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A collaborative approach to resilient and antifragile business ecosystems

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Abstract

Turbulence and unexpected disruptive events are showing with an increasing frequency and growing impact, which represent major challenges for sustainability of businesses. Therefore, finding how organizations can strive and even improve or gain benefits in disruptive environment scenarios became a relevant research area, for which resilience and antifragility represent two significant approaches. This paper argues that collaboration in business ecosystems is a promising approach to cope with disruptions. A brief overview of existing strategies as potential building blocks for resilience and antifragility is presented. Then, in order to study the strategies that can better apply, a modelling and simulation framework based on multi-agents and system dynamics is introduced, and the main modelling issues are discussed considering the context of Industry 4.0.

Keywords: Resilience; Antifragility; Collaborative Networks; Business Ecosystems

1. Introduction

In recent years industry and services are going through a profound transformation. This process, often represented by the term digital transformation, or Industry 4.0 and its siblings such as Economy 4.0, Agriculture 4.0, Health 4.0, etc. [1], [2], [3], involve growing levels of interaction between the involved physical and cyber components. The fields of Cyber-Physical Systems (CPS) and Internet of Things (IoT) play a central role here, but this transformation results from a wider convergence of technologies including extensive sensorial capabilities and context awareness, artificial intelligence, with special relevance to machine learning and analytics in data-rich contexts, intelligent and collaborative robotics, and other “exponential technologies”.

As we move towards systems-of-systems, composed of smart components with varying degrees of decision-making capability, with a distributed and socio-technical nature, there is also an increase in systems complexity and inter-dependencies. In parallel with systems integration and hyper-connection, there is a growing focus on value chains and novel business models that leverage the collaborative potential among all involved stakeholders.

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At the same time, contemporary business environments, and society in general, more and more must face unexpected and disruptive events. The impact of such events, which are increasing in frequency, can be rather severe and unpredictable. As such, the concepts of resilience and antifragility [4], [5] are gaining increasing importance as promising directions to deal with unexpected disruptions. However, most of the recent works on resilience and particularly on antifragility remain at a rather conceptual or speculative level [6].

In this context, the establishment of collaboration ties among organizations, creating "pools" of shared competencies and assets, offers a promising approach to increase organizations' agility, share risks, and better cope with unforeseen disruptions. Among the multiple forms of collaborative networks that emerged in the last decades [7], [8], collaborative business ecosystems [8] represent a particularly promising organizational structure. Getting inspiration in natural ecosystems, business ecosystems emphasize the idea of community, often linked to a given geographical region, and the creation of mechanisms to protect the community against attacks [9], [10]. On the other hand, as a special case of a "virtual organization breeding environment" [11], the business ecosystems act as a facilitator for the rapid creation of goal-oriented virtual organizations to respond to business opportunities (a facet of agility). But collaborative business ecosystems also bring new sources of vulnerability as organizations need to "open their borders", risking losing critical assets. It is therefore important to devise effective ways of creating the ability to harness exogenous and endogenous shocks in a generative / transformative way that can in turn benefit the business ecosystem and its members. Such ability would let the ecosystems not only cope with disruptive situations but also to improve themselves with stress. One relevant dimension of analysis is the study of the impact of disruptive events on the available portfolio of competencies of the ecosystem and, thus, its capability to respond to future business opportunities. As such, the research question taken in this paper is: *What could be a suitable set of mechanisms and governance strategies to help a business ecosystem increase its resilience and even become antifragile regarding its portfolio of competencies?*

To this end, our research work envisages a modelling and engineering environment that supports interactive experiments through simulation with intelligent agency and system dynamics, towards identifying suitable solutions to resilience and antifragility. The approach, ongoing developments, and preliminary results are presented and discussed considering industry scenarios.

2. Industrial business ecosystems

Our assumption is that a collaborative networks perspective strengthens the business environment in a context of market turbulence namely through supporting an agile combination of competences, and sharing of assets, risks, and benefits. This is materialized in the capability of establishing goal-oriented networks (virtual organizations/virtual enterprises). Our research further aims to verify that collaboration can support resilience and antifragility.

The multiple forms of collaborative networks that have emerged in the last decades can broadly be grouped into two major classes: (1) long-term strategic networks, typically represented by "virtual organizations breeding environments" (VBEs), and (2) "goal-oriented networks" such as "virtual organizations" / "virtual enterprises" (VO/VE) [7]. A VBE typically aims to have its members prepared to rapidly respond to business opportunities by allowing fast configuration of goal-oriented consortia (VO/VE). A business ecosystem corresponds to a particular case of VBE [11]. Other related organizational structures, corresponding to earlier forms of collaborative networks, include industry clusters and industrial districts.

The collaborative networks area represents one of the key enablers of the ongoing digital transformation process, and thus at the core of the challenges in Industry 4.0 [3]. This is briefly summarized in Table 1 that exemplifies the role of collaboration in all dimensions of Industry 4.0.

Table 1. An overview of challenges of collaboration in Industry 4.0

	Industry 4.0 Dimension	Collaboration-related issues
1	Vertical integration or networking of smart production systems	▪ Enterprise seen as a network of smart systems, that must collaborate to support agile processes. ▪ Need to move from a "CPS & embedded systems" view to collaborative Cyber-Physical Systems; digital twins. ▪ Establishing higher collaboration levels between humans and robots / machines. ▪ Future enterprises seen as multi-layer networks – involving the interplay of smart production/manufacturing systems, smart logistics, organizational units, smart products, and people. ▪ Real-time data and enterprise wide analytics and augmented reality supported by a collaborative model.
2	Horizontal integration through global value chain networks	▪ Further levels of collaboration are required among all stakeholders involved in the value chain. ▪ Organizational transformation through materialization of business ecosystems. ▪ Promoting sharing of resources data, information, and knowledge throughout the value chain. ▪ Global optimization and flexibility require dynamic creation of goal-oriented networks. ▪ Collaboration supported on high level of sharing is a requirement for resilience. ▪ Tracking and tracing features imply high levels of transparency and sharing along the value chain. ▪ Integration of the concepts of smart manufacturing and smart cities, towards sustainability.
3	Through-engineering across the value chain	▪ Effective collaboration is needed to support the involvement of customers in product design (co-design), as well as close interaction among engineers (co-engineering). ▪ A full lifecycle perspective of product and the materialization of the circular economy require collaboration effective among stakeholders. ▪ "Service-enhanced products" require collaborative networks involving manufacturers and service providers.
4	Acceleration of manufacturing	▪ The rapid introduction of new technologies in industry requires more dynamic involvement of the new players at all stages of the value chain. ▪ Some of the so-called "exponential technologies" rely on AI and more and more envisage collaboration among machines (M2M). ▪ The adoption of mobile technologies and 5G, which challenge the "closed ecosystem" models, point to the development of nomadic collaborative systems. Blockchain-related technologies support implementing fairness and responsibility in collaboration, being useful to build anti-fragile/resilient distributed systems. ▪ 3D printing allows "distributed and localized manufacturing", resorting to collaboration of actors from different geographical locations. ▪ Progressive adoption of augmented reality and/or virtual reality as collaboration-support tools.
5	Digitalization of products and services	▪ Notion of smart product leveraged through effective collaboration along the value chain (ako stigmergy). ▪ Effective history records and tracing need collaboration. ▪ The availability of (rich) data close to the product requires collaboration among all stakeholders involved along the product life cycle. ▪ The association of value-added services to a product often requires contributions from various stakeholders. ▪ Development of smart products motivates the creation of new business services, often leading to collaborative communities around the product (a kind of product-related ecosystems).
6	New business models and customer access	▪ Customer intimacy further extends "horizontal integration", with tighter collaboration along the value chain (co-design/co-creation of products/services). ▪ Addressing global markets considering local specificities (idea of *glocal* enterprise) requires collaboration. ▪ Moving towards "servitization" requires tight collaboration. ▪ Addressing concerns of social responsibility and sustainability requires strong collaboration between industry and a variety of other actors in society. ▪ "Hybrid value chains", which combine for-profit and not-for-profit organizations, also require collaboration.

3. Approaches to cope with disruptions

To facilitate a better understanding of the resilience and antifragility based strategies and their applicability, following our previous research [6], Fig. 1 presents an overview of the identified strategies classified according to 6 meta-levels: (1) "discovering" (understanding the environment), strategies to detect critical sources of disruptions and estimate how the system is expected to change with disruption, e.g. "mapping", (2) "avoiding", strategies to prevent threatening situations, e.g. "buffering", (3) "do nothing", strategies to accept the risk of disruption, e.g. "wait-and-see", (4) "reducing", strategies to mitigate vulnerability and negative consequences, e.g. "information sharing", (5) "managing", strategies to manage system complexity, e.g. "contingency planning", and (6) "learning and adapting", strategies to solve problems creatively, e.g. "trial-and-error".

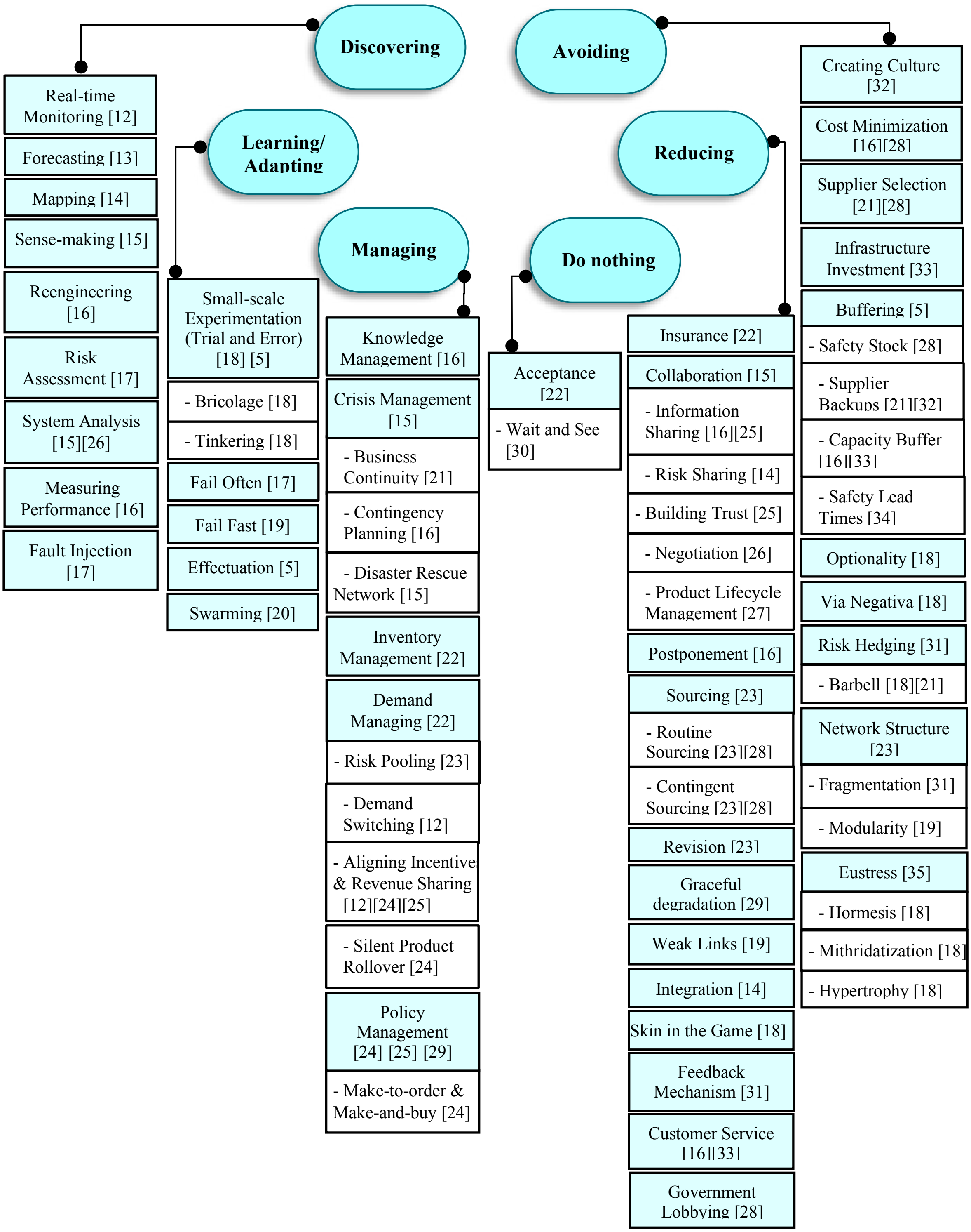

Fig. 1 – Survey of resilience / antifragility strategies

4. Handling disruptions in business ecosystems

4.1. Scope

The aim of this work is to analyse the impact of disruptive events on collaborative business ecosystems (CBE) [9], namely on their portfolio of competences. In a world of so-called “Black Swans”, negative and positive disruptive events may surprise businesses at any moment with their extreme impacts, being the big challenge for decision-makers to manage their ecosystem through applying appropriate strategies that take into account negative uncertainties (risks) and take advantage of positive disruptions (opportunities). Therefore, the focus of this work involves:

- Studying the effect of disruptions on the competences and potential of the ecosystem to respond to business opportunities (BO).
- The assumption that there is a flow of business opportunities (Fig. 2), with some random distribution, originated in the market (exogenous or endogenous). The purpose is to analyze how the ecosystem responds to these opportunities before and after a disruption. Disruptions may affect the availability of resources and skills, and thus reduce the ecosystem’s response potential. The level of resilience and antifragility of the ecosystem, under this perspective, is a function of the response potential.
- Measuring the ecosystem’s capability to respond to BOs, not the actual number of acquired BOs, which depend on the market / customer, other competitors, etc. In other words, we focus on the “potential” of the ecosystem.
- Collaboration: a response to a BO typically may involve skills and resources that are not possessed by a single organization, requiring the formation of a virtual organization. This response naturally depends on the set of available competences, the organizational and governance structure of the ecosystem, but also on the behavioral characteristics of its members and other elements such as roles, location, goals, etc.

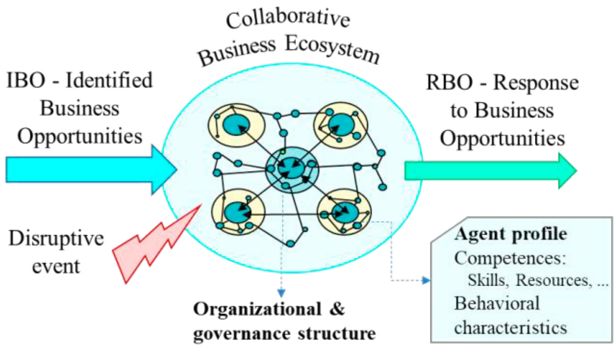

Fig. 2 Response of a business ecosystem to business opportunities

Furthermore, we make the following general assumptions:

- Even under normal operating conditions, i.e. without disruptions, the ecosystem does not respond at the level of its full potential (RBO < TBO, where TBO <= IBO is the theoretical maximum response of the ecosystem). Some typical reasons include:
  - When there is no stressor, organizations may tend to respond to BOs by themselves, not seeking collaboration with others, either due to some selfish behavior or to avoid the overheads of collaboration.
  - To reduce overheads of collaboration and motivated by trust, organizations tend to limit their collaboration to partners they have worked with before, instead of exploring all possibilities inside the business ecosystem. This trend reduces the number of possibilities to generate VOs for emerging BOs.
- When there is a disruption it might happen that some of these “constraints” are removed. E.g.:

- The uncertainty introduced by a disruption makes organizations more open to collaboration namely, to share risks and increase business opportunities.
- As some of the traditional partners of one organization might have been affected by the disruption, and even disappear, this organization is forced to look for alternatives.

As a result, the ecosystem, although having lost some competences, might respond better than before, thus showing some antifragility. It is also expectable that the adoption of specific strategies for the ecosystem's governance can lead to an increase of its resilience and antifragility.

4.2. General approach

To study the behavioural aspects of the CBE we model it as a self-organizing multi-agent environment, where agents represent the entities constituting the ecosystem. As main inputs of the proposed modelling framework (Fig. 3) - **CRABE** (Collaborative Resilience and Antifragility framework for Business Ecosystems) – we consider:

- The organizational structure and collaboration mechanisms are based on existing knowledge from the collaborative networks area [7], [36]. Of special relevance are the classes of "long-term strategic network" to model the CBE, and the "goal-oriented network" to represent the dynamic virtual organizations created to respond to business opportunities. We assume that each member of the CBE can act as a broker, thus able to acquire and bring in new business opportunities.
- In terms of governance, we assume that the CBE management can resort to a catalog of capabilities and a catalog of strategies to cope with resilience and antifragility. Examples of strategies, briefly mentioned in section 3, can be found in [6]. An advice / recommendation mechanism is planned to suggest appropriate combination of strategies to face each type of disruptive stressor.
- A measurement system is conceived to assess the resilience / antifragility levels of the CBE. This component is inspired by the work on performance indicators for CBEs reported in [37] and [38].
- A learning mechanism is also considered to help both the CBE governance and the individual agents to improve their resilience / antifragility capability.

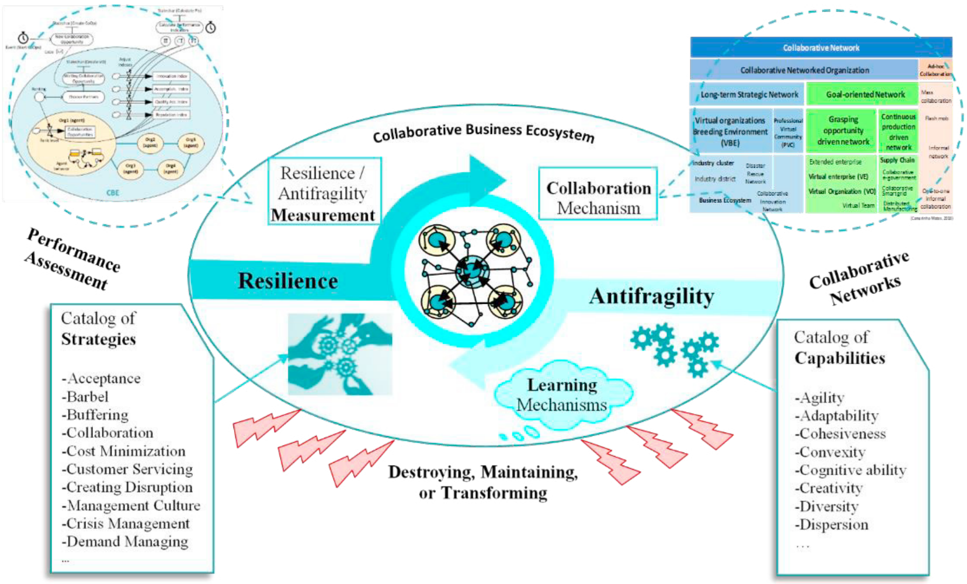

Fig. 3 Main input areas for a resilient and antifragile business ecosystem

As a development environment for CRABE implementation, the AnyLogic multi-paradigm modelling and simulation framework is adopted. A multi-agent perspective is followed to represent the ecosystem and its members. System dynamics, with its notions of stocks and flows, are used to model behavioural aspects. Discrete-event models will be evaluated regarding modelling of disruptive events and their impact.

4.3. Modeling challenges

Our ongoing work focuses on modelling core elements of the CBE and its exogenous interactions in order to understand the role and benefits of collaboration in supporting resilience and antifragility. This includes:

- *Model of business opportunities*. We assume that a flow of business opportunities, following some statistical distribution, emerge in the market. Each opportunity is basically characterized by the required skills, capacities and other facets such as delivery time, constraints, location, etc. This flow is a basic input for the CBE which is supposed to analyze the requirements and decide to respond or not to each opportunity. In a later stage we need to model the impact that disruptions can also have on the flow of business opportunities.
- *Model of resilience / antifragility indicator*. In our approach, the level of resilience and antifragility is determined by the variation of the response potential of the CBE when subjected to a stressor. As such, we compare the RBO metric before and after an attack and its relation to TBO.
- *Model of agent characteristics*. The members of the CBE are modeled as agents in our simulation framework. Each agent is characterized by a profile that includes elements such as competences, roles, goals, location, etc. A key element is the notion of competence, for which we adopt the definition proposed in [39]:

  Competency = {Capability / skill, Capacity, Conspicuity/certification elements, Cost}

  The agent model also includes its current level of commitment (committed workload and corresponding time schedule), and list of preferred partnerships. Furthermore, the behavior of an agent, and thus its decisions regarding response to potential business opportunities, depend on the nature of the corresponding organization.

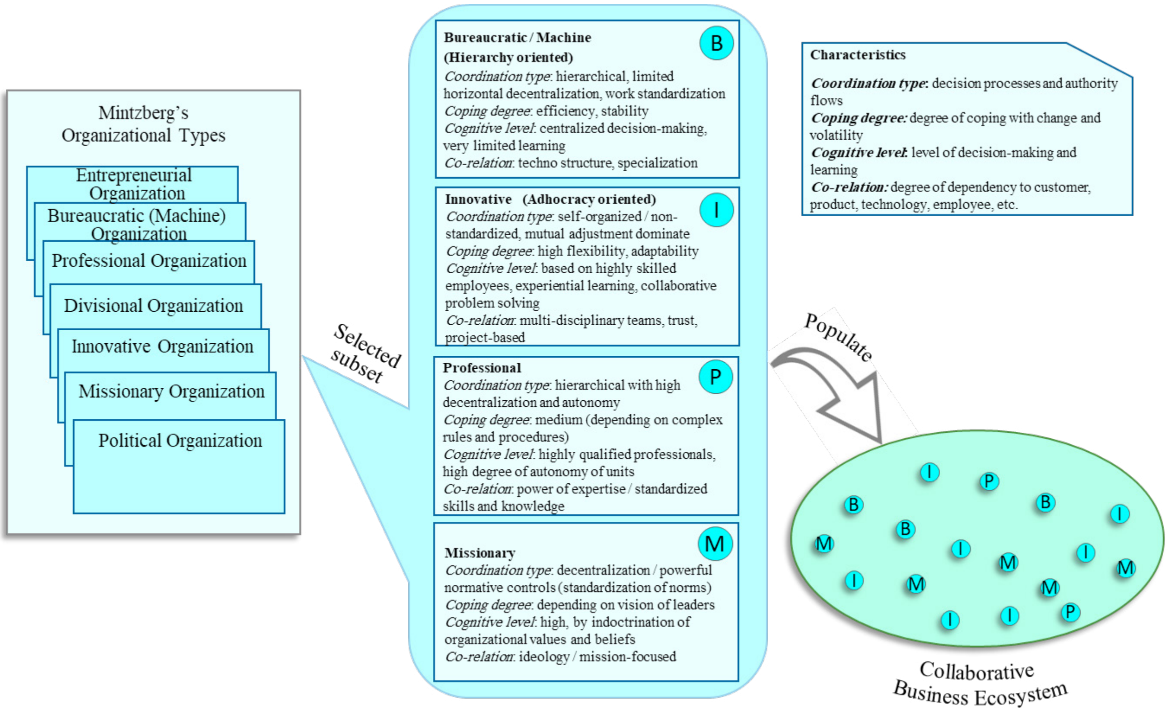

Fig. 4 Organization types

According to Mintzberg [40], there are seven types of organizational structure (Fig. 4): "entrepreneurial organization, machine organization (bureaucracy), professional organization, divisional organization, innovative organization (adhocracy), missionary organization, and political organization". Therefore, an important part of the agents' model tries to capture the behavioral characteristics of each type of organization. For each simulation scenario, the CBE is populated with agents belonging to various organizational types. Currently and for proof of concept, as shown in Fig.4, we consider only a subset of the Mintzberg's types.

- *Model of business ecosystem*. The CBE is modelled as a "Virtual Organization Breeding Environment", including the typical roles of this class of long-term strategic networks [7]. Within a CBE different Virtual Organizations (VO) can dynamically be formed gathering the required competences in response to business opportunities.
- *Model of disruptions and their effects.* This component focuses on representing the characteristics of a disruptive event composed of three dimensions (Fig. 5): Location, Severity, and Time duration. This model also investigates the impact of the disruption into the behavioral facets of the agent's model, as well as its propagation inside the CBE.
- *Model of intelligent decision-making module of agents*. This component is focused on representing how an agent reacts to a business opportunity. Two main cases are considered: (i) When the agent acts as a broker (finding a BO) and has to decide which parts of the BO could be shared with other partners; (ii) When the agent is invited to join a VO being created and has to decide if it accepts or not and under which conditions. This module is dependent on the nature of the organization represented by the agent and affected by the dimensions of the disruptions.

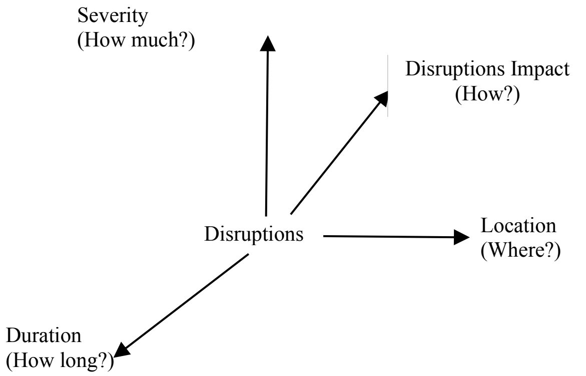

Fig. 5 – Disruption dimensions

- *Model of intelligent strategy recommender at ecosystem level*. This component considers the composition of the CBE, the characteristics of the disruptive event, available resilience/antifragility coping mechanisms, and the catalog of strategies to deal with disruptions in order to propose a suitable (promising) combination of strategies.
- *Model of strategies.* This component includes meta-information about each strategy, namely about its applicability context.
- *Role of learning.* This component, which is left for the next phase of development, will focus on the acquisition of new knowledge to improve the decision-making of agents and the strategy recommender module.

Although the proof-of-concept of CRABE is still being developed, a parallel activity was launched to collect real data from existing CBEs to tune the simulation model and validate the proposed models. This involves the following steps: (i) Identify a list of target CBEs including industry clusters and research clusters; (ii) Establish contacts with managers of those target cases and elaborate a description of each case (identification, location, purpose/scope, contacts, how easy it is to access relevant information); (iii) Elaborate a protocol identifying which relevant information items should be collected from each case, followed by data acquisition; (iv) Finetune the simulation model based on acquired data; (v) Discuss simulation results with lead users of selected clusters and collect their feedback.

5. Conclusions

In a context of large turbulence and occurrence of frequent disruptive events, the sustainability of business ecosystems depends on finding appropriate approaches to cope with stressors and even seek benefits from them.

The topic is attracting growing attention of the research and business communities and as a result it is possible to identify a considerable number of strategies to promote resilience and antifragility. However, many of these strategies have been applied to specific cases, and a sound understanding of their applicability and underlying context is lacking.

In this paper we argue that collaboration, combined with proper governance strategies, is a key approach to cope with disruptions in business ecosystems. A general framework is proposed to allow studying the impact of disruptions on the competences of an ecosystem and to evaluate the role of different governance strategies.

Ongoing work is focused on completing a proof-of-concept through a multi-paradigm simulation environment, combining agents and system dynamics models. In parallel, an activity of data acquisition from various target business ecosystems is being carried out in order to tune the proposed models.

As part of future research, we plan to add a learning component to the developed framework.

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