Digital Art and Dissipative Structures

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Abstract. By briefly introducing the theory of dissipative structures and its philosophical inspiration, this paper interprets and analyzes artworks directly inspired by the theory. It illustrates on the one hand the relationship between complex systems and digital art, and on the other hand, explains the basic conditions for self-organization. The latter is one of the characteristics of complex systems. While making a distinction with the theory of autopoiesis, we try to model certain digital art creations with several features of dissipative structures. These creations incorporate different materials, with an evolutionary approach, such as interactive artworks based on living plants, and on genetic algorithms. In this way, we demonstrate the value of investigating the self-organization process of dissipative structures within both the methodological and theoretical framework of interactive digital art.

Keywords: Complex science · Dissipative structures theory · Self-organization · Digital art theory · Human-computer interaction · Genetic algorithms

1 Introduction

In the 20th century, the emergence of complexity science profoundly influenced the transformation of humanities. In the 1940s, general scientific methodologies (e.g., system theory, information theory and cybernetics) achieved different aspects and strengthened the links between different disciplines. The development of self-organization theory in the late 1960s (whose main scientific methodologies include dissipative structures theory, synergetics and hypercycle theory) revealed a concern with the whole, and with the evolution of systems in scientific research. In the 1980s, research around complexity science concepts such as nonlinearity and emergence flourished.

These complexity science studies seeped into the arts at various times, driving new media art developments, especially digital art. Not to mention, of course, the influence of complexity science on today's research on the simulation of complex systems (e.g., artificial life systems, neural networks). For example, in the 1960s, "cybernetics and art" became popular. In robotic art, we can see that Tom Shannon's *Squat* (1966) is a complex cybernetic system: a living plant is connected to a robotic sculpture and the observer controls the motors of the sculpture by touching the plant [1]. Erich Jantsch summarizes the main ideas of the self-organizing paradigm at the time in *The Self-Organizing Cosmology* (1980): "*primo*, a specific macroscopic dynamics of process systems; *secundo*,

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continuous exchange and thereby co-evolution with the environment, and *tertio*, self-transcendence, the evolution of evolutionary processes” [2]. By the 1970s and 1980s, the concepts of evolution and co-evolution were receiving more attention. Here, in the potential of computer development, robotic art showed an interest in telepresence, as in Eduardo Kac’s 1986 robotic performance *RC Robot*, radio-controlled telerobot can talk to visitors in real time [3]. In addition, self-organization has become one of the key words in research related to the term “artificial life” coined by Christopher Langton in 1987 [4]. The combination of artificial life and bio-art has contributed to the development of generative art, such as the work of Australian artist Jon McCormack, who has been working with artificial life and evolutionary systems since the 1980s.Take for example, in *Turbulence: An Interactive Installation Exploring Artificial Life* (1994), he used genetic algorithms[1] to demonstrate virtual species and a computer perspective on nature and our relationship with it [5].

The complexity science study, which deals with complex systems, takes a non-reductionist approach in different disciplines. The physical chemist Ilya Prigogine, a Brussels School representative, made an early contribution to the field with his dissipative structures theory. Furthermore, in their 1979 book *La nouvelle alliance: métamorphose de la science*, Prigogine and Isabelle Stengers introduced the notion of “complexity science”, but Prigogine did not give a clear definition of “complexity”. Different schools of thought hold different ideas on the concept of “complexity”. Nevertheless, complex systems usually contain the following characteristics: “Nonlinearity, Distributedness, Scale and Interaction, Multiple Levels of Observation, Self Organization, Emergence, Adaptivity, Flexible Decision Making and Feedback Loops” [6]. And dissipative structures theory describes the phenomenon of self-organization that occurs in open systems as they interact nonlinearly with their environment, acquiring macroscopically stable structures.

Here, it is important to note that self-organizing system is easily confused with the autopoietic system that appeared in the same period. According to Hermann Haken [7], a self-organizing system is one in which the internal elements of the system and the external environment interact to acquire a spatio-temporal or functional structure, provided that the external world acts in a non-specific way and is not imposed on the system. Examples include the formation of crystals and the production of lasers. An autopoietic system, as defined by Francisco Varela and Humberto Maturana [8], refers to a network that maintains itself by replicating itself. This network contains circles of production process and constituent elements, such as living cells.

On the distinction between the two, Hideo Kawamoto [9] explains it by taking the example of crystals constantly being generated in a beaker. He says that if we consider the generation of crystals as a self-organizing system (in another case, the continuously generated crystals are regarded as the self-organizing system, and the solution in the beaker is the environment), the process of generation is the object of our attention. Once crystallization has taken place, then, in the case of a self-organizing system, the

[1] Genetic algorithms are a type of evolutionary algorithms. According to Holland’s *Adaptation in natural and artificial systems: an introductory analysis with applications to biology, control, and artificial intelligence* (1992), this is an algorithm that solves optimization problems by modelling the biological evolution process and is an adaptive probabilistic search.

same type of generative process continues to occur. For the self-organizing system as a production process, the output crystals are like factory waste. If one were to describe the self-organizing system in terms of an autopoietic system, it is only "当析出的结晶能够再次生产出产生自我的生成过程的时候, 出现了生命, 自生系统才开始运动" (when the precipitated crystal regenerates the self-production process that life emerges and the autopoietic system will begin to move) [9]. It follows that self-organization focuses on the production process, while autopoiesis focuses on the maintenance of a circular network of production processes. In short, both focus on the self-reference, but while self-organization emphasizes the formation of new structures, autopoiesis emphasizes self-replication.

In this paper, our focus is on the production process of new structures. Given the weakness of autopoiesis in this aspect, the paper takes a dissipative structures theory approach. On the one hand, it helps us to understand what is necessary for a self-organizing system; on the other hand we will illustrate the relationship between the complex behavior of the structure in the production process and artistic creation, and its richness for digital art theory.

2 Dissipative Structures Theory

Dissipative structures theory contains evolutionary laws in complex systems within the study of nonlinear nonequilibrium thermodynamics. The theory is based on the "Minimum Entropy Production Principle" proposed by Prigogine in 1945. It was then introduced in his paper entitled "Structure, Dissipation and Life" in 1969. Almost simultaneously with this theory came another version theory of self-organization: the theory of synergetics. Established by Haken, synergetics "is concerned with the cooperation of individual parts of a system that produces macroscopic spatial, temporal, or functional structures" [10]. Both theories provide a theoretical framework for the interconnection of living and nonliving systems that possess conflicting laws. Dissipative structures theory states that these two systems - living and nonliving - are governed by the same systemic laws under certain conditions.

Dissipative structures, according to Prigogine [11], are dynamically stable and ordered structures formed by open systems far from equilibrium through the constant exchange of matter, energy and information with the outside world. More specifically, in the dissipative motion, when the change of external conditions reaches a certain threshold, the self-organization phenomenon is generated through internal actions – such as fluctuations and mutations: the system spontaneously changes from the original disordered state to the macroscopically ordered state. For instance, a famous dissipative structure - Benard convection [12]: heating the liquid from the bottom of a pan, when the temperature gradient reaches a critical value, a regular cellular convection of the liquid occurs. This theory is also called "Self-Organization in Nonequilibrium Systems" [13], of which the focus is to put forward the irreversibility of time and the study of self-organization phenomena.

After its introduction, the theory contributed to the development of complexity science research and expanded the theory to life, ecology, brain, meteorology, and philosophy. It is to be noted that the theory has shortcomings: it uses a local equilibrium approach [14] and its application is limited. At the same time, “在远离平衡情况下,怎样合理地定义熵和温度等基本的热力学变量,仍是个很困难的问题” (how to reasonably define basic thermodynamic variables such as entropy and temperature is still a complicated problem when far from equilibrium) [15]. However, the application of this theory is still broad, and under certain conditions, it is suitable for systems in different fields.

Although Prigogine’s thinking “has had little or no effect on the ‘textbook science’ of late twentieth century (and indeed early twenty-first century) school science curricula” [16], the theory’s interdisciplinary mode of thinking has had a heuristic impact on the humanities. In the philosophical context of thinking about chaos and order, for example, Manuel de Landa [17] argues that when armies adopt decentralized tactics that are task-oriented and leave the details of execution to subordinate organizations, they act as self-organizing dissipative structures: forming some “islands of stability” and thereby leading from chaos to order.

3 Dissipative Structures Theory, Nature and Art

Dissipative structures exist widely in nature, for example, hurricanes, tornadoes [18], mineralization structures, living organisms [14]. From this perspective, living and non-living are connected. In an interview about science and art, Prigogine says, “physics, by becoming a matter of probability and emphasizing the new and a certain indetermination in nature, produces a vision that emphasizes creativity. And creativity is the most important aspect of art” [19]. He wants to try to eliminate the contradiction between science, philosophy, and art. Starting from the different concepts involved in dissipative structures theory, some artists have thought about dissipative structures in the form of installation, photography, sculpture and video[2].

For example, artist Cameron Robbins is interested in wind, air, solar energy, tides and the earth’s magnetic field. Inspired by the relationship between stability and instability in dissipative structures, in 2007, he used a smoke machine to control airflow to create a vortex-like phenomenon – named “Apparition”[3] (see Fig. 1), - in his site-specific art installation “Merricks beach house”. The work is like a dynamic Chinese landscape painting of the Song dynasty, incorporating a grand and abstract concept into the continuous morphological changes of the rotating smoke: motion in stillness, Space is enveloped in an abstract mood of high mountains and flowing clouds of smoke. Using the vortex as a medium, the artist is very much concerned with the connection between dissipative structures and living beings, and even the whole of nature. In addition to this work, Cameron Robbins has represented the uniqueness of vortex structure in different ways in Double Vortex (2006), and Structure of Vortices (2012).

[2] See the works of artists such as Cameron Robbins, Andrew Beck, Laura Pesce and Mattia Casalegno.

[3] In 2008, in an essay entitled “Dissipative Structures - about the Vortex”, the artist introduced some phenomena and features of dissipative structures and clearly stated that he had photographed this structure for the house project. Cameron Robbins, Dissipative Structures – about the Vortex, http://cameronrobbins.com/writing/dissipative-structures-about-the-vortex/, last accessed 2021/05/29.

Fig. 1. Cameron Robbins, *Apparition, Smoke Room*: 26 Surf Street, Merricks beach house installation, 2007. (© Cameron Robbins.)

Dissipative structures, which are ordered on the macro level, including time, space or function, must constantly exchange matter and energy with the outside world. Cloud-streets are a type of cumulus that forms linearly with the direction of the wind [20]: clouds that were originally moving in a disorderly manner, under certain conditions, form neat columns and create a spatially ordered structure. It is therefore a common type of dissipative structure. During this process, clouds come alive. In 2018, photographer Andrew Beck used a set of photos called "Dissipative Structure I" and "Dissipative Structure II" respectively. This group of photos resembles computer-generated pictures, reminiscent of cloud-streets and cyclones' dissipative structures. The photographs highlight this "evolutionary dynamism" within the structure and suggest its existence between analog and digital.

4 Dissipative Structures and Digital Artworks

Similarly, out of this "evolution" or "between" thinking, in 2020, teamLab made an art installation called "Massless Clouds Between Sculpture and Life" (see Fig. 2). The installation is a way to think about "living" and "nonliving" from an entropy perspective, measuring the degree of chaos in a system in thermodynamics. They created self-organizing cloud masses that float in the air and gave them the ability to repair themselves.

Before the advent of dissipative structures and synergetics, nonliving systems followed the second law of thermodynamics and spontaneously changed from order to disorder. This reached a maximum entropy of the system, resulting in an irreversible process. The evolution of living beings is the opposite. Living and nonliving systems seem to be unrelated to each other. Nevertheless, Prigogine points out that living systems, unlike the conditions revealed by the second law of thermodynamics, are open and far from equilibrium, rather than isolated and in equilibrium or near-equilibrium. Under certain conditions, the system reduces entropy (emergence of a negative entropy flow) through the exchange of matter and energy with the environment. The proposed theory of dissipative structures suggests that there is no strict boundary between living and nonliving systems and that the same laws inherently exist. Erwin Schrödinger had stated in *What is life?* (1944), "What an organism feeds upon is negative entropy" [21]. In other words, through entropy reduction and self-organization to produce and maintain order to stay alive.

Fig. 2. TeamLab, *Massless Clouds Between Sculpture and Life*, 2020. (© TeamLab.)

TeamLab's work attempts to build a "dissipative system", with a particular emphasis on the interaction between life and the environment: "a giant white mass, floats (…) Even when people push through the sculpture and break it, it naturally repairs itself like a living thing. But, as with living things, when the cloud is destroyed beyond what it can repair, it cannot mend itself, and it collapses." [22]. Here it is necessary to give a brief explanation of the life cycle (if defined in terms of the time from condensation to dissipation) of a real cloud, using cumulus clouds as an example. The formation of cumulus clouds is based on the supply of thermals. Initially, the rise of invisible thermals produces a small wisp of cloud that is visible to an observer. Thermals then continue to flow into the cloud and out of the top into a mature cloud. For this structure to be maintained, mechanical energy needs to be dissipated and "the inflow of air from the subcloud thermal is assumed to be in balance with detrainment from the cloud into the environment" [23]. As thermals decay, the cloud begins to dry out and eventually dissipates. The formation of cumulus clouds reveals the visible presence of thermals.

In this interaction, we see that the material system in which the entire giant mass is embedded, is an open system. The space implied by the gaps between the inner masses and the observer as a representative of the external environment are the sources of information for this system. The changes in the masses caused by the involvement of the observer (traveling and or destroying) suggest the exchange of energy and information between the environment and the system. Also in this process, the degree of chaos within the floating giant mass system increases. Simultaneously, the interference of the observer intensifies the nonlinear positive feedback effects within the system, and amplifies the system's change mechanisms: the complexity within the system increases. This accelerates the system's self-organization, here manifesting as a self-healing property. For example, the giant mass system repair the parts of its organization that have been removed by the observer, bringing the system from short-term disorder to order while maintaining its "vitality". However, when the observer's interaction causes the giant mass to change beyond a certain critical range, the system's ability to self-organize will collapse and not return to its ante-interference state. This cloud system changes from order to disorder again, just like the eventual cessation of life.

Ecosystems are also common dissipative structures. When equilibrium occurs, the ecosystem also goes into death. Prigogine points out that nonequilibrium is a constant, that equilibrium is the state of a few, and nonequilibrium is the source of order. Near the threshold, a system in a nonlinear nonequilibrium state, can be subject to sudden changes in its state due to small disturbances. It occurs a bifurcation phenomenon and a re-ordered structure is formed. In advanced bifurcation phenomena, the self-organizing capacities of the sub-branches are combined, resulting in complex spatio-temporally ordered self-organization phenomena. Inspired by the questions of disorder and order, stability and instability in the theory of dissipative structures, Mattia Casalegno used the name "Strutture Dissipative"(see Fig. 3) to focus on the ecosystem from perspective of complexity theory. In the form of video projection in 2007, many particles and irregular shapes interacted with each other, evolving between symmetry and asymmetry, chaos and order. This generative artwork is a study on the combination of granular synthesis and chaotic particle systems techniques to develop live media performances and generative artworks [24]. Indeed, Philip Galanter [25] had long noted that systems combining order and disorder have long been the focus of generative artists, such as cellular automata, fractals, emergence, and other systems. As Galanter reveals, "systems are a defining aspect of generative art" [25] and suggests complexity theory as the theoretical context for systems-oriented generative art. In our understanding of the work *Strutture Dissipative*, or at least, in drawing first impressions, we also use the approach that complexity theory emphasizes for the study of systems: a combination of holistic and reductionist approaches.

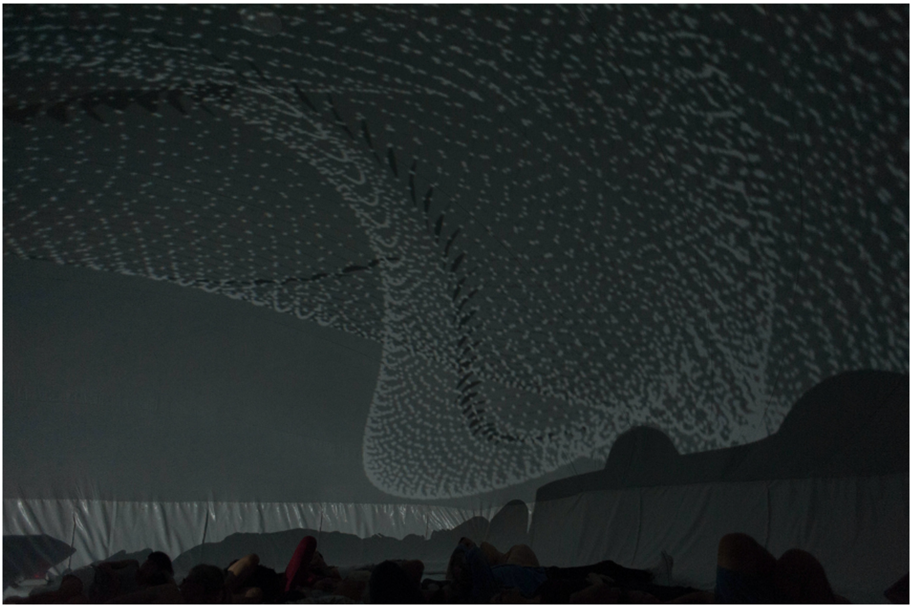

Fig. 3. Mattia Casalegno, *Strutture Dissipative*, Spherae, AxS Festival, Pasadena, CA, US, 2007. (© Mattia Casalegno.)

5 Discussion

The artists mentioned above seek to artificially create or metaphorically reproduce dissipative structures to express a concern about the evolution of nature and life. However, certain conditions need to be met in order to master this theory with restricted applications. Some of these key points are listed below:

1. The components of the system contain a large number of subsystems. Symmetry breaking[4] occurs in the system, which reflects nonlinear interactions within the system [27].
2. The system is open to the exchange of matter and energy with the outside world. In this way, the negative entropy flow injected into the system from outside, counteracts the entropy production within the system. Thus the system enters or maintains a relatively ordered state.
3. Far from equilibrium. That is, not a little bit away from equilibrium, but sufficiently away from it. It therefore needs to be distinguished from the near-equilibrium state. Because the fluctuations of the latter will be consumed and return to the average value, which makes the fluctuations seem irrelevant.
4. Bifurcations, fluctuations and mutations. Unlike evolutions of equilibrium and near-equilibrium states, there are multiple possibilities for the evolution of a system far from

[4] "Symmetry breaking", is not a term that refers to the absence of symmetry. According to Ian Stewart and Martin Golubitsky [26], it describes a certain changing relationship between an entire symmetry group and its subgroups.

equilibrium [27]. Bifurcations are one of the keys. To quote Prigogine, these "are the manifestation of an intrinsic differentiation between the parts of the system itself and the system and its environment" [28]. At the bifurcation point, random small fluctuations are amplified and produce mutations, allowing the system to acquire new macroscopic states.

Furthermore, the stability of dissipative structure is maintained by the balance of these nonlinear interactions and dissipation, constantly repeating the production process: always in a state of dynamic nonequilibrium. However, "过强的非线性相互作用或耗散作用都会使结构遭到破坏" (too strong nonlinear interactions or dissipative effects can damage the structure) [27].

When we re-examine the previously mentioned kinetic artworks in these conditions, we can see that Cameron Robbins' *Apparition* is a dynamic structure: a constant input of smoke that alters the surrounding air system, creating tiny airflows, which in turn alter the surrounding air. The fluctuations of airflows are amplified by the exquisite control of the smoke machine. Under certain invisible conditions, a vortex structure is created and its creation process is repeated. This work thus directly shows the generation of new structures and suggests their maintenance. Regarding the work of teamLab, as analyzed in more detail in the previous section, we find that this work mainly represents the maintenance of macro-structural stability and the collapse of the structure as a result of excessive nonlinear interactions. We should add here that the immersive involvement of observers and the collapse of the giant mass in this work actually reflects the dissipative structures theory's view that man's perception of nature takes place in the context of an irreversible process of natural evolution [28]. In fact, the observer's position is indispensable when talking about self-organization, as W. Ross Ashby notes that "A substantial part of the theory of organization will be concerned with properties that (…) are relational between observer and thing" [29]. In the works of Cameron Robbins and teamLab, the main components are visible to the observer. However, the production process of Mattia Casalegno's work is encapsulated in the algorithm. Thus, although it represents the evolution between disorder and order in a nonequilibrium state, it is still difficult to state, on strictly scientific terms, whether the graphs formed therein are dissipative structures or not. Through analysis we see that Cameron Robbins creates a dissipative structure and that the works of teamLab and Mattia Casalegno can only be considered to simulate, to a large extent, the self-organization of dissipative structures.

As we have emphasized repeatedly, dissipative structures theory describes a type of self-organizing phenomenon. We now return to the question at the beginning of the paper: what are the necessary conditions for a self-organizing system as learned through dissipative structures theory? According to Kawamoto's summary [9], the necessary conditions for a self-organizing system: nonequilibrium open system, changes in the system's boundary conditions, and uncertain factors within the system. The interaction with the environment that is implied by nonequilibrium open system, the uncertain nonlinear effects within the system and the fluctuations that have a triggering function, are all reflected in the works we have just reviewed. However, the boundary conditions do not seem to be deliberately emphasized in these works, but rather merge with the environment.

Gilbert Simondon [30] has made a distinction between dissipative structures as living organisms and purely physical ones. He pointed out that a purely physical dissipative structure cannot control certain external conditions and will die out as the boundary conditions disappear. Dissipative structures as organisms, on the other hand, have the ability to regulate boundary conditions and, therefore, may lead to immortality. Stuart Kauffman, in *Answering Schrödinger's "What Is Life?"*, states that "Organisms, as we shall see, *do* construct their own boundary conditions and do this by carrying out thermodynamic work to construct the very same boundary" [31]. In contrast, dissipative structures "do *not* construct their own boundary conditions" [31]. However, we need to point out that the boundary conditions still determine the shape of the dissipative structure. Kauffman explains that in Benard Convection, the shape of the pan as a container constitutes the boundary conditions. A change in the shape of the pan changes the shape and the macro pattern produced by this convection. The shape of the Benard convection can therefore be, for example, hexagonal or rolling [31].

Indeed, we can see that a strict application of these scientific conditions would make artistic creation difficult. In general, the artists mentioned above focus mainly on the philosophical inspiration inspired by the theory of dissipative structures: the intrinsic connection between the living and the nonliving, the diversity and coherence brought about by the evolution in stability and instability. This scientific theory exists here above all as a framework for the inspiration of the artists' works.

As we mentioned before, self-organization emphasizes production processes, which coincides with digital art, appealing to the nature of process. Can we then use dissipative structures theory to model certain process-oriented artistic creations, providing an interpretive tool for studying them? Or, within the framework of digital art theory and creative methods, what features of the theory are worth drawing on?

6 Dissipative Structures Theory and Digital Art Theory

The combination of complex systems and artistic creation is very common. In addition to the generative art mentioned earlier, which is closely related to complex systems, there is also the borrowing and application of autopoiesis systems in the context of art. In the framework of art theory, Niklas Luhmann, for instance, considers "the artworld" as an autopoietic social system: an operationally closed, self-referential system [32]. In artistic practice, John Mark Bishop and Mohammad Majid al-Rifaie, for example, apply the autopoiesis model to artistic creativity systems and create a drawing autopoietic artist model based on a swarm intelligence system [33].

Autopoietic systems, sometimes translated as self-producing systems. According to Kawamoto [9], the 'self' of autopoietic systems is the extent to which the system delineates its own movement, rather than being artificially specified by the observer. In contrast to the control of boundaries and the maintenance of self in autopoietic systems, in dissipative self-organization, the boundaries are constantly changing and the system's self is also continuously being re-established as the system interacts with its environment. Whether the system controls or adapts and regulates its boundaries is one of the differences between dissipative structure's self-organization and autopoiesis, and the uniqueness of the dissipative structure model in the approach to digital art creation.

If, then, the dissipative structure model is placed within the framework of artistic creation, we attempt to summarize several points:

1. Starting from the kinetic artworks above, at least two modes of creation are included. One, a self-creation method that does not require interaction with the observer. The artist outsources the creative process to the machine: the latter as a creative agent, uses the dissipative structure model as a creative framework to produce artwork with corresponding complexity features and encapsulates this process.
2. Two, the observer, participant in the work's creation, becomes the main variable and even a necessary condition of the external open environment of the object of our attention. Through the interaction with the external environment, the creation is triggered to take place. Artists not only use this interaction to contribute to the production of the work, but also make the dynamic of this production a property of the work by repeatedly embedding it in the process, so that the work exhibits a seemingly random, complex and original response to the environment. This iterative process reinforces the connection between the environment and the object of our attention, while at the same time demonstrating the object's adaptability to the environment, even as the boundaries between the two are constantly blurred, giving rise to the sense of immersion such as the observer-cloud interactions in teamLab's work.

In fact, it is easier to find similar creative modes in works of human-plant (living plant) interaction. One of the obvious reasons is that living plants, as living organisms, are typical dissipative structures. The participation of the observer, and the real environment in which the plant grows, can produce nonlinear effects within the plant. In other words, every change in environmental factors affects the growth of plants [34]. Appropriately electrifying plants is one of the most common methods for human-plant interaction. On the one hand, this affects the plant's photosynthesis, metabolic processes and other nonlinear internal interactions [34]. On the other hand, human interactions intensify the changes within the plant. In such interactions, these changes can therefore be revealed to some extent with changes in the electrical signals measured on the surface or inside the plant[5]. In some cases, plants exhibit a kind of assertion of their agency, as stated by the anthropologist Natasha Myers, mentioned by Charles Ryan John [36]: plants that appear unresponsive or delayed in their response during artistic processing. All these changes underline that living plants are not equivalent to sensors from which data measured can be easily quantified and accurately predicted. Generally speaking, in the interactive installations with living plants as the main subject, the production of a certain artistic creation caused by the plant is the object of our attention. The observer and the real environment such as the soil and air required by the plant itself together constitute the external environment for the production of this creation.

For Instance, Christa Sommerer and Laurent Mignonneau's *Interactive Plant Growing* (1992) [37] uses living plants as the medium through which the approach or touch

[5] There are variations in the methods required for different plants, or for different types of electrical signals. In plant electrophysiology, for example, to measure current changes at the cellular level, amplifiers are often needed to augment these electrical signals for artistic processing [35].

of the observer triggers the growth of virtual plants, which in turn influences the interaction of the observer, resulting in the unique qualities of the images on the screen in real time in response to the interaction. It is important to emphasize that the interaction of the observer is necessary for the existence of the work. Through the observer, the living plants extend themselves into the virtual space and change endlessly. Although the plants themselves exist here as specific materials with electronic properties, in terms of methodology, the work realizes an artistic exploration of the evolution of life through plants.

3. In his presentation of the relationship between endophysics - a kind of physics of observation from the inside out - and art, Austrian artist and new media art theorist Peter Weibel argues not only that the observer, combined with the environment in the dynamic model[6] of post-ontological art[7], constitutes a dissipative structure, but also that "Genetic algorithms that are able to separate the image from the observer-controlled context will constitute another dissipative structure" [38]. According to the previous two points, we can examine the application of evolutionary algorithms with dissipative structure features to artistic creation. Sommerer and Mignonneau's installation *A-Volve*, as an example, is based on a genetic algorithm [37]. Instead of a predetermined direction of evolution, they simulate natural biological evolution through selection, crossover and mutation. In the work, virtual creatures are created in two ways: those painted by the observers or those generated by the mating of the creatures themselves. They exist in a real environment: a glass pool filled with water. Their births, behaviours and deaths are influenced in real time by the interaction of the observer, the real pool environment and the interaction between the creatures. This community of creatures becomes a complex open system of continuous evolution. The choice and interaction of observers serve as an external environmental intervention that significantly influences the adaptation of creatures to the pool environment, amplifying the fluctuations of the community and, under the appropriate conditions, driving structural changes in the community. The work sets out that "The fittest creature will survive longest and will be able to mate and reproduce" [37]. By observing the evolution of the community of creatures, the observer is also constantly adjusting his choices and creations to select more suitable creatures or to destroy the whole community. In this work we clearly can see interactivity as an expression of the system's adaptability to its environment and as possible results that will lead to the creation of new structures.

From the points above, we are more interested in the inspiration that comes from the creations which interact with the observer (the second and third points). Because the features of the dissipative structure model are more explicitly represented in it, and enrich the form and content of the work. Although it is a challenging task to fully apply the dissipative structure model to an artistic approach, if we model artistic creation in terms of some of its features, then: in such works, the interaction of the external environment is a necessary condition for creation to take place. The environment and the work

[6] Weibel points out that in this model, the observer, the interface and the environment are covariant.

[7] Weibel mainly refers to interactive new-media art in the network.

establish a highly sensitive relationship in the development of the work: their interaction not only contributes to diversity, but also serves to maintain the life of the work. This process of creation is irreversible, irreducible to mechanical decomposition, and irreproducible. Moreover, in this type of work the object of our attention demonstrates the ability to adapt and regulate to its environment while at the same time exhibiting not only an immersion or permeability, but also a malleability and adhesion that allow for the organic integration of different types of materials. Within this dimension, Roy Ascott [39] refers to the media of bits, atoms, neurons and genes as the "Moistmedia", and this "Moist environment, located at the convergence of the digital, biological and spiritual, is essentially a dynamic environment, involving artificial and human intelligence in nonlinear processes of emergence, construction and transformation" [39]. As we can see from the previous analysis, the application of dissipative structure model to artistic creation in our hypothesis involves similar areas and processes. The prospects for the application of the model in interactive art creation will then also be explored in the framework of Moistmdia[8].

7 Conclusion

This paper is oriented towards artistic creations based on complex systems. By introducing the key ideas of dissipative structures theory, interpreting and analyzing artworks directly inspired by the theory, we briefly illustrate the influence of complex systems on digital art and explain the basic conditions for self-organization, one of the characteristics of complex systems. However, by re-examining these works on scientific terms, we find that the complete application of the dissipative structure model by the artist in the combination of science and art is a challenging task. Nevertheless, while making a distinction between self-organization and autopoiesis, we show that the emphasis on new structures and the regulation of boundary environments in the self-organization of dissipative structures imply a certain uniqueness that makes dissipative structures theory valuable to study within the methodological and theoretical framework of interactive digital art creation. To this end, in the context of case studies, we believe that some of the features of dissipative structures can be used to model certain digital art creations that have an evolutionary approach. In particular, interactive digital artworks based on living plants, and on genetic algorithms. At the same time, we point out the ability of this model to organically combine a variety of materials, and hence infer that the study of this model is suitable for the field covered by Moistmedia.

Nonetheless, this paper only presents the main ideas of dissipative structures in general, lacking a more detailed exploration of their characteristics in the scientific field and in artistic theory. Given that the paper provides only a cursory generalization of the creative approach and is limited to the context of interactive creation, the suggested conditions for modelling and the assumption of the model's applicability to the field of study are rather frivolous. In our next work, we will continue to focus on the framework

[8] On the convergence of plants, digital technology and art, Ryan [36] proposed three theoretical frameworks, which also include the field of Moistmedia. The two others are: "human-plant studies" [40], and Warwick Mules's concept of "Poiesis" [41].

of human-plant interaction, but will investigate more deeply the relationship between dissipative structures, art theory and creative methods.

References

1. Kac, E.: Foundation and development of robotic art. Art J. **56**(3), 60–67 (1997)
2. Jantsch, E.: The Self-organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution. Pergamon, Turkey (1980)
3. Kac, E.: Telepresence & Bio Art: Networking Humans, Rabbits, and Robots. University of Michigan Press, Ann Arbor (2005)
4. Gershenson, C., Trianni, V., Werfel, J., Sayama, H.: Self-organization and artificial life. Artif. Life **26**(3), 391–408 (2020)
5. McCormack, J.: TURBULENCE an interactive installation exploring artificial life. In: Visual Proceedings: The Art and Interdisciplinary Programs of SIGGRAPH, vol. 94, pp. 182–183 (1994)
6. Davidsson, P., Klügl, F., Verhagen, H.: Simulation of complex systems. In: Magnani, L., Bertolotti, T. (eds.) Springer Handbook of Model-Based Science. SH, pp. 783–797. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-30526-4_35
7. Haken, H.: Information and self-organization A macroscopic approach to complex systems. Springer, Cham (2006). https://doi.org/10.1007/3-540-33023-2
8. Varela, F.G., Maturana, H.R., Uribe, R.: Autopoiesis: the organization of living systems, its characterization and a model. Biosystems **5**(4), 187–196 (1974)
9. Kawamoto, H.: Otopoiesisu: Daisan Sedai Sisutemu ,Seido-sha Publishers (1995) (Di san dai xi tong lun:zi sheng xi tong lun, Guo Lianyou (translator), Central Compilation & Translation Press (2016)
10. Haken, H.: Synergetics. Naturwissenschaften **67**, 121–128 (1980)
11. Prigogine, I., Stengers, I.: Order Out of Chaos: Man's New Dialogue with Nature. Verso Books, London (2018)
12. Prigogine, I.: From Being to Becoming. W. H. Freeman and Company, New York (1980)
13. Prigogine, I., Nicolis, G.: Self-organisation in nonequilibrium systems: towards a dynamics of complexity. In: Hazewinkel, M., Jurkovich, R., Paelinck, J.H.P. (eds.) Bifurcation Analysis, pp. 3–12. Springer, Dordrecht (1985). https://doi.org/10.1007/978-94-009-6239-2_1
14. Kondepudi, D., Prigogine, I.: Self-organization and dissipative structures in nature. In: Kondepudi, D., Prigogine, I. (eds.) Modern Thermodynamics: from Heat Engines to Dissipative Structures, pp. 477–486. Wiley (2014)
15. Ai, ST.: Fei ping heng tai re li xue gai lun (Di er ban). Tsinghua University Press, Beijing (2017). (Introduction to Nonequilibrium Thermodynamics (Second Edition)
16. Gough, N.: Watchmen, simultaneity, and postmodern science education : the medium and its messages. In: Graphic Novels and The(ir) World. The Graphic Novel Project: 4th Global Meeting, Dubrovnik (2015)
17. De Landa, M.: War in the Age of Intelligent Machines. Zone Books, New York (1991)
18. Prigogine, I., Nicolis, G.: Self-Organization in Non-Equilibrium Systems. Wiley, Hoboken (1977)
19. Obrist, H.U.: Science and art: a conversation with Ilya Prigogine. In: Review (Fernand Braudel Center), vol. 28, no. 2, pp. 115–128, Discussions of Knowledge (2005). Research Foundation of State University of New York for and on behalf of the Fernand Braudel Center (2005)
20. Schneider, S.H.: Encyclopedia of Climate and Weather, vol. 1. Oxford University Press, Oxford (2011)

21. Schrodinger, E.: What is Life? (1944). http://old.biovip.com/UpLoadFiles/Aaron/Files/2005051204.pdf. Accessed 29 May 2021
22. TeamLab, Massless Clouds Between Sculpture and Life (2020). https://www.teamlab.art/w/clouds/. Accessed 09 May 2021
23. Heus, T., Jonker, H.J., Van den Akker, H.E., Griffith, E.J., Koutek, M., Post, F.H.: A statistical approach to the life cycle analysis of cumulus clouds selected in a virtual reality environment. J. Geophys. Res.: Atmos.**114**(D6) (2009)
24. Casalegno, M.: Strutture dissipative exp. 2 (2007). https://vimeo.com/761810. Accessed 29 May 2021
25. Galanter, P.: What is generative art? Complexity theory as a context for art theory. In: GA2003–6th Generative Art Conference (2003)
26. Stewart, I., Golubitsky, M.: Fearful Symmetry. Dover Publications Inc., Mineola (1992)
27. Wu, J.: Kua xue ke yan jiu yu fei xian xing si wei. China Social Sciences Press, Beijing (2004). (Interdisciplinary Research and Nonlinear Thinking)
28. Prigogine, I., Stengers, I.: The End of Certainty: Time, Chaos, and the New Laws of Nature. Free Press, New York (1997)
29. Ashby, W. R.: Principles of the self-organizing system. In: Systems Research for Behavioral Sciencesystems Research, pp. 108–118. Routledge (2017)
30. Simondon, G.: L'individuation psychique et collective. Aubier, Paris (1989)
31. Kauffman, S.: Answering Schrödinger's "What is life?" Entropy **22**(8), 815 (2020)
32. Luhmann, N.: Art as a Social System. Stanford University Press, Stanford (2000).Translated by Knodt, E.M.
33. Bishop, J.M., Al-Rifaie, M.M.: Autopoiesis in creativity and art. In: Proceedings of the 3rd International Symposium on Movement and Computing, pp. 1–6 (2016)
34. Dannehl, D.: Effects of electricity on plant responses. Sci. Hortic. **234**, 382–392 (2018)
35. Sommerer, C., Mignonneau, L., Weil, F.: The art of human to plant interaction. In: The Green Thread: Dialogues with the Vegetal World, p. 233 (2015)
36. Ryan, J.C.: plant-art: the virtual and the vegetal in contemporary performance and installation art. Resil.: J. Environ. Humanit. **2**(3), 40–57 (2015)
37. Sommerer, C., Mignonneau, L.: Art as a living system: interactive computer artworks. Leonardo **32**(3), 165–173 (1999)
38. Weibel, P.: The world as interface: toward the construction of context-controlled event-worlds. In: Druckrey, T. (ed.) Electronic Culture: Technology and Visual Representation, pp. 341–351. Aperture Foundation, New York (1996)
39. Ascott, R.: Edge-life: technoetic structures and moist media. In: Ascott, R. (ed.) Art, Technology, Consciousness: Mind@ large, pp. 2–6. Intellect Books (2000)
40. Ryan, J.C.: Unbraided Lines: Essays in Environmental Thinking and Writing. Common Ground Publishing, Champaign (2013)
41. Mules, W.: With Nature: Nature Philosophy as Poetics Through Schelling, Heidegger, Benjamin and Nancy. Intellect Books, Bristol (2014)