The Holonic Perspective in Management and Manufacturing

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[Abstract] The notions of holon and holarchy (the hierarchical ordering of holons)—formally introduced in 1967 with the publication of Arthur Koestler's *The Ghost in the Machine*—are more and more frequently found in the literature of management science, organizational studies, business administration, and entrepreneurship. By systematically applying the whole/part conceptual relation, we can reconsider the very same ideas of organization, management, and manufacturing. Connected to these ideas are those of holonic networks, holonic and virtual enterprises, virtual organizations, agile manufacturing networks, holonic manufacturing systems, fractal enterprise, and bionic manufacturing.

[Keywords] Holarchies, holonic networks, holonic organizations, holonic manufacturing systems, bionic manufacturing, systems, fractal manufacturing systems

Introduction

In the world of firms, management, and control in general, a silent conceptual movement has been under way for less than forty years now, beginning in 1967 with the publication of Arthur Koestler's *The Ghost in the Machine*, which formally introduced the concepts of holon and holarchy, which is conceived of as a hierarchical structure of holons (Mella, 2005).

According to Koestler (1967) and Ken Wilber (1995)—who tried to generalize the holonic perspective—in observing the universe surrounding us (at the physical and biological level and in the real or formal sense), we must take into account the whole/part relationship: any observable unit is at the same time a whole—composed of smaller parts—and part of a larger whole. By systematically applying the whole/part conceptual relationship, or the equivalent one of container/contained, the universe appears to us as a hierarchy of holons: that is, as a holarchy. The entire machine of life evolves toward increasingly more complex states, as if a ghost were guiding the machine.

Since then, the concepts of holon and holarchy have been adopted, especially in recent times, by many authors from a variety of disciplines and in different contexts and have been rapidly spreading to all sectors of research. After discussing the original meaning, this short theoretical essay will examine in what sense the holonic view is spreading to the field of management, business administration, accounting, organization theory, and manufacturing systems.

Holons and Holarchies

Holon – which derives from the combination of the Greek "holos," which means "all," and the suffix "-on," which indicates the neutral form and means "particle" or "part" (as in proton, neutron and electron) – is the term coined to represent the basic element of the *holonic view,* which considers relevant not so much the connection among elements as their inclusion in each other.

> *Parts and wholes in an absolute sense do not exist in the domain of life... The organism is to be regarded as a multi-leveled hierarchy of semi-autonomous sub-wholes, branching into sub-wholes of a lower order, and so on. Sub-wholes on any level of the hierarchy are referred to as holons*. (Koestler, 1967: Appendix I.1)

Koestler viewed the *holon* as a *Janus-faced entity*: if it observes its own *interior,* it considers itself a *whole* formed by (containing) subordinate *parts*; if it observes its *exterior,* it considers itself a *part* or *element* of (contained in) a vaster *whole*. However, in observing itself, it sees itself as a s*elf-reliant* and *unique* individual that tries both to survive (it is a *viable system*) and to integrate with other holons:

> *These sub-wholes—or "holons", as I have proposed to call them—are Janus-faced entities which display both the independent properties of wholes and the dependent properties of parts.*

> *Each holon must preserve and assert its autonomy; otherwise, the organism would lose its articulation and dissolve into an amorphous mass—but, at the same time, the holon must remain subordinate to the demands of the (existing or evolving) whole*. (Koestler, 1972: 111-112)

Each holon includes those from lower levels, but it cannot be reduced to these; it *transcends* them at the same time that it *includes* them, and it has emerging properties (Edwards, 2003). In attempting to interpret the nature, structure, and dynamics of biological and social systems (organizations), Koestler defines a holon as an entity that is, at the same time: 1) *autonomous*, in that it tries to survive as a viable system (Beer, 1979, 1981; Maturana & Varela, 1980); 2) *independent* (self-reliant); that is, characterized by a *self-assertive tendency*; 3) *dependent*; at the same time, since it is subject to some form of "control" by the superordinate entity, as it is important for the survival of the vaster structure that includes it (Capra, 1982); and 4) *interactive;* that is, vertically connected to the superior and inferior entities and demonstrating an *integrative tendency*.

Ken Wilber (1995), thirty years later tried to generalize the idea of a holon by pointing out its relative and conceptual nature. "The world is not composed of atoms or symbols or cells or concepts. It is composed of holons" (Wilber, 2001, p. 21).

According to Wilber, the holon must have four basic characteristics: a) *Self-preservation* (agency), in order to maintain its own structure "as such" (pattern), independently of the material it is made up of; b) *Self-adaptation* (communion), so that it can adapt and link up with other superordinate holons in order to react mechanically, biologically or intentionally to their stimuli; c) *Self-transcendence*, the holon has its own characteristics and qualities, which are new and emerging; the universe is not only dynamic but also "creative", since it makes new properties emerge for subsequent inclusion in superordinate holons and creates new classes of holons; d) *Self-dissolution*, the holons break up along the same vertical lines they followed when they formed.

Due to their Janus-faced nature, holons must necessarily be connected to other holons in a typical *vertical arborising structure* known as a *holarchy,* which can be viewed as a *multi-layer* system (multi-strata) (in the sense of Mesarovic, et al., 1970) or *multi-level* system, with a tree-structure (Pichler, 2000) as shown in Figure. 1.

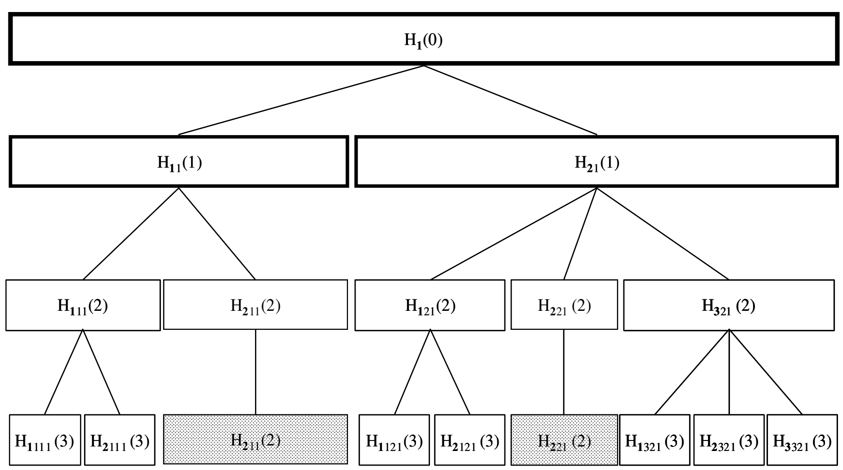

Figure 1. Model of a multi-layer Holarcy *(The holons in the grey cells are virtual holons)*

Source: Presentation of Mesarovich's schema (1970).

Each holon is a *head* holon for the subtended part of the branch and a *member* holon for the upper part. The *completeness* principle (Mella, 2005) must in any event apply in the multi-layer holarchy: each subordinate level represents holons, which are less extensive and which are recompressed into the holons at the superordinate level (*arborisation* effect), it being understood that all the base holons must be included in the final holon. It is relevant to observe that holarchies are not holons but arrangements of holons that represent conceptual entities whose function is to bring out the essentiality of the vertical interactions among holons as shown in Table 1.

Table 1. Holarchies everywhere. Examples of holons and their levels. Source: Turnbull (2001).

	DISCIPLINE/ SUBJECT	FIRST LEVEL	SECOND LEVEL	THIRD LEVEL
1	PHYSICS	Particles	Atoms	Molecules
2	CHEMISTRY	Molecules	Compounds	Bases
3	GENETICS	Bases	DNA	Genes
4	BIOLOGY	Genes	Chromosomes	Cells
5	ANATOMY	Cells	Organs	Individuals (Biota)
6	ENVIRONMENT	Biota	Ecological systems	Gaia (Earth)
7	ASTRONOMY	Earth	Solar system	Galaxy
8	SOCIOLOGY	Individuals	Families	Communities
9	ORGANISATIONS	Cells/divisions	Firms	Keiretsu /groups
10	MONDRAGÓN COOP	Work groups	Social council	General assembly/co-op
11	MONDRAGÓN SYSTEM	Cooperative	Cooperative groups	Mondragón Corporación
12	VISA CARD	Geographic unit	Member bank	VISA International
13	GOVERNMENT	Communities/towns	Regions/States	Nations
14	ENGINEERING	Components	Sub-assemblies	Machine
15	SOFTWARE DESIGN	Sub-routines	Routines	Object-oriented programs

Koestler's OHS and Wilber's Kosmos

Koestler conceives of the *holarchy* that orders all the biological beings or the social organizations as an Open Hierarchic System (OHS), a holarchy viewed as a vertical system of ever larger cognitive units possessing consciousness (and reproductive capability) in which a holon from a given level includes and coordinates those from a lower level and sends the information necessary to shape the superordinate holon.

In the OHS, all the holons of a given level include and coordinate, by means of their cognitive processes, the holons of the lower level, as well as transmit the necessary information to construct the superordinate holon, which transcends them, thereby producing different processes which *trigger* a dynamic evolutionary process.

In this sense, Koestler views the holarchy as able to self-organize its changes, producing cognitive performances and becoming a type of *machine* that produces general progress in living things through the self-organization of the holons, as if there were a *ghost manipulating the machine* (*The Ghost in the Machine*). In his "metaphysical" view of evolution towards the consciousness that characterizes man and his *social groupings*, Wilber conceives of the Kosmos as a general *cognitive holarchy* (Ashok, 1999).

Thus, the Kosmos tends towards improvement, since the individual holons interact and evolve, in part through *creative changes,* with the awareness that the improvement in their *integral and essential health* is a positive factor. Wilber spells out *Twenty Tenets* of evolution (Leonard, 2000), the most relevant of which are *Tenet 3* and the correlated *Tenet 4*, which state that in nature holons appear spontaneously with an holarchic form, in a chain of *whole/part* or *containing/contained* relations. The holons emerge not so much in the form of increasingly larger structures but as compositions of structures that have new and emerging properties.

From Cognitive Holarchies to Modular Holarchies

Koestler's OHS and Wilber's Kosmos are two important *cognitive holarchies*, since in these cases holons are basically conceived of as *cognitive units*, biological in particular (or more precisely, as *levels of awareness* of these cognitive units). We can indentify a different type of holarchy—the *operative* or *modular* holarchy—composed of *holons* understood as *elementary operating agents*—or holonic *modules*—vertically interconnected by their input and output flows so as to form a multilevel operating system of increasingly larger nested components. An *holonic module* can be observed, or defined, as an operational unit—biological, mechanical or informational—capable of producing any type of process at given levels of efficiency under conditions of limited resources by coordinating with other units in the attempt to remain vital in terms of functions and functionality. The most general *operational holarchy* is the one that forms in the decomposition of *Finite State Machines* (FSMs) into a ramified succession of machines operating in parallel and arranged on several *levels,* so that at each "*stratum*" of the holarchy the modules of that *level* always represent the entire machine.

Modular holarchies also represent the typical model of ramified sequential processes carried out by *holons* made up of subsystems of agents that operate *in parallel* at different levels in all types of organizations. *Modular holarchies* are typical both of vertical structures formed by human agents in organizations and those formed by modular machines used in production processes: both physical operations and the calculation and sequential processing of data and information, estimates and impulses (pumping networks in oil pipelines, modular networks, the nervous system, arterial and veinous structures, etc.).

Shimizu's Cognitive Computer

An interesting multilevel operational holarchy, in which a complex task is broken up into partial tasks carried out by operational elements that form a complete machine, is that described by Shimizu (1987), who introduced the idea of *bioholonics* as a discipline that studies holonic applications in biology and theorized about the construction of an *autonomic cognitive computer* conceived of as a *holarchy* of holonic modules that process information in parallel. The *cognitive computer* produces an organized synthesis, which becomes increasingly more complex, of a mass of elementary information from the base holons (*microscopic level*) that is synthesized by the higher-level holons until the *bottom holon* is able to produce a *semantic* formula to give meaning to the final synthesis.

> *In a cognitive computer elementary signals are related to each other to generate organized information. In this process, relevant correlations between elementary signals are discovered also with the neglect of some correlations. In other words, semantic correlations are found in the assembly of elementary signals. We shall call autonomic unit processors for elementary signals, or semantic correlators of elementary signals, "holons". The holons are local-rule generators* (Shimizu, 1987, p. 211).

The stable holarchy of processors, understood as a *correlator* among signals from different levels, is a *cognitive computer* if its construction, from the highest to the lowest levels, is subsequent to the semantic analysis of the *bottom holon*; it is a true holon if the processors of the higher levels are *spontaneously* created *by* the same lower level modules, as seems to have occurred in the gradual evolution of inanimate nature toward an intelligent form, or in the gradual hierarchical development of groups and of social and political structures.

Stock Exchanges and Cost Accounting Processes as Examples of Cognitive Computers

A simple and relevant holonic system, whose operational logic is similar to that of a *Cognitive Computer* in Shimizu's sense, is the *Stock Exchange*, viewed not as a market for the exchange of securities but as a progressive integrator of transaction values as described in Figure 3, which produce the dynamics of the stock exchange, often chaotic and explosive (speculative bubbles), that we often observe.

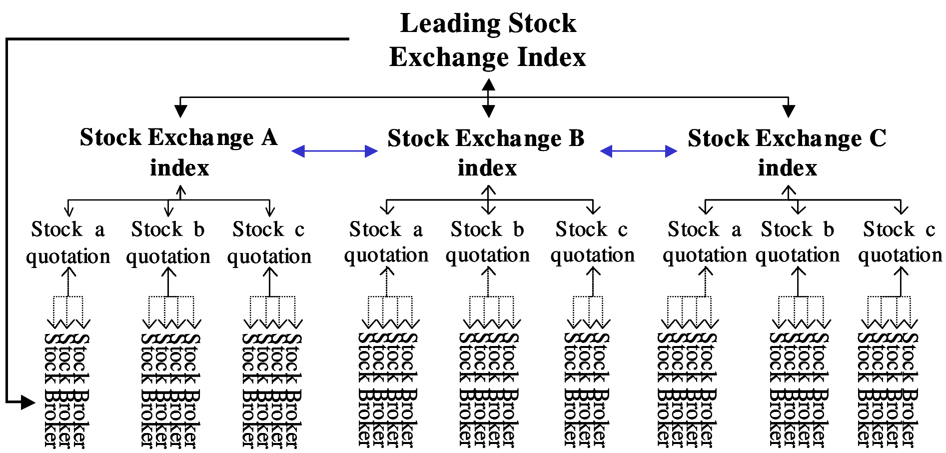

Figure 3. The Stock Exchange as an Autonomic Cognitive computer

A second interesting type of holonic system that is similar to a *Cognitive Computer* is the process for determining the cost of production through identifying and subsequently assigning elementary costs to categories having an autonomous significance (Mella, 2006). The cost of inputs represents the elementary costs, which are identified by operational sensors and can be assigned to the *base holons*. The overall production cost for the firm can be thought of as the *final holon* in the process involving the progressive accumulation of costs determined for the lower level holons (Fig. 4). Between the base and the final holon there is an expanding holarchy of subsequent intermediate cost synthesis: the costs of inputs (materials, components, services, tangible assets, etc.) are attributed to the volumes of production by *gradually accumulating them* from the *activities* necessary to obtain these same volumes and then allocating the costs of the activities to the finished products by means of specific *cost drivers*.

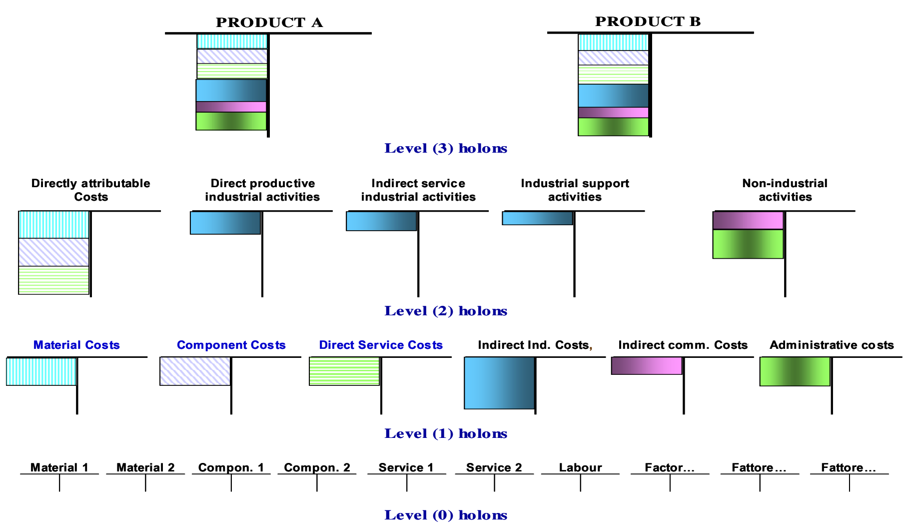

Figure 4. Holarchy Representing the Cost Syntheses of the ABCM

Organizations as Modular Holarchies

According to the *holonic* point of view, each member of the organization can be considered a *base holon* (in both Koestler's and Wilber's sense); the member-holon is a whole if observed as an organ and a part if observed as a component of a larger organ. Moreover, several similar elements can be included in *modules* that constitute organs so as to form a modular systemic structure conceived of as a *holonic organization* as shown in Figure 5.

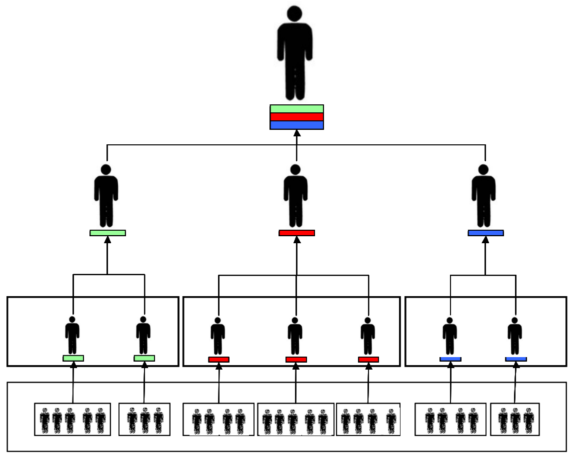

Figure 5. Holonic Organization
(The underlined icon indicates the range of functionality Source: Mella (2005).

According to these interpretations, an *holonic organization* can be viewed as a macro system set up to achieve a macro objective. We can thus immediately compare it to an *Autonomic Cognitive Computer* of cognitive holons that gather and coordinate information and make decisions (Fox, 1981). These holons make up a *cognitive* and *modular* holarchy where each organ/holon of a given level is an autonomous information and decision-making entity whose decisions influence those of the lower-level organ/holons and comprise those of the higher-level organ/holons, following a *pull* or *push* approach depending on the type of organization.

Nevertheless, there is a basic difference between the *holonic organization* and the *holarchy of organs* that comprise it which has not been fully exposed in the literature: the *holonic organization* does not correspond to the holarchy of its own organs but represents the *final holon of the holarchy*, possessing an *interiority* and *consciousness* that is *centered on* the maximum cognitive organs, which include and transcend the component *functional organs/holons* at the various levels of the holarchy (Mella, 2005).

Holonic Networks as Horizontal Arrangements of Holons

According to the Janus-faced view, a holon maintains its characteristics as a conceptual entity (unity, autonomy, interiority) even if it is considered to be part of a *network of horizontal relations*—with holons of the *same level*—that can be called a holonic network. Each holon acquires its existence and meaning from the connected elements that are observed as *antecedents* (before) and that make it up, and, at the same time, from the connected elements that are observed as *successive* (after) and that the holon helps to comprise. I shall examine the following examples of holonic networks:

1. Holonic Manufacturing Systems
2. Bionic Manufacturing Systems
3. Fractal Manufacturing Systems
4. Agile Manufacturing Systems
5. Inter-Company Networks
6. Virtual Organizations, or Agile Manufacturing Networks.

Holonic Manufacturing Systems

The *Holonic Manufacturing Systems* (HMS) are operational modular reticular holarchies (Schilling, 2000) typically found in the manufacturing or transport industries (Kawamura, 1997; Jacak, 1999). In this case, the holons are *machines* that form increasingly larger structures (parts of successive structures) that carry out elementary processes that are often arranged in modules of identical machines. Holons at a given level carry out processes that derive from those produced by holons arranged *before* or *below*, and the holons are necessary for the processes of those positioned *after* or *above*. HMSs deal in the field of the Intelligent Manufacturing Systems (IMS) programme proposed with the objective of creating a manufacturing science that can meet the needs of an increasing population of consumers.

To study the HMSs a Consortium was created that defined the technical, informational and operational specifications necessary for a network of machines to be considered an HMS. The "technical specifications" of the *HMS Consortium* (http://hms.ifw.uni-hannover.de) define a *holon* as "An autonomous and cooperative building block of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects", possessing *autonomy* (the capacity to create operational plans and strategies and to control their execution) and capable of *cooperating* with other nuclei (Adam, et al., 2002), in addition to having technical and informational attributes that allow it to plan and carry out its functions and to coordinate with the other holons (Stylios, et al., 2000).

A set of *blocks* that process materials in parallel or produce similar services form a *module*; several modules can comprise a superordinate holon that, in turn, can be included in other *blocks* at a higher level. The Holonic Manufacturing System is the "holarchy that integrates the entire range of manufacturing activities from order booking through design, production, and marketing to realize the agile manufacturing enterprise."

In a minimal configuration, an HMS for a market-oriented manufacturing firm includes three types of holons: product holons, which are the products in the catalogues and their components (sub-holons); resource holons, which specify the resources available for production; and order holons, which identify the market demand (Wyns, 1996). These holons comprise a holonic network that takes the form of an HMS, as shown in Figure 6 (other models that imply a greater number of holons are indicated, for example, in Kanchanasevee, et al., 1997).

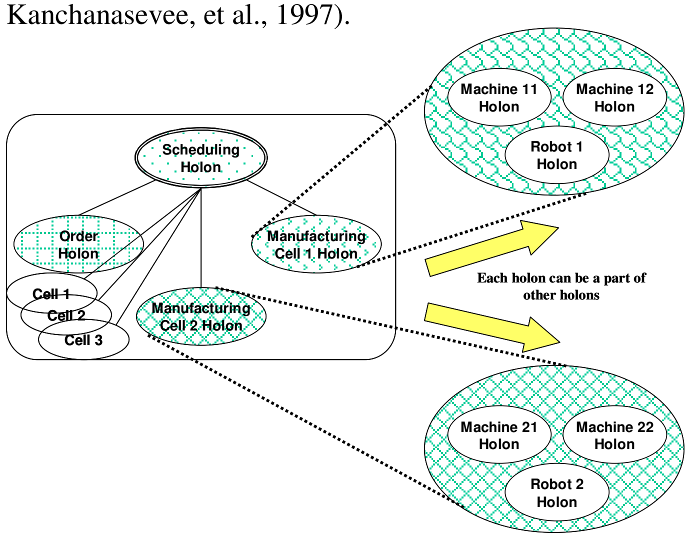

Figure 6. Holonic Modules of an Agile Manufacturing System

Bionic Manufacturing Systems

A *Bionic Manufacturing System* (Okino, 1989; Tharumarajah, Wells, & Nemes, 1996) is a special *holonic network* of production units similar to an HMS but conceived of as an interaction of elementary *operator holons* that are absorbed into autonomous cells that, in turn, are grouped into *modules*, similar to organs, and arranged in various hierarchical levels to form a holarchy similar to a biological organism. By means of the increasingly complex operations occurring at the various holarchic levels, the final holon is able to carry out some high-level operations, functions or process as specified in a *model* that "reproduces" the final result (the finished product represents the model "of itself"). The unique feature of a *Bionic Manufacturing System* is the fact that the operational units—or their groupings—are capable of autonomously deciding not only the processes to carry out but also the inputs and the output volumes needed based on two types of information that guide its activity: 1) The *primary information* is represented by that *portion of the complete model* that must be produced by each of the operational units; this *portion of the model* gains significance from the parts the subordinate units must produce, and in turn represents a part of the model which the superordinate operational units must realize. Each part of the *model* is to be conceived of as a *holon*; it is a *model/holon* that, together with the entity that produces it, is called a *modelon*. 2) The *secondary information* is comprised of the state of the processes carried out by the production units at both the same and higher levels.

Thus, the *Bionic Manufacturing System* functions as a top-down holarchy that operates according to the logic of an *Autonomic Cognitive Computer*. The *final* (or *parent*) *modelon* is both the model to be constructed and the entire *Bionic Manufacturing System* (processor system) that produces it, and of which it constitutes the terminal semantics. The *parent modelon* is broken down into second-level *sub-modelons,* and these, in turn, into third-level *sub-sub-modelons*, and so on down to the base modelons formed by elementary operational entities which themselves are considered basic processor holons as described in Figure 7.

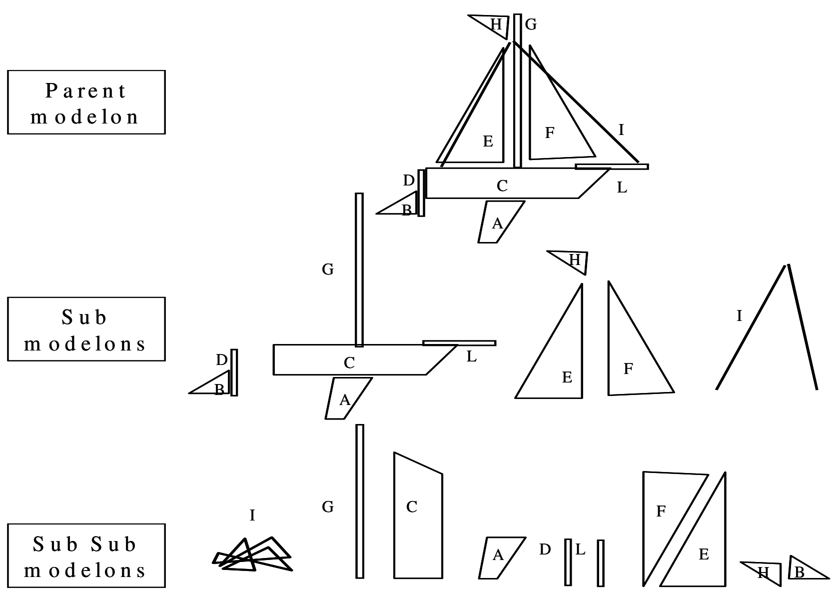

Figure 7. Holarchy of Modelons in Bionic Manufacturing System

At the various levels the operational units are coordinated by units of coordination that—by devising strategies, plans, programmes, and procedures to regulate all the production units—function as enzymes (short-term) and hormones (medium-term) do in biological systems. If the need arises to strengthen the system, the *bionic system* can also develop either through annexing other entities with the same technical and functional specifications as the module entities that need strengthening, or through the creation of smaller entities at a lower level in the holarchy, to which the same *modelon* and the same operational capacity of the original entity is transmitted through a mechanism similar to that of the transmission of DNA.

Fractal Manufacturing Systems

A different type of holonic structure are the Fractal Manufacturing Systems (Savage, 1996; Warnecke, 1993), which are complex holarchies, typically bottom-up, formed by autonomous modules whose operational logic is repeated at various vertical levels, as a fractal, reproducing at each level the characteristics of the entire structure. The holonic nature of these structures is not so much found in the processors (usually men or men-machine production units that self-coordinate) as in the subdivision of responsibilities in terms of the objectives they must pursue.

All the high-level objectives—conceived of as *final holons*—are pursued through the recursive attainment of lower-level objectives, which are, in turn, subdivided into sub-objectives, down to the primary operational entities which are assigned smaller objectives, conceived of as *primal holons*. At each level every operational entity is responsible only for the objectives of that level, and, thus, must coordinate with the other entities at its level which, on the one hand, are set up to achieve the subordinate objectives, while on the other are components for the attainment of higher-level objectives. An efficient information system must underlie the functioning of a *Fractal Manufacturing System*, since each fractal entity must be able to coordinate with the other entities, which can be achieved only through monitoring in real time the state of the attainment of the objectives of the other entities at the same level.

Agile Manufacturing Systems

According to the holonic approach, *Holonic, Bionic* and *Fractal* Manufacturing Systems are different forms of production organizations whose objective is to create *agile manufacturing systems*; that is, atomised, highly-flexible production systems—making wide use of machines, robots, work-cells and labour units—that are able to deal with the rapid changes that all the mechanized-production manufacturing enterprises, flow or special order, must face: variety and uncertainty of demand, changes in tastes, reductions in the life cycle, and the need to reduce *time to market*. The basic operational entities that characterize such Manufacturing Systems can be considered as *processor holons* that form a holarchy or an operational holonic network, but on the condition that their functioning is viewed as instrumental for the achievement of *information holons* of some type (models, objectives, decisions, responsibilities, and so on) that have a lot of variety and variability over time.

Interfirm Holonic Networks and Holonic Firms

In general terms, the *production* or *enterprise networks* are *holonic networks* comprised of autonomous firms that are variously located—characterized by different roles and different operations (Grandori & Soda, 1995; Gulati, 1998; Dyer, 1997) but integrated in terms of mission, vision, and aim of their common businesses—and connected through an *holonic network*, real or virtual, often oriented, in order to achieve a common objective through the sharing of resources, information, and necessary competencies, without any hierarchical constraints of subordination (Håkansson & Snehota, 1995; Kinoshita, et al., 1997).

In the Japanese literature the *holonic networks* are also called *holonic firms* or *enterprises,* or *holonic organizations*, and in North American terminology *virtual firms* or *virtual enterprises*. In fact, they are *organic networks.* Cooperation among the holonic components of the network is carried out through a guiding firm (nodal firm). We must emphasize that in the holonic networks the holons are not, in fact, the interconnected organizations but the capacities (functionalities) that result from the stock of know-how, information, resources and competencies that they possess and that find common meaning and functionality precisely from the reticular interconnections. Thus the *holonic network* has a similar function to that of an *Autonomic Cognitive Computer* or a *Bionic Manufacturing System.*

Agile Manufacturing Network

Due to the flexibility that characterizes them, holonic networks represent the most efficient means for creating an *agile manufacturing network* (Huang, et al., 2002), an *holonic production system* (similar in inspiration to an Agile Manufacturing System) which is flexible and open to the needs of the market and able to plan, carry out, and market various product models to satisfy in real time the demands of clients from all the participating entities (Youssef, 1992).

The various operational units that comprise *the manufacturing network* can fully be considered holonic organizations, characterized by an autonomous existence, a decision-making capacity (consciousness), and a willingness to accept coordination. If the relations among holons is achieved through an information network, the organizational network becomes a true *virtual organization*, in the form of both a virtual firm whose cognitive and operational boundaries are not clear, defined only by the interconnections (Davidow & Malone, 1992), and a network of common competencies put together in an opportunistic way by autonomous and independent holons that are virtually connected (Goldman, et al., 1995).

Present-day ITCs also allow us to conceive of purely informational networks in which the component holons are connected by information flows and not production flows. In this case the network becomes a communication network (D'Amours, et al., 1999), similar to a *neural network*, which can develop both knowledge that transcends that possessed by the individual connected entities, as well as, possibly, consciousness, thereby favouring the development of the *Networked-Digital-Economy*.

Conclusions and Challenges

One of the upcoming challenges is to examine those holarchies formed by control systems, which are systems that guide the variables towards the achievement of some objective or the respect of some constraints by measuring and cancelling the variance through one or more control levers (Mella, 2008).

Where are the Control Systems? Their presence is ubiquitous. They are within us and everywhere around us. We must be able to identify them by zooming out to catch the extreme variety, richness, and importance of the macro Control Systems, as well as zooming in to catch the infallible effectiveness of the micro Control Systems, which are so essential to life. We will realize that we are formed by Control Systems, surrounded by Control Systems, that we can exist and live thanks only to the Control Systems that regulate our environment and entire ecosystem; the world is made up of Control Systems interconnected in various ways and interacting with other systems at the same level, or at a superordinate or subordinate level.

When we observe Control Systems from an holonic perspective, we can view the holarchy of Control Systems that make up our world as an entity that produces a continuous improvement, allowing us to increase the variety and strength of the possible controls and the scope of the attainable objectives. Echoing Koestler, we can, thus, consider the holarchy of Control Systems as an Open Hierarchic System, a machine that produces general progress in life through the two-dimensional improvement—upward and downward—in the holons-Control Systems, as if there were a *Ghost in the Machine*, thereby producing an inevitable evolutionary process of improvement and progress.

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