The concept of construction

The idea that organisms are integrated, highly functional systems which can be regarded as clockworks, machines or constructions dates back at least to the Late Middle Ages. And since the idea has been accepted that organisms owe their existence to the process of evolution and that the most important mechanism by which they are controlled is natural selection, a functional explanation of the components of organisms and of their integration (termed functional morphology; morphology = science of form) has become an indispensable field of biological research. During the last two or three decades, the idea came to be accepted that evolution has only a limited choice of direction. These limitations in the process of evolution are studied by constructional morphology. Complementary to constructional morphology, theoretical morphology abstracts growth and formation programmes from the organisms in order to simulate these programmes on the computer.

Attitudes to form
Ulrich Kull, Klaus Teichmann, Joachim Wilke
p. 43

Hitherto, Sonderforschungsbereich 230 is the only project based on an approach that will permit to link the phenomenon of complexity to problems of architecture in a systematic manner. The procedures for the design of bearing structures that have been developed here exploit a diversity of forms that leads beyond the traditional language of forms adopted by architecture. If the term 'optimization' is used in this connection, this refers exclusively to the intended correspondence of form and construction in a bearing construction. Conceived in this manner, optimum quality must not be confounded with a criterion of assessment on the aesthetical level.

At the outset, we regard man-made forms as artificial. However, with the development of human cultures, forms produced by human beings have also undergone evolutionary change. In the course of quite different periods this process led to a gradual approximation of some forms to a state that could hardly be approved upon any more.

Forms are never rigid; all forms and hence all objects change. Frequently, the processes that have led to the emergence of a certain form can be identified by inspecting the form itself. Therefore one can also try to classify forms by the respective processes that originated them. In technology, changes of form brought about by human activity are functional in character, while in art they are basically devoid of function. Architecture is the discipline in which these two spheres meet.

Light-weight construction

Every material object can transmit powers, and hence it is a construction in terms of civil engineering. On the quantitative level, the ability to power transmission depends from form, material and the character of the load. If the transmission of power is brought about by deployment of limited masses - or, generally speaking, of limited energy -, that procedure is called light-weight construction.

In the world of forms occuring in living nature, relatively light constructions resulting from the evolution process are met with quite often. Therefore, man-made light-weight constructions also frequently tend to have a natural appearance.

Form-finding techniques adopted in SFB 230

Within the framework of SFB 230, a bundle of form-finding techniques came to be developed, which permits to find a basis for the realization of an 'architecture of complex forms'. What serves as a starting point is a construction concept borrowed from morphology, which permits to include a processual (evolutionary) aspect, for 'natural constructions' mostly evolve in self-generation and self-organization processes. Such a feature is of considerable consequence to the designing process and thus to the self-image of the designer. This can be illustrated by comparing the 'classical' designing process in architecture with the designing and form-finding procedure of 'natural construction' and examining the relation between subject and object in both cases. In a traditional view, the architect will invent the way in which he formulates space in complete freedom. He creates an object that is organized entirely from without, an object, whose form will in every phase of coming about follow the dictates that ideally arise mainly from the creative potential of the person who designs and plans. In this sense, the object created is a product determined completely by the inventor, an artifact in the literal sense of the word.

In distinction from this, the form-finding techniques adopted in SFB 230 conceive of the form-finding and designing process as a dialogical procedure, as a 'dialogue with nature', in which the creative input of the designer is at interplay with a 'physical input'.

On account of the inherent dynamism of the designing process arising from these circumstances, the designer is always an experimentalist as well. He posits 'boundary conditions' for processes which give rise to construction. Thereby a dialogue gets started, which through a process of self-generation or self-organization gives rise to a form that is at the same time an efficient construction. The advantage of the procedure consists in the fact that architectural form and building construction develop in synthesis within a single process instead of being isolated entities, as which they are treated in the 'classical' procedure.

In the framework of SFB 230, a combination of methods has been designed to meet this demand. These methods include experimental form finding, analytical form finding and structure optimizing. While in experimental form finding, real models are used, analytical form finding and structure optimizing make use of the potentialities presented by computer simulation. By such a coupling of methods, a procedure is created which in every phase of form finding meets architectural as well as building-constructional demands by providing them with the optimal tool.

Form and emergence
Rüdiger Vaas
p. 56

The fundamental problem of being and becoming which marks the beginning of Western philosophy - i.e. the question as to what or how something is and how or why it changes - has remained the basic problem of descriptive and explanatory science up to the present day, and it is regaining special topicality in the present self-organization paradigm. The idea that form and matter are inseparably linked - with 'form' referring to external shape as well as to inner structure - goes back to Aristotle. While today we do not inquire into the 'essence' of things any more, but try to grasp them with resort to the world in which we live and to the use we make of it, form taken in a broad sense has become the most important topic of modern science with regard to 1. properties of things we try to explain by means of experiments or wich we define expressly, and to the relations between things, 2. natural laws referring to structures and processes, and 3. abstract tools of sciences themselves (formalisms).

The individual disciplines of science are connected horizontally as well as vertically, which corresponds to the assumption of the unity of the world. The division of which into compartments that are not necessarily arbitrary is only our doing. This implies a setup in which usually the smaller compartments (levels of observation) form the basis of the larger ones and the simpler ones precede the more complex ones. Even if for methodological reasons a description 'from below' is not given (to be sure, such a description is frequently not desired and also impossible for practical reasons, since in most cases a derivation of macroscopic and complex phenomena from configurations and interactions of their subsystems by which they are constituted has not been undertaken and in some cases cannot be undertaken in principle), this does not necessarily imply an ontological pluralism (or dualism). Rather, it will be sufficient to assume a weak emergence which amounts to practical irreducibility, but in contrast to a strong emergence can assume an ontological monism and hence does not exclude at least approximative reductions. The self-organization paradigm is based on the first position. To be sure, the teleological conception held by Aristotle is thus repudiated, but his idea that we are dealing exclusively with properties and interactions inherent to matter, which need not be conceived of as something separate which is added to it, is retained. While the individual sciences have to clarify conditions and mechanisms of form origin and development, theories of structure like synergetics are able to create an abstract framework that is compatible with reductionist approaches in cases in which they seem feasible, but can take into account particularly all the formation of emergent phenomena.

In addition to these ontological aspects of being and becoming there are epistemological and practical ones. For in the first place forms also depend on our preliminary knowledge and on the conditions of our perceptive ability (in finding, we always invent as well), and since we are beings of nature, these phenomena in turn can be amenable to being studied at least to some extent. Secondly, we redesign the world and can construct new forms by deliberately influencing degrees of freedom and boundary conditions. In this way, a teleological, but also a normative dimension does enter the discussion. Science and technology can stimulate each other inasmuch as we can learn from the self-organization principles governing the origin of natural forms for our own constructions and their optimization, while in turn the technological tools (formalisms, procedures) can also enrich the sciences.

Self-organization in urban structures: Non-planned settlements and city agglomerations

Sybille Becker, Klaus Brenner, Pierre Frankhauser, Klaus Humpert, Eda Schaur

p. 57

Cities are entities which due to their complexity cannot be planned as a whole. By application of considerable abstraction, the structural-theoretical approach adopted in SFB 230 permits a systematical description of the morphogenesis of city agglomerations. This value-neutral procedure makes it possible to deal with properties of modern cities that are not culture-specific without using superficial biologisms. In this sense, city planning is perceived as the creation of suitable frame conditions for a development of different urban cultures based on internal dynamics.

Non-planned settlements

We will refer to a settlement as non-planned, if it has been set up by its inhabitants with a considerable degree of self-determination in the absence of comprehensive planning. Such settlements are not planned in the conventional sense of the term. They evolve in an interplay of self-planning and self-organization. In contrast to planning, which depends on communicability of the structures that are being planned, processes of immediate organization and shaping of a settlement area, which are characteristic for non-planned settlements, lead to the typical complexly structured forms.

What strikes the observer of these settlement structures is their similarity to certain self-generating structures which occur in experiments as well as in natural formation. Such structures are distinguished by the feature that in spite of the diversity of form they exhibit, they follow certain regularities of shape and formation processes.

These observations result in the following problem: Is each non-planned settlement a completely different entity moulded by adaptation to a singular situation, or is it possible to detect common structural features or regularities not determined by culture, but due to certain universal influences stemming from the processes by which they were brought about?

In principle, the process which leads to the structuring of a surface in a settlement can be attributed to two phenomena: to the development of the surface by paths and to its occupation by settlers. In order to 'decipher' the supposed structural correspondence, the topological features of these structures formed by paths and plots were taken into consideration. From the examination of the topological features exhibited by the structures of African, Asian and European settlements as revealed in aerial photographs and by the self-generation structures just mentioned, the 'structural family' of unplanned settlements emerged.

In self-generation processes, the structure-generating influences of different procedures of development or occupation of surfaces can be studied with the help of idealized models. Minimal paths, direct paths and systems of minimized detours are three types of such development models. Two models are suited to the process of surface occupation: the so-called 'bubble-raft' simulating a structure with the closest possible packing of partial surfaces with pre-defined size, and the so-called 'sand-model', in which the structure arises by preliminary definition of the arrangement of partial surfaces in the course of the self-generation process. A comparison of the topological properties of these model-generated structures with those of the settlement structures showed that none of the three 'path models' is decisive for structure formation. Among the two occupation models, the 'sand model' turned out to be the nearest relative of settlement structures. From that we may conclude that it is the occupation of surfaces by settlers that is decisive for the structure formation of non-planned settlements. The path systems 'evolve' secondarily when the free spaces that have formed between the surfaces are walked upon.

From container city to urban landscape

When their defensive function got lost and an efficient transport system was developed some 200 years ago, town and city walls became obsolete. Within a short period, the compact safety container dissolved. Towns assumed a completely new open structure and transformed into inkblot-shaped urban landscapes. To-day, about 50 percent of the world's population live in urban agglomerations. As a global phenomenon the urbanization process goes on unabated.

With a view to a more detailed determination of the growth and development characteristics of such city agglomerations three problems were examined: the ratio of area and border length, the determination of maximum border distance and the determination of a 'gradation curve'.

More border - less area

If modern conurbations still had the compact outlines of traditional towns, which followed, as almost 'ideal' circular forms, the laws of Euclidean geometry, their circumference would increase in linear proportion to their diameter, while their area would grow with the square of this value. Actually, however, the circumference increases almost by the same proportion as the area, which means that the settlement particles produce more and more border. This surprising phenomenon can be described nowadays in terms of fractal geometry.

'Boundary conditions'

The maximum border distance indicates how far at worst an inhabitant of a certain conurbation lives away from the border of the settlement or the nearest vacant area. Due to its compactness, the traditional town was characterized by low maximum border distances. With the growth of towns and cities, an increase of maximum border distance would have to be expected. It turned out, though, that agglomerations of different size do not exhibit any significant differences, irrespective of the continent in which they are situated. If, for instance, the settled area of Los Angeles was concentrated in a circular form, it would have a diameter of 55 kms, which means that theoretically the maximum border distance would be 22,5 kms. However, the actual maximum border distance ascertained for Los Angeles does not exceed 5,5 kms.

'Gradation curve'

If the number of settlement particles of identical size is plotted against the respective size category (ranging from 0,5 to 500 square kms), this will yield a 'gradation curve' that permits a proposition regarding the growth process of a conurbation. The further the growth process of a city agglomeration has progressed, the more this agglomeration becomes particularized. At the same time, one can tell the stage of historical development of an urban agglomeration from this gradation curve. If the same data are plotted on a double logarithmic scale, this will again yield a linear relation for European and older American metropoles. Such a relation reflects a strictly hierarchical distribution of settlement elements, which is in concord with fractal geometry of Sierpinski carpets and at the same time corresponds to the hierarchy of centres that is derived in the theory of central places from economic and functional points of view. In the homogeneous settlement patterns of American and Australian 'car cities', however, such a hierarchy formation is hardly found on the scale level of the conurbation.

Structure formation in dynamic systems
Dirk Helbing, Martin Hilliges, Péter Molnár, Frank Schweitzer, Arne Wunderlin
p. 69

Settlements, cities and regions are self-organized entities with a highly complex, involved internal structure consisting of several subsystems. The growth process of urban agglomerations, the development of a traffic network, the formation of single buildings, social processes that take place within built structures, as for instance the behaviour of individuals as pedestrians or motorists - these are all examples of processes which, on a great variety of time scales, form spatiotemporal patterns for whose understanding a science of cooperation, a theory of structure formation, is required. Such a theory, which has been termed "synergetics", was established by Hermann Haken from the University of Stuttgart approximately in 1970. Starting from a unified point of view, this theory examines processes of self-organization and cooperation in complex systems. Such processes can be discovered in totally different areas of classical scientific disciplines: in physics, in chemistry, in biology and in their derivates. However, such processes can also be identified in the humanities, e.g. in economy or sociology. This list already goes to indicate that synergetics claims to be an interdisciplinary science. In contrast to other approaches by which it has been attempted to reach a comprehensive understanding of self-organization processes, synergetics goes beyond a verbal description of these processes, since its methodological tools have been borrowed from mathematics, so that it can be classified as a mathematical theory of structure.

The general features of the systems that have already been considered in the framework of synergetics can be described as follows: the systems in question are open systems that are characterized by an exchange of energy, matter, information, etc. with their environment. The systems themselves consist of many subunits or subsystems. These subsystems, which determine the microscopic description level for the respective systems, interact with each other by a number of different mechanisms. It is significant that the dynamics of the systems is non-linear already on the microscopic level. One property of such systems is that they react to completely unspecific changes of the influences exerted by their surroundings by spontaneously organizing themselves on a macroscopic level. This self-organization is arrived at through instabilities of their existing state as compared to a qualitatively new state. These new states consist, for instance, in spatial, temporal or spatiotemporal patterns which form on the level of viewing the system as a whole, the so-called macroscopic level. Even specialized, highly coordinated function modes of a system can be the result of such self-organization phenomena.

Now, the significant results of synergetics is that the structures newly emerging at the macroscopic level can be described by a small number of collective variables which are termed order parameters. These order parameters are generated by the system itself through a sophisticated mechanism which can be described as cyclical causality: The microscopic subsystems generate order parameters at the macroscopic level, and these order parameters in turn retroact on the subsystems, indeed in such a way that their own survival is guaranteed. This is a verbal representation of the 'slaving principle' of synergetics that has been formulated in a general way by Hermann Haken. The basic insight is that in the environment of the instabilities the mathematical structures by which these processes are described are independent from the microscopic data of the subsystems and thereby take on a universal character. Thus it becomes possible to give a mathematical description of highly complex systems resorting exclusively to macroscopic data.

What can be done, however, to describe the complexity of systems for which the decisive order parameters cannot be identified quantitatively in a simple way? In such cases, basically two procedures present themselves, in which macroscopic behaviour is linked with the properties of the microscopic subsystems. The so-called 'top-down' description attempts to dissolve the entire system starting from the top into interactions of hierarchically ordered subsystems, which in turn can be further decomposed into individual elements. In this way the entire possible behaviour of the system is determined along the lines of high-dimensional ramification trees.

In contrast to this, the 'bottom-up' description starts from the microscopic elements of the system. For the interaction between these elements, assumptions are made which are mostly very simple and have only local effects (i.e. on the respective element in its respective place) and not global ones (i.e. on the system as a whole). Now the question is how the macroscopic properties of the entire system arise from these local interactions. If these properties were not already contained in the microscopic interactions right from the beginning (even though perhaps in a hidden place), they must have evolved in the course of the evolution of the system by self-organization out of local interaction of the elements. Then the system as a whole has properties which the elements taken for themselves do not have - and there must be a qualitative leap through which this new property of the system emerges. For this leap, the term "emergence" has become accepted. The fascinating thing about emergence phenomena is that the complexity of the system is mostly not based on equally complex rules for the elements, but on very simple rules which can generate totally different systematic structures, if only minor changes are made.

As a matter of principle, such a description is not deterministic. To be sure, the evolution of the system does depend on boundary conditions which act as control parameters, restricting and influencing the basic possibilities the system has for development - but it will depend largely on the fluctuations at the point of instability, which of the existing possibilities is ultimately realized. So it may be said that the system itself finds the structure, developping itself those global properties that are rendered possible by the type of interaction of elements and the given boundary conditions. In this self-organization process there may occur solutions which are unpredictable and novel. On the other hand, there is no unequivocal answer to the question as to which microscopic interactions will definitely lead to certain macroscopic properties.

The 'bottom-up' description has been applied successfully for the characterization of the complex behaviour of several systems. In the following, we want to discuss some special 'bottom-up' models which are applicable to self-organization of (or within) built structures - namely, the evolution of path networks, the dynamic behaviour of pedestrians and the forming of stop-and-go traffic on a motorway. What is common to these three examples is that for the 'behaviour' of elements (walkers, pedestrians, cars) only very simple local rules are set up, as for instance setting or following local marks, observing a recommended speed or a minimum distance from the nearest other element etc. The behaviour of the elements is linked in a non-linear way. Due to this interaction, if certain parameters (intensity of marking, pedestrian density, car density etc.) become critical, this will result in spontaneous evolution of new structures (of paths, of right-and-left traffic in pedestrians, of stop-and-go traffic on a motorway). The models of self-organization that have been developed provide clues for the critical domain in which these structures emerge, and to a certain extent they can give a realistic description for the temporal development of the transition.

Translated from the German by Martin Pfeiffer