IOP Conf. Series: Materials Science and Engineering **791** (2020) 012050 doi:10.1088/1757-899X/791/1/012050

# Problems of energy resources allocation at decision-making stages in architecture and urban planning activities

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**Abstract**. All the levels of architecture and urban planning activities (management, designing, execution of construction works) bring up various questions of the optimal distribution of energy resources. This paper shows that the energy resources allocation is connected with different classes of tasks in optimal decisions making and belongs to mathematical programming problems. Optimization tasks at the stages of scientific research, substantiation and version design should be performed on the basis of dynamic system models of the type «population ↔ environment». The article justifies the need for deductive approach and system methods and evaluation criteria of energy resources distribution at the stages of design and quality evaluation of architectural objects. It is demonstrated that in architectural theory and practice, for the purpose of quantitative measurement of the quality of architectural and construction activity products, the scientific research of the new area – architectural metrology – is needed. The energy interpretation of the general optimality criterion of integral architectural objects as systems, functioning in accordance with general system principles, is discussed.

## 1. Introduction

The global energy demand at the beginning of the 21st century has exceeded $5 \cdot 10^{17}$ kJ per year, or over 12 bln tons of oil equivalent [1 p 6]. Satisfying the growing energy demands of the modern society together with the rational distribution of energy and preserving the environment is one of the most crucial tasks nowadays. A wide range of various research and design works in the sphere of architecture and urban planning activities can be considered as transforming resources into the result.

The problems of energy resources distribution in urban development and national-economic activity are considered in a number of fundamental works [1–5]. Research in the sphere of urban and regional planning methodology is considered in various works [6–8]. Optimization of structure and functioning of architectural activity objects is dealt with in a number of works [9–15]. The aspects of parameter optimization of an architectural design object are presented in the works [16–18]. The issues of adapting the system methods of research and design of architectural objects are considered in the papers of the authors [8, 12, 17–19] etc. The issues of optimizing the parameters of technological processes and the sequence of technological operations in the sphere of design and construction are covered in a wide range of scientific and practical research works [20–25].

The analysis of the above-mentioned scientific publications and the experience of project design have allowed us making a conclusion that at present there is no unified approach to formulating tasks of energy resources allocation in architectural activity. This is a result of discrepancies in terms of research methods and architecture and urban planning activities, including those at the levels of settlement systems and general plans of cities.

## 2. Materials and Methods

The purpose of this research is determining and substantiating the tasks of optimizing energy resources allocation in the process of formation of architectural and urban planning objects as integral systems.

Research objectives:

- determination and substantiation of design stages as tasks of optimizing energy resources allocation in the process of architectural and urban planning systems formation;
- substantiation of the system approach and system methods of studying evaluation criteria of energy resources allocation at the stages of design and quality assessment of architectural objects;
- developing a structure model of an integral architectural system with specifying the place and role of the energy component of its subsystems;
- developing a thermodynamical interpretation of development processes of integral architectural systems of the type «population ↔ environment» (demoecosystems).

The object of research is design stages as the levels of optimization tasks in architectural and urban planning systems formation. The subject of research is optimization tasks of energy resources distribution in architectural systems at different levels of their organization. The methodology of research is based on methodological provisions of the general system theory with regard to architectural objects of various hierarchy levels.

### *2.1. Optimization tasks of energy resources allocation at various design levels*

Design is a process of creating a model of a future architectural object, as an eventual result of conceptual, functional and physical modeling. The combination of engineering, natural and social sciences in studying architectural systems has resulted in developing a new methodology of their research. There also appeared the synthetic, «hybrid» branches of learning, including complex systems modeling [5 p 186].

Figure 1 presents a scheme, which depicts stepwise decision making at designing architectural systems. The scheme shows a possible variant of errors in decision-making process. Field of the III level falls outside the limits of the field in the II level, which indicates miscalculation of limitations at the III level, or an error at the II level of decision making.

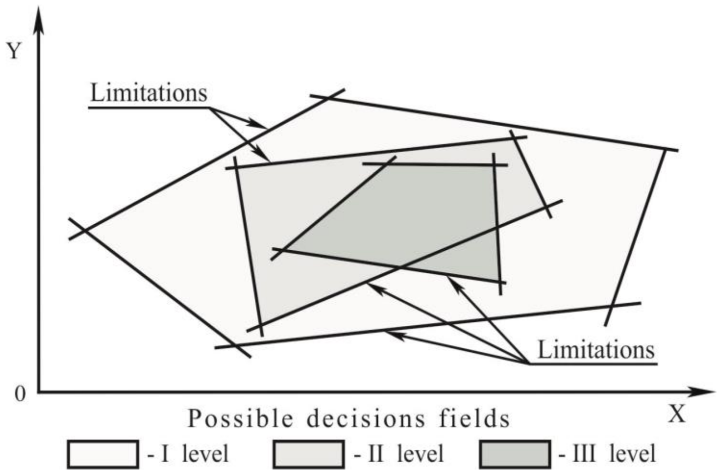


**Figure 1.** Scheme, which depicts stepwise decision making at designing architectural systems.

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Figure 2 presents a graph of comparative assessment of possible errors range at various stages of decision making (energy resources allocation). The optimal capital investments and optimal energy resources allocation at each stage of decision making with achieving the optimal quality are taken as 100%. At the stages of scientific research and substantiation, as well as at version design, the possibility to alter the quality of an architectural object is within the range from 100 to 25%. After a project goes to the construction stage the alteration of its quality is possible only within the range of ±10% [12 p 10]. So, design is one of the critical stages, determining the achievement of proper architectural objects' quality and the rational energy resources distribution. At the level of urban development and regional planning the requirements for systemacity and scientific validation are basic and reasonably necessary.

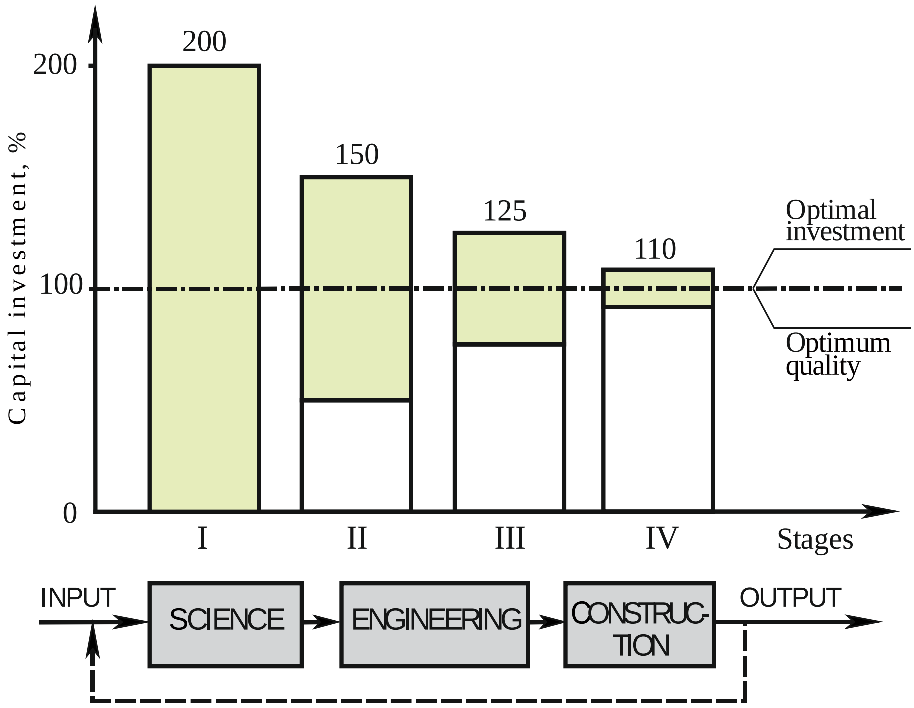



**Figure 2.** Graph of the comparative assessment of possible errors range at various stages of decision making: I – basic; II – functional; III – design-and-engineering; IV – engineering and manufacturing.

The main tasks, which arise in management, design and construction, can be included into the class of energy resources allocation tasks, as it is shown in table 1 [3 p 26].

**Table 1.** Optimization tasks at various design levels.

| Application area | Management | Design | Technological processes development |
|---|---|---|---|
| Main tasks | Various tasks of resources allocation | Optimization of design object parameters<br>Optimization of design object structure<br>Optimization of functioning | Optimization of product manufacturing route<br>Optimization of technological processes parameters |

### *2.2. Methods and criteria of evaluating the quality of energy resources allocation at the stages of design and quality evaluation of architectural objects*

To methods of solving the tasks of urban development and national-economic activities the special requirements of objectivity are specified. The present-day methods of architectural objects quality evaluation, and, consequently, of the resources allocation, are presented with four main approaches: complex approach, system approach, expert-based (intuitive) approach and technical-and-economic approach. In table 2 the methods and criteria of architectural objects quality evaluation are given. Considering these four existing approaches (methods), we can make a conclusion that the most efficient is the system approach, which meets the requirements of promptness, universality, application of computer technologies and possibilities of successful implementation into the Building Information Modeling (BIM).

**Table 2.** Methods and criteria of architectural objects quality evaluation.

| | Methods | | | |
|---|---|---|---|---|
| Characteristic of methods | System | Complex | Expert evaluation | Technical and economic |
| Method of decision taking (conclusion) | Mostly deductive | Mostly inductive | Depends on an expert's experience | Mostly inductive |
| Number of considered parameters (factors) | Determining (main) factors | Maximum possible number of factors | Maximum possible number of factors | Maximum possible number of factors |
| Nature of the criterion structure | Nonadditivity | Additivity | Mostly additivity | Additivity |
| Approach to the degree of achieving goal | Single-criterial | Multi-criterial (for a complex in general) | Mostly multi-criterial (for a complex in general) | Multi-criterial (for a complex in general) |
| Approach to decision making | Hierarchical (from a higher, more general level, to a lower, more particular) | Mostly single-level | Depends on an expert's experience | Mostly single-level |

In Figure 3 the stages of system models development from determining the system components to the experimental testing of models are presented.

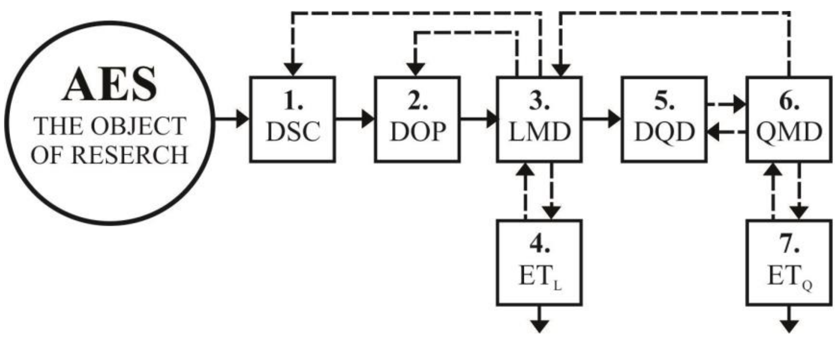



**Figure 3.** System models development stages: AES – demoecosystem: DSC – determining of system components; DOP – determining of operation principles of a system; LMD – logical models development; DQD – determining quantitative data and criteria; QMD – quantitative models development; $ET_L$, $ET_Q$ – experimental testing of models (logical and quantitative, respectively).

At each stage of problem solving the taking of an optimal decision is required. The optimal energy resources allocation and the successful forecasting in the sphere of architecture and urban planning is possible only on the basis of developing and applying mathematical models, which describe objects from the perspective of system approach and general system principles. For this purpose, first of all, it is necessary to understand and implement in mathematical models the principles of architectural and urban-planning objects behavior (functioning and development).

*2.3. The structural model of the energy component of architectural systems*

An important aspect of an architectural activity object is its definition as an ecological system of the type «population ↔ environment», including three functional-spatial subsystems: artificial (architectural and urban-planning) environment, natural environment and the population. In figure 4 the principal structural model of an ecological system of the type «population ↔ environment» is presented. This scheme singles out three main subsystems:

- P – population (society), social resources of the population involved and not involved in the production;
- AE – artificial (architectural) environment, the second nature of the human society, including scientific and technical opportunities at the given period, objects of productive and nonmanufacturing activities of the population, solutions of communications between the architectural system's elements;
- NE – natural environment, including the elements of biosphere and geosphere, climatological, topological and geological peculiarities of the landscapes' territories, natural resources for the spheres of production and consumption.

Unlike the biological ecosystems, which adapt to the changing conditions, in architectural ecological system humans actively influence their natural surroundings, creating an artificial environment, a «second nature» [5, 8, 12, 17, 18]. In figure 5 a functional model of energy subsystems and their interinfluence and interdependency principle is shown. This scheme presents a slightly generalized picture of the interaction mechanism of the main subsystems at the energy level.

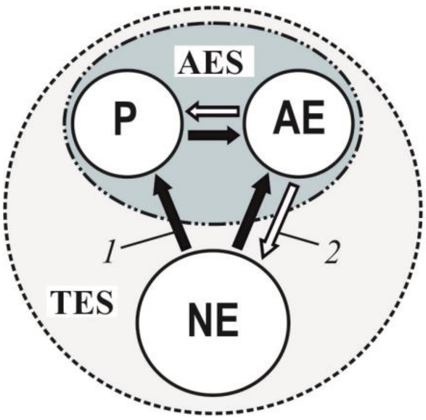
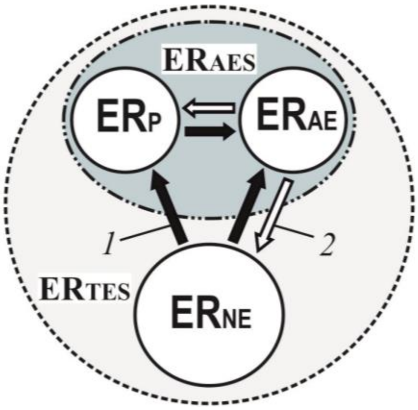


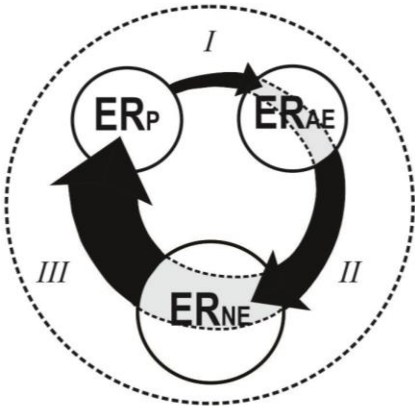

**Figure 4.** The principal structural model of an ecological system of the type «population ↔ environment»: P – population; NE – natural environment; AE – artificial (architectural) environment; AES – artificial ecological system; TES – terrestrial (natural and artificial) ecological system; 1 – direct connection; 2 – reverse connection

According to the system principle of structure invariance, in each of subsystems we can single out elements, which reflect the identity of functional processes, performed in each subsystem. These are industrial processes («production of the I kind»), municipal processes («production of the II kind»), recreation and communications (connections) of the system (figure 6).

Figure 7 presents a structural scheme, depicting the relations between types of activity in each of subsystems, however different they may be in qualitative or quantitative determination of elements or connections.




*a*




*b*

**Figure 5.** The structural model of an energy component of the «population ↔ environment» systems: *a* – functional model of energy subsystems; *b* – inter-influence and interdependency principle of elements (subsystems). $ER_P$ – energy resources of the «population» subsystem; $ER_{NE}$ – energy resources of the «natural environment» subsystem; $ER_{AE}$ – energy resources of the «artificial (architectural) environment» subsystem; $ER_{AES}$ – energy resources of the artificial ecological system; $ER_{TES}$ – energy resources of the terrestrial (natural and artificial) ecological system; 1 – direct connection; 2 – reverse connection; *I* – error at the stage of research and/or design; *II* – an error, materializing and operating in time, adversely affects the natural environment resources; *III* – systematic adverse effect of energy resources of the damaged natural landscapes on the human health.

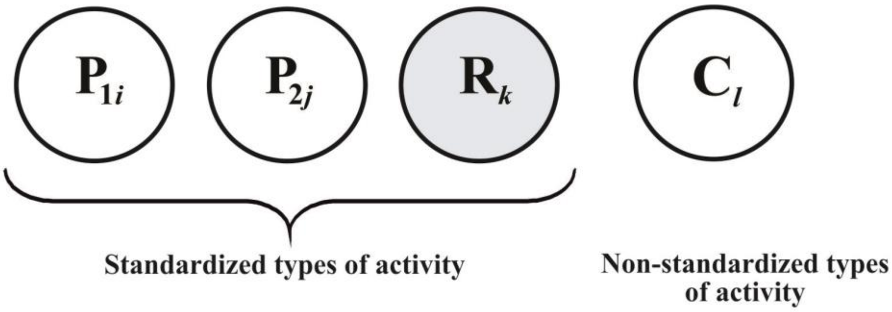



**Figure 6.** System-forming components of integral architectural systems: $P_1$ – production («production of the first kind»), *i* – 1, 2, … *m*; $P_2$ – municipal processes, social infrastructure («production of the second kind»), *j* – 1, 2, … *n*; R – recreation, *k* – 1, 2, … *m*; C – communications (connections) of an architectural system, *l* – 1, 2, … *s*.

## 3. Discussion

Exhaustibility of natural resources and the resulting influence of population on the natural environment's mechanisms make the problem of studying the regularities in reactions of human and natural environment to the impacts of artificial (urbanized) environment rather acute. Figure 5 illustrates the inter-influence and interdependency of the architectural environment subsystems at the energy level. Knowledge of these regularities is necessary in various aspects: ecological, social-economic, physiological and moral.

The energy and its potential for living (biological) and non-living (technical) subsystems should be evaluated in different values. It is hardly possible to evaluate in the same values the energy resources of the subsystems «Population», «Artificial environment», «Natural environment». Quality evaluation of the taken design solutions and architectural objects is possible in case of creating a new area in architectural theory and practice – architectural metrology [12 p 11]. One of the aspects of this branch is a science about the quantitative measurement of the architectural and construction activity product quality – architectural qualimetry.

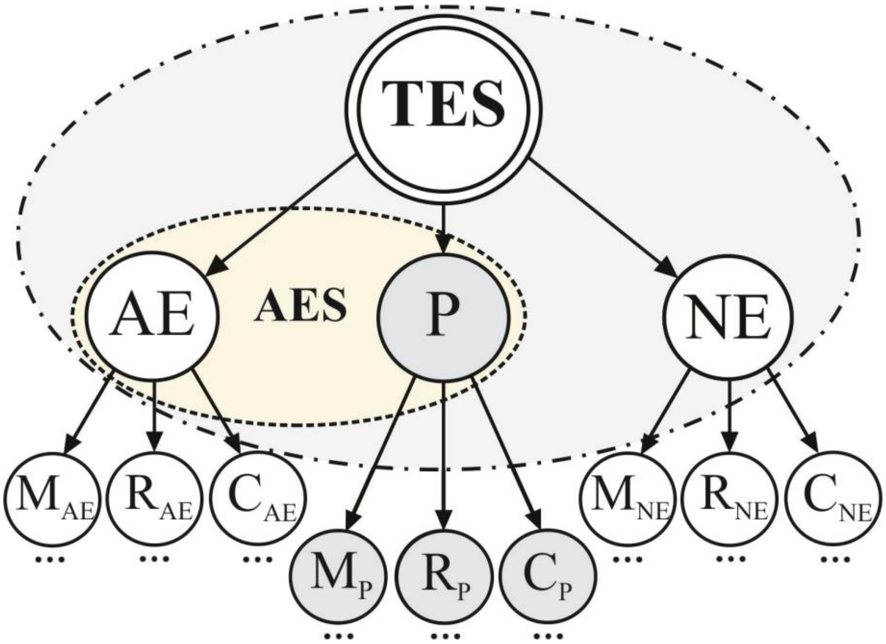



**Figure 7.** The structure of types of activity as elements of the terrestrial ecological system (TES): AES – artificial ecological system. Subsystems of artificial ecological system: AE – artificial (architectural) environment $AE = M_{AE} \cup R_{AE} \cup C_{AE}$ ; P – population, $P = M_P \cup R_P \cup C_P$; NE – natural environment, $NE = M_{NE} \cup R_{NE} \cup C_{NE}$. Subsystems of artificial environment: $M_{AE}$ – production of material-and-technical component of the productive and non-productive spheres; $R_{AE}$ – recreation of material-and-technical component of the productive and non-productive spheres; $C_{AE}$ – communications (connections) of material-and-technical component. Subsystems of population: $M_P$ – social infrastructure (cultural and social services); $R_P$ – recreation of population; $C_P$ – communications (connections) of population. Subsystems of natural environment: $M_{NE}$ – reproduction of natural resources; $R_{NE}$ – recreation (restoration) and protection of natural landscapes (geosphere and biosphere); $C_{NE}$ – intra-subsystem connections (communications) of the natural environment.

Trying to evaluate the energy costs and the quality of an architectural object by means of technical-and-economic indices, natural indices or gross figures can’t be a substantial basis for measuring the decision making efficiency on mathematical models of architectural systems. So, a number of specialists in the sphere of systems analysis [3, 8, 12] consider it promising to use energy measuring units in evaluating the efficiency of energy resources allocation and of the national economy. P.G. Kuznetsov [3] suggested the idea of the national economy planning and management on the basis of determining the so-called «energy balance of the society».

Integral architectural systems are the systems, which function in accordance with general system principles and the third law of thermodynamics (Prigozhin principle). So, the optimality criterion of architectural systems can be interpreted in terms of energy. A system, varying with time, changes its energy potential. The behavior and development of a system is its passing from one state to another. All the existing systems, which have a higher energy potential, than the surrounding systems, give

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them a certain amount of energy. So, all the things in existence can be classified by the types of energy output. According to the third law of thermodynamics, biological and social systems, accumulating information, increase the level of their orderliness and at the same time decrease the entropy level.

According to the «maximum work principle», suggested by E.S. Bauer, and the «free energy growth law», suggested by G.I. Lavrik [8, 12], development of a system is a result of increasing the external work of system as related to an energy unit, received from the environment. So, in the course of time the entropy of a system is reduced. The energy analysis of development processes in systems «population ↔ environment» (integral architectural systems – demoecosystems) was suggested by G.I. Lavrik [12 p 86], according to which *F* – energy received by the system from the environment and *A* – external work of the system are related as follows:

$$\frac{A}{F} \to \max \tag{1}$$

$$\Delta S = \frac{\partial Q}{\partial t} = \frac{\partial\left(\frac{A}{F}\right)}{\partial t} > 0, \tag{2}$$

where $\Delta S$ – entropy of system; $\partial Q$ – system state function; $\partial t$ – unit of time; *F* – energy received by the system from the environment, and *A* – external work of the system.

*F* – the energy, received by the system from outside, – can be presented as a sum:

$$F = F_1 + F_2, \tag{3}$$

where $F_1$ – part of energy, spent directly for performing the work «*A*» ; $F_2$ – part of energy, absorbed by the system. So,

$$A(F) = A(F_1 + F_2) = A(F_1),\ A(F_2) = 0\,. \tag{4}$$

Taking into account the «maximum work principle» and indentifying the values $F_1$ and *A*, we obtain the following relations:

$$\frac{A}{F} \to \max\,, \quad \frac{F_1}{F_1 + F_2} \to \max\,, \quad \frac{F_2}{F_1} \to \min\,. \tag{5}$$

Inserting into the relations (5) the determinations of subsystems' structure as elements of a terrestrial ecological system of population, we obtain:

$$\frac{A(P \cup AE \cup NE)}{F(P \cup AE \cup NE)} \to \max\,, \quad \frac{F_1(P \cup AE \cup NE)}{F_1(P \cup AE \cup NE) + F_2(P \cup AE \cup NE)} \to \max\,, \quad \frac{F_2(P \cup AE \cup NE)}{F_1(P \cup AE \cup NE)} \to \min\,, \tag{6}$$

where *P* – population; *AE* – artificial environment; *NE* – natural environment. Identifying these relations with types of functional processes, performed in subsystems, according to the general system principle of structure invariance, we obtain:

$$\frac{A(M \cup R \cup C)}{F(M \cup R \cup C)} \to \max\,, \quad \frac{F_1(M \cup R \cup C)}{F_1(M \cup R \cup C) + F_2(M \cup R \cup C)} \to \max\,, \quad \frac{F_2(M \cup R \cup C)}{F_1(M \cup R \cup C)} \to \min\,, \tag{7}$$

where *M* – manufacturing processes («production of the first kind» and «production of the second kind»); *R* – recreational processes; *C* – communicational processes (connections).

So, by the «free energy growth law» the ratio of the amount of energy, absorbed by the system at performing the work *A*, to the energy, spent directly for performing the work *A,* should decrease. This correlation reflects the «general» optimality criterion of architectural systems of the type «population ↔ environment». The «free energy growth law» and the law of capacity maintenance are invariant, uniting the natural, social (industrial) and mental processes into a unified system.

## 4. Conclusion

According to the findings of the carried-out research we can arrive at the following conclusions.

1. The tasks of resources allocation in architecture and urban planning activities have a wide application area – from the level of technological processes development and parameters optimization of a small-scale design object to the level of managing the development and functioning of large urban-planning objects. The energy resources allocation tasks, which are essentially optimization tasks at the stage of decision making in architecture and urban planning activities, in mathematical terms belong to mathematical programming problems.
2. Among the determining ones in optimization tasks of resources allocation are the stages of scientific research, substantiation and version design. These stages are aimed at achieving the optimal quality of architectural environment. At each stage the optimization should be performed on the basis of the existing limitations, taking into account its functional-dynamic character, i.e. on the basis of dynamic models of systems of the type «population ↔ environment».
3. The structural model of an energy component of the systems «population ↔ environment» includes the resources of the following basic subsystems: «Population», «Artificial environment», and «Natural environment». The energy resources allocation tasks at the stage of decision making in architecture and urban planning activities require using deductive approach and system methods and criteria of architectural object quality evaluation.
4. The system-forming components of integral architectural systems are the following types of functional processes: production («production of the first kind»), municipal processes («production of the second kind»), recreation and communications (connections) of an architectural system.
5. The problems of quantitative measurement of the architectural and construction activity product quality and the optimal energy resources allocation are the tasks of a new scientific area – architectural qualimetry, as one of the aspects of architectural metrology.

## Acknowledgments

The work is realized in the framework of the Program of flagship university development on the base of the Belgorod State Technological University named after V.G. Shoukhov.

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