Pentasphere predictive analytics for urban environment arrangement and management

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Abstract. Improvement of the quality of inhabitants’ life is the key priority in future urban development. Classical mechanism supporting organizational and management actions on urban environment development is based on two types of resources: man and technical facilities. It is found out that a new reality – digital environment – is mainstreamed along with technosphere development. Interaction criteria for pentasphere environment: noosphere – biosphere – ecosphere – technosphere – digital sphere – have been formulated. It has been proved that urban infrastructure components are not confined to residential and industrial zones so far. The algorithm for resource durability of utilities systems in urban residential estates has been developed using predictive analytics methods. It is established that the technology of augmented and mixed reality expands opportunities for remote control, maintenance and repair of various technical and engineering systems. A long-term forecast method for environment comfort metering with the modeling of variability impact of accentuated components of five spheres has been proposed. It is proved that the technology of augmented, virtual and mixed reality (AR/VR/MR), which adds information to the environment on the basis of existing data, allows making enhanced solutions and reducing errors in the field of urban infrastructure planning and construction management, accounting and distribution of housing and utilities resources.

1. Urban development and quality of urban life
Economic development of any country in the world includes several key tasks, improvement of quality of inhabitants’ life is one of priority tasks. Implementation means with regard to different spheres can be represented by flow chart of influence and significance of human environment development, and its saturation with structural components.

On practical grounds comfort environment is supported by innovative technologies implementation in urban environment development and complication of its system. Comfort environment is no longer limited to comfortable dwelling with utility systems, but extends to urban environment, adjacent transport and social infrastructure. More attention is given to state-of-the-art innovative systems.

It is logical to conclude that any environment changes are impossible without technical facilities and equipment, and conservation of bio- and ecospheres requires corresponding technologies.

Technical and technological potential available in construction is sufficient to solve above-mentioned tasks only at construction phase. Whereas operating period has legislative saturation, under variating resources it requires continuous correction not the goal as much as final results, such as comfort, sustainability, economical efficiency, safety and other.
In its turn, digital systems mainstreaming as an additional element for lifecycle control and management of buildings, structures and other infrastructure, allows to obtain data on actual structure state, compare it with statutory values, and create forecast security, ecology and comfort models in the presence of corresponding hardware and software.

The proposed scientific approaches of scientists M. Porter, Dontsova T V, A.A. Anuchin, O.N. Belenov, S.N. Glagolev, Goropashnaya A V, Gusakov E A Zorin V A A.A. Rudychev, E.D. Schetinina Telichenko V I et.al. have been taken as a basis for solution of problems concerning efficient territory arrangement and management. In general, these approaches suggest taking into account integral nature of territory functional zoning for territory competitive status assessment [1-6].

2. Pentasphere: noosphere – biosphere – ecosphere – technosphere – digital sphere

Classical mechanism supporting organizational and management actions on urban environment development is based on two types of resources: man and technical facilities.

Obviously a man uses all available state-of-the-art instruments, machine systems and technologies for comfort environment arrangement. Digital environment as an augmented reality environment is predominant among groundbreaking technologies. It becomes customary to include bio- and ecosphere conservation criteria in this process.

Structuring algorithm for five spheres of influence – pentaspheres – is proposed. Thus:
- for comfort environment a man uses collective mind resources, namely noosphere;
- basing on mechanical systems – technosphere [7];
- taking into account influence on environment impact – ecosphere and biosphere.
- development of information modeling and building site lifecycle management by means of various automated systems give accent to new – digital sphere.

Authors consider reasonable to use mathematical apparatus of predictive analytics, including data obtained by parametric testing hardware, for the study of construction processes optimization and model production [8-10].

It is proposed to include influence criterion in resources forecast calculation model taking into account operating efficiency of urban infrastructure objects at a given time period. Introduction of influence coefficients for every pentasphere is a key element of the calculation model.

Criterial provision for positive forecast is a model with minimized negative impact and maximum equipment and technology involvement corresponding to industrial level of the period under consideration. Such model will be represented by a self-adapting "digital twin" of the object.

3. Mathematical and computerized modeling

Practical implementation of above-mentioned provisions of the proposed conception is based on basic physical entity design theory, large system theory, reliability, probability and introduction of computerized modeling software capabilities. All these theories provide only kinematic description of systems under formation, but dynamic model also includes functional parameters of the object. Thus, the object can be simulated and visualized as a physical system, but such model does not describe its change over time during operating period.

It is proposed to add predictive analytics calculating methods and hardware to the model.

Engineering process of urban environment cluster zoning (UECZ) is taken as an example. Sustainability forecast for long-term period is made [11,1].

Pentasphere elements interaction: noosphere-biosphere-ecosphere-technosphere-digital sphere – is described by functional model:

\[ F_{PS}(X_{PS}, Y_{PS}, P_{PSi}, SV_{PSi}, SW_{PSi}, IK_{PSi}) \rightarrow extremum \]  

where: \( X_{PS} \) – input generalized system index, \( Y_{PS} \) – output system index, \( P_{PSi} \) – processes for pentasphere elements, \( SV_{PSi} \) – system element properties, \( SW_{PSi} \) – system links, \( IK_{PSi} \) – performance indicators of system elements.
It should be emphasized again that UECZ implementation is subjected to disturbances that have not been taken into account during design. Thus, state assessment procedure of macro- and meso-factors and development prospects of the region territory should be of particular importance for UECZ technology [13].

Competitive status coefficient of urban environment territory \((k_{uet})\) is introduced. It is the most important estimated figure as it covers both internal and external efficiency of territory development. The figure is distinguished by its integrated systemic nature, i.e. all aspects of the event under consideration are analyzed in reference to each other, and a whole set of factors affecting competitive status is taken into account.

Hardware monitoring is required for urban environment arrangement and management. Such monitoring is achieved by “digital twin” of territory functioning and status change recording. Three basic components are pointed out in “digital twin” stored logic for analytic forecast in a specific operating period [13,14]:
- profitability of strategic capital investment in territory;
- optimality level of territory development strategy;
- degree of conformity of the territory potential.

\[
k_{uet} = \frac{I_T - I_K}{I_0 - I_K} \times \frac{S_T}{S_0} \times \frac{C_T}{C_0}
\]  

(2)

where \(I_T\) - level of strategic capital investment in territory development; \(I_0\) - optimal volume of capital investment, after which increase results in territory cost reduction; \(I_K\) - critical volume of capital investment, reduction of which does not result in territory cost increase; \(S_T\), \(S_0\) - existing and optimal strategy of territory development, correspondingly; \(C_T\), \(C_0\) - existing and optimal region opportunities, correspondingly.

The first formula element has certain quantitative value for calculation, and two other figures should be taken as arithmetic average score (on a scale from 0 to 1) of degree of conformity of existing strategy factors or existing opportunities to optimal strategy factors or optimal opportunities.

A set of typical factors and their influence on territory development efficiency is determined to find out average weighted strategy assessment and opportunities of correlations \(\frac{S_T}{S_0}\) and \(\frac{C_T}{C_0}\).

Ultimately the competitive status of territory development is estimated on the following scale taking into account influence pentaspheres:
- \(0 < k_{uet} \leq 0.4\) – weak position;
- \(0.5 < k_{uet} \leq 0.7\) – medium position;
- \(0.8 < k_{uet} \leq 1.0\) – strong position.

Strategic development management of regional territory as an element system is governed by law of combinatorics, which allows to determine the number of all possible combinations out of elements of a certain finite set. Thus, it is necessary to specify maximum degree of complexity possible for territory development in the given structured system of influence pentaspheres, i.e. find out possible number of all combinations of \(n\) elements by \(k_{uet}\) combinations supporting system efficiency at the highest level [15-18].

4. Example of calculation of statistics

The result of the proposed model is given for the situation when territories were allocated for consumer service complexes with various functional complexity. Functional use, anthropogenic impact, and transport concentration indicators were taken as typical values.

Pentasphere predictive analytical model has been developed for urban environment arrangement and management in the context of effective use in technical center network development program for the period through to 2030 (figure 1).
Three territory development paths are established:
- **intensive**, development programs implementation in the shortest time possible (up to 1 year), which requires considerable financial investment, minimal consideration of parametric influence in pento-spheres. Achievement of technological result requires 2-3 years, at the same time return to bio- and ecosphere balance will be at critical level.
- **extensive**, the most acceptable situation (implementation up to 2 years), profitability in 5-8 years, during project implementation. This option is attractive as the issues of functional use extension and anthropogenic impact reduction of the territory are to be solved in parallel.
- **integrated**, implementation period is prolonged for 3 years and more, profitability time lag is 5-9 years. Such option completely reflects economic situation, real investment abilities and consumers’ attraction to the territory in question. Reduced impact on bio- and ecospheres is evident. State-of-the-art methods and technology can be involved step-by-step, and can be updated in stages. The weak point of the option is prolongation of investment period, which does not guarantee return on investment in modern economic circumstances. In this option natural resources can be involved smoothly and they can recover from human impact.

![Figure 1. Territory acceptability graph in parametric influence pentaspheres.](image)

Performance provisions for optimal values of introduced coefficients are set:
Optimal value of functional use coefficient is characterized by 100 % accommodation, high level of territory development, and is taken to be: \( k_f = 1 \).

At present many N-regional territories have the lowest value of functional use coefficient: \( k_f = 0.2 \).

Predictive model for the given set of provisions in case of extensive development path is represented by value variation within the following limits: 2018 – 0.43; 2023 – 0.71 and maximum load in 2030 – 1.0.

Positive dynamics is seen when the value increases.

It is taken that optimal value of territory anthropogenic impact coefficient for bio- and ecosphere is characterized 100% if the impact supports balance of natural environment and human economic activities: \( k_a = 1 \).

At present N-regional territories pretending to development and technical-purpose infrastructure formation are located in natural system with sufficiently high anthropogenic impact coefficient – 0.6.

Predictive model for the given set of provisions in case of extensive development path is represented by value variation within the following limits: 2018 – 0.55; 2023 – 0.50 and maximum load in 2030 – 0.4. These values point both at impossibility of efficient involvement of technological and technical innovations, and at natural restrictions on territory anthropogenic impact reduction. This does not waive responsibility on natural environment in areas of technological enterprises.
concentration, but as technical objects are elements upsetting the natural balance, it is not possible to reduce the index value.

At present N-regional territories have the lowest value of functional use coefficient of technical-purpose infrastructure – 0.32, which points at the fact that there is lack of socially important and high-demand structures.

Predictive model for the given set of provisions in case of extensive development path is represented by value variation within the following limits: 2018 – 0.55; 2023 – 0.61 and maximum load in 2030 – 0.8.

Due to economic instability it is not possible to suppose that this coefficient is equal to $k_{inf} = 1.0$ by 2030.

Positive dynamics is seen when the value increases.

“Digital twin” hardware and software extends involvement of urban environment infrastructural elements into predictive model and includes methods and technologies into database of innovative resources. This allows to perform predictive calculation and make project corrections that reduce negative impact on pentaspheres.

5. Discussion

“Digital twin” hardware and software allow to make predictive calculation and make adjustment to projects reducing negative impact on pentasphere elements under wider integration of urban environment infrastructural elements into predictive model, and introduction of equipment and technologies into database of innovative resources.

The proposed predictive modeling conception provides harmonization of equipment and technologies development for comfort improvement and environment – ecosphere and biosphere. Control for digital system integration efficiency will reduce negative impact of cyber physical self-development on human noosphere [19-22].

6. Conclusions

Ways of improvement of the quality of life of population, taking various influence spheres into account, are represented by flow chart of influence and significance of human environment development, and its saturation with structural components.

It has been established that digital systems mainstreaming as an additional element for lifecycle control and management of buildings, structures and other infrastructure, allows to obtain data on actual structure state, and compare it with statutory values.

“Digital twin” implementation and predictive analytics mathematical tools are substantiated for construction processes optimization issues.

Algorithm for operating efficiency of urban infrastructure objects at the given period of time is proposed. The algorithm includes criteria of five impact spheres – “pentaspheres: noosphere – biosphere – ecosphere – technosphere – digital sphere”.

Pentasphere elements interaction is described by a functional model, which is a basis for pentasphere predictive analytical model on urban environment arrangement and management for its effective use in technical center network development program for the period through to 2030.

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