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OVERVIEW OF COMPLEXITY: MAIN CURRENTS, DEFINITIONS AND CONSTRUCTS

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ABSTRACT

The Theory of Complexity is applied to many fields of human knowledge, and its implications are increasing, both in the market and in academia. However, usually the theory is approached by fragments in literature reviews, which does not have it as its main focus. In this way, it is difficult to understand their uniqueness, their continuity and their consistency. Thus, the objective of this work is to provide a panorama about Complexity Theory, presenting its main elements and fomenting the discussion about its potentialities of use. The research approach is qualitative, exploratory and bibliographical, focused on three of the main scientific bases: Web of Knowledge, Scopus and SciELO Brazil. It is noted that the popularity of Complexity Theory between academics and practitioners is increasing and has the potential to generate benefits not yet explored in several areas.

Keywords: Complexity; Theory of complexity; Paradigm of complexity; Definition of complexity; Complex adaptive system.

1. INTRODUCTION

From the point of view of practitioners, the behavior of economies, the advancement of technologies and the pace of innovation are examples of manifestations that lead to the idea of a more complex world. In academia, perception repeats itself (Saynisch, 2010; Sheffield et al., 2012). Taylor (2003) expresses this feeling of an unprecedented level of complexity in stating that the speed of change is greater than the ability to understand them. In this way, modern times are governed by increasing complexity, and understanding its principles to better navigate its intricacies is the most productive idea (PMI, 2013).

In this context, the Theory of Complexity arises to help in understanding the mechanisms that govern complexity. This theory is applied in several areas, for example: biology, aviation, management, computing, mathematics, physics and the environment.

Analyzing the world through the lens of Complexity Theory invites scholars and practitioners to envision new perspectives, find different solutions and innovate approaches. This new prism has important implications because it challenges the paradigm of a mechanistic universe, opening the door to understanding the world through the bias of complex systems.

Complex systems cannot have behavior inferred from their components (Whitty *et* Maylor, 2009). In these systems, the different elements interact and produce outputs that are unpredictable and non-linear (Maylor *et al.*, 2008). This uncertain behavior may explain several phenomena in human and general nature.

In terms of terminology, it is worth mentioning that the expressions “complexity theory”, “study of dynamic systems”, “nonlinearity studies”, “complex adaptive systems theory”, “complex thinking” and “complexity scien-

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ces" are often treated as equivalent (Neto, 2007). In this article, the expression "theory of complexity" will be adopted in the sense of encompassing the other expressions.

Although much studied, Complexity Theory is usually approached in fragments, through cross-sections in literature reviews, which do not have it as the main focus. This makes it difficult to understand the unicity, continuity and consistency of the theory. Thus, the objective of this work is to provide a panorama about the theory in question, presenting its elements and fomenting the discussion about its potentialities.

The Theory of Complexity opens a new range of possibilities of use in diverse fields of human knowledge, which explains its growing popularity in academia and in the market. However, their applications are still incipient. Thus, there is plenty of room for new discoveries in this area.

The following is a detail of the methodological procedures that gave rise to the results of the research. In the sequence, the evolution of Complexity Theory is presented. Subsequently, it seeks to elucidate some elements of complexity, that is, the main types, dimensions, properties and definitions. Finally, the final considerations are made.

2. METHODOLOGICAL PROCEDURES

Science is a permanent process of seeking the truth (Vergara, 2004). Knowledge is the object of science, and scientific research is the instrument of search for knowledge (Junior et al., 2007). For example, in management research, the aim is to produce knowledge to guide decision-making (Cooper et Schindler, 2003).

Thus, this article aimed to raise the history, definitions and perspectives of Complexity Theory, through a qualitative, exploratory and bibliographical approach. The exploratory research allows the researcher to better know the research problem, the objective being to make the problem more explicit and to construct hypotheses (Gil, 2010).

The technique of data collection adopted was the research in bibliographic sources. The bibliographic research explores secondary data of material already published from bibliographic sources, such as: articles, books, magazines and newspapers; And non-bibliographical, such as: CDs and Internet material. This strategy was used in this research in order to allow the researcher to cover a range of phenomena that was wider than he could directly research (Gil, 2010). The flow of data collection from the survey is shown in Figure 1.

Initially, articles, books, theses and dissertations were pre-selected from national and international databases such as: Web of Knowledge, Scopus and SciELO Brazil. The criterion of selection of the bibliography was based on the combination of the descriptors: "complexity theory", "complexity paradigm", "complexity definition", "complexity adaptive system" and their respective translations into Portuguese.

An analysis was undertaken by exploratory reading to indicate materials worthy of a critical reading. Classic authors have been favored in the theme and recent publications (last five years). Finally, a synthesis was carried out seeking points of convergence, divergence or complementarity between the authors in relation to the objective of this study.

3. STUDY OF COMPLEXITY: THE TWO MAJOR CURRENTS

Complex thinking and the complexity sciences are the two main currents that explore the studies of the complexity theme, called, respectively, as general complexity and restricted complexity (Neto, 2007). The former is more subjective and relates to philosophy and human relations. The second is more focused on scientific formalization, originating in the natural, physical, chemical, and computing sciences. The first has as main exponent the philosopher, sociologist and epistemologist Edgar Morin. The second is spreading in particular due to the work of scientists at the Santa Fe Institute, such as biologist Stuart Kauffman, physicists Philip Anderson and Murray Gell-Man and economist Brian Arthur.

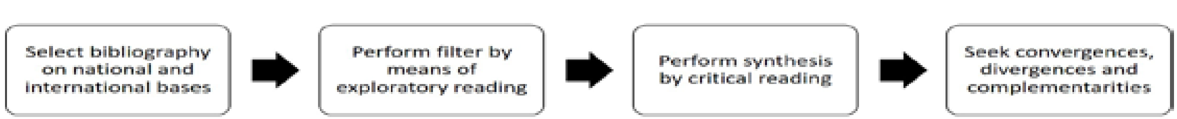

Figure 1. Research data collection flow

Source: The authors

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However, the complexity sciences add contributions from the following areas (Neto, 2007): (1) mathematical models; (2) phenomena of nature (physical chemistry, biology and biossocial aspects); (3) phenomena of humanity (sciences of mankind and applied sciences); And (4) virtual explorations (computing).

4. COMPLEXITY DEFINITIONS

The origin of the word complexity comes from the Greek *complexus*, that is, "what weaves together". According to the *New Aurélio dictionary of the Portuguese language*, complexity means "quality of what is complex". But what is complex? The same dictionary informs: (1) that which encompasses or encloses many elements or parts, (2) observable under different aspects and (3) confusing, complicated, intricate.

It is seen that it is easier to recognize complexity than to define it. People have an intuitive notion of complexity. In common sense, the idea of complexity approaches the dictionary definition and is confused with complicated, difficult to understand, possessing many interconnected parts, intricate, entangled, and knotty (Thomas et Mengel, 2008; Whitty and Maylor, 2009).

Thus, few people agree on the meaning of the word complexity (Rensburg, 2012), since the term is very widespread, and each may have its own concept of complexity (PMI, 2009). Thus, complexity has different meanings depending on the organization and the person being heard. However, several authors have proposed their definitions for the evaluation of the academic community (Table 1).

5. MAJOR *CONSTRUCTS* RELATED TO COMPLEXITY

The Complexity Theory studies the systems composed of a large number of agents, which integrate to produce adaptive survival strategies for the components of the system and for the system as a whole (Ponchirolli, 2007).

The complexity view defies the paradigm of a regular and predictable world (PMI, 2009) and contradicts the idea that the world is represented by the machine metaphor (Ponchirolli, 2007). A sample of this occurred in the episode in which Einstein, in the early days of Quantum Theory, stated that "God does not play dice", making clear his rejection of a universe of uncertain laws. However, Quantum Theory has shown that, at the subatomic level, uncertainty is constantly present, a premise also attested by Complexity Theory regarding the functioning of the world.

Historically, Wood Jr. and Vasconcellos (1993) point out that it was Jules-Henri Poincaré, a 19th-century French mathematician, who first noticed complex behavior in the midst of the current Newtonian regularity. But the major studies that allowed for the development of Complexity Theory were made in the 1960s and 1970s and suggested a very different model than previously thought (Ponchirolli, 2007). The substitution of determinism for the emerging view present in theory has also influenced scientific knowledge. Thus, examples of this influence are: quantum mechanics, Relativity Theory and Chaos Theory (Ponchirolli, 2007).

Therefore, Complexity Theory is based on the findings of other theories, such as: Chaos Theory, Evolution Theory, Theory of Self-Organization, Theory of Cybernetics,

Table 1. Complexity Definitions

Complexity Definitions	Author(s)
A complex system is an evolution generated by physical principles and simple mathematical rules, which show complicated and unpredictable behavior	Dijkum (1997)
Complexity is the measure of the inherent difficulty in understanding a complex system, as well as the amount of information needed to understand it	Bar-yam (2003)
From the structural and process point of view, complexity, respectively, is: 1) Set of heterogeneous constituents inseparably associated and 2) Tissue of events, actions, interactions, feedbacks, determinations and accidents that constitute our world	Morin (2005)
Complexity is a quantitative phenomenon due to the immense amount of interactions and interferences between a very large number of units, and comprises uncertainties, indeterminations and random phenomena; therefore, it is related to the idea of chance	Morin (2005)
Complexity can best be described by the number of states that a system can have according to the drives: variety, interdependence, ambiguity, and flow	Nedopil et al. (2011)
Complexity is the characteristic of the program, project or its environments that makes it difficult to manage	PMI (2014)

Source: The authors

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Disaster Theory, Dynamic Nonlinear Theory and Systematic Theory (Ponchirolli, 2007; Thomas *et* Mengel, 2008, PMI, 2009, Saynisch, 2010). For Wood Jr. *et* Vasconcellos (1993), the union of Chaos Theory with the paradigm of complexity and Systematic Theory is a new way of looking at complex systems.

In relation to Chaos Theory, some authors judge the name of the theory inadequate, since chaos is absence of order; however, there is a pattern in complex systems, even though this pattern does not allow predictability and controllability (Wood Jr. *et* Vasconcellos, 1993). The authors explain that, because it involves several disciplines, Chaos Theory brings together scholars from different areas and contradicts the tendency of compartmentalization of science. This theory gained widespread popularity with the publication in 1987 of the bestseller Chaos: The Creation of a New Science by journalist James Gleick of the New York Times (Gleick, 1989).

The following are the main milestones in the evolution of studies on complexity, together with a brief explanation of concepts and main characters involved.

5.1. Butterfly effect

It was while using computers to simulate the behavior of the climate system in 1960 at the Massachusetts Institute of Technology (MIT) that meteorologist Edward Lorenz discovered the principle of dependence on initial conditions (PMI, 2009). After a simulation, it re-entered with the same data in the system, and the results were totally different from the previous simulation. This behavior expressed the nonlinearity characteristic of the complex systems, since the nonlinearity suggests that the same event can be realized many times with totally different results every time (Weaver, 2007).

In other words, relying on initial conditions means that small changes in a complex system (for example, butterfly flapping in Brazil) can produce catastrophic and unanticipated effects (such as the appearance of a tornado thousands of miles in Texas). Thus, the initial conditions of a complex system determine where it is at present.

Historically, this phenomenon has become known as “butterfly effect.” Lorentz presented the results in an article titled “Predictability: The Flap of Butterfly’s Wings in Brazil Set Off the Tornado in Texas?” in December 1979 at the Annual Meeting of the American Association for Advancement of Science (PMI, 2009).

Singh *et* Singh (2003) illustrate the butterfly effect with an example: a man must pick up the only available day flight to Europe, but the alarm clock does not ring, he leaves late for the airport and misses the flight. However, when he returns to the car, he hears from the airport speaker that the flight he should have picked up fell in the Atlantic. That is, the manifestation of an unexpected initial condition (in this case, the non-wake-up call) led to unexpected conditions and effects (in this case, the loss of the dropped flight).

5.2. Chaotic attractors

Wood Jr. *et* Vasconcellos (1993: 102) define attractor as “a point or level at which a system returns, when the effects of external perturbations cease,” and chaotic attractor as “a chaotic system that converges to a set of possible values. This set is infinite in number but limited in amplitudes. Chaotic attractors are non-periodic “(Wood Jr. *et* Vasconcellos 1993: 102). In short, chaotic attractors can be understood as recurring patterns of behavior in a system.

In the early 1970s, mathematicians David Ruelle and Floris Takens developed the concept of chaotic attractors as they worked on the study of fluid turbulence behavior patterns (Ruelle *et* Takens, 1971). Subsequently, Lorenz introduced the concept of chaotic attractors to explain the recurrent patterns of behavior that certain systems have (PMI, 2009). With these almost predictable recurrent patterns, new possibilities opened up to explain the behavior of seemingly chaotic systems.

5.3. Fractals

The term fractal refers to irregular shapes that repeat themselves, in nature, in varying sizes and scales (PMI, 2009). Thus, fractals are computer generated from mathematical formulas and have similarity to images of nature, such as crystals, trees, valleys and mountains (Wood Jr. and Vasconcellos, 1993).

The geometry of fractals explains mathematically how it is possible to find the same patterns in small and large scales (Cooke-Davis *et al.*, 2007), introducing new insights into the mathematical nature of chaotic attractors (PMI, 2009). This has helped explain how complex patterns can be formed from simple guides. The fractals had great recognition inside and outside the scientific circles.

5.4. Universality and standardization

Universality refers to the fact that patterns of repetition occur in the most diverse fields of knowledge and

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nature (Cooke-Davis *et al.*, 2007). In the 1970s, mathematician Mich Feigenbuam discovered a number, called the doubling factor (approximate value of 4,669), which would explain the movement between simplicity and chaos (Feigenbaum, 1979).

The mathematician Ian Stewart (Stewart, 1996) understood this factor as another of the regular behaviors that exist in nature, such as the number of flower petals obeying the Fibonacci series and a multitude of elements of nature that respect the reason for the gold number (Cooke-Davis *et al*., 2007).

5.5. Dissipative structures

Ilya Prigogine won the Nobel Prize for Physics in 1978 for her work in the science of thermodynamics. The scientist studied dissipative structures (later known as complex dynamic systems) that constantly exchange energy (receive and emit) with the environment.

It has been shown that these systems produce unpredictable behaviors (Cooke-Davis *et al.*, 2007), because they demonstrate periods of predictable behavior and are unstable (Wood Jr. *et* Vasconcellos, 1993).

5.6. E*dge* of chaos

Chaos boundary is a theoretical point between order and chaos (Remington et Pollack, 2007). It is the point where there is some level of chaos, but the system still retains a level of order. This point safeguards coherence and internal consistency and maintains the expertise of some functions. This frees up creativity and opens up opportunities for improvement, as the exchange of information with the environment is maximal.

Morin (2005) finds that there is a strong relation between order and disorder, since both influence each other. In some cases, disordered phenomena are necessary to achieve organization. In other words, the disorder can contribute to the establishment of the organization.

In this direction, Ponchirolli (2007) informs that there are two distinct networks of links between the agents of a system: the legitimate network and the “shadow” network. The legitimate network consists of explicitly understood connections between agents. The “shadow” network is formed by connections that arise spontaneously (not predicted previously) by the interactions between the agents. In general, the legitimate network brings the system to stability, while the “shadow” network diverts the system from stability.

Thus, the limit of chaos is the paradoxical zone where there is stability and instability at the same time, where the legitimate network and the “shadow” network come into conflict, and positive feedback and negative feedback coexist without any being able to prevail . Thus, the system becomes more sensitive to the initial conditions and becomes creative due to the double learning provided by the double feedback (Ponchirolli, 2007).

Consequently, the learning of the system occurs through the mechanisms of feedback, which potentiates errors and correctness. In this way, an insignificant error can lead to system collapse, just as an opportunity can lead the system to high performance. These learning mechanisms are affected by the initial conditions of each cycle and could improve understanding in terms of why organizations succumb or thrive unexpectedly in the face of details that have occurred in their trajectory.

It is at the limit of the chaos that the greatest opportunity of evolution of the system occurs (PMI, 2009), because the disorder obliges to create new forms of order. In an analogy with water, steam represents the state of chaos, and ice represents the state of order, but it is in the liquid form that water offers the best opportunities for performing complex activities.

5.7. Emergency

Emergence is the result of the dynamic interactions between the parties (Sheffield et al., 2012). The properties of the emergency allow to emerge the characteristics and the patterns that are different, in type and degree, of the characteristics and the standards of the system components (PMI, 2009). Emergency is at the center of the process of evolution, adaptation and transformation.

5.8. Complex adaptive systems

According to the PMI (2014, page 28), a system is “considered as a collection of different components that together can produce results not obtained by the components separately.” Open systems are systems because they consist of interconnected parts that work together, and are open because they exchange resources with the environment (Anderson, 1999).

The concept of system helps in understanding the relationship between the parts and the whole and is an intuitive way of looking at the world (Remington et Pollack, 2007). The systemic approach understands companies as open systems that interact in a permanent way with the environment (Ponchirolli, 2007; Sheffield et al., 2012). In

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a system, there is a pattern of repetition, because if it does not exist, it is a simple occurrence, not a system (Remington et Pollack, 2007). To complement, it is worth noting that the behavior of a system is dynamic when it evolves over time (Ponchirolli, 2007).

Thus complexity reflects the understanding that the whole is in the parts and the parts are in the whole. Therefore, complex systems cannot be understood by the properties of individual agents, since the whole is not explained by the sum of the parts. Therefore, the way the system will behave cannot be predicted on the basis of its parts (Weaver, 2007). This holds true, for example, for schools of fish, ant colonies, and human social groups.

Purely physical or chemical systems are deterministic with constant rules; however, complex organic systems are adaptive because they evolve over time (Ponchirolli, 2007). According to Ponchirolli, this evolution depends on conditions of change that may interfere with the system, causing interactions not previously considered and provoking unexpected effects where causes are transformed into effects and vice versa.

Systems that obey Complexity Theory are called complex adaptive systems (Aritua *et al*., 2009). Yanner Bar-Yam, a professor at MIT and president of the New England Complex Systems Institute, explains that examples of complex systems are the brain, the physiology of the human body, governments, families, traffic in transit, climate, branching of infectious diseases, the global ecosystem and sub ecosystems, such as deserts, oceans and forests (Bar-Yam, 2003). PMI (2009) cites as examples of dynamic complex systems: earthquakes, cellular systems and human systems.

Thus, many changes can occur in the system and between systems and their environments, that is, adaptive behaviors contribute to system dynamics (PMI, 2014). Thus, complex systems may follow a certain pattern, but interactions are constantly changing (Sargut *et* Mcgrath, 2011).

Finally, it is important to note that complex human systems are different from complex systems found in nature, due to human unpredictability and intellect, and thus cannot be modeled in the same way (Snowden et Boone, 2007).

Figure 2 shows the complex adaptive behavior.

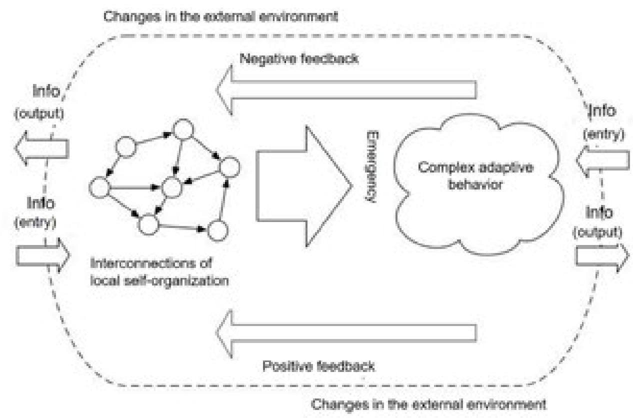

Figure 2. Complex adaptive behavior
Source: Andrus (2005)

5.9. Complex networks

Barabási (2003) defining complex network as a graph with topological characteristics (structure) special (non-trivial) composed of vertices (nodes) interconnected by means of edges (arcs or connections). Complex networks are applied in several fields of human knowledge, such as: Biology, Mathematics, Computing, Sociology, Bibliometrics, Arts, Zoology, Linguistics and Psychology.

One of the famous applications of complex networks was made by Larry Page and Sergey Brin, founders of the company Google in the late 1990s. They realized that pages that receive many hyperlinks tend to be more relevant than those that receive few. This perception was the basis for the creation of the PageRank algorithm for the ordering of web pages (Brin *et* Page, 1998).

Complex networks have gained the interest of the scholars of the area as a way of modeling complex dynamic systems. By the topology of these networks, one can better understand the behavior of the complex system.

But, in general, a network is "an abstraction that allows some kind of relationship between pairs of objects" (Figueiredo, 2011). Networks exist in many domains of nature, for example: computer networks, people, articles, neurons, proteins, predators and prey (Newman, 2010), and they evidence the notion that the whole has a behavior that is not explained by the behavior of the parties, but that the interaction between the parties influences individual and collective behavior. Therefore, networks permeate the daily lives of people and influence their lives.

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In this field of study, it is fundamental to discover, characterize and model the network (Figueiredo, 2011), since many phenomena can be better explained if they are modeled according to the network structure they operate. Thus, the functionality is influenced by the structure, that is, it can be inferred about a phenomenon only knowing the characteristics of the network that maps it.

6. TYPES, DIMENSIONS AND PROPERTIES OF COMPLEXITY

In the literature, complexity has been studied in several ways, for example: main aspects, types, dimensions, characteristics and complexity factors (PMI, 2014). In philosophical terms, complexity receives a great contribution from complex thinking, proposed by the French philosopher Edgar Morin, who published several works in the areas of Philosophy, Sociology and Epistemology.

For Morin (2005), complexity is a quantitative phenomenon due to the immense amount of interactions and interferences between a very large number of units. Thus, it comprises uncertainties, indeterminations and random phenomena, that is, it is related to the idea of chance (Morin, 2005).

According to Geraldi *et al*. (2011), complexity types, attributes and indicators were identified and regrouped in five dimensions: structural, uncertainty, dynamics, rhythm and sociopolitical. Remington and Pollack (2007) suggest four types of complexity: (a) structural complexity, (b) technical complexity, (c) directional complexity and (d) temporal complexity, as presented in Table 2.

The types of complexity can overlap. The larger the project or program, the more likely they are to exhibit one or more types of complexity (Remington *et* Pollack, 2007). Identifying the type of complexity of the project helps to direct the efforts for its management (Geraldi *et al*., 2011). For example, if sociopolitical complexity prevails, then greater effort should be directed to the management of project stakeholders.

In project management, Baccarini (1996) states that the texts in this area commonly refer to two types of complexity: organizational complexity and technological complexity. According to the PMI (2014), the causes of complexity in programs and projects can be grouped into three types: human behavior, system behavior and ambiguity, according to Table 3.

Human behavior is the source of complexity that can arise from the interaction of behaviors, behaviors and attitudes of people (PMI, 2014). The behavior of the system is the source of complexity that can arise from the connection between the interrelated components of programs and projects (PMI, 2014). Ambiguity is the state of lack of clarity: not knowing what to expect or how to understand a situation (PMI, 2014).

Hertogh *et* Westerveld (2010) argue that complexity has six dimensions: technological, social, financial, legal, organizational and temporal. These dimensions are divided into two types: complexity of details and dynamic complexity.

Table 4 shows these characteristics organized by type and size.

Table 2. Types of complexity

Type	Description of the type
Structural complexity	Large amount of structural elements.
Technical Complexity	Complexity of the project product, among others, technical and design problems. Often described as "complicated".
Directional Complexity	Non-shared goals, unclear meanings, and hidden agendas.
Temporal complexity	Impact of unanticipated results, such as changes in legislation.

Source: Remington *et* Pollack (2007)

Table 3. Types and causes of complexity in project management

Groups	Causes associated
Human behavior	Individual behavior.
	Behavior of the group, organization and politician.
	Communication and control.
	Development and organizational design.
System Behavior	Complexity of the project product, among others, technical and design problems.
Ambiguity	Uncertainty.
	Emergency.

Source: PMI (2014)

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In terms of properties, three of them determine the complexity of an environment: (a) multiplicity, refers to the quantity of potentially interacting elements; (B) interdependence, refers to how these elements are connected; and (c) diversity, refers to the level of heterogeneity of these elements (Sargut *et* Mcgrath, 2011). The greater multiplicity, interdependence, and diversity, the greater the complexity (Sargut *et* Mcgrath, 2011). In relation to characterization, structural complexity, uncertainty, rhythm and socio-political dimension are some of the recognized characteristics of complexity (Geraldi *et al*., 2011).

7. Final considerations

Through qualitative, exploratory and bibliographical research, focused on three of the main scientific bases, it was intended to provide a panorama about the complexity, presenting its main elements and fomenting the discussion about its potentialities.

An "X-ray" of Complexity Theory was elaborated in terms of: (1) conceptual introduction; (2) historical evolution; and (3) main types, dimensions, properties and definitions found in the scientific literature.

It is noted that the popularity of Complexity Theory between academics and practitioners is increasing, but there is a great potential of applications still unknown. In this way, its potential to generate benefits is promising. For example, it broadens understanding of global markets, air traffic systems, urban planning, and complex project management.

The two currents that deal with the complexity perspective - complex thinking and complexity sciences - have some complementary as well as competing and conflicting ideas. This feature helps explain why there is no widely accepted definition for the construct complexity. However, some authors have proposed their definitions; among them: Dijkum (1997), Bar-yam (2003), Morin (2005), Nedopil *et al.* (2011) and PMI (2014).

It is worth mentioning that some of the main constructs of Complexity Theory, which contributed to the historical development of the theory, were: butterfly effect, chaotic attractors, fractal, universality and standardization, dissipative structures, chaos limit, emergence, complex adaptive systems and complex networks.

In relation to the main characteristics of a complex adaptive system, in (Snowden *et* Boone, 2007; Aritua *et al.*, 2009):

- Inter-relationships: the level of complexity can be scaled by the level of stability between inter-relationships (Rensburg, 2012). In addition, complexity involves a large number of interactive elements and it increases with the number of unplanned connections between system components (PMI, 2014).

- Feedback: In feedback cycles, information circulates, is modified, and then returns in order to influence the behavior of the system in a positive or negative way.

- Adaptability: In an open system, information comes in and out constantly through feedback cycles. This information influences the components of the system, which consequently influence the behavior of the system as a whole. The flow of information changes the system continuously, which, in response, adapts to the external environment. Therefore, evolution is irreversible, and the system has a history in which the past is integrated into the present in such a way that the elements evolve with each other and with the environment.

- Self-organization: The second law of thermodynamics says that a system tends to clutter. However, for complexity theory, some systems tend to order or self-organize. That is, survival depends on the renewal and dissolution of order. For example, equilibrium and imbalance can alternate over the life cycle of a complex project.

- Emergency: The behavior of the system is not explained by the behavior of the system components. In other words, the whole is greater than the sum of the parts, and the solutions cannot be imposed. This runs counter to the idea that, in order to manage a program or portfolio well, it is enough to manage projects individually.

- Non-linearity: small changes in the initial conditions or in the external environment can cause unforeseeable consequences in the outputs of the system. In non-linearity, small changes can radically change the behavior of the system, and the whole is very different from the sum of the parts (Anderson, 1999). For example, human relationships are nonlinear (Weaver, 2007).

- Unpredictability: The system may seem orderly, predictable, and be described by generally simple equations, but external conditions and constant changes do not allow predictions based on history. Thus, it is not possible to foresee or predict the behavior of a complex system.

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Table 4. Dimensions of Complexity and Its Characteristics in Practitioners' View

Dimensions of Complexity	Complexity of details	Dynamic complexity
Technological	Products with extensive scopes Many interconnections between the parts of the product	Unpublished technology Technical uncertainty
Social	Large number of stakeholders Many interconnections between stakehol-ders	Differentiated understandings and perceptions Changes of interest throughout the project Changes in project coordination
Financial	Difficulty calculating the cost of all product elements	Changes in market conditions Different perceptions about definitions and agreements Misinterpretation of strategy
Legal	Need for a large number of permits and licenses, which are usually interconnected and interrelated	Changes and conflicts with laws Many decisions without transparency on the best solutions Future developments that influence the organi-zation of project deliverables
Organizational	Large number of organizations involved Interference of many work processes Large number of contracts with numer-ous interfaces	Researchers are part of the system
Temporal	Planning separate activities and their rela-tionships	Long period with continuous developments There is no sequential implementation process Planning has to deal with a number of ambigu-ous and uncertain processes

Source: Hertogh et Westerveld (2010)

It is also worth noting the use of Complex Networks Theory for the representation of complex dynamic systems. This theory contemplates the modeling of countless real natural and social networks. A theoretical implication is the stimulation of new researches that analyze the reflexes and connections of Complexity Theory in other fields of scientific literature. In practical terms, the theory in question has direct applications in several areas. In this way, it can give practitioners a new way of looking at current and future problems.

It is natural that research has some restrictions. Thus, a limitation refers to the choice of databases for tracking, since, because it is multidisciplinary, it is likely that other databases will have work on the Complexity Theory.

We sought to minimize this restriction with the choice of the main databases in Brazil - SciELO Brazil - and abroad - Web of Knowledge and Scopus -, in the academic point of view, regarding the quantity and quality of the bibliography of the databases. It is observed that the popularity of the theory between academics and practitioners is increasing; however, there is a great potential of unknown applications. Thus, its potential to generate benefits is promising.

As a result of this research, it is suggested to set up theoretical frameworks that specify applications of Complexity Theory for certain sectors, for example, in the field of management; a cut on the application of Complexity Theory could be made in: projects, finance, marketing, strategy and others.

Finally, it is hoped that this study may help to arouse the interest of practitioners and scholars, as well as to make them aware of the importance of complexity for understanding the world.

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