Biosystems Engineering: Unification or Redomaining?

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Abstract— Concepts arising from philosophy of science and technology can fruitfully help to identify the emergence of a new technologic domain, such as Biosystems Engineering. The contributions of Arthur [1] and Dosi [2], largely inspired in Kuhn’s scientific progress model, stress three basic elements shared by science and technology: the organization of scientific and technological domains, the concept of scientific or technological paradigm and the corresponding community of practitioners. We try to identify some attributes of new technological domains in the infant Biosystems Engineering. Is there any deep novelty here, a new paradigm, or is it just a new bottle for old wine? Do old problems deserve new approaches? Or traditional approaches are just grouped in a new way?

Index Term— Biosystems Engineering, Social Studies of Technology, Innovation.

I. INTRODUCTION

New domains always appear from some established field. The original parts and foundational intuitions are constructed or borrowed from one or more pre-existent domain. The computers didn’t appear from processors or buses, but from practices and components of the 1940’s valve technology. The technology emerges from itself. (Arthur, [1], p. 204) A new domain, when it emerges, it is never identified at once. It seems little more than an agglomerate of concepts and methods put together by chance. In this stage the new born domain still belongs to its field of origin. After some time this cluster acquires its own vocabulary and its own way of thinking. The new domain will, little by little, move away from its original domains and the practitioners acquires are mindful of belonging to a distinct group.

As time goes by the choice of a domain to accomplish some purpose may change. The movement of wings surface and airplane’s tail has changed from the mechanical and hydraulic domain to the digital domain (fly-by-wire). Arthur [1], p.73, says that in this case the airplane’s controls were dominated in a different way, or “redomaining”. Frequently innovations may be an improvement of a given technology, but the more meaningful are, as a rule, a “redomaining”. The same purpose or functionality is translated in to a new set of components withdrawn from another domain. The provision of driving force went successively from the waterwheel to the domain of steam technology.

The change of domain – redomaining – is the principal way by which the technology develops. The domains of a given period define not just what is technically feasible, but the style of the period. (Arthur [1], p. 74). For instance, the Victorian Age is inseparable from the steam locomotive. The British punctuality as arisen with the synchrony of the train stations. Today the information technology reshapes even the more intimate aspects of the private life.

This study sheds light on current overlapping but not identical views on the emerging branch of Biosystems Engineering found in literature and professional organizations. It can be useful to support the design of undergraduate and graduate programs. It also shows a case for research in Engineering Education, and Sociology and Philosophy of Technology. Universities offering or intending to offer programs in Biosystems Engineering or related fields can benefited from this exploratory research. Studies in professional organization and regulation can find a case of ambiguity during the redefinition of professional branches.

II. TECHNOLOGICAL PARADIGM

A. Exemplar achievements

A scientific or technological paradigm can be revealed by the presence of one or a few exemplar achievements in the field. Epic and simplified versions of the story of the founding fathers are presented to students in text books and other pedagogical instruments used during the professional training. We were not able to find in Biosystems Engineering an exemplar achievement with the same status of Newton’s gravitation theory in classical Physics or the Lavoisier’s principle of mass conservation in Chemistry. There is, however, an expressive amount of work inspired by the same strategy: the use of information embodied in systems in which non-humans living beings are relevant elements, with the purpose of understanding, modelling and acting on them. Image processing of live elements of biological systems to extract useful information has deserved a lot of research and development effort. This body of knowledge can be regarded as evidence of existence of a technological paradigm, playing the role of a seminal achievement.

In this sense, Ibañez-Asensio et al. [3] establish relationships between color and some relevant soil properties in semiarid regions; Novotny and Suk [4] employed image processing techniques to quickly and at low cost identify the species of trees in Central Europe forests, obtaining information about tree populations and their dynamics. Yao et al. [5] developed

B. Common use of devices, materials and methods of research and development

Information Technology is the base that makes possible the approximation of different branches of science and technology focused on non-human biological systems. Obtaining, storing and processing data, as well as designing and intervening in such systems, become activities performed with electronic devices, as sensors, processors, and actuators. Despite the huge diversity of applications and contexts, there is one general structure in which an interface translates physiochemical properties of elements included in the system into bytes, and another interface that translates pieces of information into action over the system. Between these interfaces lies an information processor.

For instance, Aquaculture seems to constitute a branch of animal production in which arise many opportunities of technically and economically relevant use of information related to live organisms. Stien, Gytre, Torgersen, Sagen and Kristiansen [12] in the Institute of Marine Research in Norway are developing an automatized system to evaluate the animal welfare of fishes in cages submerged more than 30 meters. The ‘welfare meter’ connects a multiparameter sensor, a control unity, a dedicated software, and a web page. The sensors obtains data on water column in cages and send the data by cell phone to the Norwegian Marine Data Centre and to the Institute of Marine Research. In real time the software process the data and provides an evaluation of environmental conditions in the cages

C. Focus on a narrow set of relevant technological problems

Biosystems Engineering as a merge of preexisting biological systems oriented branches of Engineering, such as Environmental, Agricultural and Forestry Engineering, and maybe Animal Sciences, embraces a wide and diversified spectrum of applications and interests. Nevertheless, these applications can be classified in transversal sets of problems shared by these traditional Engineering branches: development of biosensors, sustainability of agricultural systems, food security, and natural resources management. Topics traditionally assigned to Agricultural Engineering, such as bioenergy generation, agricultural automation, and irrigation, are usually included in the scope of Biosystems Engineering.

It seems, however, that some degree of ambiguity still persists in the demarcation of the object of Biosystems Engineering. Some people use the expression as a synonymous of Biological Engineering, focusing in non-human live beings and their interactions, excluding or leaving in the shadow more mechanical topics of Agricultural Engineering, as agricultural automation, irrigation and precision agriculture. Some topics that could be included in a wide definition of Biosystems Engineering fall in a twilight zone between origin branches and the emerging one. Genetic Engineering and Food Engineering are examples of the difficulties related to the borders between technological fields. It is symptomatic that the French name of the Canadian Society for Bioengineering is “Société Canadienne de Génie Agroalimentaire et Bioingénierie”, separating in French what is merged in English.

Briassoulis, Panagakis Nikopoulos and Ayuga [13] excluded Biotechnology and Biomedical Engineering from the field of Biosystems Engineering. Biotechnology is defined as a set of techniques that use living organisms or parts thereof for obtaining products, genetically enhanced, or organisms capable of performing functions of economic or environmental interest. The aim of Biomedical Engineering is the health and quality of human life. Despite this assertion, Nag [14] begins his text book named Biosystems Engineering with a chapter on microarray data analysis using machine learning methods, a technique largely used in Biotechnology.

An alternative definition of Biosystems given by Kok [15] asserts that the constitutive parts are living entities. “Biosystems are defined [...] as being composite entities that are alive at the system level. In traditional biology, it is well-accepted that structures at the cellular and organism scales of organization are alive [...] many ecologists assert that Biosystems of the ecosystem scale, and even of the biosphere scale, are also living entities.”

A living entity is characterized by complexity and adaptive behavior, as well as self-organizing properties. Examples of Biosystems could range from a single cell to entire biomes, Earth’s biosphere or even biospheres of others planets. In this sense, mankind since its earliest stages practiced some kind of primitive Biosystems Engineering: “Engineering in general includes the design, construction, operation, maintenance, repair, and upgrading of a system, usually in order to achieve a particular goal in the face of a set of constraints. Historically, the engineering of large-scale Biosystems stems from agricultural, silvicultural, and aquacultural activities, which have been practiced in various forms since prehistoric times. Indeed, proficiency in these kinds of practices was probably a primary reason for the current success of the human species. These practices can all be considered as instances of the more general area of biosystems engineering [...]. This broader perspective of biosystems engineering allows one to envision other applications of the discipline, some of which may even be purely hypothetical at this time. These might range from medical applications, to the design of androids, to altering the surfaces of other planets so that they are suitable for terrestrial life”, Kok [15].
D. Presence of undergraduate and graduate courses, with stable over time similar curricula.

There are at least 56 graduate courses named Biosystems Engineering, Biological Engineering and variants like Environmental and Biological Engineering spread worldwide, mostly concentrated in North America (36). Compared to courses in traditional branches of engineering these numbers are small, but reveal a clear and sharp trend, especially when one considers that the creation of these courses is recent, beginning in the last years of the 20th century.

Text books are strong evidences of a new scientific or technological domain. Nag’s book [14], projected to cater the needs of students, researchers, and professionals, offers an example of this kind. According to Nag, Biosystems Engineering perspective is an innovation that induces other innovations in academics as well as in industry. To stake out the territory, gave a non-exhaustive list of new technologies included in Biosystems Engineering: precision systems for irrigation, production, and harvesting; a new system for bioenergy production; advanced packaging systems to maximize product quality; recycling of materials and prevention of emissions to protect the environment; and information technologies to optimize bioprocess strategies.

III. TECHNOLOGICAL COMMUNITY.

A. Presence of professional associations and organizations.

One observes the creation of new organizations as well as the repositioning of existing organizations that bring together professionals, academics and students in the areas that gave rise to Biosystems Engineering. In the United States operate several professional organizations Biosystems, including the American Society of Agricultural and Biological Engineers (ASABE), the Institute of Biological Engineering (IBE), and the Society of Biological Engineers (SOAR). In the UK, the community of Biosystems Engineering is housed in Bioengineering Society. In Canada, was established Canadian Society for Bioengineering (Société Canadienne Agroalimentaire de Génie et Bioingénierie).

Education & Research in Biosystems Engineering in Europe (ERABEE) is a network of representatives from universities that maintain courses and research programs in Engineering Biosistem in the European Community.

B. Presence of specialized journals.

A landmark of the emergence of the field of Biosystems Engineering was the change in name of the Journal of Agricultural Engineering Research, which was renamed Biosystems Engineering in 2001. The editorial of the first issue under the new name is enlightening: since the Green Revolution, the role of agriculture has changed, and Agricultural Engineering has changed with it. From provider of food and raw materials, agriculture assumed new roles, as a provider of environmental services, leisure, landscape and energy source. The rural areas in the same direction, assumed new functions. “Heightened public perceptions of global issues affecting the food chain, climate change and major ecosystems are transforming research initiatives. Within the Western World, the percentage contributions of agriculture to National Economies are declining. In consequence, the profile of agricultural engineering is also changing through diversification of product across other land-based industries and in comfort and leisure facilities. Food production from the land is being partially replaced by industrial crops or forestry, and there is much greater emphasis on the synthesis of integrated biological systems. Biological systems are more universal than the subset applied to agriculture. And the Interest Fields indicating the scope of the present journal already extend beyond the constraints of agriculture. The original title of the journal encapsulated the demands for engineering associated with agricultural production in the 1950s and the choice of name has stood the test of time for almost 50 years.”

The different agricultural and non-agricultural services offered by rural areas share the fact that they are products of biological systems. The common basis of interdisciplinary knowledge necessary to understand the functioning of biological systems approach combine branches of Engineering focused on specific economic activities such as agriculture, forestry, and environmental. The demarcation of the fields follows the division of labor, and not necessarily the logic of the required knowledge base.

The new technological domain is defined by its object, ultimately non-human biological systems or biosystems. To understand, model and make interventions in these systems, a wide set of concepts and instruments is borrowed from Biology, Physics, Chemistry, and Engineering. The goal is to improve the performance of biological systems evaluated according to environmental, social and economic criteria. Biosystems Engineering is thus defined as research in physical sciences and engineering to understand, model, process or enhance biological systems for sustainable developments in agriculture, food, land use and the environment.

The School of Biosystems Engineering, in Dublin, publishes the journal Biosystems Engineering Research Review, that encompasses Food Engineering, Natural Biological Resources, and Environmental Engineering areas.

Bioprocess and Biosystems Engineering is published by Springer Verlag since 1986. Like Biosystems Engineering, the former Bioprocess Engineering was renamed in 2000. In the first issue under new name, the editors stated that from then the focus on multidisciplinary approaches in design of integrative process, based on hierarchical structures and modularity of biosystems would be reinforced. Again, the name change is enlightening: the focus shifts from isolated processes to systems that integrate multiple processes.

C. Knowledge domains mobilized in professional practice.

Arthur [1] suggests that the identification of technological domains can be carried by assigning its elements and the manner by which these elements are connected. Science and technology are among many different fields of human activity intentional systems, in which elements or subsystems are disposed in order to perform tasks oriented to achieve some definite end. Science and technology are intentional systems supported by phenomena. Both start with assertions about physical or social external world.

The phenomena that support the operation of intentional systems are one of the distinctive features of knowledge
domains. Biological systems are complex, characterized by a very large number of potentially relevant variables. Besides the astonishing number, the system variables relate to each other in a complex way, with feedback effects, and cumulative dependence on trajectory. This scenario poses for the "new" field of Biosystems Engineering and its practitioners, both a challenge and an opportunity. Considering the challenge, it is necessary to understand that the class of problems claimed by this specialization of engineering is defined essentially as belonging to the domain of "nonlinear systems". This means that the best contributions of Biosystems Engineering will be in their ability to solve complex problems, uncertain outcomes; containing feedback loops; disproportion between cause and effect; chaotic behavior, etc.. Right here lies the opportunity, from an academic and occupational view, to establish a field of knowledge that crosses different disciplines. As Kok [15] pointed out, "Biosystems are defined as adaptive, complex, dynamic systems that are alive to some degree […] Nonlinear dynamics and complex systems theory are also very applicable to the current understanding of large scale biosystems, and so these topics are also briefly touched upon. Finally, the definition of biosystems used here specifies that they are living entities in their own right". According to Kok [15], biosystems are composed of dissipative structures, in other words, self-organizing systems, or autopoietic systems. In such a system, elements or parts are able to transform or produce other parts, in a way in which the system continuously changes itself. This attribute of biosystems results in the emergence of path dependence and high sensitivity to initial conditions. Face the huge amount of information embodied in biological production systems, technologies massively adopted until recently used a very small available subset of information. In a historical perspective, however, Green Revolution farming technologies were efficient; despite sporadic outbreaks of animal and plant diseases, food contamination and depletion of natural resources. Before the availability of low price information processors, it is possible that the low amount of information needed to operate agriculture technological packages was one of the sources of its success. The intensive use of information latent in farming systems can contribute to improve the performance of agriculture evaluated by productivity gains and risk reduction. According to the selective pressure in the environment, the answer will depend on the balance between the costs of obtaining and processing information and the benefits generated by using the information, among then the expected productivity gains, the expected environmental benefits, and the meanings assigned by social groups affected to the new technology. The challenge facing the biosystems engineer is to identify the information which monitoring and control has the potential to increase productivity and / or reduce risks in agricultural production, and then develop techniques for the productive use of information. Information technologies have intense and continually lowered the cost to collect, store and process information, which creates opportunities for economically viable uses of underutilized information in agricultural production so far.

IV. CONCLUSIONS
Common sense wisdom according to which the technology is “applied science” is not supported by any theory of technology. It does not hold, due to epistemological reasons (it is not possible to deduce the structure of an apparatus from the phenomena that support its operation), as well as for historical reasons (for a long time, technology was at the forefront of science). Relevant innovations arise with "redomaining" a technological problem, ie, proposing a new solution based on different domain than that had been required to provide material for the "traditional" solution. Information technology, for its flexibility and generality, opens up endless possibilities of "redomaining".

The emergence of new technological domains often follows from the split of a previous field, due to the specialization in problems, specific methods or techniques. Thus, for example, Electronics has emerged as a specialized branch of electrical technology. In the case of Biosystems Engineering, a process of merging of former separate domains, but with substantial overlap, is going on. According to Morin [16], in the 1950s there was a convergence between information theory, with Shannon Weaver (1949); cybernetics, with Norbert Wiener (1950) and molecular biology from Watson and Crick (1953). He says that since then, "biology also had to resort to principles of organization that were unknown to Chemistry, like the notions of information, code, message, program, communication, inhibition, repression, and expression control. All of these concepts have a cybernetic character, since they figure the cell as a self-regulated and informationally controlled machine." Arthur [1] notes that it is common during the process of redefinition of a technological field the persistence of some confusion between domains and technological communities. We identified three distinct conceptions of Biosystems Engineering, quite possibly correlated with technological areas of origin of the professionals involved:

(i) Biosystems Engineering as the fusion of Agricultural Engineering, Forestry and Environmental, motivated by reducing the weight of agriculture and the new roles that the rural areas assumes in developed economies;
(ii) Biosystems Engineering as the application of Information Technology to management systems in which (nonhuman) living beings occupy a central role;
(iii) Biosystems Engineering as set knowledge and techniques required to intervene in the "living systems" , ie complex systems with the ability of self-organization.

The difference of the latter conception in relation to the foregoing refers to how the object is modeled, not the object itself. Complexity or simplicity are the property of symbolic representations of objects. If, for example, the soil is depicted as a passive time invariant substrate, this model will do for mechanization, whereas if the ground is represented as an element that interacts with living beings, and this interaction explains the dynamic of soil-living beings system (see an example of this approach in Latour [17], chapter 2, we should be embracing the third conception of Biosystems.

The lack of a consistent theoretical framework about technology (and innovation) may contribute to the inefficiency of the policies of technological development, as well as
deficiencies of professional training processes. Driving forces external to just the technological field can play a role: Lattuca et al. [18] describes a deep change in the evaluation of undergraduate engineering programs induced by labor market. The curricula of undergraduate Biosystems Engineering are influenced by how different actors represent this nascent field - it is possible that under the same name coexist profoundly different educational proposals.

REFERENCES