a system to maintain the basic structure and patterns of behaviour through absorbing shocks or stressors under dynamic conditions	Mugume (2015) [218]	Juan-Garcia (2017) [9]
181	Ability to recover from or to resist being affected by external shocks, impacts or stressors	Ning (2013) [219]	Juan-Garcia (2017) [9]
182	Ability of a system to recover from process upsets	Weirich (2015) [220]	Juan-Garcia (2017) [9]
183	Ability of a system to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions	Xue (2015) [221]	Juan-Garcia (2017) [9]
184	Ability of a system to recover from disruption	WERF (2010) [222]	Juan-Garcia (2017) [9]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
185	Ability to cope with, and recover from, disruption, and anticipate trends and variability in order to maintain services for people and protect the natural environment, now and in the future	Ofwat (2015) [223]	Juan-Garcia (2017) [9]
186	Ability of systems to anticipate, absorb, adapt to and/or rapidly recover from a disruptive event; the systems have five properties: Resistance, Reliability, Redundancy, Response and Recovery	Conroy (2013) [224]	Juan-Garcia (2017) [9]
187	Resilient systems have 10 properties. 1—Robustness or absorptive: Ability to reduce severity of unexpected perturbation and to maintain its function operating in dynamic conditions; 2—Rapidity or recovery: Time to recover from a perturbation to the previous steady state; 3—Flexibility or adaptive: Accommodate changes within or around the system; and establish response behaviours aimed at building robustness and recovery; 4—Connectivity: Degree of interconnectedness or duplication; 5—Redundancy: Degree of overlapping function in a system; 6—Homeostasis: Effective transmission of feedbacks between component parts; 7—Omnivory or resourceful: Diversifying resource requirements and their means of delivery; 8—High Flux: High availability of resources through a system; 9—Flatness: Avoiding hierarchical systems to adjust behaviour quicker in front of sudden perturbances; and 10—Buffering Design with studied excess capacity	Juan-Garcia (2017) [9]	Juan-Garcia (2017) [9]
188	Ability to succeed under varying conditions	Hollnagel (2011) [179]	Kilskar (2018) [38]
189	To reduce impacts by maintaining or restoring a regular level of activities in the shortest time possible	Leobons (2019) [72]	Leobons (2019) [72]
190	Resilient systems have four properties: Robustness, Redundancy, Resourcefulness, Rapidity. Robustness and Redundancy properties are related to the system" ability to maintain an acceptable level of service; Resourcefulness and Rapidity are associated with the severity of the event, and the availability and quality of the resources offered	Leobons (2019) [72]	Leobons (2019) [72]
191	Ability to maintain the activities in acceptable levels	Leobons (2019) [72]	Leobons (2019) [72]
192	Capacity to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies	DHS (2018) [225]	Liu (2020) [11]
193	A resilient system demonstrates three characteristics: reduced failure probabilities, reduced failures consequences, and reduced time to recovery	Chang (2004) [202]	Liu (2020) [11]
194	Ability of a system to reduce the chances of shock, to absorb such a shock if it occurs, and to recover quickly after a shock	Cimellaro (2016) [226]	Liu (2020) [11]
195	Degree to which the system minimizes level of service failure magnitude and duration over its design life	Diao (2016) [227]	Liu (2020) [11]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
196	Ability of a system to maintain and adapt its operational performance in the face of failures and other adverse conditions	Herrera (2016) [228]	Liu (2020) [11]
197	Capacity to absorb and perform under perturbation	Pandit (2016) [229]	Liu (2020) [11]
198	Ability of system to withstand stresses and cope with failures	Piratla (2016) [230]	Liu (2020) [11]
199	Capability of overcoming stress or failure conditions	Todini (2000) [231]	Liu (2020) [11]
200	System resilience is characterised by the four infrastructural qualities of robustness, redundancy, resourcefulness and rapidity	Yazdani (2011) [209]	Liu (2020) [11]
201	Ability of a system to absorb external disturbance and maintain expected performance	Zhao (2015) [232]	Liu (2020) [11]
202	Ability to recover from a failure state after failure has occurred	Zhuang (2013) [233]	Liu (2020) [11]
203	Ability of a system to recover from events that disrupt its operation and usually cause damage	Christodoulou (2017) [234]	Liu (2020) [11]
204	Ability to maintain satisfactory performance when being exposed to disturbances and to regain satisfactory performance in the event that a failure has taken place	Cuppens (2012) [212]	Liu (2020) [11]
205	Ability to absorb disturbance and recover after a disturbance	Joyce (2017) [235]	Liu (2020) [11]
206	Robustness and restorability of a system under extreme conditions that exceed the design frequency	Lee (2017) [236]	Liu (2020) [11]
207	Degree to which the system minimizes the level of service failure magnitude and duration over its design life when subject to exceptional conditions	Mugume (2017) [237]	Liu (2020) [11]
208	Ability to minimize the magnitude and duration of the impacts of extreme events	Mugume (2014) [217]	Liu (2020) [11]
209	Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions	Schoen (2015) [29]	Liu (2020) [11]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
210	Ability of to prepare for anticipated hazards, to adapt to changing conditions, to withstand and recover rapidly from disruptions	NIST (2016) [238]	Liu (2020) [11]
211	Capacity to sustain a level of functionality or performance over a given period range	Cimellaro (2015) [239]	Liu (2020) [11]
212	System functionality recovery versus time	Esposito (2013) [240]	Liu (2020) [11]
213	Ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions	Golara (2017) [30]	Liu (2020) [11]
214	To anticipate, absorb, adapt to, and recover from a disruptive event	Alipour (2016) [241]	Liu (2020) [11]
215	Ability of a system to cope with disturbances and recover its original function after a loss of function	Calvert (2018) [242]	Liu (2020) [11]
216	Ability to experience a negative, potentially damaging event and return to a healthy state of operations in a reasonable amount of time after that event	Chan (2016) [243]	Liu (2020) [11]
217	Function of the robustness of a system to resist the initial adverse impacts of a disruptive event and the speed with which that system is able to return to an appropriate level of functionality	Mojtahedi (2017) [244]	Liu (2020) [11]
218	Ability to adapt to hazards so as to maintain an acceptable level of service	Murray-Tuite (2006) [111]	Liu (2020) [11]
219	Indicator that accounts for performance and recovery pattern under disruptive events	Nogal (2016) [245]	Liu (2020) [11]
220	Capacity of a system exposed to hazards to adapt by resisting or changing in order to reach and maintain an acceptable level of functioning	Nogal (2017) [246]	Liu (2020) [11]
221	Ability of a system to cope with disturbance and to recover its functionality	Tang (2018) [247]	Liu (2020) [11]
222	To restore the system to its original level of service	Ye (2014) [248]	Liu (2020) [11]
223	System's coping capacity, along with the effects of pre-disaster preparedness and adaptive response actions that can be quickly taken in the disaster's aftermath while adhering to a fixed, small budget and short duration of time for implementing	Zhang (2015) [249]	Liu (2020) [11]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
224	Ability to withstand or adapt to external shocks and to recover from such shocks efficiently and effectively	Zhang (2017) [250]	Liu (2020) [11]
225	Ability to withstand and recover from severe disruptions	Gao (2017) [251]	Liu (2020) [11]
226	Ability to recover quickly from a disruption	MacKenzie (2013) [252]	Liu (2020) [11]
227	Capacity for a system to withstand, absorb, and recover from a disruption	MacKenzie (2016) [253]	Liu (2020) [11]
228	Joint ability to resist (prevent and withstand) multiple possible hazards, absorb the initial damage, and recover to normal operation	Ouyang (2012) [254]	Liu (2020) [11]
229	Ability of a system to anticipate and withstand external shocks, bounce back to its pre-shock state as quickly as possible and adapt to be better prepared to future catastrophic events	Panteli (2015) [255]	Liu (2020) [11]
230	Capacity to restore or adapt as quickly as possible functions and infrastructures when encountering unpredictable events	Liu (2022) [46]	Liu (2022) [46]
231	Ability to react, absorb, adapt to, and recover from disruptive events rapidly and effectively	Engler (2018) [59]	Liu (2022) [46]
232	Ability of system-wide recovery after disasters when infrastructure systems suffer local damage after extreme natural or human-made disruptive events	Ouyang (2019) [256]	Liu (2022) [46]
233	To minimize the probability of failure, possess the redundant connectivity, shrink the recovery time, and limit impact propagation, which corresponds to four properties of robustness, redundancy, rapidity, and resourcefulness	Sun (2020) [95]	Liu (2022) [46]
234	Ability that a system adapts its behaviors to maintain the continuity of function (or operations) when disruptive events occur	Alderson (2015) [257]	Liu (2022) [46]
235	Comprehensive measure of the disaster resistance, response, recovery and adaptive capacities of systems	Timashev (2015) [35]	Magoua (2023) [73]
236	Multi-attribute measure that describes the ability of a system to withstand a disaster shock, and its ability to recover within an acceptable envelope of time and cost	Timashev (2015) [35]	Timashev (2015) [35]
237	The ability of a system is exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in an efficient manner, through the preservation and restoration of its essential basic structures and functions	Kahan (2009) [258]	Mahzarnia (2020) [74]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
238	Resilience is the ability to mitigate the negative consequences of "low-frequency, high effect" events and has four features: (1) Resourcefulness, the ability to manage a catastrophe at the time of its occurrence and after that; (2) Robustness, the ability to absorb an unexpected disastrous event and maintain the performance of a system at an acceptable level; (3) Adaptability, the ability to learn from the historical data in order to enhance the resilience of a system against similar events that may occur in the future; (4) Rapid recovery, the ability to restore system elements and provide services after the occurrence of an external shock as fast as possible	NIAC (2010) [259]	Mahzarnia (2020) [74]
239	Ability of a system to predict a rare disastrous event, withstand or absorb it, to adapt to its consequences, and quickly recover its performance to an acceptable level after facing such an event	Arghandeh (2016) [260]	Mahzarnia (2020) [74]
240	Ability to anticipate what may happen, monitor what is going on, respond effectively when something happens, and learn from past experiences	Hollnagel (2017) [165]	Malakis (2023) [75]
241	Broader socio-technical perspective on the system's capacity to maintain or quickly recover its function after a disruption or a disaster	Mattsson (2015) [76]	Mattsson (2015) [76]
242	System's capability to maintain its function and rapidity with which the system returns to a state of normal function after a severe perturbation	Rose (2007) [201]	Mattsson (2015) [76]
243	Resilience includes recovery from disasters, reliability of day-to-day fluctuations in demand and capacity as well as sustainability of the system with respect to long-term changes such as climate change	Wang (2015) [261]	Mattsson (2015) [76]
244	New way of thinking about safety, focussing on proactive processes rather than reactive defences with the goal of increasing the number of things that go right rather than decreasing the number that go wrong	Woods (2006) [170]	Mattsson (2015) [76]
245	Broad sociotechnical framework to cope with infrastructure threats and disruptions including preparedness, response, recovery and adaptation	Worton (2012) [262]	Mattsson (2015) [76]
246	Ability to withstand and stay operational during the impact of a disruptive event	Janic (2015) [263]	Mattsson (2015) [76]
247	Ability of a system to respond to perturbations and changes through passive and active feedback mechanisms—returning the system state or system form to a starting position or transitionning to another suitable state or form	Mayar (2022) [1]	Mayar (2022) [1]
248	Capability to endure a severe event without misfortunes, loss of profitability or life, and less significant support from others	Zhou (2010) [264]	Mohamed (2019) [2]
249	Resilience is a multi-aspect capacity, comprising avoidance, absorption, adaptation and recovery from disturbances	Madni (2009) [265]	Mohamed (2019) [2]
250	Capability for anticipation, absorption, adaptation, and recovers quickly from a troublesome occasion	UK CO (2011) [266]	Mohamed (2019) [2]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
251	System's ability to continually change and adapt yet stay within critical thresholds	SRC (2016) [267]	Mohamed (2019) [2]
252	System's capability and its components to anticipate, absorb, adjust, or recuperate from the effect of a dangerous occasion in adequate and effective manner, with a guarantee that its basic infrastructure and functions are maintained, restored or improved	IPCC (2018) [268]	Mohamed (2019) [2]
253	Capability to prepare and adjust to varying situations, withstand and rapid recovery from turbulence	Rogers (2012) [269]	Mohamed (2019) [2]
254	System's ability, which is likely to be exposed to risks of adaptation, through resistance or change to attain and retain a reasonable performance. This is achieved by the system's capacity to organise itself and extend this by learning from previous disasters, in order to better protect the future and ameliorate risk mitigation actions	UNISDR (2005) [270]	Mohamed (2019) [2]
255	Capability to gradually deteriorate under increasing exertion and rapidly recover to its predicament secure status	Overbye (2012) [271]	Mohamed (2019) [2]
256	Robustness and recovery qualities of system infrastructure and operations that evade the service interruption during the unusual and dangerous events	Keogh (2013) [272]	Mohamed (2019) [2]
257	Resilience is the system's capability to anticipate, absorb and recover from the serious occasions in a convenient and successful way. It alludes to the system's capability to recover rapidly after a disaster, or in general the ability to anticipate the exceptionally and HILP events, the rapid recovery from troublesome occasions, and absorbing experiences to adjust its infrastructure and operations, to prevent or alleviate the effect of same future events	Field (2012) [273]	Mohamed (2019) [2]
258	Capacity to withstand a noteworthy disturbance inside adequate retrogression parameters and recoup inside a worthy time and composite expenses and dangers	Haimes (2009) [174]	Mohamed (2019) [2]
259	Capability for anticipation, absorption, adaptability, and quickly recover from adverse events	Mohamed (2019) [2]	Mohamed (2019) [2]
260	Preventive and restorative plans which can be considered to reduce the effect of extreme weather events and prevent cascading failures	Arab (2015) [274]	Mohamed (2019) [2]
261	Ability to maintain a steady state or recover from a disruptive event to be able to operate as normal	Sheffi (2007) [198]	Mohebbi (2020) [77]
262	Ability to predict disturbances in addition to adapting and recovering from them	NIAC (2009) [108]	Mohebbi (2020) [77]
263	Capacity to recover from unexpected and severe disturbance in a dynamic environment	Tamvakis (2012) [41]	Mohebbi (2020) [77]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
264	Ability of a system to absorb the consequence of disruption, to reduce the impacts of disruption, and to maintain operations	Ta (2010) [275]	Mohebbi (2020) [77]
265	System's ability to maintain its expected level of service or to regain that level of service within a specified time interval after the disturbance	Heaslip (2010) [276]	Mohebbi (2020) [77]
266	Ability of systems to resist failure and attack, including their ability to adapt and maintain their structure and connectivity during disasters	Osei-Asamoah (2014) [277]	Mohebbi (2020) [77]
267	Ability to imagine what to expect, to protect and resist a disruption, to absorb the adverse effects of disruption, to adapt to new conditions and changes caused by disruption, and to recover the system's normal performance level after a disruption	Mottahedi (2021) [10]	Mottahedi (2021) [10]
268	System's ability to prepare and plan for, absorb, recover from, and successfully adapt to disruptive events	National Academies (2012) [278]	Mottahedi (2021) [10]
269	Resilient systems reduce failure probabilities, reduce consequences from failures, in terms of lives lost, damage, and negative economic and social consequences, and reduce time to recovery	Bruneau (2003) [145]	Mottahedi (2021) [10]
270	The degree of a passive survival rate plus a proactive survival rate	Youn (2011) [199]	Mottahedi (2021) [10]
271	System's ability to prepare and respond quickly and reduce its losses	Liu (2013) [279]	Mottahedi (2021) [10]
272	Proportion of affected performance of the system after disruption to the normal performance of the system without disruption	Barker (2013) [280]	Mottahedi (2021) [10]
273	Ability of a system to recover its normal performance level	Teodorescu (2015) [281]	Mottahedi (2021) [10]
274	Function of the recovery process duration and the system performance level after the recovery process	Teodorescu (2015) [281]	Mottahedi (2021) [10]
275	System's ability to withstand a change or a disruptive event by reducing the initial negative impacts, by adapting itself to them and by recovering from them	Nan (2016) [282]	Mottahedi (2021) [10]
276	System's ability to resist potentially high impact disruption events, and it is characterized by the ability of the system to mitigate or absorb the impact of disruption and quick recover to normal conditions	Jin (2016) [120]	Mottahedi (2021) [10]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
277	Ability of a system to adjust its functionality in the presence of disturbances, external threats, and unpredicted changes, and to withstand internal and external disruptive events without letting the system become discontinuous by performing system functionalities	Hosseini (2016) [68]	Mottahedi (2021) [10]
278	Ability to resist the effects of a disruptive force and to reduce performance deviations	Nan (2017) [283]	Mottahedi (2021) [10]
279	System's ability to recover to the desired level from disruption event within an acceptable time, which is measured by the total satisfaction level under the interactions of resilience capacities, dispatch strategies, and disruption events	Zhao (2017) [284]	Mottahedi (2021) [10]
280	System's ability to recover rapidly from the worst performance under disruption to its original state	Lu (2018) [285]	Mottahedi (2021) [10]
281	System's ability to withstand a much wider range of atypical, yet not entirely unlikely, operating conditions characterized by the simultaneous failure of several system components, or at least to deteriorate moderately and promptly recover	Karangelos (2020) [286]	Mottahedi (2021) [10]
282	A resilient system can anticipate possible disruptions, adopt effective actions to reduce the losses of system components before and during disruption, and recover services quickly	Zhang (2018) [287]	Mottahedi (2021) [10]
283	Aggregate characterization of systems encompassing their ability to maintain their main modes and levels of services, and on their own to develop and mobilize resources to adapt to and sustain disturbances over time	Faber (2017) [288]	Mottahedi (2021) [10]
284	Ability to resist all kinds of hazards, withstand the consequences of initial incident, and quickly restore back to normal operation	Wang (2019) [289]	Mottahedi (2021) [10]
285	Quality that reduces vulnerability, minimizes the consequences of threats, accelerates response and recovery, and facilitates adaptation to a disruptive event	Rehak (2018) [290]	Mottahedi (2021) [10]
286	Ability to maintain its performance to serve the required functions before, during, and after the occurrence of a natural hazard	Mostafavi (2017) [291]	Mottahedi (2021) [10]
287	System's joint ability to resist (prevent and withstand) any possible hazards, absorb the initial damage, and recover to normal operation	Ouyang (2015) [292]	Mottahedi (2021) [10]
288	Ability of a system to prepare and plan for, absorb, recover from, and successfully adapt to disruptive events	Klise (2017) [293]	Mottahedi (2021) [10]
289	Ability of a system to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptive events	Ayyub (2014) [294]	Mottahedi (2021) [10]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
290	System's ability to sustain external and internal disruptions without discontinuity of performing the system function or, if the function is disconnected, to fully recover the functions rapidly	Cai (2018) [295]	Mottahedi (2021) [10]
291	Ability to anticipate, absorb, adapt to, and rapidly recover from a potentially disruptive event	Francis (2014) [37]	Mottahedi (2021) [10]
292	Ability of a system exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, for the preservation and restoration of essential services	Petersen (2020) [296]	Mottahedi (2021) [10]
293	Ability to limit the extent, severity, and duration of system degradation following an extreme event	Papic (2020) [297]	Mottahedi (2021) [10]
294	Capacity of a system to tolerate disturbance and to continue to deliver services. A resilient system can speedily recover from shocks and can provide alternative means of satisfying service needs in the event of changed external circumstances	Brugnetti (2020) [298]	Mottahedi (2021) [10]
295	A resilient system possess the following five abilities: the ability to imagine what to expect; the ability to protect and resist a disruptive event; the ability to absorb the adverse effects of a disruptive event; adaptability to the new conditions and changes of disruptive events; the ability to recover the system's normal performance level after a disruptive event	Mottahedi (2021) [10]	Mottahedi (2021) [10]
296	Ability to adjust the system's functioning prior to, during, or following events (changes, disturbances, and opportunities), and thereby sustain required operations under both expected and unexpected conditions	Hollnagel (2016) [165]	Muecklich (2023) [43]
297	Capability of the system to sustain system functionality in different conditions and deal with uncertainties caused by natural hazards or human interventions	Naghshbandi (2020) [78]	Naghshbandi (2020) [78]
298	Capability to bounce back from disruption, restoring some degree of before-shock performance, and exceeding it after recovery is desirable	Hosseini (2016) [68]	Naghshbandi (2020) [78]
299	The resilience of a system is to be able to prepare itself for an emergent situation by increasing system's awareness, determining weak nodes and components by monitoring them; predicting the possibility of failure by monitoring key points; being robust; exploiting redundancy; recovering functionality to fulfil system objective; and learning to improve future resilience	Naghshbandi (2020) [78]	Naghshbandi (2020) [78]
300	Ability to bounce back to a desirable stable behaviour, often after a perturbation that leads it to temporarily be in an undesirable regime	Naghshbandi (2020) [78]	Naghshbandi (2020) [78]
301	Capability of a system to withstand and recover from a disruptive event	Osei-Kyei (2022) [79]	Osei-Kyei (2022) [79]
302	System's ability to absorb a specific shock or threat, and the time it takes to restore balance, which should be as minimum as possible	Osei-Kyei (2022) [79]	Osei-Kyei (2022) [79]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
303	Ability to subsist to an unpredictable event by planning, absorbing, recovering and adapting efficiently and quickly all system's elementary functions and structures	Murdock (2018) [299]	Osei-Kyei (2022) [79]
304	Ability to prepare for, absorb, recover from, and adapt to disturbances	Ganin (2019) [300]	Pan (2021) [80]
305	Capability of bearing the impact of extreme weather, operating in such weather and quickly recovering from the impact	Diab (2020) [301]	Pan (2021) [80]
306	Abilities of the system to resist and adapt to external disturbance and then quickly return to a normal service level to meet the original demand after being disturbed by internal or external factors	Pan (2021) [80]	Pan (2021) [80]
307	Ability to experience a negative, potentially damaging event and return to a healthy state of operations in a reasonable amount of time after that event	Chan (2016) [302]	Pan (2021) [80]
308	Ability to withstand the impacts of extreme weather, to operate in the face of such weather and to recover promptly from its effects	UK DoT (2014) [303]	Pan (2021) [80]
309	System's capacity to maintain or quickly recover its function after a disruption or a disaster	Mattsson (2015) [76]	Pan (2021) [80]
310	Ability of the system, with the help of immediate recovery activities, to meet the demand, as well as to recover and ensure the persistence of the performance level at a rational cost within a limited period, when faced with disruptions to the system caused by unconventional emergency events	Chen (2017) [304]	Pan (2021) [80]
311	Ability of a system to absorb disturbances, maintain its basic structure and function, and recover to a required level of service within an acceptable time and costs after being affected by disruptions	Wan (2018) [99]	Pan (2021) [80]
312	A resilient system possesses the following properties: redundancy, efficiency, diversity, strength, adaptability, autonomous components, collaboration, mobility, safety, and the ability to recover quickly	Liao (2018) [305]	Pan (2021) [80]
313	Ability to absorb disruptive events gracefully, maintaining a demonstrated level of service, or to return itself to a level of service equal to or greater than the pre-disruption level of service within a reasonable timeframe	Freckleton (2012) [151]	Pan (2021) [80]
314	Speed at which a system returns to equilibrium after a disturbance away from equilibrium	D'Lima (2015) [306]	Pan (2021) [80]
315	Ability to maintain the services in acceptable levels	Leobons (2019) [72]	Pan (2021) [80]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
316	Ability of a system to cope with disturbances and recover its original function after a loss of function	Calvert (2018) [242]	Pan (2021) [80]
317	A feature of some systems that allows them to respond to an unanticipated disturbance that can lead to failure and then to resume normal operations quickly and with minimum decrement in their performance	Fairbanks (2014) [307]	Patriarca (2018) [23]
318	Ability to recover from irregular variations, disruptions and degradation of expected working conditions	Nemeth (2016) [308]	Patriarca (2018) [23]
319	Ability of the system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required performance under expected and unexpected conditions	Robson (2013) [309]	Patriarca (2018) [23]
320	Capability of recovering safely and efficiently from abnormal events	Patriarca (2018) [23]	Patriarca (2018) [23]
321	Ability of a system to absorb any changes or disturbances	Pawar (2021) [81]	Pawar (2021) [81]
322	Ability of a system to bounce back when hit with unfavorable conditions	Dinh (2012) [33]	Pawar (2021) [81]
323	Resilience is concerned with the observation, analysis, design and development of theories and tools to manage the adaptive ability of organizations in order to function effectively and safely	Nemeth (2015) [310]	Penaloza (2020) [82]
324	Resilience is the expression of how people, alone or together, cope with everyday situations—large and small—by adjusting their performance to the conditions	Hollnagel (2017) [165]	Penaloza (2020) [82]
325	Resilient systems have four abilities: 1—Responding (knowing what to do); 2—Monitoring (knowing what to look for); 3—Learning (being able to acquire the right lessons from the right experience); and 4—Anticipation (knowing what to expect)	Hollnagel (2017) [165]	Penaloza (2020) [82]
326	Resilient systems should: support the monitoring of everyday variability; provide feedback in real-time to those directly involved in the execution and supervision of production activities; facilitate learning from what goes well, in addition to what goes wrong; offer insights into the management of trade-offs between safety and other dimensions; evolve due to the changing nature of complex sociotechnical systems	Penaloza (2020) [82]	Penaloza (2020) [82]
327	Ability to cope with adverse circumstances, disasters and disturbances. This is reflected in the key ideas such as recovery, withstanding major disruptions, absorbing disturbances and change, and adjust, adapt and/or maintaining function and structure	Pillay (2017) [44]	Pillay (2017) [44]
328	Resilient systems absorb stresses and continue to operate normally. These systems can (and sometimes do) fail, but their repertoire of capabilities allow them to recover, recalibrate and continue operations without being significantly affected	Pillay (2017) [44]	Pillay (2017) [44]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
329	Ability to expeditiously design and implement positive adaptive behaviours matched to the immediate situation, while enduring minimum stress	Mallak (1998) [311]	Pillay (2017) [44]
330	Characteristic of managing the system's activities to anticipate and circumvent threats to its existence and primary goals	Hale (2006) [127]	Pillay (2017) [44]
331	Capacity a system to anticipate and manage risk effectively, through adaptation of its actions, systems and processes, so as to ensure its core functions are carried out in a stable and effective relationship with the environment	McDonald (2006) [141]	Pillay (2017) [44]
332	The art of managing the unexpected, or how a team or organization becomes prepared to cope with surprises	Woods (2006) [170]	Pillay (2017) [44]
333	Ability of a system to keep, or recover quickly to, a stable state, allowing it to continue operations during and after a major mishap or in the presence of continuous significant stresses	Wreathall (2006) [181]	Pillay (2017) [44]
334	Ability to adapt or absorb disturbances, disruption, and change	Patterson (2007) [312]	Pillay (2017) [44]
335	The maintenance of positive adjustment under challenging conditions such that the system emerges from those conditions strengthened and more resourceful	Vogus (2007) [122]	Pillay (2017) [44]
336	Emergent property of a complex system and comes from the joint interaction of a structure, its functions and an environment where they can take place	Bracco (2008) [313]	Pillay (2017) [44]
337	Ability to recover from or adjust easily to misfortune or change	Epstein (2008) [314]	Pillay (2017) [44]
338	Ability of a system to handle unanticipated uncertainties that arise from changes in the environment and/or because the textbook envelop is incomplete, limited or wrong	Grote (2008) [315]	Pillay (2017) [44]
339	Ability of an organisation to survive, and potentially thrive in an environment of change and uncertainty	Stephenson (2010) [316]	Pillay (2017) [44]
340	Ability of a system to adapt or absorb disturbances, disruptions and changes, especially those that fall outside the textbook operation envelop	Malakis (2008) [317]	Pillay (2017) [44]
341	Paradigm of safety management that focuses on how to help people cope with complexity under pressure to achieve success	Costella (2009) [318]	Pillay (2017) [44]
342	A broader definition of adaptation, whether the system can handle variations that fall outside the design envelop	Chialastri (2008) [319]	Pillay (2017) [44]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
343	Human factors approach for minimising damages to a system arising from an unexpected situation, and restoring it promptly to its original state through human performance and teamwork	Komatsubara (2008) [320]	Pillay (2017) [44]
344	Monitoring and managing performance at the boundaries of competence under changing demands	Mendonça (2008) [321]	Pillay (2017) [44]
345	Intrinsic ability of a system or an organization to adjust its functioning prior to and/or following changes and disturbances, so that it can sustain operations even after a major mishap or in the presence of continuous stress	Schafer (2008) [322]	Pillay (2017) [44]
346	Proactive management approach that allows future risk to be anticipated and the safety level in an organization to be maintained, based on perceptions of current and changing safety levels and recognition of acceptable limits	Han (2010) [323]	Pillay (2017) [44]
347	Developing an organisation's behavioural and cognitive capability such that it is able to effectively adjust and continue performing optimally near its safe operating envelop in the presence of everyday threats and environmental stressors at all levels of the organisation	Pillay (2010) [324]	Pillay (2017) [44]
348	Inherent capacity to cope with complex and unexpected events	Shirali (2012) [325]	Pillay (2017) [44]
349	Paradigm for safety management that concentrates on how to help people to create foresight, and to anticipate the different forms of risk in order to cope with complexities under pressure and move towards success	Shirali (2012) [325]	Pillay (2017) [44]
350	Ability of organizations to monitor and revise risk modes, to create processes that are robust yet flexible, and to use resources proactively in the face of disruptions or ongoing production and economic pressures	Pillay (2010) [324]	Pillay (2017) [44]
351	The key indicators of a resilient system include: top-level commitment, awareness, learning culture, just culture, flexibility, and preparedness	Wreathall (2006) [181]	Pillay (2017) [44]
352	Sophisticated approach for managing organisational system safety through the development of cognitive, behavioural, and cultural abilities to enable organisational members at all levels to actively anticipate, respond, monitor and learn to operate close to the boundary of safe operations as part of normal work, by narrowing the gap between work as imagined and work as performed	Pillay (2017) [44]	Pillay (2017) [44]
353	Developing an organisation's behavioural and cognitive capability such that it can effectively adjust and continue performing optimally near an its safe operating envelop in the presence of everyday threats and environmental stressors at all levels of the organisation	Pillay (2010) [44]	Pillay (2020) [31]
354	Ability of a system or an organisation to react and recover from disturbances at an early stage with minimal effect on dynamic stability	Heese (2013) [326]	Pillay (2020) [31]
355	Ability of a system to adapt its functioning before and during disturbances, so that it can continue operations after a major mishap or in the presence of continuous stresses	Shirali (2013) [327]	Pillay (2020) [31]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
356	A paradigm for safety management that concentrates on how to help people create foresight, anticipate the different forms of risk in order to cope with complexities under pressure and move towards success	Azadeh (2014) [328]	Pillay (2020) [31]
357	Intrinsic ability of a system to adjust its operation before or following changes and disturbances, so it can maintain operations after an accident	Azadian (2014) [329]	Pillay (2020) [31]
358	Inherent ability of a system to adapt its function before and during the situations where normal functioning is disrupted, so that it can continue operations after a major disaster or in the presence of constant stresses	Azadeh (2016) [330]	Pillay (2020) [31]
359	Intrinsic ability of a system to adapt its function before, during, or after major mishaps or changes, so that it can continue the operations required under both expected and unexpected conditions	Shirali (2016) [331]	Pillay (2020) [31]
360	Capability to sustain or rapidly return to a steady state that allows the organization to continue operation during or after a major event or in the presence of continuous stresses	Shirali (2019) [332]	Pillay (2020) [31]
361	Ability of an organization to regulate its function before, during, and after perturbations and fluctuations, so that it can continue the operations required under both predicted and unpredicted situations	Zarrin (2019) [333]	Pillay (2020) [31]
362	Perspective for organisational safety management which enables organisational members to actively anticipate, respond, monitor and learn; by adapting to operate at the boundary of safe operations by narrowing the gap between work as imagined and work as performed; and manifested in an organisation's culture, cognition and behaviours	Pillay (2020) [31]	Pillay (2020) [31]
363	System's ability to withstand, respond to, and recover from disruptions	NRC (2012) [278]	Poulin (2021) [83]
364	Resilience is maintaining performance above the critical threshold, recovering within the time threshold, or remaining within both thresholds	Poulin (2021) [83]	Poulin (2021) [83]
365	A resilient system (i) reduces the probabilities of failure, thereby reducing the likelihood of damage and failure of infrastructure, systems and components; (ii) reduces the consequences of failures, regarding deaths, injuries, damage and negative economic and social impacts; and (iii) reduces the time of recovery for restoring a specific system or group of systems to their original functioning level (prior to failure)	MCEER (2005) [334]	Quitana (2020) [84]
366	A resilient system has: (i) the capacity to withstand a change or disruptive event and thus reduce the initial negative impacts, which comes down to its absorptive capability; (ii) the ability to adapt on its own, or with the minimum external help possible, to this event, or adaptive capability; and (iii) the ability to recover from the adverse consequences and reach a similar or better steady state than the original, or restorative capability	Nan (2017) [283]	Quitana (2020) [84]
367	To return quickly to the functional acceptable state from disruptions	Le Coze (2016) [335]	Rahi (2019) [85]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
368	Ability to deal with disruptive events that cause alteration, degradation or cessation of operations	Somers (2007) [336]	Rahi (2019) [85]
369	Ability of an organization to survive and thrive changes and uncertainties	Sapeciay (2017) [337]	Rahi (2019) [85]
370	Ability of an organization to maintain its operations, adapt, and recover from a disaster	Kim (2016) [338]	Rahi (2019) [85]
371	Ability of an organization to avoid disruptions, and if unsuccessful recover quickly	Pettit (2016) [339]	Rahi (2019) [85]
372	Capacity of a system to adapt and recover when facing disruptions	Duarte Alonso (2015) [340]	Rahi (2019) [85]
373	Ability of a system to be aware and prepared, adapt and recover from undesirable events	Borekci (2015) [341]	Rahi (2019) [85]
374	Ability of an organization to respond and adapt rapidly to unexpected events	Pal (2014) [342]	Rahi (2019) [85]
375	Ability of an organization to transform its structure prior to, during, or following disturbances	Murray (2013) [343]	Rahi (2019) [85]
376	Capability of a system to prepare for, and respond to disturbances	Sullivan-Taylor (2011) [344]	Rahi (2019) [85]
377	Capacity to be aware of irregular variations and disruptions in order to manage the unexpected	Tillement (2009) [345]	Rahi (2019) [85]
378	To adjust performance before, during, or after any disruptive event	Hollnagel (2006) [25]	Ranasinghe (2020) [86]
379	System's potential for adaptive action when information varies, conditions change, or new kinds of events occur to challenge the viability of previous adaptations, models, or assumptions	Woods (2009) [346]	Ranasinghe (2020) [86]
380	Ability of a system to withstand, adapt and recover from disasters	Raoufi (2020) [87]	Raoufi (2020) [87]
381	Ability of the system to withstand disasters (low-frequency high-impact incidents) efficiently while ensuring the least possible interruption of operations, sustain critical services, and enabling a quick recovery and restoration to the normal operation state	Raoufi (2020) [87]	Raoufi (2020) [87]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
382	Speed at which—and the pathway along which—a system returns to its equilibrium after a shock, as well as to the perturbations/shocks that can be absorbed	Gibson (2000) [347]	Reggiani (2015) [88]
383	Resilience concerns the response of the system, that is: its elasticity or capacity to rebound after a shock, indicated by the degree of flexibility, persistence of key functions, or ability to transform	Seeliger (2013) [348]	Reggiani (2015) [88]
384	Ability of an entity or system to maintain functions, when shocked; and the speed at which an entity or a system recovers from a severe shock to achieve a desired state	Cox (2011) [155]	[88]
385	Four dimensions of the concept of resilience: "(1) resilience as rebound from trauma and return to equilibrium; (2) resilience as a synonym for robustness; (3) resilience as the opposite of brittleness, i.e., as graceful extensibility when surprise challenges boundaries; (4) resilience as network architectures that can sustain the ability to adapt to future surprises as conditions evolve	Woods (2015) [156]	Righi (2015) [89]
386	Paradigm that focuses on how to help people cope with complexity under pressure to achieve success	Woods (2006) [176]	Righi (2015) [89]
387	To enhance the ability of a complex sociotechnical system to adapt or absorb disturbance, disruption and change	Hollnagel (2006) [25]	Righi (2015) [89]
388	Proactive approach that focuses on the need for organizations to adapt to changes in the environment in which they operate, supporting workers in a safe adaption when necessary	Anderson (2013) [349]	Righi (2015) [89]
389	Ability to withstand and recover from a potentially disruptive event	Berkeley (2010) [259]	Sathurshan (2022) [90]
390	Resilience combines risk management, vulnerability, reliability, robustness, flexibility, and survivability	Faturechi (2015) [60]	Serdar (2022) [91]
391	A resilient element could absorb (or sustain) a sudden disturbance and recover its normal capacity within an acceptable timeframe	Calvert (2018) [242]	Serdar (2022) [91]
392	System's ability to absorb a disturbance (reduction in service due to an event) and the time to recover from its effects	Adjetey-Bahun (2016) [350]	Serdar (2022) [91]
393	Ability to preserve an operational level in both normal and abnormal situations	Tamvakis (2012) [41]	Serdar (2022) [91]
394	Ability to recover, within a predetermined period of time, in the aftermath of extreme events	Shadabfar (2021) [92]	Shadabfar (2022) [92]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
395	A resilient system copes with a hazard event through either absorption or recovery: absorption can be attributed to the instant response of the system to disruption wherein inherent the characteristics and capabilities of the system itself are the main safeguards against the failure; recovery represents the required measures planned to restore the affected system quickly and to reduce the subsequent impact spreading through neighboring infrastructures	Jesse (2019) [70]	Shadabfar (2022) [92]
396	Measure of the system's ability to prevent the damage during extreme events and to recover the system function after such events	Shi (2022) [93]	Shi (2022) [93]
397	Criterion to assess the ability of a system to withstand and recover from natural disasters or deliberate attacks	Khomami (2019) [351]	Shi (2022) [93]
398	Property of systems that adapt their performance to both expected and unexpected disruption	Shakou (2019) [352]	Son (2020) [94]
399	System's capability to handle disruptions that fall outside a designed performance envelope; adaptations to unanticipated situations	Woods (2006) [188]	Son (2020) [94]
400	System's inherent ability to adjust its functioning before, during, and after changes and disturbances	Hollnagel (2011) [179]	Son (2020) [116]
401	System's adaptive capacity or adaptation to variable conditions in and around the system	Lundberg (2012) [353]	Son (2020) [94]
402	The adaptive capacity, or the ability of the system to identify and to adapt to handle unanticipated perturbations in order to keep the system under control	Aguilera (2016) [354]	Son (2020) [94]
403	How quickly and completely can one recover after the event prevents reasonable operations	Caldwell (2014) [355]	Son (2020) [94]
404	Capacity of the system/organization to successfully handle disturbances, including the surprising ones	Gomes (2014) [356]	Son (2020) [94]
405	A resilient system is able to withstand the effect of stress and strain and to recover from adverse conditions over long time periods	Hollnagel (2006) [25]	Son (2020) [94]
406	Capacity of a system to absorb disturbance, undergo change, and still retain essentially the same function, structure, identity, and feedbacks. In other words, the system has the ability to bounce back after a surprise	Longstaff (2008) [357]	Son (2020) [94]
407	Resilience is adaptation to the changes in the situation, for instance an unusually high demand for limited resources, often together with breakdown of communications technology and other technical systems	Lundberg (2012) [353]	Son (2020) [94]
408	Ability of a system to adjust its operation, before, during or after disruption in order to maintain the necessary operations under both expected and unexpected conditions	Righi (2016) [358]	Son (2020) [116]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
409	A resilient organization must have the adaptive capacity and resource management capability to cope with complexity and surprise	Voshell (2008) [359]	Son (2020) [94]
410	Resilience is the ability to prevent something bad from happening, or the ability to prevent something bad from becoming worse, or the ability to recover from something bad once it has happened	Westrum (2006) [360]	Son (2020) [94]
411	Ability to anticipate, prevent, detect, and recover from harmful events	Woltjer (2006) [40]	Son (2020) [94]
412	Ability of an organization (at any level) to remain under control when faced to hazardous situations, uncertainty, time pressure and threats, from outside and inside	Wybo (2006) [361]	Son (2020) [94]
413	Ability of a system to respond to, absorb, adapt to, and recover from a disaster; it is related to the dynamics (i.e., absorptivity, adaptability, and transformability) of the system, covering the damage, but focusing mostly on both the response and recovery phases	DHS (2008) [171]	Sun (2020) [95]
414	Capability to resist and absorb disaster impacts and rapidly adapt through redundancies and excess capacities	Zhang (2015) [362]	Sun (2020) [95]
415	A resilient system should have a small probability of failure, redundant connectivity, minimal time to full recovery, and limited propagations of the effects	Sun (2020) [95]	Sun (2020) [95]
416	Ability of the system to absorb surges in demand and recover from disruptions	Ta (2009) [96]	Ta (2009) [96]
417	Ability to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize disruption and mitigate the effects of future disasters	Tierney (2007) [363]	Ta (2009) [96]
418	Actions before the disaster, during the disaster, and after the disaster that contribute to reduce the probabilities of failure, the consequence of failure, and the time for recovery	Ta (2009) [96]	Ta (2009) [96]
419	Ability to mitigate hazards, contain the effects of disasters when they occur, and carry out recovery activities in ways that minimize disruption and mitigate the effects	Bruneau (2003) [145]	Ta (2009) [96]
420	Resilience includes apparent opposites such as: redundancy and efficiency, diversity and interdependence, strength and flexibility, autonomy and collaboration, and planning and adaptability	Bruneau (2003) [145]	Ta (2009) [96]
421	Ability for the system to absorb impacts from a disruption and continue operations	Ta (2009) [96]	Ta (2009) [96]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
422	Resilience has 6 properties: Redundancy (availability of more than one resource to provide a system function), Autonomous components (parts of a system that have the ability to operate independently), Collaboration (engagement of agents to promote interaction, share ideas, build trust, and establish routine communication), Efficiency (optimization of input against output), Adaptability (system flexibility and a capacity for learning from past experiences), and Interdependence (connectedness of components of a system or the dimensions of a system, including the network of relationships across components of a system, across dimensions of a system, and between components and dimensions)	Ta (2009) [96]	Ta (2009) [96]
423	Ability to recover from or adjust easily to misfortune or change	Bruneau (2003) [145]	Ta (2009) [96]
424	Ability for a system to absorb shocks and reduce the consequences of disruptions	Ta (2009) [96]	Ta (2009) [96]
425	Ability to absorb the impact of an event then recover afterwards	Proag (2014) [364]	Tachaudomdach (2018) [97]
426	A resilient organization is one that is still capable to accomplish its core objectives in the face of adversity by developing resolutions and activities to intent, look after and respond to a threat occurrence in order to reach the desired effects	Hugues (2014) [365]	Tachaudomdach (2018) [97]
427	Ability of a system to react from stresses that challenges its performance	Tamvakis (2012) [41]	Tamvakis (2012) [41]
428	System's capacity to respond to both normal and suddenly increased demand, and to restructure itself during normal operations in order to enhance quality to confront new and unanticipated changes	Nemeth (2008) [190]	Tamvakis (2012) [41]
429	Ability to operate at a certain level, both in normal and extreme conditions. In case of unanticipated events, resilience is the system's ability to respond to regain balance and return to normal operations	Tamvakis (2012) [41]	Tamvakis (2012) [41]
430	System's ability to maintain its services under stress and in turbulent conditions	Goessling-Reisemann (2019) [366]	Thier (2020) [98]
431	Ability of an entity or system to bounce back to a normal condition after its original state being affected by a disruptive event	Henry (2012) [367]	Wan (2018) [99]
432	Ability of the system to predict, absorb, adapt, and/or quickly recover from a disruptive event such as natural disaster	NIAC (2009) [108]	Wan (2018) [99]
433	Inherent ability of a system to alter its functionality in the face of unexpected changes	Hollnagel (2007) [25]	Wan (2018) [99]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
434	Capability of an entity or system to maintain function and to recover rapidly from a severe shock to achieve a desired state	Cox (2011) [155]	Wan (2018) [99]
435	Capability to resist and recover from a disruption and disaster	Adams (2012) [154]	Wan (2018) [99]
436	The ability of a system to maintain continuity in operations under disruptions	Ishfaq (2012) [368]	Wan (2018) [99]
437	The ability of a system to react from stresses that challenge its performance	Tamvakis (2012) [41]	Wan (2018) [99]
438	Ability for a system to absorb the consequences of disruptions to reduce the impacts of disruptions and maintain services	Chen (2013) [369]	Wan (2018) [99]
439	Ability of a system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation and the capacity to adapt to stress and change	Nursey-Bray (2013) [370]	Wan (2018) [99]
440	Capacity/ability of the system to absorb shocks without catastrophic changes in its basic functional organisation	Reggiani (2013) [371]	Wan (2018) [99]
441	A dimensionless quantity representing the rapidity of the system to revive from a damaged condition to the pre-damaged functionality level	Venkittaraman (2014) [372]	Wan (2018) [99]
442	Ability to absorb shocks while maintaining function	Chang (2013) [373]	Wan (2018) [99]
443	Ability to resist and adapt to disruption	Faturechi (2015) [60]	Wan (2108) [99]
444	A function of the extent of loss experienced at time and the speed at which the system recovers	Baroud (2014) [374]	Wan (2018) [99]
445	Ability of a system to absorb disturbance and still retain its basic function and structure	Becker (2015) [375]	Wan (2018) [99]
446	Ability to withstand and stay operational at the required level of safety during the impact of a given disruptive event	Janić (2015) [263]	Wan (2018) [99]
447	Quality that leads to recovery, reliability and sustainability	Wang (2015) [261]	Wan (2018) [99]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
448	Resilience accounts not only for the system's inherent coping capacity, but also its ability to efficiently adapt post-event	Zhang (2015) [362]	Wan (2018) [99]
449	Capacity of an organization to maintain or return to a dynamic, stable state, which allows it to continue its operations during and after a major incident, or in the presence of continuous stress	Altintas (2009) [376]	Wang (2107) [101]
450	Ability to anticipate, prepare for, respond and adapt to events both sudden shocks and gradual change in order to survive and prosper	Cutter (2013) [377]	Wang (2017) [101]
451	Ability of a system to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance	Carlson (2012) [378]	Wang (2019) [12]
452	Resilience is the response to and the ability to recoup losses and recover stability after a natural disaster	Proag (2014) [364]	Watson (2022) [102]
453	Ability to recover from multiple hazards and hazard types while maintaining critical functions and subsequently adapt the system to improve planning and respond processes for future threats	Linkov (2019) [379]	Wells (2022) [103]
454	A resilient system is expected to consistently deliver high quality services, withstand disruptive events and continually adapt, learn, and improve	Wiig (2020) [104]	Wiig (2020) [104]
455	Capacity to adapt to challenges and changes at different system levels, to maintain high quality service	Wiig (2020) [104]	Wiig (2020) [104]
456	To bounce back to some equilibrium state after stress, disruption or surprise	Wiig (2020) [104]	Wiig (2020) [104]
457	Ability of a system to return to some normal condition or state of functioning after a disruptive event; to cope with pressure and problems by being flexible without compromising system performance; or to adapt to a new normal state, where system functioning is reorganised or enhanced in some way in response to the disruption they face	Macrae (2019) [380]	Wiig (2020) [104]
458	Capacity to proactively adapt and to recover from disturbances that are perceived within the system to fall outside the range of normal and expected disturbances	Comfort (2010) [381]	Wiig (2020) [104]
459	Capacity to adapt to challenges and changes at different system levels, to maintain high quality services	Wiig (2020) [104]	Wiig (2020) [104]
460	Ability of a system to respond to and deal with unanticipated and adverse events	Wiig (2020) [104]	Wiig (2020) [104]
461	Capability to respond to changes and challenges that imply more positive influence	Wiig (2020) [104]	Wiig (2020) [104]

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Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
462	Resilience represents a set of human and organisational resources or activities coming together or being used in some way to address a problem, support learning or develop some new adaptation or approach to delivering services	Macrae (2019) [380]	Wiig (2020) [380]
463	Capacity of a system to proactively adapt to and recover from disturbances that are perceived from within the system to fall outside the range of normal and expected disturbances	Boin (2010) [382]	Woltjer (2015) [105]
464	Ability to repair, replace, patch, or otherwise reconstitute lost capability or performance (and hence effectiveness), at least in part and over time, from misfortune, damage, or a destabilising perturbation in the environment	Alberts (2007) [383]	Woltjer (2015) [105]
465	Ability of a system to recover from or adjust to misfortune, damage, or a destabilising perturbation in the environment	NATO STO (2013) [384]	Woltjer (2015) [105]
466	Resilience presents two perspectives: the ability to maintain functionality under disruptions, and time and resources required to restore performance level after disruptions	Zhou (2019) [28]	Yang (2022) [106]
467	Ability of the system to maintain its demonstrated level of service or to restore itself to that level of service in a specified timeframe	Freckleton (2012) [151]	Yang (2022) [106]
468	Capacity of a system to adapt to a variety of different stress scenarios	Cox (2011) [155]	Yang (2022) [106]
469	Ability to recover rapidly from a severe shock to achieve the desired state	Ganin (2017) [385]	Yang (2022) [106]
470	Ability to manage multiple-equilibrium with other connected systems, to resist and absorb all shock events, to maintain and restore rapid functions whatever disruptions, to learn and improve capacity to cope with future risks	Yang (2022) [106]	Yang (2022) [106]
471	Ability of a system to absorb and adapt to a changing environment	ISO (2021) [386]	Yang (2023) [107]
472	A resilient system is a system that possesses the ability to survive and recover from the likelihood of damage due to disruptive events or mishaps	Yodo (2016) [47]	Yodo (2016) [47]
473	A resilient system represents a system that exhibits specific resilience properties, such as ability to repel, resist, or absorb, ability to recover, and ability to adapt	Goerger (2014) [387]	Yodo (2016) [47]
474	Ability to recover the system performance level from its disruptive state to its operating state	Yodo (2016) [47]	Yodo (2016) [47]

Table A2. *Cont.*

#	Definitions, Conceptualisations, and Understandings of STS Resilience	Authors	In the Review
475	For a system to be resilient against disruptive events or potential failures, there are two essential properties that a system should possess before or after the occurrence of a perturbation: the first one is the ability of the system to maintain function without failures, or generally referred to as "reliability." The second one is the ability of the system to recover from misfortunes, or the ability to "recovery" or "recoverability"	Yodo (2016) [47]	Yodo (2016) [47]
476	Besides reliability and recovery, the resilience attributes are the ability of a system to monitor its operations, anticipate potential failures, response to failures, and learn from failures	Hollnagel (2011) [179]	Yodo (2016) [47]
477	Ability of a system to reduce efficiently both the magnitude and duration of deviation from designed performance levels	Chopra (2016) [388]	Zhou (2019) [28]
478	Characteristic indicating (1) system performance under abnormal conditions, and (2) the speed and resources required for recovery to original functional states. Resilience has ten dimensions: redundancy, diversity, efficiency, autonomous components, strength, collaboration, adaptability, mobility, safety, and the ability to recover quickly	Murray-Tuite (2006) [111]	Zhou (2019) [28]
479	Resilience has four properties:robustness, redundancy, resourcefulness, and rapidity	Beiler (2013) [389]	Zhou (2019) [28]
480	A measure of maximum agitation a system can take in before getting displaced from one state to another	Bhavathrathan (2015) [390]	Zhou (2019) [28]
481	Ability of a system to absorb disruptive events gracefully and restore the pre-disruption level of service in a specified time frame	Serulle (2011) [150]	Zhou (2019) [28]
482	A time-dependent ratio of recovery to loss suffered by the system at some previous point	Henry (2012) [367]	Zhou (2019) [28]
483	Ability of the system, with the help of immediate recovery activities, to meet the demand, as well as to recover and ensure the persistence of the performance level at a rational cost within a limited period, when faced with disruptions to the system caused by unconventional emergency events	Chen (2017) [304]	Zhou (2019) [28]
484	Ability of a system to experience a negative, potentially damaging event and return to a healthy state of operations in a reasonable amount of time after that event	Chan (2016) [243]	Zhou (2019) [28]

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