A Transdisciplinary Approach to Mechatronics

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The emergence of mechatronics acts as a proof that the research and education of the future must be modeled by complex and non-separable lines of force. Consequently, its imperative to elaborate a new approach to mechatronics, from the perspective of transdisciplinary methodology, whose purpose is the understanding of the world through the unity of knowledge. Mechatronics, through its integrative, synergic character, is an open field that transcends the limits of a single discipline. The identity of mechatronics is a trans-thematic one, founded on the thematic concept of complexity. In this context, the paper suggests the hexagonal model for integral mechatronic education using the lupascian logic. According to this model, mechatronics is symbolically positioned in the region of maximum resistance, corresponding to a triple T-state, state in which that which is contradictory does not oppose anymore, because of the conciliating role of the principle of the included middle.

Keywords: mechatronics, transdisciplinarity, complexity, trans-thematic identity, lupascian.

1 Introduction

Based on the belief that "entering the complex and transdisciplinary thinking in structures, programs and areas of influence of the University will enable progress towards its mission forgotten today - the study of universality [1], and that "mechatronics is a global vision on technology" [2], we propose through this works, a new approach to mechatronics, the transdisciplinary perspective [3]. The appearance of mechatronics was a natural result of evolution in technological development. The backbone of mechatronics is the mechanical technology that was developed independently at first. Subsequently, advances in electronic technology, especially the emergence of integrated circuits, small in size, cheap and reliable, have enabled the integration of electronic products in mechanical structures. Thus, the first step is performed: electromechanical integration. The next step was triggered by the birth of microprocessor which, with similar structural features of integrated circuits, was included in the electromechanical structures previously made [3]. Consequently, have resulted complex systems – the mechatronic systems -, able to acquire information on their internal status and external environmental conditions and from processing the information acquired to make decisions on their behavior.

2 Integration, Synergy, Complexity and Mechatronics

The first definition of mechatronics was given in 1969 by the Japanese company Yasakawa Electric and was approved and published as a trademark application in documents in 1972: "The word, me chatronics, is composed of ≪mecha≫ from mech-

anism and ≪tronics≫ from electronics. In other words, technologies and developed products will be incorporating more an more electronics into their mechanical structure, intimately and organically, and making it impossible to tell where one ends and the other begins" [4]. Chronologically, Harashima et al. were among the first [6] who emphasized that the terms synergy and integration are at the foundation of mechatronics, defined as "the synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes" [6]. Thus, a mechatronic system (from appliances or video camera to cars and modern robots) should not be regarded only as a set of mechanical and electrical components provided with one or more controllers [7], but as the result of synergistic integration of all these components [5]. Mechatronics, through its integrative nature, goes beyond a single discipline [8]: "mechatronics has come to mean the synergistic use of precision engineering, control theory, computer science and sensor/actuator technology design to design improved products or processes" [9]. To be a mechatronic engineer today means to understand and exploit the synergistic relationship between precision engineering, control theory, computer science, sensor technology and actuators.

Achieving this goal requires a change: the transition from sequential engineering to concurrent engineering [3, 2], which requires a systemic mainstreaming: "mechanical engineering professors teaching design must teach an integrated approach to design – mechanical, electronic, controls and computers..." [10]. This approach cannot exist without the ability to establish bridges between different disciplines [11], finding and extrapolating meanings of the acquired knowledge.

Integrative potential of mechatronics is clearly revealed in the definition formulated in 1986 by the Advisory Committee for Research and Industrial Development of the European Community (Doc IRDAC PM 10/17/86 /3): "Mechatronics is a synergistic combination between: precision mechanical engineering, electronic control and systemic thinking in designing products and processes. It is an interdisciplinary technology that unites these basic disciplines previously mentioned and includes both mentioned areas, which otherwise normally would not be associated" [2]. In the years that followed, in almost all EC countries have launched programs aimed to promote mechatronic philosophy in education, research and technology. A representative example is the project regarding mechatronics education in the ADAPT program, initiated in 1995 by a group of universities from several community countries [2]. The project aimed primarily at promoting interdisciplinary education and training: initial training, continuing education and professional conversion.

As a result of technological developments, the term mechatronics constantly enriched with new meanings: mechatronics philosophy, science of intelligent machines, the science of motion control, learning environment for the development of integrative thinking in the knowledge-based society. Mechatronics is present in various fields, including agriculture and construction. Terminology established in the literature - hydronics, pneutronics, termotronics, autotronics, agromecatronics etc. Is relevant in this direction [2]. In our opinion, with the integration and synergy, the key concept in understanding the deep nature of mechatronics is complexity [12]. According to Hawking, the century just started will belong to complexity [13], which is closely related to the idea of nonseparability "essential principle of all that is profound in the world" [14]. Taking into account the consistency and, at the same time, the integrative and creative valences of the transdisciplinary approach [8], we consider that the identity of mechatronics can be enriched through revealing its transdisciplinary character. An important aspect in articulating a transdisciplinary perspective on mechatronics is the familiarization process with the specific terms of Stéphane Lupasco epistemology and logic, with grounding roin transdisciplinary vision proposed by Basarab Nicolescu.

3 The Included Middle between Paradox and Reality

Given that Gottlob Frege tried to prove that mathematics is just a branch of logic by building a symbolical and formal language of pure thought, Bertrand Russell discovered, at the foundation of Frege's system, a contradiction, a logical paradox: the set (class) of all sets that do not contain themselves as members, contains itself when it doesn't contain itself, and reverse. (Russells paradox or the paradox of classes) [8, 15]. Several solutions have been proposed for the paradox of classes. The most known one is the theory of types [16], suggested by Russell

himself, who started from stating the law of the vicious circle [17], and according to which whatever involves all of a collection must not be one of the collections. Thus, the set of all sets that do not contain themselves as members cannot be defined, as it introduces a new member (the set) with the help of the collection from which it belongs (the sets that do not contain themselves) [8]. Although the theory of types is considered as the most important outcome of the logical paradoxes, there are voices that claim that Russell rather avoid the vicious circle created, the vulnerability theory itself is recognized by Russell [18].

Special kinds of paradoxes, which cannot be applied to the classical theory of types, are semantic paradoxes. The solution for the semantic paradoxes was found with the contribution of Alfred Tarski and Rudolf Carnap. Semantic paradoxes happen, says Tarski, because there is no distinction done between the situation in which a statement is used in order to talk about an object independent of it and the situation in which the statement itself is the object of the formulation. For instance, if we say "the horse is an animal", we designate the horse as object, while in the sentence "the word ≪horse≫ has five letters" the object is the expression itself. The closed nature of language generates confusion. In order to "open" it, Tarski introduces language levels. Thus, we are to distinguish between object-language, meta-anguage (which refers to the object-language), meta-meta–anguage (in which we speak of the meta-language), etc. The concepts of "true" and "false" can't be defined within the framework of the same language S, but only as part in a meta-language S1, as these concepts belong to the meta–ogical system S1 which talks of the language of the S system. Likewise, a meta-meta-logical system S2 will exist, which talks of the S1 system, etc [8,19, 20].

Based on whether it was possible for one of the languages to be its own meta-language, Kurt Gödel has shown that mathematics can be its own meta-language and proved that one of the undecidable sentences (of which one cannot say whether it is true or false) is precisely the one that states that the system is non-contradictory. By stating his famous incompleteness theorem, according to which in any class of non-contradictory systems there are undecidable sentences [16], Gödel concluded that any non-contradictory formal logic system (complex enough for arithmetic to be formalized in it) is incomplete (in the sense that it can rigorously build undecidable sentences), outlining as clear as possible the limits of the formalization of a logic-mathematical system [21].

Two observations are necessary here. First, we note that paradoxes were perceived for long time as an anomaly, a negative phenomenon, which was meant to be suppressed [11]. After Göodel's theorem formulation, the paradox cannot be regarded as a limitation of thought, but rather as "the heart of any creative thinking", as a possible opening to the investigation of a new reality in which "we cannot find a logical non-contradictory system which is consistent with everything we see or we will observe "[22]. With the development of quantum mechanics, the paradox, who dispelled the illusion of mathematical perfection of any abstract formal system, entered the real world and not just anywhere but right at the foundation. For Bsarab Nicolescu, quantum particle itself is a "contradictory unity" that "is neither particle nor wave" being "more than the sum of its classic contradictory parts (for classical representation) and approximate (with respect to quantum representation) "[11]. Transdisciplinary methodology of Basarab Nicolescu will just exploit these new values of the paradox arising through openings made by Gdels incompleteness theorem, meanings which, as will be seen below, proved to be particularly useful in our rigorous development of a transdisciplinary approach to mechatronics [3].

Secondly, we want to emphasize that for Carnap and Tarski, as for Russell,ontological dimension of logic is ignored in favor of an abstract formalism [23]. Hence, the contempt shown by Carna to traditional logic - which he calls "anemic" - and Russell's opinion, that syllogism is a "solemn humbug" [16]. Anton Dumitriu is convinced that this misunderstanding shown by quoted logistics above from Aristotelian logic "have its origins in the loss of contact with reality and therefore logic to ontology" [16]. In conclusion, the progressive dissociation between formal logic and ontology has led to the separation of logic from reality.

In view of Stéphane Lupasco, the true science must have, necessarily, an ontological foundation [24]. Seeking to articulate a non-Cartesian epistemology [23], Lupasco noticed the huge creative potential paradox, also managed to significantly close the ontological to logic [3]. Starting from the seemingly contradictory nature of reality, emphasized by the

recently stated quantum theories, Lupasco comprehends that the sign of the existence of a phenomenon is precisely its contradiction. The philosopher learns that matter is subject to such antagonistic dynamism that the actualization of one implies the potentiation of the other one; the two dynamisms must tend towards a state of equal and mutual potentiation and actualization, thus achieving a dynamic equilibrium. The more difficult it is for the antagonistic forces get free from the equilibrium the longer the endurance of a system [25].

Any quantum event simultaneously embodies itself both wave and particle, which sends to the continuous- discontinuous dualism. There are continuous energies of homogenization, that are represented by photon particles, that do not respect Pauli's exclusion principle, and antagonistic energies, discontinuous, of heterogenization, retrievable in the electronic type of particles, that submit to this principle. Starting from here, Lupasco discovers another antagonistic dualism: homogenization (identity) – heterogenization (diversity), which makes life possible: both extreme differentiation and also absolute uniformization would lead to an eternal immobility, to cosmic death [11].

Lupasco postulates that to each logic event e there has to be a logical anti-event $\bar{e}$ accompanying it, the actualization of e establishing the potentiation of $\bar{e}$, and reverse, without either one of them being able to reach absolute potentiation, thus disappearing through the absolute actualization of the other. When e and $\bar{e}$ reach the same level of actualization or potentiation, they will not mutually cancel each other (as in classic logic) but will be reduced to T state, in which it is considered that both e and $\bar{e}$ are, each towards the other, semi-actual and semi-potential in the same time; T state corresponds to a maximum antagonism, to a maximum density of energy or, informationally speaking, to a maximum systematization. Non-contradiction can't actualize itself in a perfect, absolute way, because of the residual contradiction, that cant be null, thus no logical event can be absolutely non-contradictory. Therefore, we can't talk of an absolute truth and an absolute false, neither of them being able to perfectly and rigorously actualize themselves. T state is that third value of the Lupascian ternary logic, the nor true nor false' value [25].

The Lupascian ternary logic has a strong ontological feature, replacing the Aristotelian principle of the excluded middle with the so called principle of the included middle, which allows the conciliation of the opposites, because of the existence of the T state. Starting from the observation that not any ternary or triad involves the included third party, Nicolescu points out that included third party has a paradoxical nature to the extent that necessarily involves the unification of the contradictory couple mutually exclusive (A, non-A) [26]. Through this constitutive relation of contradictory complementarity the rational and the irrational, identity and non-identity are linked together [27]. Thus a synergic relation is established between the opposites. Through its implications the philosophy of tefan Lupasco has proven to be a conciliatory, integrative one, his role in the substantiation of the transdisciplinary vision suggested by Basarab Nicolescu being a decisive one [3]. According to Basarab Nicolescu, lupascian philosophy, unique in the way that started from modern physics and axiomatic logic, proves to be also a great novelty, "opening a road whose importance cannot yet be assessed" [24].

The transdisciplinary methodology elaborate by Basarab Nicolescu facilitates our exit from a world in which thought is fragmented by the scalpel of the indisputable dichotomy of binary logic, crushed under the load of excessive specialization, a "disciplinary big-bang" (Nicolescu, 1999). As finalities of pluridisciplinarity (the study of an object that is specific to one discipline by more disciplines, simultaneously) and of interdisciplinarity (the usage of the methods that are specific to one discipline in the territory of other disciplines) remains on the disciplinary investigation, they are unable to answer the human beings unitary need of knowledge (Nicolescu, 2002). Therefore, Basarab Nicolescu introduced a complementary concept, transdisciplinarity, defined as "what is, in the same time, in between disciplines, inside different disciplines, and beyond any disciplin"; the finality of the transdisciplinary measure is the understanding of the world through the unity of knowledge [1].

Transdisciplinary methodology is based on three postulates. The first postulate (ontological) states that in nature and in our knowledge of nature there are different levels of Reality and perception. The level of Reality is defined as "a gathering of systems invariant to the action of general laws"[1] such as quantum entities that obey laws totally different from the ones encountered in the macro physical

world. According to the second postulate (logical) the passage from one level of Reality to another is done using the logic of included middle (Hidden Middle) [28]. Passing from one Reality level to another, the laws and concepts change, and there is a fracture, a discontinuity (an essential concept to quantum mechanics) between two neighboring levels. The unification of A and its opposite non-A on the same level of Reality is accomplished on the next higher level of Reality through the T state, of the Hidden Middle. As it is impossible to construct a complete theory that describes the group of Reality levels, their structure is an open one, in accordance with Gödel's theorem [11]. According to the third postulate (epistemological), each level of Reality is what it is because all other levels of Reality exist at the same time. The roots of this postulate are in the bootstrap principle from quantum mechanics, which reveals that a particle is what it is because all other particles exist simultaneously. The bootstrap principle reveals that complexity is an essential characteristic of the world [11]. Hence, we consider that the transdisciplinary approach of mechatronics requires the study of complex systems, defined as a numerous ensemble of simple interactive entities which allow the appearance of emergent phenomena, with a strong synergistic nature.

4 Complexity, Self-Organization and Emergence

In classical mechanics, solving a dynamic problem (the Hamiltonian formalism) is reduced to choosing a set of canonical variables for which the Hamiltonian of the system has the most appropriate structure (canonical Hamiltonian form), followed by writing the canonical equations. Canonical equations, once established, containing a priori properties of the whole dynamics evolution. That means that if the initial conditions of the system are known, further evolution of the system is completely determined. In conclusion, canonical form of the Hamiltonian contains the whole truth of the dynamics of the system [29]. According to the second principle of thermodynamics, any isolated thermodynamically system irreversibly evolves towards the macroscopic state with the highest probability of realization. The expression of statistical entropy is:

$$S = kln\Omega \qquad (1)$$

where Ω represents the number of the system's microstates that are compatible with a given macrostate. Consequently, the state of equilibrium is characterized by the maximal value of entropy, the fluctuations of the system being relatively small and forced to rapid regressions around the state of equilibrium [30].

The infinitesimal variation of total entropy of an open system is:

$$dS = d_iS + d_eS, \qquad (2)$$

in which d_eS is the entropy exchanged with the environment, while d_iS is the irreversible change of entropy within the system [31]. Prigogine showed [32] that the P function, called "production of entropy", has the following expression:

$$P = \frac{d_iS}{dt} = \int_V \sigma dV, \qquad (3)$$

where σ represents the local production of entropy per unit of volume in unit of time, while V is the volume of the system. The local production of entropy is the result of the contributions of all the products between generalized forces, X_i, and the corresponding flows of the various irreversible processes, J_i, specific to the particular process being studied:

$$\sigma = \sum_i J_iX_i \qquad (4)$$

In the state of thermodynamic equilibrium, the flows and the forces are, simultaneously, null [33]. If the system is near equilibrium, where the thermodynamic forces are relatively weak, there is a linear dependence between the flows and the forces. In this region, according to Prigogine's theorem of the minimum production of entropy [34], any system evolves to a non-equilibrium steady state in which the production of entropy reaches the minimum value. The steady state, in which the system transfers entropy to the environment, is stable with regard to the local perturbations. In conclusion, the systems described by equilibrium thermodynamics and by the linear non-equilibrium thermodynamics do not allow spontaneous manifestations which would enable patterns of increased complexity to appear.

The adaptable behavior of mechatronical open systems, integrated in the world through continuous exchange of matter, energy and information with the environment has proven to be similar to that of the living systems, which are being led by more complex

laws than those offered by Newtonian mechanics or by the thermodynamics of equilibrium [29, 30]. The systems level of adaptivity is measured by the capacity of the system to self-organize itself. Self-organization is an interdisciplinary key concept that describes the formation of specific patterns in the presence of unspecific driving forces [31]. Further on, we will explain the meaning of complexity starting from the roots of selforganization: the nonlinear thermodynamics [35].

For the systems from the linear region, whatever the limit conditions are, $\delta 2S$ is a Liapunov function [34], namely it satisfies the two mathematical conditions (the necessary and the sufficient one) which ensures the stability of the system, due to the amortization of the perturbations [12]. Nonetheless the same thing doesn't happen in the case of thermodynamic systems that are far enough from equilibrium for the relations between the flows and the forces to become non-linear. In this region the sufficient condition for stability is not satisfied, the system becoming unstable and is therefore lead by laws specific to itself [33].

The prototypes of far from equilibrium thermodynamic systems are the chemical reactions in which autocatalization appears; if the value of a control parameter changes progressively, beyond a critical threshold, the system reaches, through the amplification of fluctuations, to a bifurcation, beyond which appear oscillations of the products of chemical reactions. These oscillations represent stable spatio-temporal structures (called dissipative structure), the emergence of a global order, at a macroscopical level. The bifurcation points are situated in the proximity of unstable regions in which the far-from-equilibrium open system "chooses", through symmetry-breaking, between its multiple possible future evolutions. Several successive bifurcations are possible, as the value of the control parameter increases [31]. The appearance of patterns at a macroscopic level arises in the absence of any external constraint; therefore, the system self-organizes itself. This phenomenon also occurs, for instance, in the case of spontaneous magnetization or of Bnard cells [29]. The systems that are in the non-linear region become, near the bifurcation point, extremely sensitive to small external fluctuations, perceiving differences that are impossible to distinguish by systems that are in equilibrium or in its nearness. These small differences lead to the process of self-organization,

by selecting certain external perturbations which, through positive feed-back (autocatalization), are amplified, leading to multistability (the coexistence of stable spatio-temporal structures).

What the self-organizing systems have in common is the fact that the activity at microscopically levels spontaneously generate patterns at a global level in the system [35]. Emergence represents this manifestation of certain coherent patterns at the level of the whole system, which, although being the result of the interactions between the systems components, cannot be deduced by studying these isolated parts apart from each other [36]. Complex systems are often defined as a numerous ensemble of simple interactive entities, which allow the appearance of emergent properties [37]. The emergent properties transform the system not just into a larger entity than the sum of its components but the system enriches itself with new valences, previously inexistent [2, 38]. In conclusion, we can state that emergence is the product of the self-organization of far-fromequilibrium systems [35, 39].

5 The Transdisciplinary Nature of the Homeokinesis Concept

The coherence specific to open systems that are far-from-equilibrium is found at the *edge of chaos*, that is, in a narrow intermediary area situated in between the chaos of thermal equilibrium and the turbulent chaos of non-equilibrium [35]. Thus, a complex cybernetic system must, on one hand, produce a sufficiently high variety of actions in order to cope with the possible perturbations (that is, the system must be kept sufficiently far from equilibrium for there to be enough tangible steady stable states), while selecting the most appropriate state for counteracting the destructive effect of the perturbations (the steady states of the systems mustn't be too many, or too unstable, so, the system mustn't be pushed too far from equilibrium), which can compromise the existence of the whole system [40]. The emergence of the spatio-temporal structures is, therefore, the consequence of the flexibility of complex systems when these are subjected to the influence of the fluctuations of the environment under the action of the cause-effect circularity (the effect of a cause influences the cause itself) represented by the two feed-back mechanisms: positive and negative [12]. Thus, selforganization is a result of the "compromise"

between a driving force (positive feed-back) which amplifies external perturbations and a regulating force (negative feed-back) which tries to stabilize the system [41].

In the field of artificial intelligence, particularly in evolutionary robotics, the adaptivity is the main goal of an autonomous agent. Adaptivity means much more than stability: the system must operate in a regime situated somewhere between the chaotic behavior and the ordered state of homeostatic equilibrium [12]. In this edge of chaos regime the robot is able to adapt his behavior to changing external condition searching for new functionalities [42]. The behavior of a robot can be considered as a spatial-temporal pattern which is formed in the complex interaction between the robot and its environment. Thus, true autonomy must involve the emergence of self-organized behaviors for robots, through symmetry-breaking [12, 43]. The self-organization of the robot means that its evolution must not be driven into a desired direction by a semantic introduced from outside, like in supervised learning or in reinforcement learning. In other words, a self-organized robot must adapt to the environment by developing functional behaviors which do not depend on an imposed target or a reward signal. The principle of homeokinesis, the "dynamical pendant of homeostasis" [44], provides a mechanism for the self-organization of the robot, in which the goal of the agent is not to remain in a stationary state (i.e. homeostatic equilibrium), but to attain a definite internal kinetic regime. The robot, endowed with an adaptive, internal representation of its behavior (self-model), is able to discover its own semantics, using the misfit between the behavior predicted by the model and the true behavior as the learning signal for the adaptation of both the model and the controller.

The experiments show [42, 43, 44, 45] that the mechatronical complex system (the robot) governed by the home kinetic principle adapts its exploration according to the knowledge of the world: as long as the misfit is small the knowledge is large, the prediction quality of the system increases, favoring the explorative mode. If the misfit increases, the predictability decreases and leads to the avoidance behavior. In other words, the environmental changes generate changes in sensor values, which progressively destabilize the robot, leading it towards a chaotic regime. So, the robot is in harmony with the environment, providing a counteracting effect: the requirement that the effects of the robot's actions must remain predictable.

In conclusion, learning under the principle of home kinesis drives the mechatronical complex system (the robot) towards the edge of chaos, a working regime where the system is characterized by the "optimum payoff between creativity and stability" [42]. The mechatronical systems behavior is explorative (the robot is creative, exploring sometimes risky regions) but remains, in the meantime, predictable (is able to adapt to slow environmental changes, keeping a stable, non-chaotic behavior).

Using the Lupascian logic language, the actualization of the pure explorative behavior means reaching maximum heterogenization, and the robot will move chaotically. Reversely, the actualization of the pure predictive behavior means reaching maximum homogenization: the robot gets stuck in a sterile stable state. For the mechatronical system to function the actualization of explorative behavior means the potentiation of predictive behavior and reverse, without either one of them being able to reach absolute potentiation or actualization. According to Lupascian logic, the maximum antagonism, or, informationally speaking, the maximum complexity is reached in T state in which the two behaviors are both semiactual and semi-potential. Thus, we can now claim [12] that the T state represents, in the case of the studied mechatronical systems, the edge of chaos, the state in which certain explorative-predictive behavioral patterns emerge.

The home kinesis principle ensures the functioning of the mechatronical system on the edge of chaos, reaching its autonomy through realization of a dynamic harmony between the "interior" and the "exterior" world of the system. , in Basarab Nicolescu's transdisciplinary approach [1], knowledge is, simultaneously, external and internal, the study of the Universe and of the human being complementary supporting each other [12].

The contemporaneous growth of interest in mechatronics has identified a need for a new educational paradigm, which favors the formation of engineers and teachers endowed with a comprehensive, creative, integrative thinking in the technological area. In this context, the necessity to transcend the limits of a single discipline becomes an imperative educational request. Therefore, after I proved the transdisciplinary character of mechatronics, by highlighting

the links between the Lupascian logic, the nonlinear thermodynamics, the self-organization of complex systems and the emergent robots behavior derived from the home kinetic principle, we will exploit further the integrative valences of the Basarab Nicolescus methodology, proposing a new transdisciplinary approach of mechatronics.

6 Grimheden's Position on the Nature and Evolution of Mechatronics

According with Grimheden's approach (2006), any analysis of an educational subject (teaching, didactic subject) X (as it is mechatronics) involves four aspects. First, we have to ask the question of what exactly is X, namely to put forth the *identity* of the subject. The identity can be described in terms of the two extremes: disciplinary identity and thematic identity. The identity of the subject is a disciplinary one if a strong consensus exists regarding the definition, content and structure of a subject, and also regarding its classification, organization or curriculum. This is the case of mature, traditional subjects, such as mathematics, physics, biology, etc. In the absence of this consensus, one can only speak (usually with regard to recently developed subjects) about the existence of a theme that is at the origin of the subject, its identity being therefore a thematic one. For example, this is the case of systems engineering, which is founded on the idea or theme of system. Therefore, according to Grimheden, mechatronics has a thematic identity, idea also defended by the fact that there is no universally accepted definition of mechatronics or a common curriculum. Grimheden's suggestion is that of looking for the common denominator among its varied definitions, as these elements are important clues regarding the theme that gives identity to mechatronics. Consequently, Grimheden identifies two common elements: the idea of synergy and the need for complementary skills. The evolution of mechatronics has undergone, in Grimheden's opinion, six stages. The last stage is the one in which we can speak of an identity of mechatronics, a thematic one according to Grimheden (2006).

The second issue is the *legitimacy* of the subject that is its reason to exist. Legitimacy is the consequence of the relationship between the result of training offered by universities and the requirements that society has in regard to the abilities of the graduates. Legitimacy can be formal or functional, depending on the type of knowledge promoted. Formal knowledge is what can be read, understood and assimilated form books, courses, etc. Functional appearance of legitimacy has to do with practical skills that cannot be learned from books, but can be gradually acquired by laboratory experiments, trial and error type exercises, etc. From this point of view, Grimheden believes that the legitimacy of mechatronics is a functional one (Grimheden, 2006).

Thirdly, the *selection* problem of the most important aspects of the subject X to be studied must be analyzed. There are two extreme types of selection. The first one is "the horizontal", or by representation, which provides a broad and comprehensive perspective on the whole subject. The second is "vertical", step during which, by example, only a limited number of the subjects aspects are deeply studied. According to Grimheden, the thematic identity of mechatronics requires a *vertical* selection, by example, following the formation of practices and practical skills focused on key words (synergy is one of them), which are its fundamental themes (Grimheden, 2006).

Finally, the last aspect is *communication* that is the most efficient way to send subject X to graders and students. There are two forms of communication. The first is the active communication, where the teacher-student relationship is similar to the feed-forward open loop control, the educational act being centered on how the teacher should act to achieve its objectives. The second form is interactive communication, similar to closed loop control, where the feedback that the teacher receives from the student has the essential role. According to Grimheden, there is a close link between the functional legitimacy of mechatronics and its appropriate form of communication: the practical skills required by the industrial market can be formed only through teamwork, learning based on problem solving and projects, which necessarily involves opting for an *interactive* form of communication of mechatronics (Grimheden, 2006).

7 The Trans-Thematic Identity of Mechatronics

All philosophies of science agree on the meaningfulness of two types of scientific statements: the

phenomena ones that refer to empirical matters of fact, and those concerning logic and mathematics, the latter being of analytic nature [46, 47]. Holton assigns a system of two orthogonal axes to these two types of sentences O_x and O_y, respectively that represent the dimensions of the plane of any scientific discourse. In this plane, called the contingent plane, a scientific concept or a scientific proposition has both empirical and analytical relevance. Starting from the notion of contingency[46], Holton assigns a new meaning to this term, but one that is related to its primary meaning in logics [47].

Carrying on, Holton adds another axis, O_z, that is perpendicular to the contingent plane, representing the dimension of *themata*: themata represents fundamental ontological presumptions, generally unconscious, that, although incapable of being scaled down to empirical observations or analytic judgements, are dominant in the thinking of researchers [48, 11]. As Basarab Nicolescu asserts, themata refers to the most intimate and profound part involved in the genesis of a scientific idea [11]: "these themata are hidden even for the one that uses them: they do not appear in the constituted body of science that perceives only phenomena and logical and mathematical sentences."

A *thematic concept* is analogous to a line element in space which has a significant projection on the Oz axis, the thematic dimension [47]. Purely thematical concepts are rare. Therefore the thematic concepts usually have considerable values of their projections on the other two axes (as, for example, the case of the concept of energy). While the contingent plane Oxy is adequate when we are dealing with a purely scientific discourse, we must use the tridimensional Oxyz space every time we plan on doing a complete analysis, including of historical, sociological and epistemological nature of certain concepts, processes or scientific approaches.

Returning to Grimheden's perspective on the identity of mechatronics, we've stated above that he considers (by looking at what is common to several definitions of mechatronics) the idea of synergy as being the conceptual essence, the theme on which the identity of mechatronics is based on. The notion of synergy is integrated, however, together with that of emergence in the theory of complex systems or the complexity theory [35]. *Entropy* is a concept that plays an essential role both in non-linear thermodynamics and in information theory [3]. On the other hand, the notion of *information,* belonging firstly to information theory, also plays a fundamental role in mechatronics [2].

The concept of *self-organization* belongs to nonlinear thermodynamics and mechatronics alike. Regarding the role of self-organization in mechatronics, our previous papers presented two types of selforganization of complex mechatronical systems: through stigmergy (Berian, 2008), respectively homeokinesis (Berian, 2009b). The integration of all the notions and fields mentioned above is due to the notion of *complexity* (Figure 1).

Coming back to the problem of identity, it can be stated that, in mechatronics, complexity is a thematic concept, in the sense defined by Holton, concept that gives the measure of the identity of mechatronics. A first argument favoring this sentence is that of the fact that the term integration is a central one in mechatronics [2], while complex mechatronical systems have an inherent power of integration (due to the emergent properties of synergic character) that grows higher as the degree of complexity grows higher [35].

Themata usually appear in the shape of alternatives [11]: continuous-discontinuous, unity-hierarchical structure, holism-reductionism, etc., each new *thema* implying the separation, the opposition of alternatives. Particularly, in the present case, we have the dyad made of the contradictories simplicity-complexity. Therefore, on the one hand, complexity has integratory valences while, on the other hand, it appears to be the source of a separation. In Basarab Nicolescus opinion, however, the themata must be seen as facets of symbols, while the symbol assumes the unity of the contradictories; for example, Bohr's complementarity represents a symbol that "realizes in itself the unity of the contradictories continuous-discontinuous, waveparticle" [11].

Specifically, complexity appears as a facet of the bootstrap principle, a symbolic principle that "conceives nature as a global entity, fundamentally inseparable" (Nicolescu, 1999). Thus, we consider that *complexity represents the theme at the base of the identity of mechatronics* (Berian, 2011). The idea of complexity is more comprehensive than that of synergy, as self-organized mechatronical systems distinguish themselves firstly through their complexity, due to the existence of emergent properties with a pronounced synergic character [35].
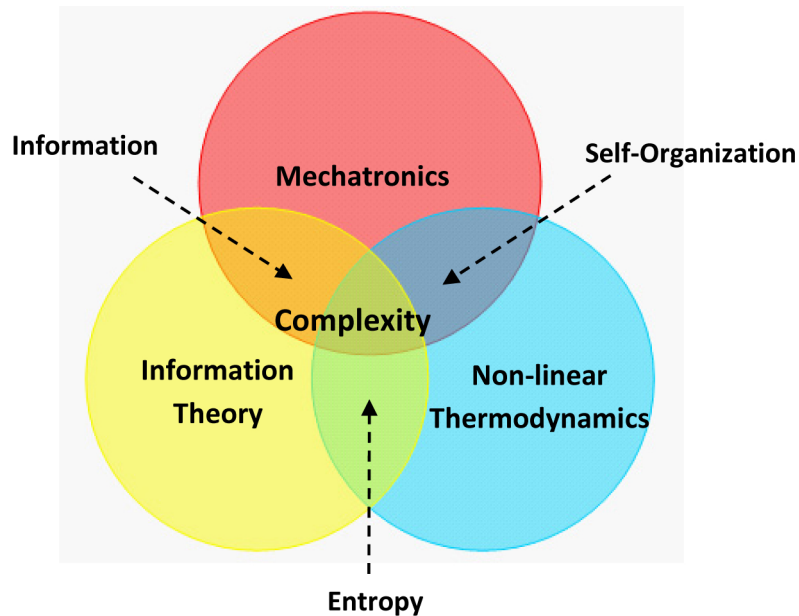
Figure 1: The Integrative Potential of the Thematic Concept of Complexity.

In Basarab Nicolescu's opinion, a theory founded on a symbolic idea is an open theory, as its feature of permanence is guaranteed precisely by the existence of the symbolic idea. Such a theory can undergo changes of the form level (particularly of mathematical formalism), but its direction remains unchanged [11]. Therefore, viewing mechatronics from the perspective of transdisciplinary methodology, its identity is based on a symbolic principle (that plays, in addition, the role of an epistemological principle), which leads to mechatronics being an open field [46].

In a transdisciplinary approach, mechatronics transcends, therefore, the limits of a simple thematic identity. In conclusion, we claim that the identity of mechatronics is trans-thematic, founded on the idea of complexity [23].

The Hexagonal Model for Integral Mechatronic Education As ahown, according to Stéphane Lupascos epistemology, the two antagonistic dynamism of the system tend, during the transition from current to potential or vice versa, to reach the T state, state where the organization and resistance of the system are maximum. Therefore, "maximum strength" (corresponding to maximum efficiency) of a teaching model which provides a integral education is achieved when the antagonism of opposite forces is maximum. There are three pairs of dynamic antagonistic regarding mechatronics: formal legitimacy / functional legitimacy, horizontal selection / vertical selection and active communication / interactive communication. Updating the formal legitimacy requires functional legitimacy potentialization and vice versa, the same reasoning appling to the other two pairs of dynamism as well (selection and communication). Absolute update of any dynamics is the equivalent of adopting an incomplete education approach, which neglects the benefits of antagonistic dynamism updating, since the latter will be completely potentialized, so sterile. Consequently, in terms of a model for a integral mechatronics education [3], mechatronics is symbolically located in the area of maximum resistance, which corresponds to a triple T state (each pair of dynamics having its own T state), state in which the contradictory are not contrary because of the reconciliating role of the principle of the included middle (Figure 2).

In other words, the model presented, based on the logic of the included moddle, outlines the nonseparability and the existing unity between the sides of mechatronics that seem to be irreconcilable: formal legitimacy/functional legitimacy, horizontal selection/ vertical selection, active communication/ interactive communication. The detailed analysis of how this reconciliation is achieved of this sides of mechatronics can be followed in our work [3, 46].
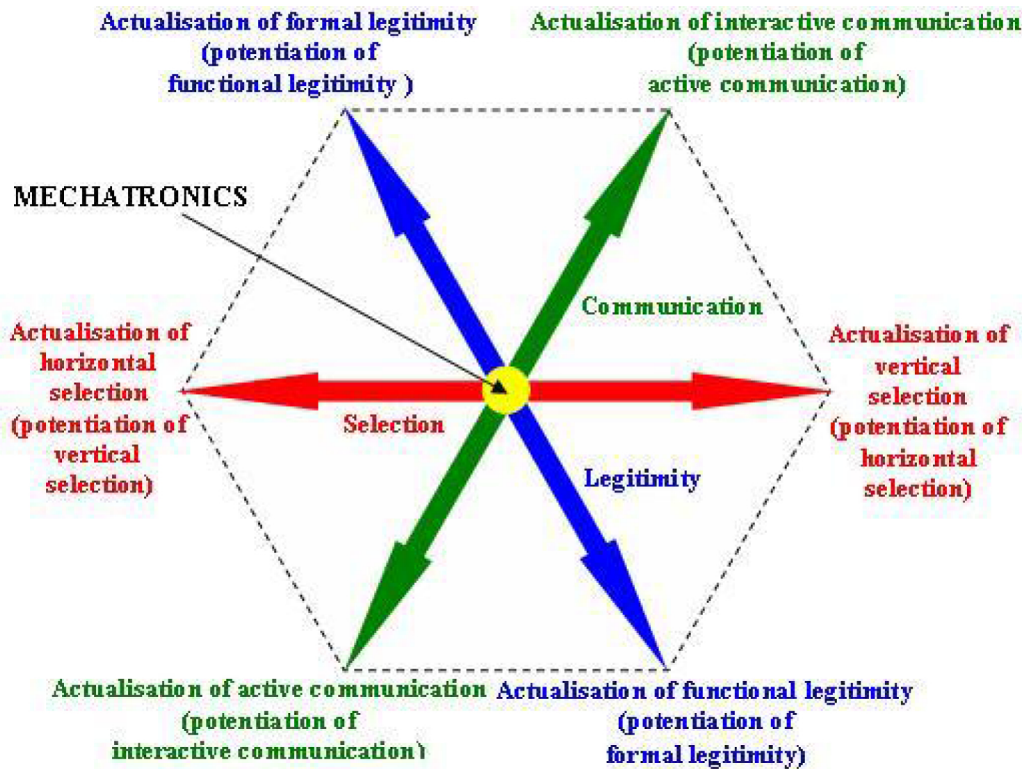
Figure 2: The Hexagonal Model for Integral Mechatronic Education.

8 Conclusions

From a transdisciplinary approach, mechatronics is an open field, so its identity transcends the limits of a simple thematical identity. The stating and the argumentation of the idea that the identity of mechatronics–founded on the thematic concept of complexity–is transthematic, serves as a starting point in the substantiation of a future complex and rigorous transdisciplinary approach to mechatronics. The results of theoretical, didactical, and experimental research of the authors of this paper represent openings to new investigations in the area of technology and mechatronic education. These openings are justified both by the creative potential of transdisciplinary methodology and by the positioning as an open field attributable to mechatronics. Some of these openings are: the developing, at a conceptual level, of the hexagonal model for integral mechatronic education and its validation in organizing project competitions and mechatronic products; research and definition of new openings regarding the expansion of the content of discipline curricula from mathematics and natural sciences, through the integration of certain modern applications of the principles, laws and phenomena of physics, chemistry and biology in mechatronics and biomechatronics; research, development and implementation of educational interactive technologies on mechatronic platforms and the development of the innovative potential of the portable laboratory and of the multifunctional regional laboratory of mechatronics, in the advancement of the dialogue between science and society.

As demonstrated in the contents of the present paper, mechatronics is capable of providing conceptual resources and applicatory instruments, with the purpose of establishing additional studies, starting from the openings previously mentioned.

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