Structural organization and operation of the structure-system

Valerii Vyrovoy\textsuperscript{1,a}, Oksana Korobko\textsuperscript{1,b}, Oleg Pishchev\textsuperscript{1,c} and Hanna Varych\textsuperscript{1,d}  
Odessa State Academy Civil Engineering and Architecture, Department of Architectural Structures, Didrihsona st. 4, 65029 Odessa, Ukraine  
E-mail: \textsuperscript{a}vyrovov@ukr.net, \textsuperscript{b}okskorobko71@gmail.com, \textsuperscript{c}tapi74@ukr.net, \textsuperscript{d}varich09@gmail.com

Abstract. The main factor is presentation of the building construction as open complex self-organizing system. The initial theoretical provisions on processes of self-organization of the construction both during its production period and during operational loads action period are formulated. The active elements of structure material are selected. Representation of the construction as system allows determining the conditions for safe functioning of the construction-system in the system of similar constructions.

1. Introduction

Building objects of various purposes, individual products, constructions and materials can be considered as certain type systems \cite{1, 2}. Presentation of individual building objects as specific systems \cite{3, 4} allows determining the level of intra-system connections, to assess the reliability of the object-system under the action of various external loads and thus to solve problems of object safe operation. Of basic importance is a choice of the object in the building complex, which to be represented as system. This allows systems of other hierarchical levels to be analyzed through the dedicated system object. Representation of the building construction as system makes it possible to integrative examines the construction itself and analyzes its role in the system of construction-systems (buildings, structures). This approach allows to reasonably including the material in the analysis of the state of building object-systems.

The system of construction-systems puts forward specific conditions to the individual construction-system. The construction-system to satisfy these conditions must have the strictly defined set of properties. The material is the end element of the future system, technological solutions of which will determine a future safe operation of construction-systems and, as a result, the system of construction-systems. Representing the construction as system assumes an existence of certain structural organization, which allows acquiring the set of specified properties. Constructions lose their functional abilities under action of a complex of external loads and influences. This is due to a change in properties of the material from which they are made. In turn, a change in properties is determined by corresponding changes in the structure of material, and, therefore, construction. Based on this, the task was set to analyze a role of the construction in the general building hierarchy, taking into account its structural organization and features of functioning as open complex self-organizing system.

2. The foundation for a representation of the building construction as certain type system

The building construction as open complex self-organizing system. 

The material as independent object does not exist and manifests its properties in samples, products, constructions. Moreover, material properties level depends on type of the construction in which it is applied. Therefore, to present the material as basic object-system is senselessly. This suggests that the construction should be represented as system in which the material properties should be manifested
and realized. In turn, the construction-system is part of the system of construction-systems, forming buildings and structures – different level systems.

All systems, regardless of their nature, perceive external influences and react accordingly to them. Building constructions, regardless of their purpose and location in buildings and structures, are constantly forced to repel environmental attacks. This means that building constructions is open systems and implies continuous interactions of constructions with their environment.

The construction can be considered as specially figuration material. In turn, the material consists of different in nature, amount and dimensions of initial components, which through rather complex physical-chemical processes of hydration and physical-mechanical processes of structure formation provide the required set of mechanical characteristics of the end product. The complexity of any building construction as open system is related not only to complex mineralogical compositions of mineral binders, but also to the multifaceted phenomena and processes that occur both during structure formation and during operation. Processes of force stationary and dynamic action are superimposed on complexity of material structure that leads to development of local and general deformations in the material. This, in turn, provokes redistribution of forces between components, local changes of structure parameters, diffusion migration of pore fluid, etc. Due to the fact that the material is poly-structural, consisting of structural heterogeneities that are different in mechanisms of structure organization, each structural level has the individual complexity and characteristic properties. All of the above allows analyzing building constructions as complex systems.

Building constructions as open complex systems have the ability to transform their structure under influence of external factors in such a way as to preserve properties of the system under operating conditions. Such spontaneous structural changes are self-organization processes. Self-organization processes in the construction material can be divided into two types: - self-organization processes in the technological period of construction production; - processes of spontaneous structure restructuring in the period of operating constructions.

Spontaneous processes of structure organization during its production of the construction cause spontaneous generation and development of diverse set of structural elements, which can be classified into active, metastable and conservative [6]. A distinctive feature of active elements of the material structure and construction is their adequate response to almost any external and internal influences. Cracks and inner surfaces of partition, which exist in the material at different levels of structural heterogeneities, are active elements. In addition, local and integral fields of technological (initial, residual, hereditary) deformations are formed at the construction level. The construction as open complex system enters an active phase of functioning with a certain set of structural elements that spontaneously originated in the technological period of its production.

Changing parameters of active elements causes change in system structure parameters. An adequate reacting to external and internal influences implies that active elements, which «sensitive» to certain effects, change their parameters in a timely manner with influences. The term «sensitivity» here means ability and speed of response to certain influences. One of the ways to ensure safe functioning of the construction-system in the system of construction-systems at a negative action of operation environment is to preserve networked relations of active elements at all levels of subsystems. This can be achieved by directed organization of the structure taking into account phenomena of self-organization in the technological period of constructions production.

The building construction reacts to whole complex of external and internal loads that arise as a result of environment actions. Multi-component material and complexity of structure organization, complex of physical-chemical processes of binder hydration and physical-mechanical processes of structure formation at all hierarchical levels of the system, constant structural transformations under influence by external and internal factors during operation period indicate complexity of the construction. Self-organization processes of structure determine periods of creation and operation of the construction. Thus, the building construction can be represented as open complex self-organizing system.
The interrelation of material structure and construction structure.
The material of construction is always present as changing factor, regardless of structure hierarchical levels of the building. This is particularly emphasized in scientific papers [5, 6], in which the construction is considered as specially figuration material.

Representation of the building construction as especially figuration material in certain geometric shapes implies the following: - construction properties are determined by material properties; - structural features of the material are automatically included in construction structure; - geometrical construction parameters create local and integral fields of residual deformations in the material in the technological period of material production; - formation nature of residual fields of deformations leads to fluctuations in a density of concrete mixture, change of kinetics of physical-chemical hydration processes, change of mechanical and deformation characteristics of concrete in various volumes of the construction; - change of concrete properties in various parts of a particular construction suggests that the properties of concrete of the same composition should differ in the product with different geometric characteristics; - existence of material properties gradients in the construction leads to an uneven development of humidity and thermal deformations, diffusion mass transfer processes of different intensities, etc.; - permanent change of material structure and therefore its properties during the period of operation loads results in permanent non-equilibrium state of the construction; - concrete quality indicators in operated construction should be determined by a special method depending on type of the product; - average characteristics of material properties cannot give reliable information about the product condition considering that all catastrophic processes start from localized zones.

All these factors, as well as many others that have been left without due attention, indicate, in our opinion, at least three fundamental points. The first point is due to the fact that it is irrational to consider technical and economic tasks of designing optimal concrete compositions without taking into account type of the construction with possible fluctuation of properties by their volume. The second point is that methods should be developed that allow, at the stage of designing construction, to take into account not only average characteristics of strength and deformation properties of the material, but also its structural features related with this construction. The third point is based on the fact that it is not technically and economically advantageous to design concrete compositions for construction production without taking into account possible influences of operating environment.

The emphasis on structural organization constructions, taking into account the material structure, gives opportunity to study its structure, to determine the structural components of the material, which can remove the construction from conditions of safe functioning, to assess its role in ensuring cooperation with its environment.

The construction as system in system of construction-systems.
Construction-systems, depending on their individual structural figuration, determine creation and functioning of buildings, structures and their complexes as systems of construction-system, in turn, imposing requirements on their own basic elements, including the material from which constructions are made. This approach makes it possible to evaluate contribution of material to organization of structural levels of hierarchical systems of any kind of complexity, to identify structural elements that ensure the preservation of construction properties under influence of operational loads, to present its structure as a function of movement, which determines through change of structural parameters safety of functioning of the object-system in the system of object-systems.

The selection of the construction-system as basic integral element in the general building hierarchy implies the following: - the construction-system, being an element of the system of construction-system, creates continuous structural series of any type systems complexity; - presentation of the construction-system in the system of constructions-system and in mega-systems allows considering issues of the rational use of material and technical resources from single technical and economic positions taking into account environmental requirements both at the construction stage, and during
operation of individual constructions, structures and town-planning complexes; - the construction-system, being a knot of inter-structural interactions in the system of constructions-system, determines the safe functioning of the whole system by own state; - the structure and therefore properties of the material are realized in the construction-system, that allowing entering a material into all structural levels of hierarchical systems.

The role of the construction-system in the general building hierarchy is demonstrated by the scheme shown in figure 1.

Figure 1. The role of the construction-system in the general building hierarchy.

Mega-systems are complex-organized formations with multi-purpose functioning. Components of mega-systems are self-contained systems, which include different for the purpose buildings and structures (systems of construction-systems).

The building (structure) can be reasonably presented as complex open system. This implies that the building is in the certain way structurally hierarchical formed and perceives all influences of the environment. Structural figuration allows distinguishing individual subsystems of the building: subsystems in the form of electric power supply, water supply, ventilation and heating (sewage and communication systems are not included in our tasks). Load-bearing walls or a frame can be selected as subsystems depending on the design features of buildings. Building bases and foundations, overlapping and flat roofs, stair landings and flights, elevator shafts, etc. can be are individual subsystems. The principle of subsystems selection is based on their role in the building, types of perceived loads, design features and required properties. At the same time, an interaction of subsystems is necessarily taken into account that implies manifestation of emergent in the building, and rather complicated organization of the subsystems themselves. We will accept that the building is built of concrete and reinforced concrete of appropriate types and purpose. Therefore, concrete can be included as the subsystem in the previously selected subsystems. In turn, concrete is a poly-structural material with a rather complex structural organization at each level of structural heterogeneities [7]. Structural heterogeneities can be interpreted as subsystems of subsystem at the concrete level, which in turn is the subsystem of subsystem at construction level or structural element level.
The selection of individual building construction as research object makes it possible to decompose the construction itself and analyze its role in individual structural schemes of the building and the building itself (Figure 2).

![Diagram of System-objects](image)

**Figure 2.** The analysis of a role of structure organization of the construction-system in the system of construction-systems.

This allows evaluating properties of construction; to determine main factors that define them, and to assess a role of the construction in the system of objects, both at individual structural schemes level, and at the entire object level as system with a certain structural figuration of structural elements. This approach seems to be the most rational, because it allows studying an influence of structural organization of the material on construction properties and determining its role in individual structural schemes and in a building itself. The representation of the construction as system allows determining its structural organization, which ensures the realization of its functions, and analyzing an impact of changes in the functional construction properties on working state of individual structural schemes and whole building-system.

3. **Functioning of the construction-system.**

The construction-system is for realization individual purposes, so special attention should be paid to the period of functioning. It is during this period that the effectiveness of design and technological solutions is determined. At the beginning of realization of main functions (τ₀) the construction-system (CS) is structurally figurate in a certain way, which determines its state CS-I (Figure 3).

During operation, the construction perceives external influences, and the material of construction is subject to internal factors action. The response to external influences is the reaction of the structure material. Material response is compensatory structural changes (CI), which prevent required properties from being out of value tolerance. Internal factors action is to processes that cause structure changes (SI).
Figure 3. Functioning of the construction-system: 1 – the complex of external influences; 2 – the complex of internal influences; К_C(I)…К_C(N) – the functional state of construction-systems; CI…CN – the complex of structural changes under external influences; SI…SN – the complex of structural changes under internal factors influences; PP_0…PP_N – properties parameters.

Integrated changes of structure (CI+SI) after \( \tau_1 \) time transfer transfer the construction to the state of CS-II with the structure parameters CII and SII.

For the entire period of active functioning of \( \tau_N \), structural parameters of construction-system change proportionally to the periods of action of external and internal factors to C_N and S_N values, which determines the functional state of construction-system CS-N. The functional state of construction-system meets the requirements if material properties are within the specified limits.

There is the peculiar history of properties parameters (PP) changes during the active functioning period of construction-system. Each story begins with a certain event or point in time. The history of changing material properties begins from the time the construction was operated.

The parameters of material properties are changed to the level of PP, remaining in allowable limits, under external influences, which are perceived by material during the construction operation period \( \tau_1 \). The further predicted safe functioning demands clarification of the reasons of properties change and a description of the history of construction behaviour during the previous operational period.

In process of extension of terms of operation to \( \tau_N \) values in the conditions of permanent influence of operating environment, the next stage of changing properties to PP_N critical level occurs at the end of the existence material history satisfying to the level of requirements. A new history of completion of the stage of construction functioning begins with transition to the stage of irreversible degradation.

Presentation of the construction as system \textit{a priori} assumes its structural figuration. This gives rise to different interpretation of the history of structural parameter changes and, therefore, properties of the construction-system. For different interpretation, functioning of the construction-system should be presented as continuous structural transitions in which the system homeostasis is preserved in conditions of external and internal factors influences. The safe limits for changing properties of the construction-system are set by the range of changes in construction parameters.

The very fact of continuous change of structure indicators allows representing the structure as a function of movement, which sets a certain range of change of material properties and determines functional state of the construction-system. Structural transformations intensity of the material under acting of operational loads on the construction depends on initial qualitative composition and quantitative ratios of structural elements (CoSo). Initial structure parameters are defined as a certain
set of structural elements at the time of construction operating. At this point, the structure of the construction-system has already passed a certain history of formation and development. The beginning of this story falls during the system formation period. Disparate models prior to this begin to merge into the construction-system model.

Due to the fact that functioning of construction-systems is considered as continuous processes of structural transformations, which depend on the history of structural figuration, it is necessary to solve the following tasks: - a choice of construction-system structure model taking into account possible options of its interaction with its environment during the operation period; - identification of dominant elements of the structure, which should ensure safe operation of the construction-system under influences of external and internal factors; - design of concrete compositions and assignment of technological modes for concrete mix production taking into account geometrical parameters of the construction to create required set of structural elements according to their qualitative composition and quantitative ratios; - purpose of production technology of the construction-system with required set of physical-mechanical characteristics.

The adoption of rational technological decisions to obtain the construction-system with required structural characteristics at this stage of technology development of production of building materials and products is based primarily on determination of structural elements, which provide the appropriate level of required properties and which are able to maintain this level in adverse operating conditions. It should be noted that the original structure is an instant «portrait» of the structure, which entered the «family album» of the construction-system not by some exceptional internal characteristics, but by the fixed date. From this point on, the history of functioning of the construction-system in the system of construction-systems begins.

The motivated source of initiation and development of self-organization processes can be considered active elements in the form of cracks and inner surfaces of partition, which are inherent components of individual subsystems. A developed network of cracks and inner surfaces of partition connects all hierarchical levels of material into a single dissipative system. Therefore, the structure of complexly organized material can be represented as the network of active elements, which organized according to the principle «network within networks» at individual levels of heterogeneities.

The «Large» network of cracks and inner surfaces of partition includes the network of cracks and inner surfaces of partition of different scale heterogeneities at the level of material structure.

Each individual network in the integrated network is a certain set of active elements at a certain level of structural heterogeneities (subsystems). With this model of material representation it is possible to distinguish interaction zones of different-level network-components, in which they manifest themselves through internal and inter-structural connections. A different order in transition zones is formed in case of structural changes caused by internal or external factors. Structures automatically emerge that are new to each individual network and the only ones possible to preserve the interconnected network of active elements in the product material as complex system. If it is not possible to incorporate individual networks into the global network, the interconnectedness of structural elements is violated. At the same time an uneven load on individual network elements arises, the transmission of information about the state of individual subsystems ceases and, as a result, the principle of auto-support is violated. This leads to formation of the fundamentally different material structure. The new structure is active due to the fact that its organization has manifested itself as a response to the formation of active elements with critical parameters. The new structure turns the basic system into a scleronomous one through its desire for self-organization. The base system loses its ability to perform its functions.

One of ways to ensure safe functioning of the construction-system in the system of construction-systems at negative action of the operational environment is to preserve interconnected relations of active elements at all levels of subsystems. This can be achieved by directed organization of the structure taking into account the phenomena of self-organization during the technological period of construction production. A certain set of active elements at all levels of structural heterogeneities
should be created in the material by the time the construction starts working in the system with similar ones. The individual set involves designing an interconnected and interdependent network of active elements, taking into account their interaction and self-support during the period of action of external and internal loads on the system. Thus, the principle of system self-organization will be realized throughout the entire period of its functioning that makes it possible become apparent whole complex of adaptation mechanisms and thereby avoid crisis situations for systems.

4. Summary

The analysis leads to the conclusion that the building construction can be represented as open self-organizing system. Such presentation will make it possible to realize more fully joint efforts of designers and technologists aimed at further revealing potential possibilities of realizing material properties formed in the construction. Special attention should be paid to active elements, as they are able to change their own parameters under influence of external and internal factors. Changing parameters of active elements causes change in the system structure. When critical parameters of self-developing active elements are reached, catastrophic loss of functional properties with early failure of the construction-system may occur. Favourable structural changes associated with self-support and self-development of active elements network make it possible to realize adaptation effects (structural self-organization), which allows the construction-system to function during the standard period. Due to the individual structural organization, which provides manifestation of required properties, the individual building construction should be identified as independent research object. Representation of the construction as system in system of construction-systems allows determine structural components of the material, which provide the required construction properties and preserve them in predetermined values during the period of operation loads action. This makes it possible to work together in the system of similar construction-systems through spontaneous manifestation of internal and external safety effects (homeostasis phenomena).

References

[1] Travush V I and Fedorova N V 2018 Survivability of structural systems of buildings with special effects Magazine of Civil Engineering Vol. 81 Issue 5 pp 73–80
[2] Hewitt E, Oberg A, Coronado C and Andrews C 2019 Assessing “green” and “resilient” building features using a purposeful systems approach Sustainable Cities and Society (Elsevier) Volume 48 https://doi.org/10.1016/j.scs.2019.101546
[3] Artyukhov V V 2009 General systems theory: Self-organization, sustainability, diversity, crises (Moscow: Librocom) 224
[4] Soroko E M 2006 Golden ratios, processes of self-organization and evolution of systems: Introduction to the general theory of harmony systems (Moscow: KomKniga) 264
[5] Sukhanov V G, Vyrovoy V N and Korobko O A 2016 Material structure in construction structure (Odessa: POLIGFAF) 244
[6] Vyrovoy V N, Dorofeev V S and Sukhanov V G 2010 Composite Building Materials and Constructions. Structure, Self-organization, Properties (Odessa: TES) 152
[7] Cherniavsky V L 2008 Adaptation of Abiotic Systems: Concrete and Reinforced Concrete (Dnepropetrovsk: DNURT) 4125