administrative sciences

MDPI

Review

A Categorization of Resilience: A Scoping Review

Alexander Nieuwborg [1,2,*], Suzanne Hiemstra-van Mastrigt [1], Marijke Melles [3], Jan Zekveld [2] and Sicco Santema [1]

[1] Department of Design, Organisation and Strategy, Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands
[2] Innovation Hub, Royal Schiphol Group, Evert van de Beekstraat 202, 1118 CP Schiphol, The Netherlands
[3] Department of Human-Centered Design, Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands
* Correspondence: a.b.d.nieuwborg@tudelft.nl

Abstract: The COVID-19 pandemic exposed the existential public health and economic fragilities of the civil aviation industry. To prevent future public health disruptions, the civil aviation industry is gaining interest in becoming more "resilient" but rarely elaborates on its meaning, hampering decision-making and strategy development. When looking into the academic literature it seems that a proliferation of resilience-related concepts occurred. Although enriching resilience, it also dilutes its meaning and reduces its use for practice. This paper aims to create concept clarity regarding resilience by proposing a categorization of resilience. Based upon a scoping review, this categorization dissects resilience into four reoccurring aspects: fragility, robustness, adaptation, and transformation. This categorization is expected to support sensemaking in disruptive times while assisting decision-making and strategy development on resilience. When applying this categorization in the civil aviation and public health context, the transformative aspect seems underused. Further research will focus on maturing the categorization of resilience and its use as a sensemaking tool.

Keywords: antifragility; resilience; transformation; disruptions; aviation; COVID-19

Citation: Nieuwborg, Alexander, Suzanne Hiemstra-van Mastrigt, Marijke Melles, Jan Zekveld, and Sicco Santema. 2023. A Categorization of Resilience: A Scoping Review. *Administrative Sciences* 13: 95. https://doi.org/10.3390/admsci13040095

Received: 15 January 2023
Revised: 27 February 2023
Accepted: 18 March 2023
Published: 23 March 2023

1. Introduction

In the wake of the COVID-19 pandemic, the need for creating a "resilience" strategy significantly increased within the civil aviation industry (Tuchen et al. 2020; ICAO 2020; Terry 2020; Gössling 2020; Lenot and Stewart 2020; Arora et al. 2021; and Bouwer et al. 2022). As the civil aviation industry is arguably one of the hardest-hit industries by the pandemic and instrumental in the spread of COVID-19 (Nakamura and Managi 2020; Sokadjo and Atchadé 2020; Zhang et al. 2020; and Coelho et al. 2020) the value of being more resilient is becoming apparent. However, there is no concept clarity on resilience in general, and the literature on aviation likewise rarely elaborates on what resilience means. This is assumed to hamper the civil aviation industries' sensemaking capabilities while obstructing decision-making and strategy development on resilience.

When looking into the academic side, resilience has become an almost elusive concept. Originating from the Latin verb 'resilire' meaning 'to bounce' (Alexander 2013) the concept was initially used to refer to a system's ability to bounce back after a disruption (Dahlberg 2015). However, a proliferation occurred creating a sprawl of resilience-related concepts such as ecological resilience (Holling 1973), engineering resilience (Holling 1996), community resilience (Norris et al. 2008), and transformative resilience (Ramezani and Camarinha-Matos 2020) just to name a few.

Although these resilience-related concepts tend to have a lot of overlap, novel meanings have been linked to the concept such as robustness or indifference to disruption; transformation or fundamentally changing after a disruption; and antifragility or gaining from exposure to disruptions. All these nuances enrich resilience but also dilute its meaning, making it an umbrella term (Hillmann and Guenther 2021). If an organization wants

to implement resilience as a strategy, should it then aspire to a more robust, transformative, or antifragile approach? By having these ambiguities, misalignment might occur thus reducing the effectiveness of resilient decision-making and strategy.

During the COVID-19 pandemic, the resilience-related concept of antifragility (Taleb 2012) seemingly gained popularity (Diedruch et al. 2021). Although an intriguing concept, its relation to the broader resilience field remained ambiguous. The unclarities in the civil aviation industry and the academic literature regarding resilience in combination with the emergence of antifragility formed the starting point of this study. The aim is to conceptualize a novel categorization that consolidates resilience and antifragility while distinguishing its main aspects. Additionally, the research will lay the resulting categorization on top of the civil aviation industry in the context of the COVID-19 pandemic. The goal here is to gain an initial insight into how the aspects are already applied and to detect areas of opportunity. The overall ambition of the categorization is to support the civil aviation industry with sensemaking in disruptive times, with an emphasis on public health, while assisting decision-making and strategy development.

2. Materials and Methods

To better understand the many interpretations of resilience and antifragility, a scoping review was conducted using the approach of Arksey and O'Malley (2005) with the goal of identifying gaps in the literature. This approach consists of five stages: identifying the research question(s); identifying relevant studies; study selection; charting the data; and collating, summarizing, and reporting the results. The underlying ambition is to dissect the main aspects of resilience in relation to antifragility and categorize them.

First, the research question(s) were identified and defined as: "how does resilience relate to antifragility?" and "what aspects does resilience consist of?". In accordance with Taleb (2012) resilience and antifragility were primarily approached as an outcome or a state after facing a disruption giving it an ex-post quality (Canizares et al. 2021). Secondly, relevant studies were identified by consulting three electronic databases: SCOPUS, Web of Science, and PubMed. The search term used was "antifragil* AND resilien*". This search query yielded a total of 210 articles and decreased to 127 after deduplication.

Thirdly, selection occurred by screening the title and abstract while keeping in mind the research questions. Additionally, inclusion criteria were added which initially focused on the aviation and COVID-19 context. However, this did not yield any results. Subsequently, the inclusion criteria were expanded to resilience and antifragility in the context of disruptions, organizations, and complex systems. This resulted in a total of 29 articles. After a full review, six articles remained. Additionally, snowballing added another six resilience-related publications. The inclusion of the snowballed publications was based on references from the six original publications and suggestions from peers. Only journal articles and conference proceedings in English were included. No date restrictions were applied.

Charting the data occurred by using a physical and digital whiteboard (Miro). On these whiteboards, all different aspects of resilience (40) were consolidated and clustered. The aspects were clustered based on their meaning and the interpretation of the authors. This process was initiated by the first author and then reviewed and discussed with all the other authors. The clustering process consisted of three rounds and narrowed down to four clusters in the first round. However, the nuances between each cluster remained subject to discussion throughout the following rounds. The clusters, further referred to as aspects, form the basis of the resulting categorization. Finally, the results were collated, summarized, and reported in this study. The identification and selection protocol is visualized in Figure 1.

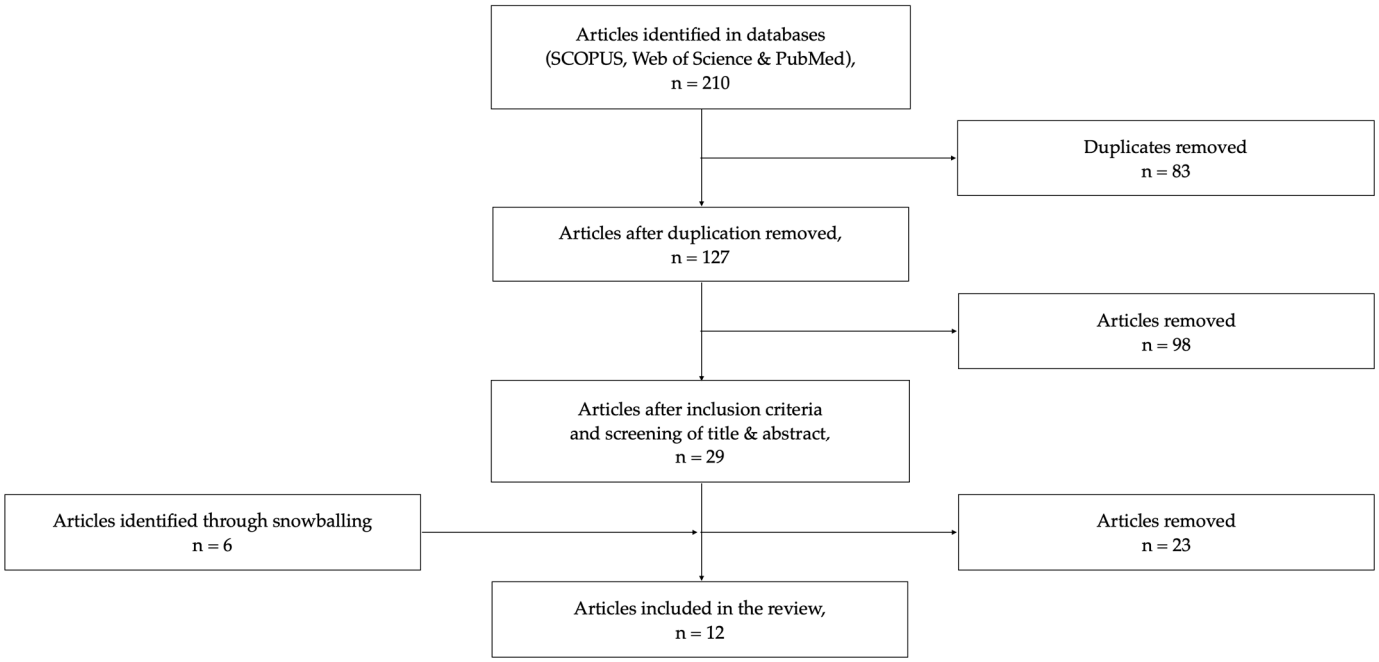

Figure 1. Identification and selection protocol.

3. Results

To better understand the many interpretations of resilience, the following section reviews all resilience models of each included article. Subsequently, these models are dissected into their respective aspects or characteristics. In section four, a categorization is presented based on these outcomes. Table 1 gives an overview of each model and its key aspects.

Table 1. Overview of the included resilience-related model and their aspects.

Author	Aspects			
Holling (1996)	Engineering Resilience *Stability; Return to an equilibrium state; Efficiency of function; Temporary*	Ecological Resilience *Persistence; Flip between equilibrium states; Existence of function; long-term*		
Cutter et al. (2008)	Vulnerability *Potential for harm*	Absorptive Capacity *Absorbing impacts; Predetermined coping responses*	Adaptive Resilience *Reorganization, change, and learning*	
Martin-Breen and Anderies (2011)	Vulnerability *Does not continue to function after shock*	Robustness *Small time scale; Continues to function after shock; Does not change*	Adaptive Capacity *Small time scale; New ways of operating; Maintains identity*	Transformability *Long time scale; Changes identity*
Taleb (2012)	Fragile *More downside than upside after shock*	Robust/Resilient *Resists shocks & stays the same; Perfect robustness is unattainable*	Antifragile *Gets better due to shocks; growing capacity*	

Table 1. *Cont.*

Author	Aspects				
Chroust and Aumayr (2017)	Fragile *Breaks down in face of a disruption*	Fault Tolerant/Robust *Remain unchanged against pre-defined disruptions; undesirable long-term*	Elastic *Change & return to the original state; Incremental change*	Resilient *Return to a new acceptable state*	Antifragile *Learning from disruptions and improving; the ability to create new conditions of fitness*
Manca et al. (2017)	Absorptive Capacity *Absorbs a disruption without changing; Short-term; Small disruptions*	Adaptive Capacity *Incremental change while being flexible; Greater disruptions*	Transformative Capacity *Improvement; Shift from the status quo; Unbearable disruption*		
Ruiz-Martin et al. (2018)	Fragile *Unable to withstand a changing environment and thus collapse*	Robust *Survive changes within pre-designed parameters*	Resilient *Capable to survive unforeseen events*	Antifragile *Prosper and thrive in turbulent times*	
de Bruijn et al. (2020)	Fragile *Breaks due to exposure to randomness; undesirable but essential for achieving antifragility*	Robust *No significant changes when exposed to disruptions; Fragile in the long term.*	Resilient *Absorption of disruptions and a possible reorganization; learning capability*	Antifragile *Long-term; System always gains more than it loses after a disruption*	
Ramezani and Camarinha-Matos (2020)	Fragile *Breaks due to disruption*	Robust *Sustains shocks & remains unchanged*	Resilience *Absorbs shocks & returns to an acceptable state; Stability; Absorptive coping capacity; Persistent response*	Transformative resilience *Reorganize, reconfigure, restructure & reinvent; Dynamic stability; Adaptive & transformative capacity; Elastic response*	Antifragility *Absorbs shocks & gets better; Improvement Learning capacity; Transformative response*
Blečić and Cecchini (2020)	Fragile *The only possibility of harm*	Robust *Does not lose or gain anything; Finite number of disruptions*	Resilient *Possibly low gains from disruptions*	Antifragile *Possibility of large gains*	
Hillmann and Guenther (2021)	Stability domain *Ability to maintain; Ability to bounce back or recover; Ability to resist; Ability to recover (speed); Ability to cope*	Change domain *Ability to adapt; Ability to renew, reconfigure and/or reinvent*	Growth domain *Ability to emerge strengthened; Ability to learn from experiences; Ability to thrive, grow & flourish*		

Table 1. *Cont.*

Author	Aspects		
Munoz et al. (2022)	Robustness *Ability to maintain; Ability to resist; Ability to cope*	Resilience *Ability to bounce back or recover*	Antifragility *Ability to emerge strengthened; Ability to learn from experiences; Ability to thrive, grow & flourish*

3.1. Engineering Resilience and Ecological Resilience (Holling 1996)

Regarded as one of the founders of the resilience concept (Dahlberg 2015; Ruiz-Martin et al. 2018), Holling (1996) introduced "engineering resilience" and "ecological resilience" using respectively an engineering and ecology lens. Engineering resilience emphasizes stability or the return of a system to an equilibrium state after a temporary disturbance. Maintaining the efficiency of function in the short term is a key tenet in the theory of Holling.

Ecological resilience refers to the ability of a system to absorb changes while being able to switch between multiple equilibrium states. The emphasis is on the existence of function, the persistence of relationships, change, and unpredictability. Holling (1996) describes ecological resilience as a long-term strategy where flexibility is essential.

3.2. Disaster Resilience of Place Model (Cutter et al. 2008)

Cutter et al. (2008) created the Disaster Resilience of Place (DROP) model which conceptualizes the relation between vulnerability and resilience in the context of natural disasters at the community level. In this model, vulnerability is defined as a characteristic or quality of a system that creates the potential for harm.

DROP implicitly dissects resilience into two aspects: absorptive capacity and adaptive resilience. The absorptive capacity refers to the ability to absorb impacts with predetermined coping responses. Adaptive resilience can come into play when absorptive capacity is exceeded. It emphasizes reorganization, change, and learning.

3.3. From Vulnerability to Transformability (Martin-Breen and Anderies 2011)

Martin-Breen and Anderies (2011) define resilience as "the capacity of a system to continue to function given external shocks". They link resilience with the following system capacities: vulnerability, robustness, adaptive capacity, and transformability. First off, vulnerability is labeled as the antonym of resilience referring to a system that does not continue to function after a shock. Robustness is similar to resilience in the sense that a system "continues to give function" due to a shock. However, it is argued that robustness is typically applied to a fixed set of systems and shocks implying that it is predominantly useful over small time scales. It also suggests a large degree of stability as the system and anticipated shocks do not change.

Finally, Martin-Breen and Anderies (2011) label adaptive capacity and transformability as "aspects" of resilience. Adaptive capacity refers to the capability of a specific system to cope with shocks and, although not explicitly mentioned, the capability to generate "new ways of operating". Similar to robustness, adaptive capacity is mostly used in small time scales. Transformability is the capability to reorganize into new systems when the current system is no longer sufficient. It implies a larger time scale. Martin-Breen and Anderies (2011) note that the adaptive capacity maintains the identity of the system while transformability changes the identity.

3.4. Antifragility (Taleb 2012)

Taleb (2012) introduced a new concept into the resilience family named: "antifragility". Taking a more philosophical and financial approach, he argues that anything that matters

can be classified into one of three categories: fragile, robust, or antifragile. Note that he seemingly does not make a nuance between robustness and resilience thus merging them into one concept. The fragile refers to things that experience more downside than upside from certain shocks, leading them to break over time. Taleb (2012) elaborates by stating that the fragile do not enjoy volatility, randomness, uncertainty, disorder, errors, and stressors.

The robust (or resilient) is indifferent to shocks. As Taleb (2012) states "the resilient resists shocks and stays the same". However, he nuances that perfect robustness is unattainable thus giving it a finite nature. The antifragile refers to things that get better due to exposure to shocks. It is framed as the antonym to the fragile thus the antifragile loves volatility, randomness, uncertainty, disorder, errors, and stressors. Although not explicitly mentioned, Taleb (2012) seems to suggest a strong adaptive and transformative nature by often referring to a growing capacity.

3.5. Reaction of Systems (Chroust and Aumayr 2017)

Chroust and Aumayr (2017) classify systems into five states or vulnerability classes based on their reaction against disruptions which include: fragile, fault-tolerant or robust, elastic, resilient, and antifragile. The fragile state refers to a system breaking down in the face of disruption. Chroust and Aumayr (2017) seemingly use fault-tolerant and robust as nascent concepts. Fault-tolerant emphasizes absorption while the robust remains unchanged. Systems in both categories can only cope with a limited set of pre-defined hazards. Maintaining this state might be undesirable due to costs, high effort, and difficult evolution.

Elastic is defined as a short state change whereafter the system returns to its original state. While referring to physics, 100% elasticity is not possible thus implying that the original state is incrementally changed. Resilient is interpreted as the capacity of bringing a system into an acceptable state after a disruption. This acceptable state can be different from the original state implying change or growth. Finally, antifragile refers to a system being able to learn from disruptions and becoming better at countering similar events. It includes the system's ability to create new conditions of fitness (François 2004).

3.6. Framework on Vulnerability and Resilience (Manca et al. 2017)

The European Commission's Joint Research Centre developed a framework for vulnerability and resilience (Manca et al. 2017). The framework defines three capacities of resilience when facing a disruption which are context-specific: absorptive capacity, adaptive capacity, and transformative capacity. Absorptive capacity is related to stability and resistance. The system absorbs a disruption without changing its behavior. The absorptive capacity has value in the short term with low-intensity disruptions. Adaptive capacity plays a role when the duration and intensity of the disruption increases. However, it is implied that the disruption remains "bearable". The adaptive capacity allows for incremental change while being flexible. Finally, the transformative capacity has value when a disturbance becomes unbearable and when the required change is too large. This capacity can be deliberate but also forced by its surroundings. It implies learning from past events and improvement of conditions considering current constraints. It is seen as a shift from the status quo.

3.7. Four-Level Maturity Model for Organizational Resilience (Ruiz-Martin et al. 2018)

Ruiz-Martin et al. (2018) approach resilience as an aspect of a larger dynamic concept, the Maturity Model for Organizational Resilience, which evolves over time. An organization can shift through four of these aspects or levels: fragile, robust, resilient, and antifragile. A fragile organization is referred to as unable to withstand a changing environment and thus will collapse. A robust organization can survive some changes in its environment. However, if these changes fall outside so-called "pre-designed parameters", the organization will collapse.

A resilient organization goes beyond being robust and can survive unforeseen events. Finally, the antifragile organization is not only able to survive unknown disruptions but can also prosper and thrive in disruptive times.

3.8. Four System Types (de Bruijn et al. 2020)

Similar to Ruiz-Martin et al. (2018), de Bruijn et al. (2020) define four system types: fragile, robust, resilient, and antifragile. As the fragile breaks by exposure to randomness, it is approached as an undesirable system type. However, the authors point out that fragility is an essential part of achieving antifragility. The robust shows no significant changes in behavior when exposed to disruption. Small positive or negative changes are possible, but they tend to cancel themselves out. The robustness becomes fragile in the long term.

Resilient emphasizes absorption of disruptions and a potential reorganization after the shock. The resilient has a learning capability, making it less susceptible to disruptions it already experienced. The antifragile is approached as a long-term survival capability as the system always gains more than it loses when facing a disruption.

3.9. Transformative Resilience (Ramezani and Camarinha-Matos 2020)

Ramezani and Camarinha-Matos (2020) see resilience as a type of response to disruption for systems and organizations. They identify five typologies: fragility, robustness, resilience, transformative resilience, and antifragility. Ramezani and Camarinha-Matos (2020) define fragility as a system that is destroyed or broken as a consequence of a disruption. Robustness refers to the capability of sustaining shocks and remaining unchanged.

Resilience in this case refers to a system capable of absorbing shocks and returning to an acceptable state emphasizing stability, persistence, and an absorptive coping capacity. Ramezani and Camarinha-Matos (2020) introduce a novel concept of transformative resilience inspired by Dahlberg (2015). It refers to a system's ability to "reorganize, reconfigure, restructure and even reinvent" in response to a disruption. Transformative resilience maintains a "dynamic stability" meaning that a system can evolve to a new "acceptable state" after a disruption. This suggests an adaptive and transformative capacity giving the system an elastic response. For antifragility, Taleb's (2012) definition of a system that absorbs shocks and gets better afterwards is used. They argue that resilience and transformative resilience are different from antifragility due to their focus on absorption while having a dynamic stability. Antifragility emphasizes improvement by not only surviving shocks but also employing them to become stronger. It contains a strong learning capacity, allowing for a more fundamental long-term system transformation.

3.10. Resilience as a Limit Case of Antifragility (Blečić and Cecchini 2020)

Blečić and Cecchini (2020) make use of a response (gain-harm) $\times$ responsivity (static-dynamic) matrix. It consists of four aspects: fragile, robust, resilient, and antifragile. Fragile is labeled as both a static (e.g., an object) and dynamic (e.g., a system) concept that only has a possible harmful outcome. The robust does not get harmed but also does not gain anything. It is seen as a static limit case of fragility as it can withstand a finite number of disruptions.

The resilient is put in the dynamic category and could gain from disruptions; however, these gains remain low. Antifragile is put in both static and dynamic categories and refers to the possibility of large gains. Antifragile can be seen as the superlative of resilience.

3.11. Six Conceptual Domains (Hillmann and Guenther 2021)

Hillmann and Guenther (2021) conducted a systematic review of organizational resilience including an analysis of 71 definitions of the concept. The systematic review clustered these definitions into six conceptual domains with three of them being relevant for this study as they refer to resilience as a state: stability domain, change domain, and growth domain. Note that Hillmann and Guenther (2021) see the stability domain as the

most essential domain for understanding resilience. Although other domains enrich the concept, they argue that it moves resilience away from its original meaning.

The stability domain consists of five abilities: the ability to maintain an organizational configuration; the ability to bounce back or recover while maintaining the same structure and functions; the ability to resist thus enduring or bearing the impact of change or a disruptive event; the ability to recover refers to the recovery speed; and the ability to cope referring to the capability of improvising and finding solutions.

The change domain talks about the ability to adapt and the ability to renew, reconfigure, and/or reinvent. Note that the nuances between both abilities remain vague. The ability to renew seems to have more of a proactive nature and has dynamic capabilities while the ability to adapt emphasizes an adaptation to a disruptive event. The growth domain refers to the growth organizations can experience in the wake of a crisis. It includes the ability to emerge strengthened; the ability to learn from experiences and develop new capabilities; and the ability to thrive, grow and flourish despite adversity.

3.12. Clustering the Conceptual Domains (Munoz et al. 2022)

As Hillmann and Guenther (2021) emphasize stability as the essential domain for resilience, Munoz et al. (2022) argue to move away from this singular interpretation while dissecting resilience into multiple "outcomes after facing adversity". Based on Hillmann and Guenther's (2021) conceptual domains, they see three outcomes: robustness or insensitivity to change; resilience or performance degradation followed by recovery; and antifragility or upside gained.

According to Munoz et al. (2022), robustness is closely related to Hillmann and Guenther's (2021) essential domain of stability. It encompasses Hillmann and Guenther's (2021) ability to maintain; the ability to cope; and the ability to resist. Munoz et al. (2022) emphasize the absorptive nature of robustness while noting, in accordance with Holling (1973), that it is a temporary capacity, as systems cannot be robust for infinity.

Munoz et al. (2022) make a nuance regarding resilience. As it refers to the ability to bounce back and the ability to recover, which was previously placed in the stability domain by Hillmann and Guenther (2021). Munoz et al. (2022) argue that absorbing a disruption is distinctively different from recovering from a disruption thus making it a different outcome.

Finally, antifragility refers to Taleb's (2012) definition of gaining from adversity and is coupled with Hillmann and Guenther's (2021) growth domain including the ability to emerge strengthened; the ability to learn from experiences and develop new capabilities; and the ability to thrive, grow and flourish despite adversity. Since growth is fundamentally different from absorption or recovery, Munoz et al. (2022) classify it as their third outcome after facing adversity.

4. A Categorization of Resilience

This section summarizes and categorizes the resilience models of the previous section. Regarding the categorization, Norris et al. (2008) anecdote regarding a theory of relativity formed a key inspiration. This anecdote argues that relativity might only be a metaphor or abstraction. They note that there is no variable called "relativity" in the theory of relativity while leading to revolutionary hypotheses about energy, mass, and the speed of light.

Analogous to the theory of relativity, our resulting categorization does not contain an aspect called resilience. Instead, the overarching concept is referred to as resilience and consists of four aspects: fragility, robustness, adaptation, and transformation. The relation between the included resilience models and each aspect of the categorization is presented in Figure 2. An overview of the categorization of resilience is shown in Figure 3.

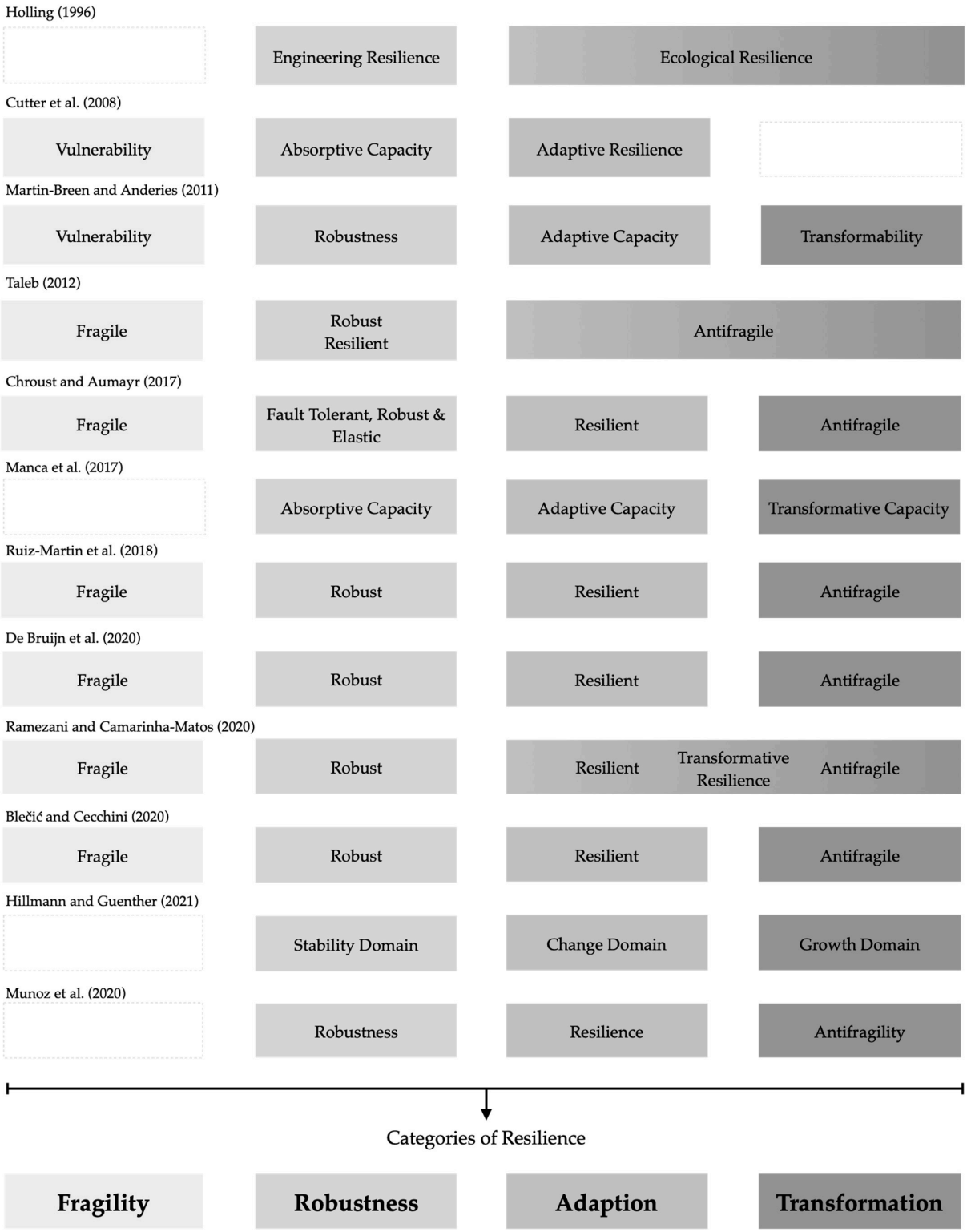

Figure 2. The relation between the included resilience models and each aspect of resilience. (Holling 1996; Cutter et al. 2008; Martin-Breen and Anderies 2011; Taleb 2012; Chroust and Aumayr 2017; Manca et al. 2017; Ruiz-Martin et al. 2018; de Bruijn et al. 2020; Ramezani and Camarinha-Matos 2020; Blečić and Cecchini 2020; Hillmann and Guenther 2021; Munoz et al. 2022).

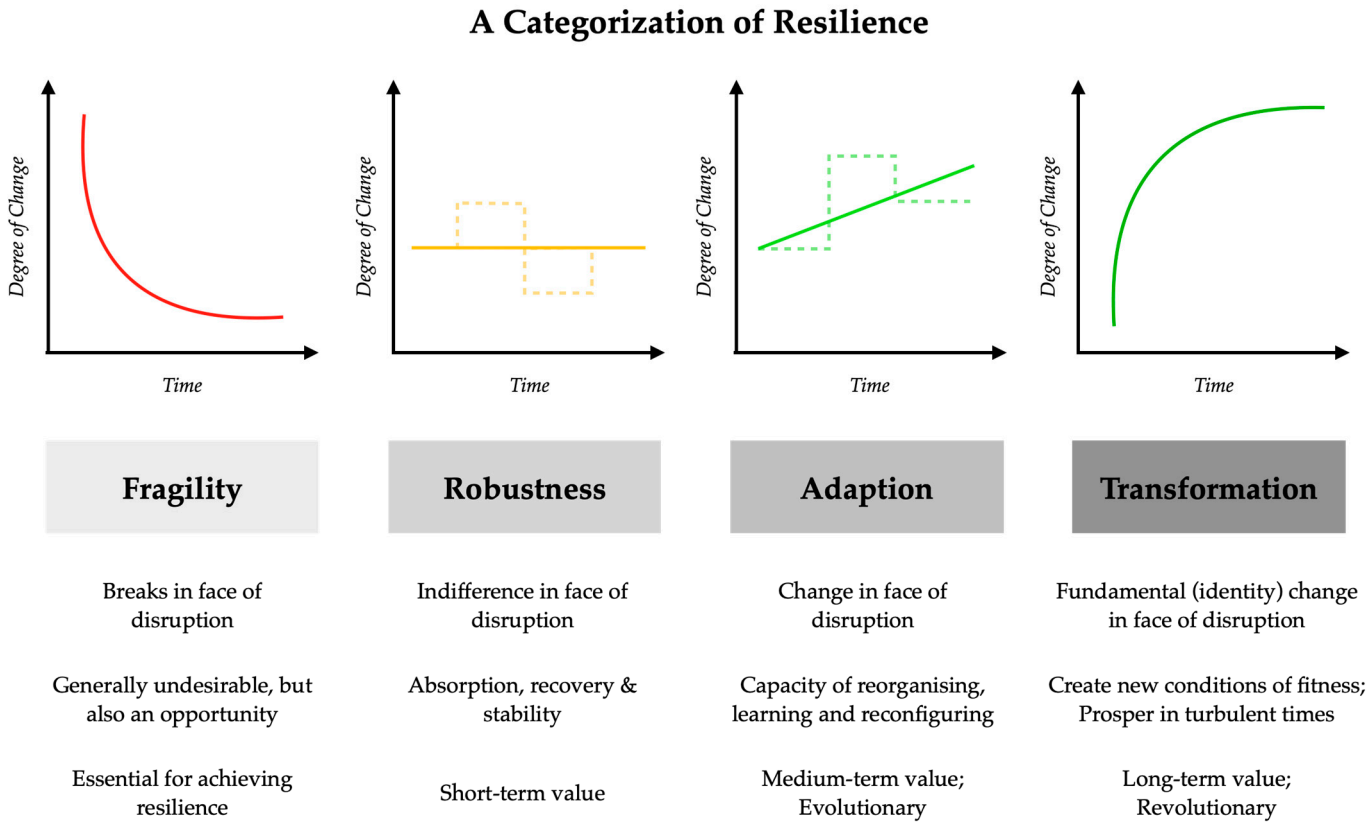

Figure 3. A categorization of resilience including graphs as an illustrative support.

We believe that all these aspects contribute to the overarching concept of resilience. For example, when a system does not change due to a disruption it manifests the robust aspect of resilience. The choice of terminology in the aspects aims to reduce ambiguity and increase actionability. We want to note that one aspect is not necessarily more desirable than another. For example, antifragility seems to be more desirable than adaptation; however, financial, time, and/or complexity constraints can make it unfeasible for the organization to become antifragile. The following section will delve deeper into what each aspect means, and how it relates to the previous models and illustrate it with an example from the civil aviation industry and COVID-19.

4.1. Fragility

Regarding the aspect of fragility there is consensus between the resilience models of all included articles. It refers to a system that deteriorates or breaks when exposed to a disruption thus not fulfilling its intended function. The fragile is included in this model since it is an essential trait for achieving overall resilience. As Holling (1973); Taleb (2012); and de Bruijn et al. (2020) point out, a system needs a degree of fragility to adapt and/or transform making these concepts strongly related. Although fragility is generally undesirable, using fragility intentionally might transform it into a desirable trait.

To illustrate, the civil aviation industry showcased existential economic and public health fragilities when exposed to an infectious disease. By facilitating intercontinental connectivity, COVID-19 was able to spread creating a pandemic and resulting in major public health disruptions. Subsequently, multiple countries started to impose travel restrictions, or bans, pushing the civil aviation industry into an economic recession.

4.2. Robustness

Similar to fragility, there seems to be a lot of consensus amongst the included authors about the concept of robustness. In this categorization, robustness contains the following

traits: stable nature, indifference to shocks, absorptive capacity, and value over a short time scale. The latter emphasizes that permanent robustness cannot be achieved since systems are bound to degrade at some point and become fragile.

A point of discussion is the notion of recovery or bouncing back. Several concepts related to this such as engineering resilience; the elastic state; the stability domain; and resilience in general. To what extent does recovery reflect indifference or stability, the key traits of robustness? de Bruijn et al. (2020) notion of robustness offers insight by stating that the robust can change; however, gains and losses cancel each other out over time. To summarize: if a system recovers while its net changes are zero, it is labeled as robust.

Robustness can be observed in the air cargo during the COVID-19 pandemic. While passengers' numbers decreased dramatically, cargo remained relatively stable and occasionally grew due to the high demand for medical supplies, e-commerce, and vaccines. Few cargo airlines were even able to profit during the COVID-19 crisis (Jeong 2020). Although the increased profitability of these airlines might imply antifragility, no actual change is occurring thus keeping air cargo in the robust category.

4.3. Adaptation

In our categorization of resilience, adaptation expands on robustness's mere stability by adding a net change component. Although there is no clear consensus on the traits and naming of this aspect, several themes reoccur. Multiple authors mention the evolution towards a new state implying a capacity for reorganizing, learning, and reconfiguring. Other authors add the notions of improvement or gaining from disruptions. Note that the resulting changes, or gains, are usually seen as larger than the robust but less than the transformation, thereby giving it an evolutionary nature. Additionally, the adaptive is only able to withstand a limited range of disruptions on a limited time scale.

The included authors use different names for the aspect of adaptation such as ecological resilience, adaptive resilience, adaptive capacity, antifragility, resilience, transformative resilience, and the change domain. Although resilience and its denominations are the most prevalent, adaptation is chosen as the overarching aspect as it offers a stronger portrayal of the net change component and seems more actionable. Additionally, the overall model is called a categorization of resilience with the assumption that resilience consists of four different aspects. Labeling one of those aspects as resilience might create confusion. Note that some concepts seem to fit both in the adaptation and transformation category, similar to ecological resilience, Taleb's antifragility, and transformative resilience.

To illustrate, a case of adaptation occurred during the introduction of the Digital Covid Certificate (DCC) in the civil aviation industry by the European Union (European Commission n.d.). Resulting health certificates allowed the industry to process passenger health credentials (e.g., used testing regime or vaccination status) automatically and uniformly thus making international travel more accessible. Prior to the introduction of the DCC, verification of health credentials happened manually leading to immense queues in airports and increases in demand for customer support due to unclarity regarding travel regulations. DCC is considered adaptive since it is in essence an adaptation of the World Health Organization's International Certificate of Vaccination or the "Yellow Card".

4.4. Transformation

Similar to adaptation, there is no explicit consensus regarding transformation but there are multiple reoccurring themes. First, several authors distinguish a revolutionary or fundamental change taking place, referring to a change of identity; the ability to create new conditions of fitness; prosper, thrive, and flourish in turbulent times; and transform. It has a long-term value with the potential for large gains.

Although this categorization uses transformation as the overarching aspect, several authors use nascent concepts such as ecological resilience, transformability, antifragility, transformative capacity, transformative resilience, and the growth domain. The transforma-

tion was chosen as it strongly represents the fundamental change component thus giving the aspect a more actionable nature.

Examples of transformation in the civil aviation industry during the COVID-19 pandemic seem missing until now. While restrictions are being lifted and passenger numbers are increasing, the underlying operational and organizational dynamics that allowed for this pandemic to occur in the first place are assumed to remain. As the impact of the COVID-19 pandemic seemingly shimmers down, the urgency and interest in a transformative strategy decreases as well. Failing to fundamentally address current pandemic fragilities can make the industry prone to future public health and economic disruptions.

5. Discussion & Limitations

As the civil aviation industry unwillingly facilitated the spread of COVID-19 (Nakamura and Managi 2020; Sokadjo and Atchadé 2020; Zhang et al. 2020; and Coelho et al. 2020) and subsequently was hit by an immense economic recession, interest in a more "resilient" approach gained popularity throughout the sector (Tuchen et al. 2020; ICAO 2020; Terry 2020; Gössling 2020; Lenot and Stewart 2020; Arora et al. 2021; and Bouwer et al. 2022). Preparing for future public health disruptions thus has a clear societal and economic value. However, discussions remain about what resilience means in this context. The proposed categorization of resilience aims to bring clarity by dividing resilience into four aspects: fragility, robustness, adaptation, and transformation. Currently, it is assumed that all aspects contribute to achieving overall resilience.

The results of this scoping review are seen as a first step towards a unified categorization of resilience. In its current state, the categorization can also function as a sensemaking tool that can support organizations in decision-making and strategy development in disruptive times. As the categorization aims to create a common understanding of resilience and its aspects, decision-makers are equipped with more granular terminology. This allows for a more accurate description of one's resilience when facing disruption and creates a common understanding.

To further mature this categorization of resilience, future research is required. Currently, two research gaps are identified in the literature: the operationalization of aspects; and the occurrence of the aspects in practice. Although the categorization of resilience is meant as a sensemaking tool, research is needed regarding strategies or tools that are required for operationalizing each aspect. For example, imagine an organization wanting to use the fragility aspect as an asset. How could this be operationalized? Inspiration can be drawn from cybersecurity's "honeypots", whereby cybercriminals are purposefully lured into a fragile information system so that their way of working can be monitored and analyzed. Further maturing the aspects of resilience and its strategies can support its operationalization and serve as inspiration during disruptive times.

Secondly, further research on the occurrence of each aspect in the industry is needed to assess their value in practice. When coupling back to the civil aviation industry and COVID-19, anecdotal evidence was gathered to illustrate each aspect. As a result, the notion of transformation seemed underdeveloped but necessary as the pandemic instigated an existential public health and economic crisis. Expanding the anecdotal evidence of the occurrence of the aspects of resilience in the civil aviation industry during disruptive times is seen as a critical next step.

Currently, this study has limitations regarding the terminology of the aspects, the included literature, and resilience as a process. First off, the categorization of resilience aims to create concept clarity but a degree of ambiguity can remain due to the choice of terminology. Reducing this ambiguity is assumed to be a continuous process with dialogue between academia and practice.

Although the focus of this study was on resilience and antifragility, a broader systematic literature review that combines resilience with for example transformation, adaptation, robustness, and/or fragility seems critical to propose more complete insights. Additionally,

the resulting categorization and visualization are made by the authors of this paper and based on their interpretations of the resilience models.

Finally, this study approached resilience primarily as an outcome and ex-post value. However, resilience can be interpreted in many ways such as an ability, capacity, behavior, process, or a mix (Hillmann and Guenther 2021). Although the distinctions between these interpretations are often vague, the notion of resilience as a process is not explicitly present in this study. At this point, it is suspected that systems can move through the aspects of resilience thus for example going from fragile to transformation and then robustness. However, further research is required on how the aspects relate to resilience as a process and concepts such as the Panarchy Theory (Holling 2001).

6. Conclusions

The raison d'être of this paper originated from the civil aviation industry's interest in a "resilience" strategy for future health disruptions in the wake of the COVID-19 pandemic. However, the concrete meaning or significance of resilience remained vague thus hampering decision-making and the creation of a long-term strategy. When consulting the academic literature, this trend seemed to reappear as the concept of resilience proliferated in the last years and evolved into an umbrella term.

In response, a scoping review was conducted to dissect resilience leading to the categorization of resilience. This categorization divides resilience into four distinct aspects: fragility, robustness, adaptation, and transformation. These aspects are expected to support sensemaking in disruptive times while assisting decision-making and strategy development.

When overlaying the aspects of resilience over the civil aviation industry and the COVID-19 pandemic, a transformative approach seems significantly underdeveloped but of existential value for overcoming future disruptions. Further research will focus on maturing the categorization of resilience and how it can be the basis for actionable decision-making and strategy development in disruptive times.

Author Contributions: Conceptualization, A.N., S.H.-v.M., M.M., J.Z. and S.S.; methodology, A.N., S.H.-v.M. and M.M.; formal analysis, A.N.; investigation, A.N.; data curation, A.N.; writing—original draft preparation, A.N.; writing—review and editing, A.N., S.H.-v.M., M.M., J.Z. and S.S.; visualization, A.N.; supervision, S.H.-v.M., M.M., J.Z. and S.S.; project administration, A.N.; funding acquisition, S.H.-v.M. and S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by a Public-Private Partnerships for Research and Development (PPP allowance) from the Dutch Ministry of Economic Affairs and Climate Policy via Click NL and the Royal Schiphol Group.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank Ed Oomes for his input, expertise and feedback.

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

References

Alexander, David E. 2013. Resilience and Disaster Risk Reduction: An Etymological Journey. *Natural Hazards and Earth System Sciences* 13: 2707–16. [CrossRef]

Arksey, Hilary, and Lisa O'Malley. 2005. Scoping Studies: Towards a Methodological Framework. *International Journal of Social Research Methodology* 8: 19–32. [CrossRef]

Arora, Mohit, Stefan Tuchen, Mohsen Nazemi, and Lucienne Blessing. 2021. Airport Pandemic Response: An Assessment of Impacts and Strategies after One Year with COVID-19. *Transportation Research Interdisciplinary Perspectives* 11: 100449. [CrossRef] [PubMed]

Blečić, Ivan, and Arnaldo Cecchini. 2020. Antifragile Planning. *Planning Theory* 19: 172–92. [CrossRef]

Bouwer, Jaap, Vik Krishnan, Steve Saxon, and Caroline Tufft. 2022. COVID-19's Impact on the Global Aviation Sector. McKinsey. Available online: https://www.mckinsey.com/industries/travel-logistics-and-infrastructure/our-insights/taking-stock-of-the-pandemics-impact-on-global-aviation (accessed on 5 May 2022).

Canizares, Jose Carlos, Samantha Marie Copeland, and Neelke Doorn. 2021. Making Sense of Resilience. *Sustainability* 13: 8538. [CrossRef]

Chroust, Gerhard, and Georg Aumayr. 2017. Resilience 2.0: Computer-Aided Disaster Management. *Journal of Systems Science and Systems Engineering* 26: 321–35. [CrossRef]

Coelho, Marco Tulio Pacheco, João Fabrício Mota Rodrigues, Anderson Matos Medina, Paulo Scalco, Levi Carina Terribile, Bruno Vilela, José Alexandre Felizola Diniz-Filho, and Ricardo Dobrovolski. 2020. Global Expansion of COVID-19 Pandemic Is Driven by Population Size and Airport Connections. *PeerJ* 8: e9708. [CrossRef]

Cutter, Susan L., Lindsey Barnes, Melissa Berry, Christopher Burton, Elijah Evans, Eric Tate, and Jennifer Webb. 2008. A Place-Based Model for Understanding Community Resilience to Natural Disasters. *Global Environmental Change* 18: 598–606. [CrossRef]

Dahlberg, Rasmus. 2015. Resilience and Complexity: Conjoining the Discourses of Two Contested Concepts. *Culture Unbound* 7: 541–57. [CrossRef]

de Bruijn, Harald, Andreas Groessler, and Nuno Videira. 2020. Antifragility as a Design Criterion for Modelling Dynamic Systems. *Systems Research and Behavioral Science* 37: 23–37. [CrossRef]

Diedruch, Dago, Nicolas Northcote, Tido Röder, and Karolina Sauer-Sidor. 2021. Strategic Resilience during the COVID-19 Crisis. Available online: https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/strategic-resilience-during-the-covid-19-crisis (accessed on 17 February 2023).

European Commission. n.d. EU Digital COVID Certificate. Available online: https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/safe-covid-19-vaccines-europeans/eu-digital-covid-certificate_en (accessed on 11 May 2022).

François, Charles. 2004. *International Encyclopedia of Systems and Cybernetics*, 2nd ed. München: K. G. Saur.

Gössling, Stefan. 2020. Risks, Resilience, and Pathways to Sustainable Aviation: A COVID-19 Perspective. *Journal of Air Transport Management* 89: 101933. [CrossRef] [PubMed]

Hillmann, Julia, and Edeltraud Guenther. 2021. Organizational Resilience: A Valuable Construct for Management Research? *International Journal of Management Reviews* 23: 7–44. [CrossRef]

Holling, Crawford S. 1973. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics* 4: 1–23. [CrossRef]

Holling, Crawford S. 1996. Engineering Resilience versus Ecological Resilience. In *Engineering within Ecological Constraints*. Washington, DC: National Academy Press, pp. 31–43.

Holling, Crawford S. 2001. Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems* 4: 390–405. [CrossRef]

ICAO. 2020. *Council Aviation Recovery Task Force (CART)*. Montréal: ICAO, p. 18.

Jeong, Eun-Young. 2020. How a Fortunate Few Airlines Profit in a Pandemic: Lots of Cargo. *Wall Street Journal*, September 22, sec. Business. Available online: https://www.wsj.com/articles/how-a-fortunate-few-airlines-profit-in-a-pandemic-lots-of-cargo-11600779463 (accessed on 11 May 2022).

Lenot, David, and Cheryl Stewart. 2020. COVID-19: The Need for Resilience Propels Innovation. ACI. June 29. Available online: https://blog.aci.aero/covid-19-the-need-for-resilience-propels-innovation/ (accessed on 12 May 2022).

Manca, Anna Rita, Peter Benczur, and Enrico Giovannini. 2017. *Building a Scientific Narrative towards a More Resilient EU Society. Part 1, A Conceptual Framework*. LU: Publications Office. Available online: https://data.europa.eu/doi/10.2760/635528 (accessed on 19 December 2022).

Martin-Breen, Patrick, and J. Marty Anderies. 2011. *Resilience: A Literature Review*. Brighton: Bellagio Initiative.

Munoz, Albert, Jon Billsberry, and Veronique Ambrosini. 2022. Resilience, Robustness, and Antifragility: Towards an Appreciation of Distinct Organizational Responses to Adversity. *International Journal of Management Reviews* 24: 181–87. [CrossRef]

Nakamura, Hiroki, and Shunsuke Managi. 2020. Airport Risk of Importation and Exportation of the COVID-19 Pandemic. *Transport Policy* 96: 40–47. [CrossRef]

Norris, Fran H., Susan P. Stevens, Betty Pfefferbaum, Karen F. Wyche, and Rose L. Pfefferbaum. 2008. Community Resilience as a Metaphor, Theory, Set of Capacities, and Strategy for Disaster Readiness. *American Journal of Community Psychology* 41: 127–50. [CrossRef]

Ramezani, Javaneh, and Luis M. Camarinha-Matos. 2020. Approaches for Resilience and Antifragility in Collaborative Business Ecosystems. *Technological Forecasting and Social Change* 151: 119846. [CrossRef]

Ruiz-Martin, Cristina, Adolfo Lopez-Paredes, and Gabriel Wainer. 2018. What We Know and Do Not Know about Organizational Resilience. *International Journal of Production Management and Engineering* 6: 11–28. [CrossRef]

Sokadjo, Yves Morel, and Mintodê Nicodème Atchadé. 2020. The Influence of Passenger Air Traffic on the Spread of COVID-19 in the World. *Transportation Research Interdisciplinary Perspectives* 8: 100213. [CrossRef]

Taleb, Nassim Nicholas. 2012. *Antifragile: Things That Gain from Disorder*. Random House Trade Paperback edition. New York: Random House Trade Paperbacks.

Terry, Bryan. 2020. *COVID-19: Rising to the Challange with Resilience. Airline Sector*. London: Deloitte.

Tuchen, Stefan, Mohit Arora, and Lucienne Blessing. 2020. Airport User Experience Unpacked: Conceptualizing Its Potential in the Face of COVID-19. *Journal of Air Transport Management* 89: 101919. [CrossRef] [PubMed]
Zhang, Yahua, Anming Zhang, and Jiaoe Wang. 2020. Exploring the Roles of High-Speed Train, Air and Coach Services in the Spread of COVID-19 in China. *Transport Policy* 94: 34–42. [CrossRef] [PubMed]