PHYSICAL DESCRIPTION AND DETERMINANTS OF EVOLUTION OF STRUCTURES. AN ATTEMPT TO ANALYSE THEIR IMPLICATIONS FOR OPTIMISING ARCHITECTURAL AND URBAN SPACE PLANNING

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SUMMARY

Physical conditions for spontaneous growth and development of complex structures are discussed: using the concept of {free energy (thermodynamic negentropy)} $\rightarrow$ {structural information (Shanonnian) negentropy} transformation. The phenomena of structure ageing and decay are analysed. Degree of complexity of a structure, direction of its evolution is related to the number of elementary configurations (of constructing of its elements) that could be used to construct its identity. Practical conclusions which are drawn refer to the proposition of the optimum architectural design and city planning. As a criterion in this optimisation the best conditions for human well being, development and assuring the best conditions for flourishing of their creativity. Important for non mathematical scientists: presentation is written in simple language using only simple mathematical formulas. It is illustrated by examples in house construction.

KEY WORDS

CLASSIFICATION

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INTRODUCTION

FORM AND MATTER

Any piece of matter we can think of has to have some form[1], matter moulds itself into forms, it cannot express itself but through forms. Forms are not static. Any form can engender another form. Can anything change into anything? No. Observation teaches us that some forms have no self-inherent power to change into other forms. Or rather that they can change only in one direction. A house may dilapidate; walls will crack and fall apart. But not the other way round. A heap of rubble will not change spontaneously, by itself into walls and ceilings. There is an intrinsic irreversibility in the transformation of forms which exist in the inanimate world. This irreversibility suggests that these forms are differing from each other by some essential quality which is, so to say, correlated with the flow of time: direction of its changes is parallel to time's arrow. From past , through the presence, to future.

In the inanimate world forms that succeed each other in the course of time become, so to speak, hazier, less ordered, less distinct. Could this degree of haziness, or of distinctness, be somehow teoretically distilled from forms themselves and defined in a universal manner, applicable for discussion of any forms whatsoever? Could a quantitative, physical description of forms account for this phenomenon of irreversibility of transformations in the inanimate world and at the same time of reversibility in the living world? The answer to these questions is a positive one. How can this be done?

First we have to consider forms as complex entities consisting of some elements connected together by some links. We may think for example about atoms or molecules when studying the structure of a crystal. When studying the form of a house separate bricks or perhaps even some grosser architectural elements (like windows, walls etc.) could be chosen as the appropriate elements.

A priori the elements can be interrelated and interconnected in many different ways. A particular form is realized by a particular mode of interconnecting the elements. If a given form is not very sophisticated there are many ways in which these elements can be interrelated without changing identity[2] of this form. On the other hand, if the form is very refined then almost any changes of interconnections will change it into another form. This basic observation is quantitatively generalized and expressed by the concept of entropy. To talk about it, to define it first we have to introduce the concept of elementary configuration.

NUMBER OF ELEMENTARY CONFIGURATIONS
- A MEASURE OF UNIQUENESS AND COMPLEXITY OF FORM

What is elementary configuration? To introduce this concept we shall use an example. Let us consider a heap of bricks. Using a mathematical language we would say: a set of elements called „bricks" assuming the form called „heap". An elementary configuration (of bricks within the heap) is defined if to any brick (element) there is ascribed an exact position in space (and eventually in time). A change of position of any brick corresponds then to a change of elementary configuration. Now, within a heap positions of bricks can be interchanged in whatever manner we like and heap will always remain heap. It does not matter what exact place within a heap occupies a given brick. This particular form is also insensitive to the angular orientation (of bricks).

The situation is different when the bricks assume a more complicated form, for example that of a house. The position of any brick within the space occupied by the house is not so indifferent as within that occupied by a heap. They must be placed within the volume

occupied by walls in an orderly manner, i.e., parallel or perpendicularly to the symmetry axes. But again, it is not important whether the brick number one is on the top of the wall and the brick number two at the bottom or vice versa – at least as long as the bricks are identical. Respective positions of bricks (elements) within the wall have no importance. Any repartition of identical bricks within the wall will make the same wall so that the form called „house" corresponds also to a number of elementary configurations (of bricks). It could be shown, however, that this number is much smaller than the number of elementary configurations corresponding to the form „heap".

There are, however, examples of forms which correspond to very few elementary configurations. Consider for example a system in which elements are electronic parts like transistors, capacitors, mini-circuits, resistors etc. making the form called „computer". It is obvious that almost any change of places between the elements will change the form „computer" into the form „assembly of electronic parts". There is perhaps only one or very few configurations of these elements which make this particular form. All other configurations make another form.

We could perhaps announce the following general statement: some forms are more sensitive to changes of interrelations among the elements which make them than other forms; the sensitivity of a form is inversely proportional to the number of elementary configurations of which it could be constituted.

Also „the degree of order" or „complexity" could be defined as entities inversely proportional to the number of elementary configurations (very complex forms are, generally speaking, very intolerant to the arbitrary changes of interrelations of elements which make them up).

ENTROPY

We are now prepared to define a quantity which may classify and characterize all forms irrespective of the particular nature of elements and their interrelations. This quantity is called entropy and it depends only on the number of elementary configurations of which a particular form or pattern could be constituted. This dependence is so defined as to increase it with this number. When the occurrence of any of the elementary configurations is equally probable then entropy is defined as a quantity proportional to the logarithm of that number.

FROM BEING TO BECOMING: NEGENTROPY

We humans are interested in creation of forms, in expressing ourselves in ever more complicated and efficient actions, in becoming. Existing forms and states are our starting points, which we then transform or transcend is our daily plight. So we should be more interested in changes of entropy than in its absolute value.

A „heap", a quantity of material, a set of loosely packed elements are characterized by the greater value of entropy than a more sophisticated form into which they may be transformed. The becoming expressed by creation of forms, by a passage into finer states, by emerging of order is characterized therefore by the decrease of entropy. The decrease of entropy mathematically can also be expressed as increase -of negentropy. These are different ways of speaking about the same thing. The word „negentropy"[3] has been coined from the expression „negative entropy" – meaning something opposite to entropy which, taken tout court, is a symbol of chaos disorder. The opposite of disorder is order. Development of forms, appearing of order, becoming of finer states, may therefore be, very summarily and very generally, described as: production of negentropy

To express the above said in formulas we can write:

$$N = -\Delta H, \tag{1}$$

where N is negentropy and H entropy (the notation appearing in many texts $N = -H$ is wrong. Negentropy appears or disappears only when there is a change of entropy. Curiously enough this fact has been noticed and discussed in depth not by a physicist but by a sociologist K. Bailey [1].

When we are primarily concerned with human situations, by activities in most cases implying a more or less conscious effort, then perhaps we are even more entitled to use the term „production of negentropy". Especially when we are more interested in kindling and sustaining a dynamic process itself (i.e., in producing negentropy) than in achieving this or that goal of action and/or producing this or that material object. It does not mean that achieving of some chosen goals of action or producing some material objects is not important. In many cases it is just indispensable (as for example when building houses or producing food) for sustaining this process of negentropy production for a length of time.

ORIGIN OF IRREVERSIBILITY: WHY THINGS SPONTANEOUSLY GET OLD?

Let us again come to the concept of irreversibility mentioned already in the first section.

Consider two structures (forms): one which can be realized by many elementary configurations (let us say by one million of them), the other only by one unique configuration. Let us label this one unique configuration with the letter C.

No complete and everlasting isolation of a system is possible. Sooner or later there appear various external forces and influences acting on it and changing its elementary configurations (even if it were possible to isolate a system completely and „forever" there is always a possibility of internal fluctuations, caused for example by inevitable thermal agitation of molecules). Now, if the first system (or, stated more precisely, some of its specific form) can exist in this million of elementary configurations, it is very unlikely that any external forces (or internal fluctuations) will cause the loss of its identity. There are very high chances that any practically realized change of elementary configurations will remain in that million of elementary configurations (permissible for subsistence of the system's identity).

Clearly it is just the other way round with the other system – that which can be expressed only by one configuration C. Now the situation is very unstable: any change of elementary configuration will result in the loss of the system's identity.

In normal conditions a spontaneous change of this system into a system of the former type is much, much more probable than the other way round. That is the phenomenon of irreversibility. That makes the new change into old, dead bodies and trees into soil, etc.

REVERSIBLE PHENOMENA

But there were these small words „in normal conditions", „if unattended", etc. People have known for a long time – and Ilya Prigogine and his co-workers have developed this empirical knowledge into a new and exciting science of „far from equilibrium irreversible thermodynamics" – that under special conditions, even in the physical, unanimated systems, macroscopic structures can spontaneously develop (like Benard's cells, Lisegang spirals, pearlitic structures, etc.).

The whole world of living beings is also the world of reversible phenomena. To this we should also include human, society and the (artificial) world.

In this paper we are interested by this last world especially that created by architecture and city planning. We shall look into its interaction with the dynamics of the human world of the

human creativity and well being. Is it friendly to it, when it will assure the best conditions for our development on all planes of existence ?

What are these conditions? How to formalise them physically?

In the following we shall discuss these questions in more detail for a specific kind of structures, structures of spatial-temporal character (with emphasis on the second part of this word): those created in the human world, by human (purposeful) activities and evolve from haziness into distinctness, from high into low entropy, from a more probable form to a less probable one, from the virtual space of the possible into some material reality.

DYNAMIC STRUCTURES (PATTERNS) IN THE HUMAN WORLD

THE SPACE OF POSSIBILITIES

Humans, both as individuals and as groups, live in the open world; which opens for each individual into the space of a priori physically possible courses of actions or modes of behaviour, and which is is (more or less) opened for each group of people as a space of possibilities comprising all possible interpersonal relations and structures.

When an individual has more possibilities of action, this space is „greater" or encompasses more possible courses or paths, or, as formulated above, there are more „elementary configurations" which are a priori accessible. This situation – as in the case of purely spatial structures - may be also described by entropy defined in the spatial-temporal space. The more possibilities there are, the greater is this entropy - called an a priori entropy of action. The number of a priori possible courses of action depends on the characteristics of an individual and of the environment in which he/she is acting.

CHOICE, DECISION AND ACTION: COLLAPSE OF ENTROPY VALUE

Entropy of a system after a choice has been made and some course of action adopted, called an a posteriori entropy, decreases considerably. If the state that has been chosen is defined very sharply in a very fine manner, it may be even said to assume the zero value. In this last case the change of entropy caused by a decision and action process is numerically equal to the a priori entropy value. For non-random choices and activities this change is always negative: we have a negative increment of entropy (i.e., its decrease), or stated otherwise, there appears negentropy. Any process of selection (choosing) and decision-making, and of its implementation, is a process accompanied by appearance of negentropy. Thus we might look at any such process as a means to produce negentropy.

Note: Let not the reader be mislead to think that assuming the zero a posteriori entropy value means that no more negentropy can be produced. The dynamics of the system comes to a standstill.

Why is it so? To see the best would be to make use of simple formulas for the (information) negentropy NI:

$$NI = H_1 - H_2 \tag{2}$$

where H_1 is an a posteriori value of entropy and H_2 is an a priori one.

Let the system in question pursue two goals of action first the goal A then the goal B. Then according to the Shanonian definition of entropy (used also by Brillouin) we shall have:

$$H_1(A) = p_1(A) \cdot \ln p_1(A) + \ldots + p_n(A) \cdot \ln p_n(A) \tag{3}$$

$$H_1(B) = p_1(B) \cdot \ln p_1(B) + \ldots + p_k(B) \cdot \ln p_k(B) \tag{4}$$

Where $p_n(A)$ is an a priori probability for the system to settle spontaneously in n-th state (form) related to the goal A of action. Similarly, $p_n(B)$ is that probability for the goal B.

Now we can think – independently for the goal A and for the goal B – about the moment of choice and decision (collapse of the entropy value).

The system chooses only one of the terms of the sum (2) or (3). Then as its probability becomes one we have:

$$H_2(A) = H_2(B) = 0$$

The production of negentropy involved in the action A is:

$$NI(A) = H_1(A)$$

and in the action B:

$$NI(B) = H_1(B)$$

Assumption of zero a posteriori value – related to some given goal of action – does not mean then that the overall dynamics of the system is finished.

A PRIORI PROBABILITY SPECTRUM

A priori probabilities of various options - determining the value of negentropy production in a decision process – depend on very many factors. These factors predetermine, so to say, the choice of options that are most likely to be taken up by the subject. This possibility spectrum may naturally vary from individual to individual. Options quite natural for some people are practically impossible for others. The idea of this spectrum is a similar concept to the so called „attitude vector" proposed in social physics (synergetics) by W. Weidlich [2 – 4] (social synergetics is a special application of general synergetics developed by H. Haken [5]).

AVAILABLE (FREE) ENERGY AND NEGENTROPY

It is evident that any human activity is intrinsically connected with its material basis – and therefore also with the energy sources. The decrease of entropy must be paid for by dissipation of some portion of energy that is available to the human organism[4]. The relation between these two quantities is not always simple and linear. This means that decisions involving more negentropy do not necessarily imply dissipation of more energy. The dissipation depends not only on the value of produced negentropy but above all on efficiency of the transformation process:

$$\{\text{available (free) energy}\} \rightarrow \{\text{negentropy}\}$$

It seems that one of the most important potentially available sources of this free energy (for transformation purposes) lies in the possibility of a synergetic reinforcement which may exist among people [6]. The question is how to obtain this reinforcement in a long term and on a mass scale – possibly of the planetary radius?

There are two major requirements for obtaining a powerful (laser like) reinforcement. First, there is a need for a certain synchronicity, simultaneity (in time and in space) of a choice of options (of Weidlich's attitudes). (For example, two people living under the same roof – if they want to reinforce each other, they should share at least some interests, not have conflicting life styles, etc.). Second, the common options should be so chosen as to positively catalyze the negentropy transformation power of all, or at least of the majority, of individuals in a group. The second requirement can be more easily satisfied in small groups.

The fulfillment of synergistic reinforcement is especially important for groups involved in any creative process, which requires high disposability of free energy sources. Or, stated

differently, it may be achieved only in moments characterised by high transformation intensity rates. This problem has been discussed in detail in many places by the author [7 – 9].

Attaining a certain degree of synchronicity for large population, however, or at least avoiding negative interference or mutual cancellation of efforts, is a very difficult problem (it becomes especially difficult when we it comes to spiritual and moral reinforcement). This one of the most difficult challenges for our civilisation.

THE SPACE OF POSSIBILITIES AND THE ARCHITECTURAL SPACE – INTERPRETATIONS FOUNDED IN INFORMATION THERMODYNAMICS

How the architectural space created by city planners, architects, interior decorators and structure designers should be in the best manner designed to keep the human creativity space wide open – to assure for every one the best conditions for the negentropy transformation process?

The modern living conditions in cities, the modern means of fast communication, liberalization and permissiveness on all levels of social life, expansion of all kinds of information media, dramatically increase the volume and density of information signals imposing themselves on everyone. For every individual only few of these signals carry a positive semantic content – may positively catalyse the negentropy transformation processes. Most of them are at least redundant if not dangerously disturbing these processes. A necessary filtering and selection in this ever increasing bulk of deluging information noise imposes – according to the Brillouin Principle of Information- increasing negentropy costs, increasing dissipation of available, free energy. A possibility of a bad choice, of an error of judgment – of a choice not leading to the increase of negentropy production – becomes in such conditions ever more difficult to avoid. The best design of architectural space should aim at reducing to minimum these negative effects of social density, of ubiquity of redundant information, of information menacing psychological homeostasis and social stability.

The aim could be realised (among others) by creation of, as many as possible, and wherever possible

(i) empty spaces,

(ii) isolated (small) spatial enclaves.

Realisation of these postulates would considerably ameliorate the quality of life of city dwellers.

Empty spaces

- where the natural conditions allow such empty spaces - in form of common grounds - should be created within the city landscape (in Krakow there is a good example of such a space, a grassy area, an empty field about 1,5 km in length and not far from the city center, used as a recreation ground),
- city landscape should be free of advertising of unnecessary lights etc. (advertising should not impose on people; it should be localized in restricted areas in form of commercial information for those who wish to use it at a given moment).

  Billboards should be absolutely forbidden. They do not only violate the above mentioned laws of development and creativity but also violate the civil rights : freedom of choice. You can close eyes when TV shows adds but you cannot when you are driving or walking. They create conditions of hazardous driving : in the crowd of multitude of information, imposing on the nervous system at every minute and in any place and direction, road signs and regulations can be easily omitted.

- in interior decoration: use of few ornamental and decorative details, preference of semi-empty walls and interiors (Japanese style) etc. In planning of apartments their considerable area

should be consecrated to hide away places for things that are not presently used in the living area (as are in the Japanese houses).

The spiritual goal for the use of empty spaces: the spatial emptiness is friendly to create the state of deep relaxation of the nervous system , the state sometimes described as the state of „mental emptiness" of the brain. The momentary emptiness – freedom from bothering thoughts and emotions – the perfect homeostasis of the brain. This phenomenon is well known in Zen philosophy and taught by its masters and also, in general, well known and recognised for its value in eastern philosophy and spirituality.

Design of isolated spatial enclaves

- creation of secluded, semi-isolated (by verdure, architectural forms and other means) enclaves in parks, on city squares, in railway station halls and in other open, public places wherever possible,
- isolation of pedestrian lanes and pavements from the motor traffic by verdure (ex. in form of thick tall hedges) and other means,
- it is deplored that in the current style of tree grooming in city parks and green patches reigns the style once used in the Victorian parks in England (and reigned in royal gardens in Paris).

Tree branches are cut up to the height of few meters. Thus parks and other green places are exposed to the city traffic. Also some beautiful churches and castles become hidden by tree foliage of trees which deprived of leaves near to the ground develop huge tree crowns above (alas that's the case of Krakow where instead of seeing the Wawel royal castle a park pedestrian is exposed to car traffic).

The application of these postulates, as possible devices in attainment of the general goal – of reducing to minimum the negative effects of social density – would considerably ameliorate the quality of life of city dwellers.

NOTES

[1]We take that word in its broadest annotation sense, i.e., a shapeless, hazy, „diffused" body also has a form: a shapeless, hazy, „diffused" one.

[2]We are not going to discuss here when a given form looses its identity, when it becomes another form. This problem is pertinent rather to the research on pattern recognition. We are rather concerned with the entropic description and the physical conditions which must be fulfilled before a form can appear. A region between one identity of a form and another one succeeding it, might be a „mushy", hazy region. (There is that famous example with Plekhanov's beard: one hair does not make a beard, neither two, three, ..., ten, ..., fifty, etc. make a beard. But where in that point in this sequence when adding one hair changes a collection of hairs into a beard?). But nevertheless, in whatever way we delineate this region, decrease or increase of the number of elementary configurations and its connection with irreversibility is a fairly clear concept.

[3]Some people are strongly opposing „this horrible word negentropy". In one aspect they are right: negentropy stands for something very positive so the prefix „neg" might be misleading. On the other hand, life phenomena - in the words of von Neuman - „are lone islands bravely facing the ever growing tide of the average entropy increase". This counteraction is our „no", or defying, our „neg"ation of decay and annihilation. „NO" to increase of entropy! – in short: „NEGENTROPY". It must be remembered at the same time that – as explained in the text above – that negentropy is not simply „minus entropy" (but rather its decrement).

[4]In fact, any living system absorbs from environment exactly the same amount of energy as it gives back to it. However, it degrades it: it has less power to be changed into work, movement, etc. As degradation of energy is connected with thermodynamic entropy value, we can – with more precision – express the transformation principle only in terms of negentropy:

{thermodynamic negentropy} $\rightarrow$ {structural negentropy}.

This equation is a generalization of the well known Brillouin's Principle of Information Gain. (Brillouin has discovered that no information gain can be obtained without degradation (dissipation) of some portion of energy (see [9]). This, in turn, is an extension of the Second Law of Thermodynamics into information yielding and structure building processes.

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FIZIKALNI OPIS I ODREDNICE EVOLUCIJE STRUKTURA. POKUŠAJ ANALIZIRANJA NJIHOVIH POSLJEDICA NA OPTIMIRANJE ARHITEKTONSKOG PLANIRANJA I PLANIRANJA GRADA

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SAŽETAK

Razmatrani su fizikalni uvjeti za spontani rast i razvoj kompleksnih struktura primjenom koncepta pretvorbe {slobodna energija (termodinamička negentropija)} → {strukturna informacija (Shanonnova) negentropija}. Analizirane su pojave strukturnog starenja i raspada. Stupanj kompleksnosti strukture i smjer njene evolucije su povezani s brojem elementarnih konfiguracija (povezivanja njenih elemenata) pomoću kojih je moguću konstruirati identitet strukture. Izvedeni zaključci primijenjeni su na prijedlog optimalnog arhitektonskog dizajna i planiranja grada. Kao kriterij optimiranja odabrani su optimalni uvjeti za ljude te osiguranje optimalnih uvjeta za razvoj njihove kreativnosti. Izložene cjeline potkrijepljene su jednostavnom matematikom razumljivom nestručnjacima. Izloženu materiju ilustriraju primjeri konstrukcije kuća

KLJUČNE RIJEČI

negentropija, socijalna sinergetika, arhitektura, planiranje grada