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Ergoecology: evolution and challenges

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Abstract. This work details the conceptual and methodological evolution of 'Ergoecology' and its relationship to certain comparable disciplinary proposals and standards, with a view to making its current status known and fostering discussion and development of it in a broader context. 'Ergoecology' is a discipline which relates the ergonomic system to 'environmental factors', stressing the relationships between ecological-geographical aspects and human activities. After analyzing previously-developed and partially-validated methods, strengths are established, together with areas where there is room for improvement, based on conceptual validity. The objectives, principles, and premises of 'Ergoecology' will be revised and therefore it will be able to be compared with other disciplinary and regulatory developments. Finally, new concepts and notions are proposed, together with basic principles and axioms that will enable 'Ergoecology' to advance in both, the theoretical and the practical dimensions, leaving the door open to be disseminated and applied.

Keywords: Ergonomics, Ecology, Ergonomic system, Ergoecologic system, Eco-productivity, Eco-efficiency

1. Introduction

To understand why is found today in force the Ergoecology, which conceptual proposal was presented more than a decade ago [1], it is necessary to know its theoretical bases [2] as well as to revise the methodological and conceptual development of what has been subjected to. [3-6]

Defined as a scientific and technological discipline, the Ergoecology was developed to integrate evaluation and intervention processes generally used by ergonomics, and environmental management systems. It "looks forward –from a systemic focus–, to take care of studying the human being and its relationships with the environment -through its activities (work)- to establish, analyze, reduce, prevent, control and rectify the impacts (positives and negatives) that derive from such a relationship"[4].

Therefore, and inside the framework of *sustainability*, Ergoecology seeks to reach *'eco-productivity'* and *'eco-efficiency'* of the ergonomic system in relation to the *ecological-geographical* environment factor, through the use of *energies*, *material* and *information*, that will bring a dynamic equilibrium and an environmental balance. It also proposes the rationalization of impact variables to control the productive system, so that it tends to an operational equilibrium.

2. Ergoecology principals

To achieve the objectives presented, organizational interventions or readjustments of processes and technologies are needed, therefore, Ergoecology's *ultimate goal* is to eliminate the differentiation between natural environment and built environment, thus the relationship with the medium environment can have a tendency towards equilibrium.

From this viewpoint it is evident that the *anthropocentric focus* is a primary principle of Ergoecology; whether the object of study is presented as an abstract entity (interactions), the effects take place in

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concrete entities (human beings, built environment and natural environment), which includes a purpose.

The second principle is supported in the *systemic focus* (system complex behavior) which allows to consider the existing relations among the elements of the specific system (interactions) for the analysis (to the interior of specific situations in function of *inputs and outputs* –energy, matter, information–), favors the construction of indicators (for the appraisal and comparison of impacts and not lineal relations) and the generation of accurate recommendations for the improvement of private operations, without losing the global vision of the processes in its entirety.

This principle is complemented with the *scalability focus,* which characterization permits to identify inter-systems relations (not lineal) and to define if the analysis is carried out in perspective or in depth.

Finally, but not less important, it must be pointed out that the concept of *sustainability* –in its moment 'sustainable development'– [2] underlies to the general approach of Ergoecology. It may be said now, that from the social studies point of view, it has been talked about *cultural ecosystem*, *social-ecology*, and then, included in this last one, *housing-ecology*. This view approaches the idea of understanding society as a system with a symbiotic relationship with the ecosystems. The ergonomics as a field that intervenes in the manufacturing processes and in products development cannot be more compromised. It has to work on the production systems, social systems and ecosystems to achieve equilibrium among them.

To improve *ergonomics system* from an *ergoecological* point of view has to be done efficiently in two ways:

- The consumables, raw materials and material that take part in the manufacturing of a product (we are talking about the design of the duties that have to be contemplated to have the most efficient sequence of actions) have to be controlled oriented and rationalized.
- The output of quality products also have to be controlled, oriented and rationalized, (avoid rejection of parts and finished products), and the amount of damaged materials and scraps has to be reduced to a minimum.

Then, we consider an ergonomist responsibility to participate in the creation of environmental regulations at the work place, as well as the securing of policies and programs to recover the environment's quality (i.e. recycling and recuperation of waste programs can help the adaptation of conditions in the place of work) [2].

The concept of *'sustainable development'* was understood as an equilibrium among systems, inside a plan of values that could move the humanity toward a common objective: the time in which present and future generations could live in harmony with the environment; from there Ergoecology can be assumed as a valid alternative to face the diverse problems related to the planetary sustainability that affect so much the developed countries, as well as those developing (today called emerging economies).

In turn, as a complement to the concept of *sustainability*, another concept that also considers the Ergoecology is *'eco-efficiency'*, which in a productive process implies the use and appropriate knowledge of technology in such a way that neither the human being nor the environment should be damaged or be put at risk. This necessarily implies an ergoecological use of technology. Evidently, evaluations of environmental impact of activities, as much in micro as in macro scale, can be done from an ergoecological analysis allowing the distribution of variables of impact to control the productive system and make it so it tends to an operational equilibrium.

3. Methodological development

The Ergoecological Analysis Method (MAE) arises in response to the need of a methodological guide to apply the principles established by Ergoecology, in such a way that they can be contrasted, analyzed, evaluated, and corrected. Its development is based in *'conceptual phases'* constituted by *'steps'* that involve specific actions to deepen in the analysis and intervention of productive processes. It is important to mention that these *'conceptual phases'* group the steps and actions to continue during an ergoecological intervention within an operating and logical plan; nevertheless, they do not imply a sequence of dependent execution. This is in order to avoid creating a *'methodology'*.

Later, it will be mention in chronological order, the different Ergoecology application models that have been tried to be validated and therefore have evolved from their application in diverse productive environments.

Evidently each application –although its validation has been partial– has generated changes or contributions in the original model. Even so, not necessarily in all the cases the changes in the application of the

model represent a conceptual advance for the Ergoecology. It is only stressed the strengths of each mo-del, and those representative aspects associated to the Ergoecology conceptual development. Though the models have their own importance, these, should be assumed as a tool that intends to make viable the application of Ergoecology; the present work concentrates on its evolution and its current challenges. Each model will not be explained, expecting that the reader can be remitted to the documents where the development and validation projects are described [3-6].

3,1. Ergoecological Analysis Method–MAE, 1999

The first version of the MAE, was structured in five phases:

– Phase 1: Systems outline.
– Phase 2: Identification.
– Phase 3: Analysis and recognition.
– Phase 4: Implementation
– Phase 5: Monitoring and feedback.

This first model was built keeping very much in mind the principle of *scalability* and the concepts of *eco-efficiency* and *eco-productivity* generating its main strength: the plans of *'feedback'* established in phase five. Said plans arise from the activities of follow up and verification at the phase of monitoring, and they impact the phases of system outline and identification. They are oriented to improve efficacy levels, equipment performance levels, and human being performance levels [3].

In this same line, another great strength associated to the previous one, is the design of the model itself, which favors and maintains in each step –from the beginning to the end– the *systemic focus* proposed by Ergoecology. Finally, on this model two more things should be said: first, that in its original form never was contrasted through an application to a case of study; before the first validation this was modified. And second, that it will be seen in the following models how its basic structure is kept.

3.2. Ergoecological Analysis Method–MAE, 2003-2005

This second model covers two moments: an initial review before being validated in an application about the design processes and the construction of a military river boat [4]; and a general reorganization as a methodological and conceptual contribution from the results of the validation project [5]. In said initial review, the model consists of seven phases and the achievement of each one is established. This model is structured as follows:

– Phase 1: Initial preparation.
– Phase 2: System Recognition.
– Phase 3: Ergoecological factors analysis.
– Phase 4: Interactions identification.
– Phase 5: Ergoecological analysis.
– Phase 6: Application.
– Phase 7: Monitoring.

Also in the initial review the model maintains the systemic focus as methodological pillar and even though it was mentioned before, it must be indicated as its main strength; nevertheless, it should also be noted that simultaneously loses the scalability focus, because of the forecasted difficulty to apply in the steps of each phase, the supra, macro, and micro scales. To supply it, the processes focus is assumed [7] which becomes the analysis axis and in another important benefit of the second model.

Already in the second moment, as a consequence of the validation, it is exactly the representation of the processes that favor the tools analysis design system. Each operation is assumed as a system and for the first time is represented in each one of the input and output flow.

The ergoecological system proposed as the Ergoecology study object was redefined from the application of the methodological model. The product (positive system output) was incorporated as another element of the system, allowing to connect within itself the different process' operations and to relate – through this element (input/output) – to the different systems that are established in the ergoecological analysis. It is important to have in mind that in the project of validation phases 6 and 7 presented in the model were not run, because of conjectural limitations within the project's reach. This situation generated what the investigators called "the step from analysis activities to intervention activities", leading to the following model of the method.

3.3. Intervention method for the Integral Performance of Productive Processes–MIDI-PP, 2006

With the approach of this new conceptual model, was sought to emphasize the intervention character that Ergoecology presented specifically in phase 6. Though, from the new name of the method this characteristic was announced and declared its interest to reach integral performances in productive processes, their basic structures as well as the Ergoecology

principles were maintained as conceptual and theoretical axis of the new proposal. Paradoxically and in contrast with what is proposed in this work, one of the method's strengths was based on the incorporation aspects of efficiency, efficacy and effectiveness, declaring openly the abandonment of the concepts of eco-efficiency and eco-productivity for the quality management aspects [8]. This change had the intention of expanding the field of application of the *MAE* (integral management) and involving themes as the continuous improvement, the vision by processes and traceability. [5]

This proposal maintained the structure of the seven phases presented in the second version of the *MAE* already refined, clear and operating within its reach and objective. In some cases, the steps that make up them were modified in order to give greater solidity to the formulation of the Ergoecological Diagnostic and to the tools developed for harvesting and analysis information.

Their validation was carried out also in the modality of case study, but this time, applied in two Colombian micro-businesses from different sectors, one from the cosmetic sector and another from the metal-mechanical sector, the last one favoring the verification of the versatility of the method in different scales. Without a doubt, the main strength of this version concentrates on the construction of indicators (of relation and impact) for the appraisal of the impact levels of the systems delimited as critical operations [6].

4. Ergoecology New Routes

4.1 Purpose

Ergoecology ultimate goal is to reduce the gap between the built environment and the natural environment. The built environment (by the human being) needs to follow more the laws and parameters of the natural ecosystems, this is, not only to replicate functional nature parameters to imitate them in technological developments (bionic), but based in a deeper and more holistic understanding of nature (biomimicry) to avoid to impact or to unbalance the environment, or worse still, to continue with the exploitation of the natural resources and the no renewable resources.

4.2. Postulates

As it was mentioned in the introduction, Ergoecology intends to achieve –inside the sustainability framework– eco-productivity and eco-efficiency. It should be understood then, the first one, as the system capacity to transform energy, material, resources, and information (without squander or waste), in a product or service, without generating negative impacts in other systems that interacts with.

In turn, the eco-efficiency is understood as the balanced performance of the systems in the human-technologies systems, as well as in the earthlings' ecosystems (biological, climatic, etc.). If negative impacts in the ecosystems were produced upon interacting with the systems human-technologies, eco-efficiency would not be achieved.

4.3. Objetives

- Main objective: To seek for eco-productivity and eco-efficiency of the ergonomic system, in relationship to ecological-geographical factor, through the use of energies, materials and information, looking for a dynamic equilibrium and an environmental balance, the last understood as the capacity of establishing equity between quality of life and survival of all planetary species.
- Complementary objectives:
  - To reduce the system energy consumption. This is to increase the percentage of energy incorporated and to reduce the energy dissipated.
  - To make eco-efficient the system's energy use and consumption, to comply with its activity, in equilibrium with the other systems that interacts with.
  - To seek the eco-productivity that implies ecosystems balance, instead of for the traditional productivity that seeks an increment of the production (traditional economy).
  - To increase the certainty in the communication processes. In other words, reduce the noise in the information's exchanges and developments without squander or waste time and energy. This is, to guarantee the certainty and to reduce the entropy.
  - Improve the performance of the ergonomic system, (human being – physical space – Objects /machines) without affecting the

performance of the subsystems that compose it.
- To increase the reliability and security of the whole system and its relationship with the environment (surroundings), so it does not damage the human being, does not affect the physical space, and avoid the deterioration of objects/machines. At the same time it must not impact negatively the ecosystems that interacts or coexists with (other planetary species).
- To contribute, during the system dynamics, with what is necessary for the availability and ease of maintainability without squandering the energy, resources, and information.
- To improve the system input levels of adaptation and balance, (energy, materials, information useful and incorporated), versus the output losses (dissipated energies, wasted materials, and unused information).

4.4. Axioms

- Some initial axioms are presented, that can operate in Ergoecology, as part of the conceptual basis from the systemic focus. Said axioms permit to quantify the interactions between the elements of a built system and the interactions in relation to its environment. The starting point is to understand the inputs and outputs between subsystems, that is to say, the linkages between operations or processes where energy, material/resources and information are exchanged or used.

- Energy: in energy terms every system requires of energy for its operation. For the case of purpose systems (compliance of a goal) the energy is invested to comply with the purpose. In the ergonomic systems case, the energy can be understood as the capacity to perform a work. Therefore, if a system complies with a work (in a process, sub-process or service), always is implicit the use of energy for such end. The energy consumed is then, a parameter to measure the demand of a system to comply with transformations or movements of determined materials and/or information in a product (purpose) or a service that has implications of order and intention.
- *Exergy*: this is conceived as a system maximum fraction of energy in which basic theoretical conditions of reversibility is transformed into work. This always happens when there is a system and an environment or minimum two systems that interact, [9]. The exergy is the energy really used by the subsystems or systems to maintained and achieve the transformation of materials, resources and information, in other words, to comply with its purpose. The exergy is divided into two energy types: the necessary energy for the component or subsystem to be maintained alive or in operation (this part of exergy will be called basal); and the energy that is used or remains "incorporated" in a product/service for the transformation of materials, resources and information (this part of exergy will be called gray energy).
- *Anergy*: is the residual or remaining energy that remains after a process of transformation. The anergy is conceived as a loss, or energy that could not be used to carry out the system's work. Many times is seen as thermal residues or contamination of resultant products.

It is important to mention that there can be two general magnitudes to quantify the eco-efficiency in energy terms: first there would be the Joules (J) of the international system, to be able to measure the energy and the matter. The Joule is the physical magnitude to quantify the capacity to carry out a job, or the capacity to act, to transform and to put in movement something. Second there would be the Watts (w) that are power.

From the previous concepts, the axiom to measure the energy eco-efficiency would be:

$$\sum \text{total energy} = \sum \text{exergy} + \sum \text{anergy}$$

$$\sum \text{total energy} = \sum \text{basal exergy} + \sum \text{incorporated exergy (gray energy)} + \sum \text{anergy}$$

Given this equation, a system will be more eco-efficient when uses the least total energy in relation to similar systems or previous versions. A system will be oriented to the eco-efficiency when a bigger percentage of the exergy is transformed or incorporated in the products or information, or greater percentage of gray energy, necessary minimum of basal energy, and smaller quantity of anergy or unused energy.

- Raw materials: are those resources that can be identified and quantify with weight and volume and that has the potential to be utilized, incorporated, or wasted to obtain a product/service.
  - Incorporated Materials (supplies): all raw materials have properties that allows the transformation of said raw material into supplies and at the end, incorporated as part of the products.
  - Rejected Materials (waste): during the transformation process, a percentage of the raw material becomes waste or useless material to obtaining said product/service. Waste is a quality that is given to a raw material when is yet to be determined its usefulness, but in essence, continues being potentially a raw material.

In the case of raw materials the following axiom can be given:

$$\sum \textit{raw material} = \sum \textit{incorporated materials (supplies)} + \sum \textit{no incorporated materials (waste)}$$

Given this equation, a system will be more eco-efficient when the least waste or not incorporated materials are left in the end, and the most material is incorporated in the product/service.

- Information: the conditions for the definition of an axiom for information are more complex, not only because probabilistic equations must be established, but because the information should also be understood in its meaning and linguistic sense. In other words, to establish an only axiom on the efficiency of the information is diminishing because said focus does not contribute anything significant to the comprehension of the information as content of the message in a determined language.

A central concept transferred from thermodynamics proposed by Clasious in 1876, is that of entropy, where it designates the part of energy of a system that cannot be transform into mechanical work, or the energy that is dissipated.

From information theory, the entropy notion has acquired another meaning, thus the entropy is the 'measure of the uncertainty, ambiguity, or ignorance of the meaning'. Therefore, the total entropy is understood as the disinformation (related to noise), the interference, and ignorance of the reference codes or the problems in the message transmission media.

Now it is required an opposite concept: the negantropy. It means the 'degree of order, certainty or total information'.

Based on what just been discussed, the following relation can be established for information:

Efficient information = greater percentage of negantropy, smaller entropy percentage.

On the basis of this relation percentages of entropy and negantropy can be established having the interaction of a system shaped from Ergoecology, where eco-efficiency is recognized as far as the information management is concerned.

5. Discussion and future work

The concept of *'sustainable development'* has been appropriated by the classical economy, to continue analyzing the idea of development as growth *ad infinitum* from the monetary base, where economic incentives are given to the businesses geared towards initiatives and environmental regulations, therefore, it is argued that the economic growth can continue as long as it is apply under the idea of a *'sustainable development'*. The speeches, theories, and concepts about *'economic growth'* put forward that it is essential to seek the *'sustainable development'* as a new quality. It seems as if the *'sustainable development'* implies a level of conscience and action that frees us of the responsibility that the current economic development has on the environmental deterioration and the wear of non renewable resources. Nevertheless, there are other positions that show the notion of *'sustainable development'* as a concept that encloses a contradiction, an oxymoron [10]. If we really want to continue surviving as civilization and species, we need to consider the possibility of a decrease economy, understood as a creative opportunity to promote the human development, seeking equity between the diverse societies and the ecosystems [11].

From the previous perspective the initial advanced of the Ergoecology [1-2] is maintained, even defining it from the notion of *'sustainable development'* from the assumption that the Ergoecology was in charge of understanding and shaping a equitable and *equisinergical* relation with the *'built*

environment' (anthropocentric) as well as with the natural environment (eco-centric).

It should be emphasized that although Ergoecology was conceived from its start with systemic and integral focus [1-2], its academic diffusion was local and its impact in productive sectors marginal, while the integral management, although is subsequent and arises from a fundamentally instrumental perspective, has had a stimulus and growing interest due to the application of quality standards [8], health, and security [12], management environmental [7] and more recently the social responsibility (ISO 26000) [13] as strategy of business positioning. Therefore, a business that has obtained certifications shows them as a letter of introduction in front of the competition in a global market, as well as in front of consumers to earn their trust.

The current setting of businesses with more tradition and structure in processes of quality management, health, and risks, speaks of integral management (EHSQ / SHEQ). This management has been based fundamentally in the norms of management previously mentioned and still more recently the importance to establish a theoretical base that supports what it has been achieved in practice of the integral management [14].

This integral vision allows businesses to work strategically on four axes: Quality, the ways of life, sustainability and socio-environmental ethics in its more extensive senses.

Ergoecology can include the normative package relevant to the integral management previously mentioned; in addition of the relation with ergonomics and to the environmental aspects, as references but by no means can be reduced to an application or normative compliance. Besides, the quantity of norms is it very extensive and demanding in time to contemplate them as nuclear axis. Additionally it indicates the opportunity of growth and impulse that Ergoecology could have if it is received and integrated to the initiative of the IEA that conformed recently the *Technical Committee IEA Human Factors and Sustainable Development* to fortifying the relations between the human factors and the sustainability [15].

As opposed to the implementation of norms like the OSHAS 18000 that seeks fundamentally the certification of a business, methodologies developed inside Ergoecology perspective seek that businesses have a model of management for the gradual and continuous improvement, not only of their processes, but of their products/services.

The certifications that give the norms are necessary so that the businesses generate and maintained a culture of management of safety, health, and environment, but they are not sufficient for the businesses be involved in processes of continuous innovation regarding rationalization of material, energy resources, supplies and information. The normative compliance and the consequent certification show a first step of the business commitment with the integral management. Nevertheless, upon meeting the goal, a business certificate can break its evolution with regard to the competence and soon after feel threatened by have not an orientation that was beyond the normative compliance. Ergoecology should continue improving its current methods and developing new proposals that involve the regulations in integral models. It can make evident the need to direct the innovation processes towards processes and products genera-ting less negative impacts in the ecosystems. In the review developed on similar approaches to the proposal of Ergoecology, systems that related directly the areas of environmental management, ergonomic studies, and quality were not found.

This stands out the importance of Ergoecology as an innovative vision and that does not only evaluate the processes but intervenes for its improvement. Ergoecology should continue developing axioms and postulates that integrate other useful notions to analyze, to evaluate, and to measure the performance of the interactions of the systems and concepts. Some of said notions are: Compatibility [16]; adaptation levels [17], and state of the equilibrium/imbalance of energy, matters and information. This last one, understood as the relation of consumption, effective and efficient use.

Impacts (positive and negative) in the natural systems, of the human activities developed inside built environments must be established. If the dynamic behavior generates negative impacts, they should be mitigated, prevent, control and correct. If the dynamic behavior produces positive impacts, they should be stimulated to maintain and to extend.

6. Final considerations

Ergoecology should seek the equity and the equilibrium among the built systems (systems of work, social systems, technological systems (appliances/services) and the natural systems (biosystems without human intervention).

without human intervention). Ergoecology should go beyond the dominated notion of "sustainable development" and to be oriented toward "sustainable dynamic" among systems, that is to say, coexistence or co-dependence of systems, even based on theoretical focus as the decrease economy. It is necessary to maintain the idea of scalability to pass from analysis in perspective to analysis in depth in the systems and subsystems. Ergoecology ultimate goal is to transcend their current status so it does not impact or unbalances the environment, avoiding the irresponsible use of natural resources.

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