NEW FOUNDATIONS FOR THE BUILDING INDUSTRY: NINE BASIC CONCEPTS TO PROMOTE SUSTAINABILITY

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ABSTRACT

Truly sustainable solutions for the built environment must be developed using some fundamental concepts, recycling being but one of them. Other characteristics are: minimum entropy increase in the environment, metal ban from all building processes and products, high energy structures for recycling through biodegradability, bottom-up processes for high performance with minimum material usage, link between levels for the promotion of emergence, steady-state production and consumption, development of new technological solutions based on biosynthesis examples, and co-evolution of technologies and cultural values. All these concepts are intertwined in various ways, forming a new paradigm for the built environment and pointing to a new direction for technological development. This paper presents them and discusses their relationships with the concept of recycling, the possibilities of implementing them and the benefits derived from the adoption of this new paradigm.

Keywords: technological paradigm, construction technology, entropy, biologically inspired design, sustainability.

1. PRESENT DAY SITUATION OF THE BUILDING INDUSTRY

The present day production of the building industry, including industrialization of materials and components, design and construction of buildings, is entirely based on premises that can no longer be validated in today’s world. That is true whether one looks from an economic, environmental or political perspective. From the economic point of view, the concept of an ever expanding economy has shown to be fallacious, because that would require an infinite quantity of actually finite raw materials. Environmentally, it is estimated that the building industry consumes up to 60% of all resources extracted from the earth’s crust [1], thus destroying the landscape more than any other industry. Besides this, the construction industry is responsible for half of the carbon dioxide generated by human activities and dispersed into the atmosphere [2]. This industry also produces huge amounts of residues, most of which will pile up uselessly in landfills. Politically, this industry has asserted itself as one that builds huge and – by today’s standards – sophisticated buildings. However, those who actually build these buildings can only dream of occupying them, since the industry, because of its costs, must rely on low wage labor, with a large percentage of exploited immigrants (legal and illegal) in the developed countries, and on an unqualified and illiterate work force in underdeveloped ones.

So far, the remedies sought for this situation are mainly of two kinds: environmentally friendly low impact and low density technological solutions, using wood, vegetable fibers and adobe, among other materials of the same kind; and mitigation through recycling and re-use
of industrial and construction residues and by-products, in order to reduce the pressure on materials sources and the environmental impact of the building industry. However, these initiatives, although meritable in their purposes, cannot replace the enormous volume of building produced with today’s technology, either because it is characteristically low density, as in the first case, or because its materials are based on residues, and so, limited in volume.

The building industry needs a new approach, one based on premises capable of dealing with the reality of a finite and fragile Earth. Cole and colleagues have called for a new “world view” that incorporates those premises in the building practice [3]. Fernández-Solís saw the need to define the philosophical grounds where the construction industry could be founded [4], taking into consideration its specificity. In this paper, several concepts are articulated in order to, in an integrated way, found new bases for the building industry. These concepts are related to the general idea of sustainability, which can be defined as the capacity to keep, for indefinite time, essential processes that characterize a system.

2. STRUCTURING CONCEPTS FOR THE NEW APPROACH

Moser [5] created a series of concepts aimed at helping the process of designing sustainable solutions, that is, ecologically sound and technically feasible engineering solutions. Many of his concepts are closely related to the ones presented in this paper, with one coinciding: co-evolution. Thomas J. Hahn has also proposed a new approach for the design of buildings, taking nature as reference [6]. This is extremely important, but it is not sufficient, because we cannot just mimic natural solutions. There are many other considerations to be taken, as it will be seen ahead.

The concepts presented here are not homogeneous in their amplitude. They were built upon a variety of sources. However this does not permit the illusion that they cannot be brought together to form a consistent and meaningful vision of what shall be the guidelines for the building industry as a sustainable activity.

Nine concepts were considered the fundamental ones (that is, underived from any of the others) and each of them received a section dedicated to their analysis. These concepts are: minimum entropy increase, recycling, emergence, biologically inspired design (BID), high energy structures, metal ban, steady-state, bottom-up technologies, and co-evolution. All these concepts are interrelated in different ways and have different levels of applicability, meaning that some of them will have a straightforward way into the design and construction processes, while others will have a more indirect influence on processes and decisions. Their combined use will hopefully produce what one could call super-high-tech solutions. These solutions are not feasible at this moment, for a series of reasons. But to pursue them, it is necessary first to clarify the meaning of the basic concepts.

2.1 Minimum entropy increase

Today, the main locus of the building industry activity is the city, so it will be taken as the system to be analyzed. The entropy of the city should not vary, in order to maintain it organized and viable. However, its natural trend is to increase its entropic level. Consequently, to avoid this increase of entropy within the city, it is transferred to outside the

1. Moser elected the following concepts as principles to be followed: diversity, interdependence, material cycles, energy flow, flexibility, co-evolution, area, dual nature of living systems, durability/ sustainability, and chaotic elements are always part of nature.
city. In this way, the sustainability of the city is obtained through an increase of entropy outside its borders. The physical condition of remaining at the same entropic level is called steady-state. It occurs not only in the city, but in all systems that promote their own sustainability and do it through an entropy increase outside their borders. That is valid for systems within the city (like a building, a tree or a person) and for systems outside the city. However, all entropy increase that is transferred to outside the city jeopardizes the stability of the systems located there.

This transference of entropy may or may not be accounted for in monetary terms. If not so, it is defined as an externality, an economists’ term to define costs that are not paid for [8]. The existence of externalities in a process distorts the decision process if it is based on monetary value [9]. It also promotes the accumulation of a sustainability debt that eventually will have to be paid. So, to reduce the extension of damage, a minimum entropy increase must be sought in all processes that occur within the city. That is to say that all entropic increase that can be avoided, will not have to be transferred to outside the city’s borders, and consequently will not affect the environment. In order to understand – in general terms - how that can be done, it is necessary to look at the concept of entropy more closely.

Entropy is an essential concept in Physics, closely related to the concepts of energy and work. In accordance with the second law of thermodynamics, the entropy of an isolated system tends to increase until this system arrives at equilibrium, that is, until it does not have any capacity left to produce work. In fact, entropy can be defined as the incapacity of the energy contained in a system to produce work, that is, the lesser the availability of “useful” energy, the greater the entropy of the system.

This powerful concept can be used as a parameter in the evaluation of production processes and their results [10]. However, it is not frequently applied to the analysis and proposals to deal with the built environment. Kigawa and Furuyama [11] developed the concept of ‘urban entropy coefficient’ which tries to measure the degree of tension between the spatial form of the city to remain unaltered (a city of rituals) and the need to change in order to adapt to the new activities (a city of games).

The relation between the concepts of energy and entropy is important for the understanding of sustainability. However, measuring the energy of a system does not automatically elucidate how to evaluate its entropy. Different forms of energy can enter in a system, within which they can be accumulated, transformed and/or transported, and then leave this system. All these processes occur in different ways for different types of energy, with diverse implications for the level of entropy of the system and its surroundings. The common characteristic of all these processes is that, according to the first law of thermodynamics, no one of them is 100% efficient, which means that some energy is dispersed and goes to the environment. It is important to know how much entropy increase a specific energy process will promote. To know that, one has to consider the different ways in which an increase or decrease of entropy can manifest itself.

2.2 Recycling

The term recycling is linked to the idea of a process within a system. A process is the sum of a number of steps sequentially performed, and it can be closed or open. A closed process is cyclic, because it returns to the first step after the last one has been effected and the recycling in the process can deal with the flow of matter, energy or information. An open cycle, on the contrary, does not return to its beginning. This means that matter, energy or information that

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2.For a more rigorous mathematical treatment of the problem applied at the planetary scale, see Kleidom and Lorenz [7].
has been flowing in the process, once it passes through the last step, does not return to the beginning, although it may remain in the system.

The concept of recycling in closed processes is central to the idea of sustainability of a system and, although a system that is built on open processes can be maintained for a long time, this would imply the consumption of matter and energy many times superior to those necessary when the recycling strategy is present in the system. Consequently, the system should somehow receive from outside the resources it consumes and send to outside the residues it generates in its processes.

The concept of recycling has been applied to the building industry in a rather loose way. Indeed, most of the activities classified as recycling are, in fact, simple re-use of materials and, less frequently, of energy. The difference between these two concepts is important, because re-use has no commitment with perpetuation, whilst recycling is meaningless without the idea of perpetuating cycles. Every recycling is, at some point, the re-use of matter. But it also has to be the re-use for the same purpose somewhere along the process, otherwise the cycle (or circle) will never close, therefore impeding perpetuation. On the other hand, not every re-use is a recycling, because it can be part of an open cycle.

So, recycling of industrial by-products or, as it is being called today, co-products, is if fact re-use of these products. This possibility has been extensively studied under the concept of industrial ecology [12], where the byproducts (formerly called wastes) of an industry are used as raw materials for another. The building materials (specially the cement industry) and, to a lesser extent the construction industry, have increasingly used this concept in order to reduce their costs. It is also important to mention the concept of re-use in the building industry, where components are used for the same purpose [13]. The problem here is the same as with re-use for different purposes: there is no concern with perpetuation of cycles, only with slowing down entropy increase.

The concept of recycling requires two conditions to be fulfilled, in order for it to be meaningful for the built environment: that the recycling happens in the short term (STR) and that the new energy spent in the recycling is minimal. The length of the cycle is not relevant. Consequently, it can encompass as many steps as necessary. Likewise, the process can include human as well as natural activities as steps, having them working in a symbiotic interaction. In fact, the probability is high that the inclusion of natural activities is a necessary condition to achieve the minimum consumption of energy. The processes of biotransformation related to chemical reactions are, in many cases, much more efficient than the technologies available today, due to the almost universal use of enzymes that catalyze reactions, reducing their energy of activation [14]. In economic terms, recycling is meaningful when externalities are accounted for, that is when they can be expressed in monetary terms and are charged to those who generate them. And the minimum consumption of energy, leading to a minimum entropy increase, points to that direction. There is a whole body of literature that deals with the concept of externality through the concept of services that Nature freely provides to mankind [15]. But, there are limits to it that have to be respected.

2.3 Emergence

Emergence is defined as the phenomenon that happens when a quality or pattern comes forth at a certain level of complexity, being absent in the lower levels [16]. In this sense, emergence is the result of a bottom up process, because it is not the result of an intentional effort from the top level to produce it. It just emerges.

Emergence can be found in most of the biologically built composites, structures and populations. Organisms and colonies present emergent behavior because in many cases it is
more effective to organize matter from simple to complex, at different scales. A certain quality or pattern may not be present at a lower scale, which is formed by simple interactions and materials. However, as the scales build up, new properties emerge. However, emergence is not a quality that can be incorporated in a straightforward way into the design. It is rather to be sought up in bottom up approaches.

Emergence is a fundamental concept because the designer can detect emergent qualities at a certain level and incorporate them in the design process to define the characteristics of the levels above. So, emergence is observed and used afterwards as the boundary between different levels. As a consequence, in the development of new solutions for engineering, emergent qualities cannot be used as the starting point of the entire design. This may sound strange to all of those who are used to design and plan directly at the macro-scales, but the very concept of emergence is refractive to this approach. There are some emergent behaviors that can be predicted based on experience, but that is rather the exception than the rule, and they most probably will be predicted in static rather than in dynamic systems.

2.4 Biologically inspired design

Biologically inspired design (BID) is a concept with two purposes. The first one is to draw attention to the properties (from a designing point of view) found in solutions developed by living organisms. Many of these properties are the same as the ones proposed in this paper. Indeed, such solutions are constructed using a bottom up approach to the process, constitute high energy sophisticated and complex structures, possess emergent qualities, are completely recyclable, use metals in a very parsimonious way, are built using the minimum possible amount of energy, promote steady state dynamical conditions and allow co-evolution. The second purpose is to use the vast library of solutions that are accepted in the natural environment, especially at the molecular level, but also in other levels, to deploy them in specific engineering problems. There is a growing community of scientists and engineers that see BID both from a problem based perspective, when searching for solutions to already identified problems, and from a solution based perspective, trying to understand the principles employed by different organisms, and their potential for application to different engineering situations [17].

The result of a BID is the mimicking of organic structures, which may be part of a living being or be of biological origin (which is produced by a living being but is not part of it, like oyster shells, sponge spicules and coral structures). This mimicking is called biomimetics.

Although in principle the search for biomimetic solutions offers great potential, it should be undertaken carefully. First, some biomimetic solutions developed today do not present biodegradability, because the choice of materials is done having in mind solely the optimization of physical properties of the composite. Second, it is not always possible (in fact it is infrequent) to easily reproduce organic structures in all their complexity and sophistication, so the decision to simplify the solution is a constant temptation, the most frequent situation being mimesis in some level (nano or macro level), thus jeopardizing the performance of the solution developed.

2.5 High energy structures

The tendency towards constant increase of entropy obliges inorganic matter in nature to undergo chemical reactions that will systematically produce substances with the least possible level of available energy. That is, they possess very little usable energy, being extremely stable from a chemical point of view. They are the oxides and salts.
On the other hand, living organisms tend to maintain their entropic level, which is much lower than that of inorganic matter around them. The low entropy of organisms is sustained through processes occurring in many levels, from molecular all the way up to the whole organism. During recycling, organic structures are decomposed down to the molecular level in order to be absorbed by other organisms. There are three main types of organic molecules: proteins, lipids and carbohydrates. Except for water and the minerals present in bones, these three types constitute practically all matter in living organisms. The chemical bonds in these molecules are formed through endothermic reactions. Consequently, they store chemical energy that will be liberated when these bonds are broken. All animals and bacteria have processes by which they are able to break these bonds to use the energy. However, these processes are extremely specialized, so they cannot absorb the energy of every bond, but only of those that form specific molecules, among the three types mentioned earlier.

Molecules that can be broken through organic processes are called biodegradable. Minerals and plastics are not biodegradable in the short term, because there are very few organisms with a specialized process that will break them down. However, the reasons for that are different in each case. Minerals are not biodegradable in the short term because they do not have energy available in their bonds, so they do not attract much interest. Plastics have a lot of energy in their bonds, but the shape of these molecules makes them unsuitable to be broken by any biologic process. So, they remain almost intact.

2.6 Metal ban

The banishment of metals from all processes of manufacture seems radical at first glance, and there are serious advocates of metal recycling [18], but we consider that there are three important reasons for metal ban. First, there is the problem of exhaustion of metal deposits on a highly enough concentration which permits their extraction in an economically viable way. Second, there is the problem of metal pollution [19], expressed more dramatically on the problem of metal poisoning. Third, there is the problem of energy consumption. Metals require large amounts of energy to be processed and reprocessed. These problems are particularly important for the construction industry, one of the largest consumers of metals.

The first problem refers to the well known fact that metals are non renewable resources. The idea of recycling, although meritorious, is confronted by two insurmountable problems: recycling is linked either to economic interest or to ecological consciousness. In the first case will be found the practices of underdeveloped countries, where the population has a low level of income and education. In this case, recycling occurs because the cost of the energy consumed by the worker’s body to do the job of gathering metal scraps is cheaper than the price of the metal he gathers. So, for him it is worthwhile to spend that energy. This accounting is positive for aluminum, for example, but it is negative for carbon steel. In the second case will be found the practices of developed countries, with a high income and educated population. In this case, the cost of food (and consequently of energy for the body of a person who gathers the metal pieces) is always more expensive than the price of the metal. In this situation, due to environmental consciousness of the population, people donate their energy and do the job for free, because they see the common good of not letting metals pollute their environment. However, in both situations recycling in always incomplete. Percentages can vary widely, but for aluminum, for example, the best percentage is above 80% in Japan [20] and Brazil [21]. For the copper cycle, numbers are essentially the same. In 1994, Europe sent to landfills approximately 13,7% of all copper used [22]. This means that there is always at least 15% that will be lost at each cycle. In reality, numbers are much worse and we can assume that worldwide at least 50% of all metal mined is not recycled.
Here comes the second problem, because the important part is not what is recycled, but what is not. What happens to the metal that does not return to the furnaces? It follows the second law of thermodynamics. Since a metallic object is an extremely organized body, according to the second law its tendency is to disorganize itself. The energy it contains in its metallic bonding will gradually be given away and disaggregate and, with time, it will spread literally all over the surface of the earth. That includes land and water bodies like rivers, lakes and oceans. And, unfortunately, it also includes the inside of all living beings, including humans.

The third problem refers to the amount of energy spent in processing metals. Metallic oxides and salts may form crystals which do not possess outstanding mechanical properties and cannot be manipulated to produce tools and devices of all shapes and functions. Pure metals and subsequently their alloys are obtained by chemically reducing their oxides, drastically reducing their entropy. This process involves enormous amounts of energy and, as a consequence, the entropy of the environment is substantially increased through the used energy. The reduction of metals is – except for very few cases – an instable situation, so metals obtained in this way tend to return to the equilibrium point, becoming oxides and salts again. As soon as it is reduced, the metal starts a slow process to turn back into rust. This is partially prevented by human action, at the cost of more energy and, consequently, more entropy increase in the environment. The other problem with processing metals is that they do not dissolve in polar or non-polar solvents in their metallic form, so they have to be manipulated through melting, again using large quantities of energy.

2.7 Steady state

Steady state is a condition where the basic flows of a system remain constant, and the system can perpetuate its cycles without major fluctuations. A steady state economic condition brings two important consequences with it. First, its long term continuation implies that it will depend exclusively on renewable resources for economic activities. Second, recyclability of resources must happen in the short term, except when the level of consumption of a resource is just a small fraction of the total volume available. And evidently it would be an egregious mistake to assume that a steady state condition would be compatible with the ideology of consumption [23] that is hegemonic today.

Resources considered here are energy, land, labor, materials and capital. Labor and capital are essentially anthropogenic and should, in a first moment, be considered always available and renewable. Energy, land and materials are the most sensitive resources, and the ones tending to be the limiting constraints to certain levels of activity or technological options. Since land is by definition the immovable resource, it could also be said that in a steady state condition, physical flows of matter and energy into the anthropic environment remain in constant quantities. However, economy textbooks insist in focusing only on labor and capital as the resources that deserve attention [12].

Although steady state is the only possible long term scenario, all economic forces acting today behave as if eternal growth and even worse, accelerating growth (since a fixed percentage of growth is a geometric and not an arithmetic progression) is the most viable future condition. Technologies developed for application in accelerated growth can hardly be employed in a steady state economy. The reason for that is that resources have completely different relative value in these two situations. So, metals, other elements and petrochemicals, are finite resources being intensively and extensively used today. The case with metals was already discussed in this article. In a steady state economy, their use would be extremely parsimonious, and all processes would consider, above all, the problems related to the increase of entropy. Energy usage also must be considered. Energy flow also has to be
considered as an important determinant of technological definition [24]. Processes with high energy consumption are preferred when fossil fuels are used. However, if only the incoming solar energy is considered, low energy high efficiency technologies are preferred.

Technological solutions are shaped by the existing economic conditions. And these conditions are changing at an accelerated rate [25], obliging for the search of new technological paths, compatible with a more stable flow of matter and energy, and a limiting availability of land.

2.8 Bottom-up Technologies

Technological processes can be classified as top-down and bottom-up [26]. In the first case, as the name properly indicates, process organization takes place at the highest level (whether this hierarchy is in decision or in scale), and all activities submit to this high level command. On the other hand, bottom-up technological processes occur through a sequence of steps that organize the flow of matter, energy and information from the lowest level up. Consequently, a characteristic of this kind of process is that it is essentially unaware (or unconscious) of the processes that take place at the levels above it. Top-down processes are normally faster, spend more energy, and are less efficient in organizing matter than their bottom-up counterparts.

An example of a bottom-up technology in scale and top down in decision is present in the textile industry in the weaving of a cotton fabric. There, the cotton fibers are organized by the cotton plant from the atomic level up, a bottom up process both in scale and in decision (if one considers each cell as self-sufficient in decision terms). From there, man-made processes turn the fibers into a thread, and the threads into a fabric. In contrast, the production of a non-woven fabric is a top-down technology in scale as well as in decision. There, the fibers have to be kept together by some sort of bonding or through thickening of the fabric, either spending more energy or more material than the woven product, although the process requires much less time.

2.9 Co-evolution

The concept of co-evolution emerged in the development of the Darwinian Evolutionary theory. In that context, co-evolution means a process of continuous and mutual adjustment between two species or a species and its environment in what is called a niche construction [27]. This concept was appropriated by other disciplines to describe situations where two variables, or subjects, were mutually influential in some way. One of these areas is the interaction between industries using certain technological systems, and the socio-cultural phenomena that surround them [28]. Other studies describe co-evolutionary behavior between certain technologies and cultural, economic and legal systems, showing how they have evolved together [29]. Building technology has been the subject of such analyses and it has been shown that it coevolves with those systems [30].

Co-evolution is an important principle for two reasons: first, it can guide or at least help in the analysis of what has been called a socio-technical system [31], identifying the reasons why certain technologies have been chosen under certain socio-cultural and economic conditions. Second, it permits to anticipate which technologies would best fit certain conditions, thus orienting the efforts of those involved in the development of new solutions as, for example, recycling of household wastes [32]. Besides, this understanding can guide the participation of stakeholders and create the proper conditions for the adoption of new technologies which Frame and Brown called post-normal technologies [33].
Specifically in the building industry, the present technological stage has fulfilled needs related to high density urban environments, introducing and maturing technologies, allowing and even stimulating further development of the urban paradigm in its socio-cultural and economic dimensions. In this sense, developing technologies oriented or limited to produce only low density housing, as is the case with most environmentally inspired low-tech solutions, will have only a very meager impact in terms of innovation to the construction industry. On the other hand, new technologies also exert influence on the socio-cultural and economic dimensions, transforming them as these technologies mature, creating their own expressions.

Co-evolution of construction technologies must occur in the field of materials, components and subsystems of buildings, and they must co-evolve in the interaction between them as well as through the interplay with solutions of private and public spaces, whether in the scale of individual dwellings, or in the larger urban landscape. However, there is no methodology available today to cope with the complexity of a solution that takes all factors in a real co-evolutionary process. And yet, “an engineering or economic solution that is blind to ethical, moral, emotional, legal or institutional constraints is not a real solution. However, these constraints have frequently served as excuses for engineers and economists to remain busy while blaming others for failing to solve the problem.” [12].

3. SUPER-HIGH-TECH SOLUTIONS

The concepts discussed are related to each other in different intensities. However, it is proposed here that they all should be seen and used as interwoven and mutually reinforcing. There are some which present a higher degree of correlation with other concepts, while others are linked to just a few.

The concept of super-high-tech solutions refers to those technologies that are able to incorporate, at the same time, all the principles previously mentioned in this article. Thus, they would have to: a) present minimum entropy increase in the production, as well as in the discharge of materials, components and subsystems; b) generate materials completely recyclable in the short term, without jeopardizing the environment; c) develop solutions that present emergence as one moves from one scale to the next; d) use the knowledge of biological solutions and produce BID (biologically inspired design); e) create structures composed by high energy molecules and composites, which can be metabolized in the short term by existing microorganisms; f) promote metal ban, so that the process of dispersion through entropy increase is ceased; g) remain viable in a steady-state economy, without loss or reduction of any important characteristic; h) apply bottom-up process technologies, so that matter is organized from the atomic level up, allowing for maximum performance of structures. And finally; i) be guided by the concept of co-evolution when promoting solutions in all levels.

Such technologies, in almost every case, do not exist today. In fact, many of them are not in the realm of feasibility at the moment, whether because of internal or external impeding reasons. Internal reasons are related to two main factors: project and production process. In terms of project, there is an enormous lack of knowledge about many of the principles enunciated in this article. In some of the fields, conditions are more precarious, as is the case with multi-level structures that start at the nanometer scale. In terms of production process, except for the macro-scale, where there is the assembly of components, bottom-up processes are not usually the main practice. In short, construction technology needs to be infinitely more subtle in understanding and handling materials properties than it is today.
External reasons relate to the present practice of acceptance, or at least tolerance, of externalities. Construction processes today generate enormous externalities, and society at large presents a cultural proclivity to accept that as a fact of life. That is changing, however, after decades of work done by environmentalists. Externalities severely distort the actual cost of technological options existing today, and hamper the ineluctable emergence of new technologies which will abide by the principles enunciated here.

It will be a long journey until a useful technology is available to the new building industry. The concepts presented here hopefully will contribute to the foundations of this industry.

REFERENCES


