Article

Emergence Aiming Innovation for Sustainability

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Abstract: The nature of the sustainability crisis is characterized by high levels of complexity, thus it is not amenable to be approached from the linearity or reductionist paradigm. Emergence is a multilevel phenomenon that is characterized by qualitative novelty and is recognized as an important attribute of complex systems produced by self-organized processes, unveiled from a holistic stance. This conceptual-analytical article explores the emergence phenomenon and questions whether it can be a way of enhancing the solution process to meet the sustainability challenges. Emergent properties or behaviors emerge only when the system parts interact in a wider whole. Moreover, a systemic approach is proposed as an intermediary component in the process of emergence of creative and wise solutions to the wicked problems of unsustainability. This requires observation and entails analyzing open systems as a whole and recognizing the impact of traversing macro- and micro- scales on causal and creative emergence. The study also emphasizes synergies between emergence and creativity aimed at sustainability. Sustainable development requires leapfrogging past conventional practices, in an accelerated way, and the emergence phenomenon at play between systems levels, coupled with purposefully structured creative processes, holds the potential for catalyzing sustainable development efforts.

Keywords: unsustainabiliy; complex systems; holism; systemic approach; creative emergence; causal emergence; downward causation; macroscale; microscale; synergy

1. Introduction

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs [1] is the early 1987 definition of sustainable development. The UNESCO approach assumes that there is an environment, a society and an economy and advocate an approach that places economies and societies within environments [2]. Sustainability now entails criteria for the appropriate use of resources and for the evaluation of products in terms of economic, social and environmental impacts [3]. However, taking a holistic perspective, it can be said that there are several environments, societies and economies, all shaped by complex interactions, existing in several layers: micro (local), meso (regional), macro (continent) and mega (global), changing over time [4]. Hence, an analogy can be established with biological systems that continuously regenerate, through their natural processes, transforming biological waste into food for other biological beings, where the outputs of one cycle are processed to be the inputs of another cycle.

The nature of the sustainability crisis is characterized, among other things, by high levels of complexity and uncertainty. This suggests that people will need to develop skills and qualities that allow them to contribute to alternative behaviors, lifestyles, and systems [5]. An adaptability and regenerative approach, with high levels of commitment and agility is required to develop and implement the way out of the sustainability crisis.

The triple bottom line (TBL) essentially serves the purpose of a guideline according to which organizations develop and implement not only a traditional economically sustainable strategy, but also explicitly include strategies for environmental and social sustainability [6]. However, the three pillars are expected to be in a constant flux due to social, political, economic and environmental pressures [7]. Hence, sustainability, currently dominating all contexts of business and organizational management, is not amenable to be approached from the linearity paradigm, since the three aspects of sustainability identified in the TBL are to be aimed in balance or even harmony between economic, social and environmental aspects [3].

One way of moving toward sustainable development is through a combined organization and human systems approach [8]. This notwithstanding, being truly sustainable requires a systemic vision of the preservation of human, natural, environmental and energy resources as a normal course of activity. Having nature as a model and learning from it for the resolution of humankind's problems, acting close to the way living beings work, can potentially reduce negative impacts. Natural systems are often compared in several studies because they have much in common with the socioeconomic systems of organized communities. Both kinds of systems consume material resources, energy, and produce waste. Be it cells, organs or organisms in the natural systems or customers, workers or companies in the social systems, the flows of materials and energy, which derive from the metabolism, exchanges and continuous interactions between the actors and components of the system with each other, integrated in a whole and with the surrounding systems, make it very clear that the relations between the part (the components) and the whole (system) cannot be neglected.

The circular economy approach, resembling the cycles in nature, is a welcome contribution for the replacement of the linear economy model [9], in order to counteract the possible depletion of natural resources, and relying instead on circular production to satisfy energy and material needs. This circular economy approach aims low energy consumption, low pollutant emissions and high efficiency [10]. The implementation of circularity aims to contribute to the preservation of natural resources that, being finite, must be preserved by all the inhabitants of the planet. Intending that the inputs of materials remain in the same cycle as long as possible, a circular system gives preference to biological materials, to the regeneration of soils, to products designed for disassembly, in order to facilitate the entry to other cycles. The plans for boosting the circular economy include to 'design' waste as return nutrients and to recycle durable goods, using renewable energy. Circular economy focuses on optimizing systems instead of components [10]. With the depletion of various resources approaching and evidence of climate change and the degradation and risk to life, especially of the most disadvantaged, it is urgent to change and apply sustainable forms in relation to the three pillars of the TBL.

A more insightful, elegant, and systemic view of solutions may be possible, if based on a more comprehensive structure of the problems, including relevant values (financial, human and environmental sustainability) and barriers (cost) [11]. The expansion of the structure of the problem and the adoption of a broader perspective that includes ethical and social considerations should be part of the process of generating truly insightful solutions to the challenge of sustainability. Facing complex, human, economic and environmental systems, which integrate connections and interrelationships between them, the positive balance often involves an interaction between the parties (people, companies and environmental resources that encompass local resources) causing emerging phenomena not possible in the separate components, resulting in the creation of benefits for stakeholders. Having the ability to emerge and question implicit and deeply rooted assumptions can be a way of solving the sustainability challenge [12]. A paradigm shift in the way we solve sustainability problems requires a more systemic approach to solving problems and generating creative solutions [13]. This involves challenging the rules and assumptions of the current paradigm.

Hence, a systemic approach is likely to foster emergence of relevant effective solutions that contribute to sustainable development. There is hence interest in assessing the feasibility of making using of the systemic approach as a path to emergence of novel sustainable solutions. In the

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remainder of this article, we first present the concept of emergence, downward causation in relation to reductionism and holism as well properties of emergence. We then extract guidance from literature on scaling of causal models and the emerging differences and their implications for the levels of macroscopic and microscopic analysis. Lastly, we explore synergy among theoretical concepts to foster novelty emergence supporting design ideation processes at the service of sustainable development.

2. Emergence as a Concept

Emergence plays a central role in theories of integrative levels and of complex systems. According to Yaneer Bar-Yam [14], one of the problems in thinking about complex systems is that we often assign properties to a system that are actually properties of a relationship between the system and its environment. We do this for simplicity, because when the environment does not change, we need only describe the system, and not the environment, to describe the relationship, since the relationship is often implicit in how we describe the system [14]. In a world of widespread environmental changes, it is no longer possible to ignore this distinction as highlighted by Bar-Yam. Emergentist thought makes use of specific concepts and properties of the emergence phenomenon, to explain its theory. These properties or behaviors emerge only when the parts interact in a wider whole.

For advances in scientific thinking to emerge, it is important that definitions and terms combine with the new knowledge that is emerging. In philosophy, systems theory, science, and art, emergence occurs when an entity is observed to have properties its parts do not have on their own. There is no conceptual unification of this theory, it varies according to the areas in which it is addressed. Each of them uses its own metaphorical language, introducing changes and correlated combinations as a concept, giving rise to different definitions useful for different areas.

In Yaneer Bar-Yam's view, emergence refers to the existence or formation of collective behaviors — what parts of a system do together that they would not do alone, e.g.: a water molecule has emergent properties that arise out of the properties of oxygen and hydrogen atoms. In describing collective behaviors, emergence refers to how collective properties arise from the properties of parts, how behavior at a larger scale arises from the detailed structure, behavior, and relationships at a finer scale [14].

Emergence is generally recognized as an important attribute of complex systems [15]. Dynamic and interdependent systems are complex systems that have causal interactions between them and therefore should not be studied in isolation. The boundaries of complex systems, that is, the boundary conditions, are defined according to the objective of the study. The analysis of complex systems must pass through the recognition of phenomena with the integration of the concept of emergence.

Systemic thinking analyzes the system as a whole and not its isolated parts, emerging properties have as a basic condition to emerge from systems. Complex systems, nature, human societies, among others, in addition to establishing causal interactions between their constituent components also establish relationships with other neighboring systems.

Irreducibility is a property by which the properties of the components are determined by the way they are part of the whole, so that detaching them would change their own identity [16]. The perspective that considers emergence is often contrasted with a reductionist perspective, which thinks about parts in isolation. Reductionism is the often vilified "anti-complex systems" view of the world. The concept of a system is itself based upon a limited form of reductionism that distinguishes the system from its environment, and the parts of a system from each other. The key difference is that the non-reductionist approach considers the relationships among them [14].

In 1999, economist Jeffrey Goldstein provided a current definition of emergence in the journal Emergence [17]. Goldstein initially defined emergence as: "the arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems". In 2002, systems scientist Peter Corning described the qualities of Goldstein's definition in more detail: radical novelty (features not previously observed in systems), coherence or correlation (meaning integrated wholes that maintain themselves over some period of time), a global or macro "level" (i.e.

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there is some property of "wholeness"), it is the product of a dynamical process (it evolves), and it is "ostensive" (it can be perceived) [18]. Armed with this emergence lens, not only do we see that complexity is an emerging phenomenon produced by self-organized processes [18], but we can also start seeing the world as networks of niche creation enabling novelty, and more or less radical emergence, which creates new activities and new niches for yet further unfolding of emergence, placing us in a world of becoming that generates its own possible directions of future becoming [19].

In George Herbert Mead's pragmatic social psychology, the concept of emergence is used to explain the generation of novelty [20]. Complete determinism is not capable of explaining this. To his cohort of pragmatists, a listing of all possible causes of a phenomenon would mean that the dependent variable would have nothing left to it that had not already been explained; it would actually be nothing but its past causes [21].

Complexity theories evolved on the basis that living systems continually rely on external sources of energy [22], through causal interactions between the components of living systems and between their surrounding context, the ecosystem. Important properties of ecosystems, such as resilience, or stability, emerge from interactions between components of the ecosystem [23, 24]. Hence, in order to survive, any system must establish a positive balance with its surrounding context. The context captures the environmental, political, social, and economic climate [25] and the principle of balance defines the need to find the proper relationship between components of a complex system, in order to achieve a positive balance [26]. It is important to emphasize that positive balance often cannot be achieved by optimizing a single subset of components in a complex system [25] in addition to the rampant environmental changes that are taking place, which also have to be considered.

The properties of an emerging phenomenon can be determined by interactions with the context in which the system is inserted. The surrounding context leads us to the notion of hierarchy of levels, which we shall also discuss, in another section. These interactions become mechanisms for emergent phenomena and produce effects of various types within the system itself and in the surrounding context. The notion of downward causation, a flip side of emergence has been praised by the reductionist stance but also has a place in the holistic stance, as can be seen in the following section.

3. Downward Causation and the Reductionist versus the Holistic Stance

A desire to unveil the causes of phenomena and effects found in the universe has long been felt. This inclination to seek causes is evident in Aristotle's discussion about the Parts of Animals of causes and final causes, as well as in Metaphysics, II.1.5–6, where he writes that we cannot know a truth without first seeking a cause [27]. In his description of the final cause or telos, Aristotle views the cause as an end in itself: "Further, the Final cause of a thing is an end (telos) and is such that it does not happen for the sake of something else, but all other things happen for its sake" [27].

The principle of causality derives directly from the philosophy of René Descartes in his Third meditation of 1641 [28]. The term downward causation is attributed to Campbell (1974) [29]: "Higher-level entities manifest genuinely novel causal powers, causally affecting their constituents, so that lower-level events take place differently within them." Downward causation is further used as a designation for an alleged downward effect which emanates from the emergentically defined higher level onto its constituents in the lower level [30].

The principle that every effect has a cause is accepted a priori in physics [31], and perhaps not surprisingly, the explanations given by scientific laws are seen by many as the only ones acceptable and not contrary to the principles of science, generating strong controversy between reductionists and holists, who explain the phenomena of science at different levels. Emergence is understood in a different way, by "reductionist" and "holistic" theorists who give it different interpretations of causation [18]. Reductionism analyzes in detail the interactions of parts of complex systems to obtain an answer to "how" and it explains it through laws. With a comprehensive approach, holism explains the complexity of the emergency using a multi-level analysis to give answers to the "why", claiming that the causal effect is produced by synergies generated by the various combinations of parts, with nonlinear interaction between the constituent elements of the whole. Interactions between the parts are new structures that are generated by emerging adaptability phenomena in the system [18].

Reductive methods have made us aware of many laws that explain how natural and non-natural systems work, contributing to scientific knowledge. In physics, phenomena are translated by laws in which the total effect of the various causes that produce it is equivalent to the sum of the separate effects, to this Mill called the principle of "Composition of Causes" [32]. Two forces can be added or subtracted depending on whether they have the same or opposite directions, respectively, obtaining a resultant.

In chemistry, this is no longer the case, there is something new in the effect. Water, for example, acquires properties completely different from the properties of its constituent elements, hydrogen and oxygen, when they are separated [16]. Another example where there is something new in the effect is sodium chloride, commonly called table salt; in moderate amounts it is harmless to humans, however two toxic elements make it up, chlorine and sodium. The examples of water and salt, show the limits of the reductionist approach, justifying the need for a more holistic approach. A stronger cause than the simple relation that the same cause produces the same effect occurs in living organisms, including man, as these are susceptible to improve internal processes, triggered effectively by efficient extrinsic causes, which act following internal processes. In general, efficient causes are effective solely to the extent to which they trigger, enhance, or dampen inner processes; in short, extrinsic (efficient) causes act, so to say, by riding on inner processes [16].

4. Emergence Properties

George Henry Lewes introduced in 1875, for the first time, the term "emergent", in a context of a discussion about whether the joint effect of several causes is identical to the sum of its separate effects [33]. Lewes is quoted as having stated that if there is something new or heterogeneous in the joint effect of several causes, it will be called "emergent" [16]. That philosopher is blamed for the explosion of emergency theories in the early 20th century [18]. Jeffrey Goldstein identified several characteristics of the emergent phenomena [17]: unpredictability, not deductible from the previous conditions, appearing over time due to the interaction and only showing, however, when the system evolves. Then the emerging phenomenon suddenly exhibits new patterns and new structures that have new properties [34].

In a leadership setting, the emergent process brings together three components [35]: The first component is that the emergency is multilevel, second, it includes the mechanisms that underlie the dynamic interactions of the process, and third, it captures temporal dynamics, or the notion that emergence takes time to move through problem phases. In a more general emerging phenomenon, the explanation of its constituents is not enough to explain the global phenomenon as a whole [36].

DeLanda (2012) states that a property of a whole is emergent if it is produced by causal interactions between its component parts. These interactions, in which the parties exercise their ability to affect and be affected, constitute the emergence mechanism behind the properties of the whole [16]. Emergentism underwent a long period of oblivion and only recently was revitalized by the sciences of complexity, that are concerned with the complex emerging properties of life and mind [29]. Similarly, sustainable development requires leapfrogging past conventional practices, in an accelerated way, and the emergence phenomenon at play between systems levels, holds the potential for catalyzing sustainable development efforts.

Emergence has been used over several years by various sciences, physics, psychology, economics to explain various phenomena such as Bénard cells (convection), market awareness and behavior, respectively [18]. Cognition, and especially consciousness, can be considered an emergent property of the organism [33]. Emergence can be seen as the "magic" that brings about a leader of several elements of an interacting group solving a task [35]: to represent leadership emergence, it becomes clear that if we want to understand the magic, we need to focus on the underlying process of emergence. That is, the real mechanisms of an emergent phenomenon.

The concept of emergence, like any phenomenon for which science does not yet have an explanation, makes it a concept that may be charged with mysticism. However, contemporary philosophers like Mário Bunge, claim that the possibility of analysis does not imply reduction, and the explanation of the emergency mechanisms does not explain the emergence. [37: p.156, 16]. To talk about property emergence is no longer perceived as something that stands in opposition to scientific thought; the very term `emergence 'has become popular in the context of computer models of non-linear dynamical systems, and in complex systems research [29]. Emerging effects are associated specifically with contexts in which constituent parts with different properties are modified, remodeled, or transformed by their participation in the whole [18]. The case of water and table salt are representative examples of this definition.

Emergentism is characterized by a set of several properties, among which we emphasize qualitative novelty. Any evolution in process produces change and qualitative novelty in all domains of reality [38]. Qualitative novelty refers to certain phenomena of nature that produce material changes and cannot be explained in a simple quantitative way [18]. They cannot be explained by the simple result of the algebraic sum, addition, or subtraction of things of the same type, of the phenomena that gave rise to it. Moreover, associations of interactions cause a higher state of organizational complexity to occur, with new qualitative properties not existing in the components alone or in the whole [38].

5. Impact of Scale on Emergence

Most definitions of emergence share the assumption that emergence arises only in hierarchical systems made up of interacting components, which is why they can be described at macroscopic and microscopic levels [39]. In this hierarchical view, a component at a higher level may be represented by a complete system at a lower level. This is related to the notion of supervenience, which includes two simultaneous concepts [30]. On the one hand, the idea that all macro properties depend on a lower level, that is, none of these macro properties can exist without the lower level properties. On the other hand, it is the fact that the properties of the macro cannot be fully explained by the lower level properties nor are they reducible at that level.

Different maps convey different levels of information that lead to different insights and different views, consequently leading to different achievements. Macro-scale causal models quantitatively compared with micro-scale causal models, in terms of information effectiveness, are superior. This result, mathematically quantified, relates the causal emergence to the capacity of Shannon's channel [40]. Shannon's discovery of the ability of a communication channel to achieve more reliable communication with information is the dominant concept in the theory of causal emergence [41]. The theory of causal emergence reveals that there is a similar causal capacity in a system, but the causal capacity is limited by the capacity of the channel. A macroscale analysis removes the uncertainty of causal relationships, thus using more of the available causal capacity. Information theory applied to causal analysis, shows that the macroscale can be more informative due to focusing on the causal structure of some systems better than a very detailed micro-scale description [18].

The macro state of a system is a much simpler description of the system than its microstate, since it is based on the observation of a drop in complexity between the highest level observations of a system's behavior (the macro state) and the detail of the rules that generate these observations (the micro state) [15]. The shorter description requires a macroscopic view of the observer to recognize spatial patterns and to relate patterns that are separated by various time intervals. This description, being shorter, represents a drop in complexity which may be useful to observers. Emergence may manifest itself as a gap between the macro and the micro-state of the system. This notwithstanding, macro scales may omit critical information and causal relationships [18], as they are at best a compressed description.

An emergence mechanism can involve interacting parties, operating at different scales and exhibiting different levels of organization [16]. The analogy between natural systems and the socio-economic system is not new, previous practices justify evaluating the characteristics and processes of each other to obtain contributions from the similarities found. Scaling proves to be an effective process for perceiving and making explicit hidden variables, sometimes difficult to be perceived in other granulations. Let us take it for granted that socioeconomic organizations are replicas of biological organizations insofar as they both integrate many elements, their constituents, and are therefore highly complex systems. Life is probably the most complex and diverse phenomenon in the universe, managing an extraordinary variety of forms, functions, and behaviors over an enormous range of scales [42]. It is estimated for instance there are more than eight million different species of organisms on our planet, ranging in size from the smallest bacterium weighing less than a trillionth of a gram to the largest animal, the blue whale weighing up to hundred million grams. A system contains all possible levels and scales. It is possible to filter different pairs (level, scale) to focus on a comparative analysis, or not, defining several analysis domains within the reality. Depending on the borders and levels that we establish, it is still possible to look only within the borders, to the space that surrounds them, or to look beyond them, to the systems that are in their neighborhood.

Each phenomenon acquires macro or micro roles in relation to the context that is to be analyzed. For example, a cell is a macro property in relation to the organelles it contains, but it is a micro property in relation to the organic tissue to which it belongs [36]. However, emergence is interactive, effects are causes, new principles and new capabilities emerge at each new level with new and different properties that result in new levels [18]. Thus, this cycle ensures that the evolution of the universe is infinite.

New properties are created and identified exclusively at the macro level through the systemic interaction of the constituent elements. Level theories often use the concept of emergence as a designation for the relationship between new or unpredictable properties at the top level [30]. The impossibility of explaining the macrostate from the microstates, that is, the lack of a link between the microstate and the macrostate, is called a strong emergency; conversely, a weak emergency is defined by the existence of an irreducible link between macro and microstates [39]. The importance of choosing the scale, is tied to it determining the causal model, because each scale corresponds to a particular causal model of the represented system [41]: "causal models are those that represent the influence of subparts of a system on other subparts, or over the system as a whole". A model is a representation of a system, in part or in whole, built to study that system [43]; moreover, it is also a representation of a real-world system, which derives from the intellectual construction constructed by an observer in accordance with one or more formalisms [24]. A causal model allows a causal analysis to be performed among a set of elements of a system at various spatial and temporal scales [41]. Any system can be represented, in different granulations or in different subsets, by causal models. A subset is considered as coarse grain or macro scale, in relation to the set that gave rise to it. The micro-scale causal model, in its most refined representation, at the limit of refinement of this micro scale, represents a system in its entirety in space and time, with all its elements and states.

It takes space to isolate a system for consideration: it is necessary to define a limit, a spatial concept isolated from the rest of the universe, defining its limits [15]. Moreover, descriptions are the only way for observers to communicate about a system. Consequently, pursuing the systemic approach requires the existence, among others, of an observational component. The researcher after observation of the system under analysis, will be able to represent the components and their interactions in a systemic diagram or hierarchical relationship model of the system. Models help us to better understand and potentially develop systems. The famous saying about models is that all are somewhat wrong, but some are useful [44] and, as such, models play an important role in understanding complex systems.

6. Creative Emergence for Sustainable Development

There are common characteristics between creativity and emergence, in both phenomena there may result unpredictable or non-deductible new properties, effects or patterns. In order to argue for the similarities in the analogy that may enable better creative results in pursuing sustainable development, creativity is now explored a comparison between creativity and emergency, in addition to the previously exposed concept of emergency, we expose the concept of creativity in order to search for points of similarity among both concepts, and seek avenues to bring lessons learned from emergence phenomena in natural systems to the development of creative solutions to deal with the challenges of unsustainability. In particular, previous studies combining both concepts, albeit limited in quantity, has enabled extracting a set of interesting synergies amongst the two.

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John Gero considered already in 1996 that new and unexpected results were a necessary condition for any process to be considered creative [45]. As a concept, creativity is not only new and appropriate, but also wise [46, 11], i.e. having or showing experience, knowledge, and good judgement. Interestingly, research studies on creativity have begun to use the term emergent, to imply that images and ideas can appear unexpectedly and in radically different forms compared to any inputs that may have served as the basis for the product created [47]. According to Gero [45], for creative production of a new and unexpected result to happen, a prior restructuring of knowledge is necessary through learning and exploring the problem space, to enable decision making within this space, taking into account a set of variables. Gero attributed importance to emergence, as it was seen as playing an important role in the introduction of new variables into the design space [45].

In a landmark study of creativity in tackling sustainability problems, Conklin et al. [48] found that no level of linear thinking - no matter how much data was considered or how brilliantly it was analyzed - would present a viable solution for some sustainability problems. Given the "malice" of the problem, the researchers also propose that the solutions are secondary and the understanding of the problem is primary. What arises is the need for an ability to feel, define, frame and solve problems that include multiple factors of interaction that involve creative skills based on thinking with more imagination.

Systemic analysis, highlighting various critical points, contributes strongly to the exploration of the problem space, which induces an increase in the effectiveness of creativity for the production of sustainable solutions [22, 49]. Before specifying the problem and long before generating creative solutions, the creative problem-solving process also involves managing contradictions, tolerating ambiguities and navigating complexity [50, 11]. To solve a sustainability problem, we first need to fully frame it. A good number of the problems are highly complex, intertwined and confusing [11]. Defining and formulating problems in the sustainability discourse can be challenging, as many related issues are interconnected. When moving towards a designed solution, the main objectives are to identify and evaluate the possible and most promising alternatives [11]. By way of the systemic approach, highlighting hidden variables of the system contained in its properties, in which the possible solutions reside, creative sustainable solutions can be a way of making these properties explicit. Gero [45] states that a property that is not explicitly represented, when it can be explained, is considered an emergent property. Hence, the systemic approach to systems analysis, coupled with the creative problem-solving processes in itself is not a panacea to solve all the sustainability issues, but there is a compatibility between the two approaches that may provide synergistic opportunities.

7. Conclusion

Creative thinking is necessary, but it is not enough; perhaps the main reason why creative problem solving has not been successful so far in tackling sustainable development problems and therefore has not been fully accepted, is because the systemic and intentional framing step has been missing. The systemic approach integrates a holistic view of the system, which induces a perception of new variables that would not be detected in a view outside this context. Looking at systems as open systems, allows an awareness of internal and external variables, sometimes submerged in each system when looked at in isolation; this holistic may enable emergence of new solutions to catalyze the process of evolving towards sustainable development. Creative emergence could be the starting point for future projects of sustainable and innovative solutions for products, services or business ideas that can spring from the analysis at multiple levels of causal and association relationships existing between the components of the systems involved in the problems, detected by the systemic analysis.

Departing from an interdisciplinary stance, we explored the relationship between the theory of emergence, and creativity aimed at sustainability. Although this article reports on a wide exploration, the knowledge domain focused can evolve further as a result of the application in practical cases and experiments to obtain empirical results that may contribute to validate the theoretical contributions provided in this article.

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References

1. WCED Special Working Session. World commission on environment and development. Our common future. 1987 Jan 29;17:1-9
   URL: https://idl-bnc-idrc.dspacedirect.org/bitstream/handle/10625/152/WCED_v17_doc149.pdf
2. McGregor SL. Alternative communications about sustainability education. Sustainability. 2013 Aug;5(8):3562-80. https://doi.org/10.3390/su5083562
3. Armenia S, Dangelico RM, Nonino F, Pompei A. Sustainable project management: A conceptualization-oriented review and a framework proposal for future studies. Sustainability. 2019 Jan;11(9):2664. https://doi.org/10.3390/su11092664
4. Giddings B, Hopwood B, O'brien G. Environment, economy and society: fitting them together into sustainable development. Sustainable development. 2002 Nov;10(4):187-96. https://doi.org/10.1002/sd.199
5. Wals AE. Message in a bottle: learning our way out of unsustainability. Wageningen University, Wageningen UR; 2010 May 27. URL: https://edepot.wur.nl/157118
6. Vieira FL, Vieira PA, Coelho DA. A Data-Driven Approach to Development of a Taxonomy Framework for Triple Bottom Line Metrics. Sustainability. 2019 Jan;11(9):2717. https://doi.org/10.3390/su11092717
7. Martens ML, Carvalho MM. Key factors of sustainability in project management context: A survey exploring the project managers' perspective. International Journal of Project Management. 2017 Aug 1;35(6):1084-102. https://doi.org/10.1016/j.ijproman.2016.04.004
8. Imada AS. Achieving sustainability through macroergonomic change management and participation. InCorporate sustainability as a challenge for comprehensive management 2008 (pp. 129-138). Physica-Verlag HD. https://doi.org/10.1007/978-3-7908-2046-1_8
9. Cooper T. Creating an economic infrastructure for sustainable product design. Journal of sustainable product design. 1999 Jan:7-17.
10. Murray A, Skene K, Haynes K. The circular economy: an interdisciplinary exploration of the concept and application in a global context. Journal of business ethics. 2017 Feb 1;140(3):369-80. https://doi.org/10.1007/s10551-015-2693-2
11. Mitchell IK, Walinga J. The creative imperative: The role of creativity, creative problem solving and insight as key drivers for sustainability. Journal of Cleaner Production. 2017 Jan 1;140:1872-84. https://doi.org/10.1016/j.jclepro.2016.09.162
12. Starkey K, Crane A. Toward green narrative: Management and the evolutionary epic. Academy of Management Review. 2003 Apr 1;28(2):220-37. https://doi.org/10.5465/amr.2003.9416086
13. Cherry NL. Preparing for practice in the age of complexity. Higher Education Research & Development. 2005 Nov 1;24(4):309-20. https://doi.org/10.1080/07294360500284649
14. Bar-Yam Y. Concepts: Emergence. New England Complex Systems Institute: http://www.necsi. edu/guide/concepts/emergence. html (accessed 2020-06-29). 2011.

15. Gignoux J, Davies ID, Flint SR, Zucker JD. The ecosystem in practice: Interest and problems of an old definition for constructing ecological models. *Ecosystems*. **2011** Nov 1;*14(7)*:1039-54. https://doi.org/10.1007/s10021-011-9466-2
16. DeLanda M. Emergence, causality and realism. *Architectural Theory Review*. **2012** Apr 1;*17(1)*:3-16.
17. Goldstein, Jeffrey (March 1999). "Emergence as a Construct: History and Issues". Emergence. 1 (1): 49–72. doi:10.1207/s15327000em0101_4.
18. Corning, Peter A. (2002), "The Re-Emergence of "Emergence": A Venerable Concept in Search of a Theory", Complexity, 7 (6): 18–30, doi:10.1002/cplx.10043
19. STUART KAUFFMAN (2011) "Enablement And Radical Emergence" https://www.npr.org/sections/13.7/2011/10/31/141865856/enablement-and-radical-emergence?t=1593783653385
20. Cook GA. George Herbert Mead: The making of a social pragmatist. University of Illinois Press; 1993.
21. Franks DD. Emergence and reductionism in sociology and neuroscience. In Handbook of neurosociology 2013 (pp. 107-116). Springer, Dordrecht. https://doi.org/10.1007/978-94-007-4473-8_9
22. Coelho DA, Carrola TE, Couvinhas AF. Improvement of Certified Artisan Cheese Production through Systemic Analysis—Serra da Estrela PDO. Sustainability. 2017 Mar;9(3):468. https://doi.org/10.3390/su9030468
23. Loreau M. Linking biodiversity and ecosystems: towards a unifying ecological theory. Philosophical Transactions of the Royal Society B: Biological Sciences. 2010 Jan 12;365(1537):49-60. https://doi.org/10.1098/rstb.2009.0155
24. Gignoux J, Davies ID, Flint SR, Zucker JD. The ecosystem in practice: Interest and problems of an old definition for constructing ecological models. Ecosystems. 2011 Nov 1;14(7):1039-54. https://doi.org/10.1007/s10021-011-9466-2
25. Smith MJ, Derjani-Bayeh A, Carayon P. Community ergonomics and globalization: a conceptual model of social awareness. In Industrial Engineering and Ergonomics 2009 (pp. 57-66). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-01293-8_5
26. Smith MJ, Carayon-Sainfort PC. A balance theory of job design for stress reduction. International journal of industrial ergonomics. 1989 Jul 1;4(1):67-79. https://doi.org/10.1016/0169-8141(89)90051-6
27. Frith S. Architecture, Emergence, Order. Architectural Theory Review. 2012 Apr 1;17(1):17-26.
28. Descartes R. Meditationes de prima philosophia, Cottingham J. Stoothoff R. Murdoch D, trad. Descartes' Philosophical Writings. 3 vols. Cambridge, United Kingdom: Cambridge University Press; 1988. https://doi.org/10.1017/CBO9780511805059
29. Campbell DT. 'Downward causation' in hierarchically organised biological systems. In Studies in the Philosophy of Biology 1974 (pp. 179-186). Palgrave, London. https://doi.org/10.1007/978-1-349-01892-5_11
30. Emmeche C, Køppe S, Stjernfelt F. Levels, emergence, and three versions of downward causation. Downward causation. Minds, bodies and matter. 2000:13-34.
31. Oestreicher C. A history of chaos theory. Dialogues in clinical neuroscience. 2007 Sep;9(3):279.
32. John Stuart Mill, A System of Logic: Ratiocinative and Inductive, London, Longmans, Green, and Co., 1906, p. 243.
33. George Henry Lewes, Problems of Life and Mind. Volume Two, London, Trübner & Co., 1875, p. 412.
34. Goldstein J. Emergence, creativity, and the logic of following and negating. The Innovation Journal: The Public Sector Innovation Journal. 2005;10(3):1-0.
35. Acton BP, Foti RJ, Lord RG, Gladfelter JA. Putting emergence back in leadership emergence: A dynamic, multilevel, process-oriented framework. The Leadership Quarterly. 2019 Feb 1;30(1):145-64. https://doi.org/10.1016/j.leaqua.2018.07.002
36. Barutta J, Gleichgerrcht E, Cornejo C, Ibáñez A. Neurodynamics of mind: the arrow illusion of conscious intentionality as downward causation. Integrative Psychological and Behavioral Science. 2010 Jun 1;44(2):127-43. https://doi.org/10.1007/s12124-010-9117-8
37. Bunge M. Causality and Modern Science. Courier Corporation; 1979.
38. El-Hani CN, Emmeche C. On some theoretical grounds for an organism-centered biology: Property emergence, supervenience, and downward causation. Theory in biosciences. 2000 Nov;119(3):234-75. https://doi.org/10.1007/s12064-000-0018-0

 doi:10.20944/preprints202007.0480.v1

39. Gignoux J, Chérel G, Davies ID, Flint SR, Lateltin E. Emergence and complex systems: The contribution of dynamic graph theory. Ecological Complexity. 2017 Sep 1;31:34-49. https://doi.org/10.1016/j.ecocom.2017.02.006
40. Shannon CE. A mathematical theory of communication. The Bell system technical journal. 1948 Jul;27(3):379-423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x
41. Hoel EP. When the map is better than the territory. Entropy. 2017 May;19(5):188. https://doi.org/10.3390/e19050188
42. Cottineau C. West G., 2017, Scale. The universal laws of growth, innovation, sustainability, and the pace of life in organisms, cities, economies, and companies, New York, Penguin Press, 479 p. Cybergeo: European Journal of Geography. 2017 Aug 24.
43. Bhattacherjee A. Social science research: Principles, methods, and practices. 2012. URL: https://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1002&context=oa_textbooks
44. Box G, Hunter WC, Stuart JC. Statistics for experimenters. an introduction to design, data analysis, and model building. John Wiley & Sons,; 1978.
45. Gero JS. Creativity, emergence and evolution in design. Knowledge-Based Systems. 1996 Nov 1;9(7):435-48. https://doi.org/10.1016/S0950-7051(96)01054-4
46. Sternberg RJ, editor. Why Smart People Can be So Stupid. Yale University Press; 2003.
47. Goldstein J. Emergence, creativity, and the logic of following and negating. The Innovation Journal: The Public Sector Innovation Journal. 2005;10(3):1-0.
48. Conklin J, Basadur M, VanPatter GK. Rethinking wicked problems–Unpacking paradigms, bridging universes. NexD Journal. 2007;10(1).
49. Coelho DA, Vieira FL. The effect of previous group interaction on individual ideation novelty and variety. International Journal of Design Creativity and Innovation. 2018 Apr 3;6(1-2):80-92. https://doi.org/10.1080/21650349.2016.1216330
50. Stoycheva, Katya. "Intolerance, uncertainty, and individual behaviour in ambiguous situations." (2011): 63-73.