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NOVA University of Lisbon, Faculty of Sciences and Technology, Campus da Caparica, 2829-516 Monte Caparica, Portugal
UNINOVA-CTS, Center of Technology and Systems, Caparica, Portugal
m.ramezani@fct.unl.pt, cam@uninova.pt

Abstract. Today's business world is continuously challenged by unexpected disruptive events, which are increasing in their frequency and effects. As a consequence, it is plausible to foresee future scenarios in which turbulence and instability are no longer considered as episodic crises, but rather somewhat the "norm" or the default status. This trend naturally raises the question of how organizations can strive and even gain in such disruptive environments, and which characteristics are required for combating disruptions. Resilience and antifragility are two emerging approaches to handle disruptions. Through a literature review, this paper identifies several strategies that contribute to business ecosystem's resilience or antifragility. Furthermore, it is also shown that contributions from a number of disciplinary areas, including Collaborative Networks, Systems Thinking, Thermodynamics, Management science, and ICT, can provide complementary views and support. A set of promising examples of applications of the discussed approaches are presented and briefly analyzed. Finally, a number of open questions and directions for further research are presented.

Keywords: Resilience, Antifragility, Disruptions, Business Ecosystems, Cyber Physical Systems.

1 Introduction

Due to the rise of ever tougher challenges in contemporary business environments characterized by high complexity and uncertainty, there is a clear need for finding new solutions to address unexpected issues and disruptions. Despite the increasing capabilities offered by technology in recent years, there are still significant engineering and philosophical problems that require to be handled to embrace the unknown future [1].

Traditional risk management approaches are not effective when a company is confronted with unexpected disruptions. Those approaches are based on the assumption of some stability of the business environments, and therefore disruptive events such as explosions, or natural disasters are hard to handle deviations. Traditional methods require risk identification and quantification, which rely on past experimental data. Therefore, those methods are not useful to handle low probability, high impact disruptions. Furthermore, traditional strategies are cost-based and narrow-focused and therefore usually cause more vulnerability when dealing with unforeseeable events [2][3]. Therefore, there is a need for the emergence of new paradigms to understand, measure, and respond to these stressful conditions. Resilience and antifragility are two promising concepts to deal with unexpected disruptions [1]. A resilient system survives shocks and stays the same or evolves to another stable state; an antifragile system thrives and improves with shocks [4].

The important question which emerges here is how some organizations can overcome stressful situations better than others. In fact, there are various strategies that companies can use to achieve resilience and/or antifragility in face of disruptions. However, existing studies in the business ecosystems area do not provide a comprehensive collection of strategies to cope with disruptions. Most of the previous studies have reviewed only a few resilience-oriented strategies, and there is no systematic analysis of antifragility-oriented strategies in the literature [5][6].

This work addresses such lack of information by performing a literature analysis and proposing a categorization of disruption-coping strategies and capabilities in business ecosystems, considering: (1) their relation to resilience and antifragility, and (2) their relation to the phases of disaster management. This study addresses the above issues as follows: First, it provides a taxonomy of disruption-coping strategies. Second, it identifies the link between these strategies and resilience and antifragility. Third, it defines the relationship between the strategies and the three phases of disaster management. Fourth, it categorizes the essential capabilities, which can help organizations to achieve resilience and antifragility.

This research also seeks insights from various disciplines to identify different relevant tools, rules, and other features for a better understanding of the complex challenges in a stressful business environment. Another contribution is the identification of illustrative examples of promising approaches to resilience and antifragility. This survey is guided by the following research questions: What are emergent approaches to handle disruptions? Which knowledge areas are contributing to this issue? Which are promising/illustrative examples of approaches to handle disruptions?

The remaining of the paper is organized as follows: first, a short review of contribution to innovation in industrial and service systems is presented in Section 2; and then a set of related concepts to address disruptions in business ecosystems are explained in Section three. The main findings of the study are discussed in Section four, and finally, in Section five conclusions are provided.

2 Relation to Innovation in Industrial and Service Systems

Industry 4.0 is characterized by digitalization, automation and adaptation, communication, optimization and customization, value-added services and businesses. Furthermore, collaboration plays a central role in all dimensions of this industrial revolution [7]. In particular, the cyber-physical system (CPS) and Internet of Things promise new support to business ecosystems namely to allow real-time decisions and increased levels of system’s intelligence. Resilience and antifragility are intrinsically connected to CPS, especially in a time where systems are becoming more complex. In fact, the innovations associated with the 4th industrial revolution need to be embedded disruptions-coping strategies, namely: (1) to enhance the ability of the business ecosystems to prepare for and adapt to disruptive market environments and withstand and recover rapidly from the impacts of unforeseen disasters, and (2) to stay competitive in volatile business environments. Therefore, the characteristics of resilience and antifragility including responsiveness, learning, adaptability, etc. need to be included in the design of advanced cyber-physical systems.

3 Base Concepts

In the business ecosystems literature, disruptions have been recognized as one of the critical issues that that can have severe impacts on business and in some cases even firms' closures. In this context, disruption refers to a "predictable or unpredictable event which affects the normal operation and stability of a business" [8][9]. Generally, there are several ways in which an entity or a system responds to disruptions [4][10]. In fact, firms face different consequences as a result of unexpected disruptive events: some fail, some survive, and some even grow [4][11].

A number of relevant properties need to be distinguished here:

- **Fragility**. A system or entity that is vulnerable and can be easily broken when subjected to stress is known as fragile [12]. Fragility implies more to lose than to gain in case of perturbations or disruptions [4].
- **Robustness.** A system or entity that has is not easily affected by hazards and can stay unchanged even when subjected to shocks, is robust [4].
- **Resilience.** Some systems or entities can absorb shocks in such a way that although affected by hazards and temporarily change, they recover from those shocks; they are resilient [13].
- **Antifragility.** Some systems or entities not only have the capability of absorbing shocks and survive but even flourish and get better; they are called antifragile. Antifragility implies more gain than loss because shocks have a positive impact on these entities [4][12].

While an earlier notion of resilience was focused on the absorptive coping capacity, the concept has been evolving to represent an adaptive and even transformative capacity – transformative resilience, which partially overlaps with the notion of antifragility [14]. In other words, a system does not necessarily return to its original state but may evolve to a slightly different but stable state. Our research work is mostly focused on transformative resilience and antifragility.

4 Results and Discussions

In this section we summarize emerging approaches to handle disruptions, main contributing knowledge areas, and also present some promising examples based on the performed survey.

4.1 Emerging Approaches to Handle Disruptions

Two main aspects are included here: strategies to address disturbances in the business ecosystems and capabilities that help a business to overcome disruptions.

i. Strategies. To help a business become less vulnerable to disturbances, there is a need to define adequate disruption-coping strategies [15]. Resilience and antifragility are two emerging approaches to deal with disruptions, enhancing traditional risk management strategies. At least at a conceptual level, they are able to cope with unpredictable uncertainties through their properties such as flexibility, agility, adaptability, etc. [2][6]. Although there are several surveys about resilience and antifragility at the business ecosystems level the question "What are emergent approaches to handle disruptions?" is not yet answered. Therefore, in this section we propose a categorization of the resilience/antifragility-based strategies to deal with disruptions in line with three general phases of disaster management: Readiness, Response, and Recovery (Tables 1, 2, 3).

- **Readiness.** Disruption "readiness" involves investment in advance of a disaster to prevent, detect and eliminate the source of possible disruptions or mitigate system's vulnerability. For instance, mitigation strategies such as increasing security, and choosing facility location are proactive and focus on avoiding disruptions [16][17][18].

Table 1. Examples of strategies to prevent disruptions and prepare for disaster response.

Strategies	Description	Approach		References
		Resil	Antif	
Forecasting	Refers to techniques based on advanced information systems to predict the market, demand, etc.	✓		[2][5][10][18]
Mapping	Allows for acquiring knowledge about the current state and vulnerabilities of the ecosystem.	✓		[19]
Barbell	Investing most of the assets conservatively while taking risks with the rest.		✓	[4][6][12][20]
Creating optionality	Giving the buyer/investor freedom to experiment and benefit from opportunities. Ex: lease		✓	[1][4][6][21]
Buffering	Attempts to gain stability by establishing safeguards that protect a firm from disturbances.	✓		[2][5][6][8][17][22]
Infrastructure investment	Involves building infrastructure, and systemization. Ex: ICT adoption.	✓		[5][23]
Security Compliance	Increasing security using different policies, procedures, and technology against attacks.	✓	✓	[2][3][5]
Hormesis	Exposing a system to low doses of a harmful "substance or agent" inducing higher resistance of the system when submitted in future to higher doses of the same stressor.		✓	[4][6][24]

- **Response.** Disruption "response" is related to the immediate actions to take after a disaster occurs in order to bring the system into a temporarily acceptable operation state [10][18]. This phase involves strategies that reactively cope with disruptions such as demand management, and multi-sourcing [15].

Table 2. Examples of strategies to cope with disruptions in immediate aftermath the event.

Strategies	Description	Approach		References
		Resil	Antif	
Acceptance of disruption risk	Do nothing when the mitigation costs are higher than disruption risks.	✓		[15]
Postponement	Delaying operations or activities until the last possible moment to recognize and meet demand.	✓		[17]
Revision	Substitution and revision of plan of sourcing, operations, and facility in response to disruptions.	✓		[22][25][26]
Demand managing	Demand switching through different incentives, and pricing strategy.	✓		[3][15][22]
Graceful degradation	Allowing limited interaction and avoid entire system's downtime.	✓		[27]
Government lobbying	Attempts to influence government decisions by bringing attention to the long-term consequences of the catastrophe.	✓		[28]

- **Recovery.** Disruption "recovery" is essentially concerned with a set of activities to return the system to a pre-disruption state or, preferably, improved levels of operation. This phase involves efforts to lead the system to a long-term stable state [10][16][17][18].

Table 3. Examples of strategies to return the affected system to a pre-disaster condition.

Strategies	Description	Approach		References
		Resil	Antif	
Integration	Integration and synchronization of individual functional capabilities such as system, resource, process, etc.	✓		[5][17][19][23]
Cycle-time reduction	Service levels can be improved by reducing delivery lead times due to shorter product/process design and development time.	✓		[17]
Insurance	Refers to financial risk sharing as it transfers the risk of compensable loss to the insurer.	✓		[15][22]
Customer service	Improve responsiveness to customers to ensure future customer loyalty.	✓		[5][17]
Knowledge management	Understanding business ecosystem disruptions with the capacity to learn from past disruptions to develop better preparedness for future events.	✓		[17][26]
Feedback mechanism	Prevent the same" attack" / shock from negatively affecting the system more than once. The negative feedback mechanism attempts to reverse the changes and restore the system to the normal state.		✓	[20]

ii. Capabilities. There are several critical capabilities that influence the resilience/antifragility ability of a business system to overcome disruptions [21][29]. Table 4 provides a summary of relevant capabilities or attributes.

Table 4. Examples of attributes that enable a business to overcome disruptions.

Capabilities (Attributes)	Description	Approach		References
		Resil	Antif	
Flexibility	Ensures that the changes caused by a risk event can be absorbed through useful reactions.	✓		[2][23][25][30]
Redundancy	Having multiple assets/sources able to perform the same function.	✓		[6][17][19][22][25]
Convexity	Things with positive asymmetries that expose to exponentially more benefit as uncertainty increases.		✓	[1][6][12]
Agility	Ability of a business to rapidly respond to changes in environment.	✓		[17][25][26][30][31]
Simplicity	Ensures decrease of complexity by removing fragile and harmful elements.		✓	[4][21]
Visibility	Traceability of products and the environment of a business ecosystem.	✓		[2][17][23][26][30][31]
Creativity	Flexibility of thinking, perceptiveness of problems, and redefine and elaborate ideas.		✓	[12][14][24]
Financial strength	Capacity to retain volatility in cash flow.	✓		[2][3][5][22]

The above lists of examples are not exhaustive but nevertheless provide a global overview of existing proposals.

4.2 Contributing Knowledge Areas

Resilience and Antifragility in disruptive business ecosystems are related to or can benefit from different concepts introduced in various disciplines such as collaborative networks, systems thinking, thermodynamics, social science, biology, management science, and ICT. Table 5 further details how each discipline addresses different aspects of resilience and antifragility.

Table 5. Summary of contributions from different knowledge areas

Area	Description	Refs
Collaborative networks	**Scope:** The area of collaborative networks focuses on the structure and behavior of networks of autonomous entities that collaborate to achieve common goals. **Main contributions:** Collaboration typically facilitates building resilience and antifragility in the business ecosystem in the following ways: - Through negotiation, and collaborative problem-solving. - Creating a culture of trust and knowledge sharing. - Identification of new opportunism by increasing communication. **Recent related approaches:** - Collective awareness: Which refers to supporting environmental awareness, to influence demand changes. - Knowledge co-production: Combining a plurality of knowledge sources to generate new knowledge to address a disruption. - Collaborative adaptive management: A kind of learning-based collaborative approach that links actors' knowledge and experience to respond to disruptions.	[29] [31] [32] [33]
Systems thinking	**Scope:** This area offers a holistic approach to problem-solving that attempts to view systems from a broad perspective rather than focusing only on specific events. **Main contributions:** Systems thinking tools allow a deeper understanding of the relationships, and interactions among the components of complex systems. **Recent related approaches:** - System dynamics: A useful approach in understanding the non-linear behavior of complex systems over time using stocks, flows, and internal feedback loops. - Systems engineering: An interdisciplinary collaborative approach that uses systems thinking principles and tools including modeling and simulation, to manage complexity. - Chaos theory: A useful conceptual framework to describe the unpredictability of business ecosystems. - Complexity theory: Understanding how organizations adapt to and cope with uncertainty (e.g. self-organizing).	[10] [21] [24] [26] [33]
Thermodynamics	**Scope:** A branch of physics concerned with heat, temperature and their relation to energy. According the second law of thermodynamics entropy always moves from order to chaos (growth of entropy). According to the new meaning of the second law, open and non-linear systems like complex adaptive systems can overcome and recover from disruptions as they act far from equilibrium and can move from one stable state to another where entropy may decrease. **Main contributions:** - Describing the evolution/transformation behavior of complex systems. - Providing heuristics and adaptability-based modeling. **Recent related approaches:** - Phase transition: A useful concept to describe the transition of a complex and chaotic system from one phase to another. - Multi-equilibria: A way of modeling resilience as it keeps in play both stability and innovation through adaptation. - Path-dependence: An evolutionary approach related to the "hysteresis" concept that implies disruptions having persistence effects on the subsequent trajectory of chaotic systems.	[4] [24] [34] [35]

Management science	**Scope:** This discipline covers the application of systematic methods to solve problems and decision making in organizations. **Main contributions:** - Decision making under uncertainty. - Achieving sustainable competitive advantage. - Creating learning organizations. **Recent related approaches:** - Learning-by-doing: An approach towards adaptive governance to simultaneously manage and learn disruptions. - Y-management: Adopting a decentralized, participative management style which assumes that employees are self-motivated (tinkerers). - Convex heuristics: Heuristic based decision-making rules from risk management and antifragility metaphor.	[1] [4] [17] [36] [37] [38]
Information and Communication Technologies (ICT)	**Scope:** ICT can be viewed as the application of computer science and engineering techniques in interconnected disrupted environments. **Main contributions:** - Improving information management and collective awareness of the disrupted environment. - Embedding resilience/antifragility-based mechanisms in all phases of disaster management (readiness, response, recovery). - Learning from past experiences using tools like machine learning. **Recent related approaches:** Two dimensions: 1- To facilitate adding resilience/antifragility to the business ecosystems: - Microservices: Providing autonomous structure with scalability, self-managing, and flexibility to test, and replace services. - Multi agent-based modeling: Providing an environment to test intelligent autonomous solutions and their effectiveness on the context of disaster response. - Chaos engineering: Experimenting on distributed systems to understand the behavior of systems in the face of disruptions. - DevOps: A software development methodology which focuses on combing software development (Dev) with information technology operations (Ops) to shorten the systems' development life cycle and move toward antifragile organizations. 2- To make the ICT systems more resilient/antifragile: - Automatic bug detection and repair: Refers to software that fixes own bugs using automatic runtime bug fixing capabilities. - Auto-scaling feature: A system with this feature can measure and then dynamically scale up or down to respond to demand stressors and changes. - Continuous deployment: A process with four sub-dimensions (deploy to production, verify the solution, monitor for problems, and respond and recover) in which features, and bug fixes are continuously released in production environment. - Failure-as-a-Service (FaaS): Allows cloud services to routinely perform large-scale, online failure in real deployments.	[1] [39] [40] [41] [42] [43]

4.3 Promising Examples

Table 6 includes some representative examples of systems adopting some of the described strategies.

Table 6. Summary of promising examples

Name	Description	Refs
Netflix	**What is it?** An on-demand media service provider that is also pioneer in the area of antifragile internet-based systems. **How is antifragility/resilience addressed?** Netflix applies the "simian army," a suite of tools referred to as "monkey services," that routinely generate real system failures with the aim of using lessons learned to prevent more massive disruptions and build up resistance against future stressors. **What are related strategies/capabilities?** - Fault injection: Failing fast using software tools to decrease the probability of unexpected response. - Modularity: Exploiting microservices architecture which is running in the Amazon Web Services. Each of the microservices focuses on their work individually with the benefit of flexibility and diversity in use. - Weak links: Using circuit breakers to ensure the services are weakly connected. A circuit breaker quickly detects a problem and breaks the weak link to stop failure propagation to other services. - Redundancy: Ensuring the availability and durability of data through redundant network and data storage. **Characteristics:** Fault tolerance and isolation, Graceful degradation, Learning, Scalability, Bottom–up tinkering, Fail fast.	[20] [39] [43]

ASCENS	**What is it?** Project to develop an integrated set of methods and tools to build autonomic service-component ensembles capable of local and distributed fault reasoning. **How is antifragility/resilience addressed?** Relying on a comprehensive approach to engineer autonomic service components which offers both pragmatic and formal theories and methods to support modeling, reasoning, monitoring and dynamic adaptation. These service-component ensembles are multi-agent systems in the form of intelligent swarms that can adapt at runtime, adjusting to the state of the environment and acquiring knowledge about themselves, other service components, and their environment. **What are related strategies/capabilities?** - Self-managing: Autonomic self-adaptive systems with self-managing "objectives provide autonomy features in the form of a system's ability to automatically discover, diagnose, and cope with various problems." - Feedback mechanism: Three different feedback loops that enables continuous improvement. - Self-healing: Nodes are self-aware of changes in load and of the network structure, which calls for self-healing properties. - Redundancy: Using redundant data storage to prevent data loss in cases where nodes drop out of the system. **Characteristics:** Swarming, Fragmentation, Self-aware, Self-adaptive, Self-organize.	[42]
Tinkering school	**What is it?** "Tinkering" is at the core of student's educational philosophy and the basis of everything children do. Children with freedom to play learn life lessons through "tinkering" and gain experience of things such as uncertainty, and failure that prepare them for real world conditions. **How is antifragility/resilience addressed?** Tinkering school uses real tools, real materials, and practical problems in different ways to intentionally force students into disruption situations to encourage them to quick response and prototyping. Through different play and team working technics they learn about creativity, responsibility, persistence, adaptability, which are critical characteristics of resilient/antifragile people. **What are related strategies/capabilities?** - Learning by doing: Encourage children to create things bigger than usual in order to make mistakes and learn from them. - Trial and error: Putting children in situations that love mistakes (to become antifragile) by making numerous errors which are small in harm, even reversible and quickly overcome them. - Collaboration: Through trust and creativity leads to learning how to collaboratively design, build, solve problems to develop capable, adaptable citizens of the world. - Transformability: Related to changes of how the kids see the world and themselves through learning the ability to overcome stressors, thinking of non-obvious solutions (creativity), and confidence to change when things aren't working (adaptability). **Characteristic:** Adaptability, Tinkering innovation, and creativity, Self-reliance, Autonomy, Self-sufficiency, Growth mindset.	[4] [38] [42]

Kubernetes	**What is it?** An open-source platform to automate, deploy, and manage containerized applications and services. **How is antifragility/resilience addressed?** Kubernetes is a resilient container orchestration technology that can spread service instances on multiple nodes using an anti-affinity feature to reduce correlated failures. **What are related strategies/capabilities?** - Self-aware: Detecting the breakdown, routing around it, and taking corrective actions automatically. - Real-time monitoring: Performing regular health checks to detect failures in the services. - Fallback and graceful degradation: Restarting the container and bringing the application back to a healthy state when a failure is detected. **Characteristic:** Auto deployment, Auto-scaling, Observability, Self-healing, Self-management, Decentralization, Isolation.	[41]

5 Future Direction

The current literature on resilience and antifragility mostly remains at a conceptual and some even at speculative level. The underlying mechanisms are not yet adequately understood, and thus the design of architectures and governance mechanisms for resilient/antifragile systems is not trivial. Therefore, it is necessary to move from these theoretical approaches to practical systems that enhance their strength through experience and error in complex and disruptive scenarios. Next stage of our planned work is to suggest a self-adaptive system that can help the creation of collaborative business ecosystems that can learn from turbulence and improve when facing disruptions (i.e., become transformative resilient or antifragile). However, one crucial issue is how to evaluate such approaches? Since the behavior of complex/chaotic systems is unpredictable/non-linear, we cannot apply conventional processes, and also waiting for disruptions to happen to learn from them is too risky. On the other hand, using the real business ecosystems to "play" with them and test new ideas is not feasible. Therefore, the planned approach is to develop a multi-agent-based and system dynamics-based modeling and simulation framework to allow testing new solutions and their effectiveness on the context of disaster scenarios. The simulation of the disaster response activity is achieved by modeling each element involved in the ecosystem as an agent. Every agent learns about its environment and collaborates with other agents. Agents execute autonomously and make their own decisions about future actions. Therefore, the ongoing work includes: (1) Analyzing the combination of different strategies/capabilities and how they influence the business ecosystems' resilience/antifragility. The challenge is how to design and select an appropriate combination of strategies to make a system resilient/antifragile?; (2) Collecting empirical evidence to identify the potential of cyber-physical systems usage in the business ecosystem resilience/antifragility; (3) Propose guidelines to build resilient/antifragile systems for volatile and complex environment: (4) Introducing a mechanism to measure the level of resilience/antifragility in the ecosystem.

6 Conclusions

Resilience and antifragility are critical properties needed in future business ecosystems to allow them to survive and improve in turbulent and disruptive environments. Although there is already a good amount of literature on this subject, we are still far from having effective solutions. Through a multidisciplinary literature review, this paper analyzed different perspectives, concepts and approaches to overcome disruptions in the business ecosystem. Specifically, "strategies," "capabilities," "knowledge areas," and "promising examples," related to the emerging concepts of resilience and antifragility under the light of industry 4.0 were collected and current limitations identified.

Further ongoing research work is focusing the development of a simulation environment where different architectures and combinations of strategies can be assessed.

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