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The Verhulst equation in managing the life cycle of a real estate facility

Managing the lifecycle of a real estate facility is an important part of the reproduction process. A brief analysis of corporate lifecycle models is provided. As a scientific research hypothesis, it is assumed that the initial stage lifecycle is based on consumption of external resources, while at the final stage internal resources are consumed. The concepts of "resource consumption lifecycle model" and "resource consumption rate" are introduced. It is the rate of resource consumption that determines the end of the real estate facility lifecycle. The Verhulst differential equation for the population growth model is used as a mathematical basis. The lifecycle model has three phases: growth, stability, and degradation. This model can be applied to change the lifecycle of a construction facility. Synchronous and asynchronous types of management are described. It is proven that monitoring and forecasting are components of synchronous management of a real estate lifecycle.

Keywords: *real estate management, lifecycle, resources, lifecycle model of resource consumption, synchronous management*

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INTRODUCTION

According to GOST R 57271.1–2016, one of the real estate management advantages is "corporate development sustainability increase due to a service lifecycle analysis implementation"[1]. In this regard, analysis and development of real estate facilities' lifecycle models become relevant. A distinctive feature of regional real estate management, for example, territorial reproduction real estate systems of state institutions of higher professional education, is integration of construction process with further facility management. Such management is considered as the integral lifecycle management of headwork real estate, comprising groups of facilities.

Real estate objects can be considered as complex procedural and engineering [1] systems that solve one or more economic tasks. Real estate objects are part of urban, industrial or regional infrastructure. They can function autonomously and as part of a related facilities complex. Such complexes are characteristic of the higher education system. Being a part of the complex, real estate objects can create a synergy that is not characteristic of a separate object. An important characteristic of real estate objects is their lifecycle [2, 3], associated with viability and efficiency. An indispensable stage of any real estate object design and creation is the development of a conceptual description (information structure)[1] of the lifecycle model. Separate real estate objects have the possibility of lifecycle modification through repair, reconstruction, restoration, reengineering, etc. The possibility to prolong the lifecycle characterizes flexible and self-developing systems. The lifecycle and its modification methods research is a challenging issue for the real estate management. This work aims at creating a mechanism for managing the real estate object lifecycle and its adaptive model development.

RESEARCH METHODOLOGY

The system analysis together with the structural, comparative and qualitative ones, are the basis of the study. The materials used are publications in the field of development and management of the territorial-reproduction system of real estate of state institutes of higher professional education.

RESEARCH RESULTS

The specific feature of managing the objects of the territorial-reproductive real estate system of state institutes of higher professional education is not so much the maximum income for the owner, as the education quality improvement [4], the brand of the university and comfortable environment for the university staff. In other words, the social efficiency of a state university is more significant than profit. State universities use state-owned real estate. The dominant feature of their activity is the index of the quality of specialists' training. The situation differs for commercial universities. They are autonomous and their dominant is survival, sometimes to the detriment of the education quality.

Lifecycle models. There are different models of life cycles [5]. They are used in various fields: economics, construction, modeling, biology, cybernetics, design, transport, etc. The life cycle (LC) serves as a universal characteristic of objects, systems and processes. There are special organizational life cycle (OLC) models, among which there are five main ones. OLC models consider the functioning of an object or company as a sequence of different developmental stages. The most relevant OLC models shared the organism life cycle analogy. As the fundamental ones, we can consider the LC models proposed by Lippitt and Schmidt, Greiner, Adizes, Galbraith, Churchill and Lewis. Let's consider them briefly.

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[1] GOST R 57271.1–2016. Facility management. Part 1. Terms, definitions and scope. Enacted in 2022.

Lippitt and Schmidt [6] focused on the private sector. As part of the research, they developed one of the first OLC models. They suggest that companies move through three stages of development, facing six major ‘managerial concerns’ to progress from one stage to the next. At birth, critical challenges include creating a system and reaching the survival threshold. In youth, the main concerns are stability and reputation. During the period of functioning and maturity, achieving uniqueness and responding to a variety of social needs become the main problems. Management should resolve crises in a way that creates a solid base for dealing with future crises. When the problem is solved, companies move on to the next stage. Failures occur when managers fail to recognize serious crises arising in the life cycle of an organization.

Greiner assumed [7] that the life of a company passes through a sequence of five stages of evolution and revolution. A stage of evolution is a period of growth where no major shocks occur in organizational practice. On the contrary, revolution is a period of serious turmoil in the organization's life. The resolution of each revolutionary period provides the go-ahead to move on to the next stage. The growth stages include the following:

- creativity-driven growth is interrupted by a leadership crisis;
- direction-driven growth is interrupted by a crisis of autonomy;
- delegation-led growth is interrupted by a crisis of control;
- coordination-led growth is interrupted by a crisis of bureaucracy or a red tape crisis;
- collaboration-led growth is interrupted by a crisis of lack of internal solutions for growth.

The evolutionary periods range from 4 to 8 years depending on the industry: in fast-growing industries, the periods may be shorter, while in mature industries, the periods may be longer.

The Adizes model [8] assumes that firms go through stages due to changes in emphasis on four types of activities: achieving results (P), acting as entrepreneur (E), applying forma.rules and procedures (A) and integrating individuals into the organization (I). As the organization moves from one stage to another, it emphasizes different roles, and resulting roles combinations lead to varying organizational behaviour. Organizational decline is primarily due to excessive emphasis on bureaucracy.rules and procedures. The model assumes that organizations pass through 10 development stages: courtship, infant, go-go, adolescent, prime, maturity, aristocracy, early bureaucracy, bureaucracy and death. Progress through the stages occurs mainly due to overcoming the growth problems of successive stages.

The Galbraith model [9] is based on capturing the predictable dynamics of the organization development. The basic idea of LC is that firms move through predictable stages, but, in author's view, managers do not think in stage-wise manner, despite the predictability of these stages. His model focuses on start-ups. These companies develop a business idea consisting of a market to be served, products to be sold, a basis for niche dominance, as well as resources and their combinations to achieve dominance. The model [9] involves five stages: proof-of-principal prototype, model shop, the startup volume production, natural growth and strategic maneuvering. To move from one stage to another, firms must increase in size. Moreover, growth is guided by the product market and is related to the product lifecycle.

Churchill and Lewis [10, 11] used a combination of research and analysis of previous theoretical papers to develop a new OLC model. Their theoretical development derives from the identification of three weaknesses of the previous models. First, previous models assumed that a company must grow and go through all stages of development or die trying to do so. Second, a company is unable to grasp the important early stages of company's origin and growth. Third, they define company size mainly in terms of annual sales (although some mention the number of employees), while ignoring other factors such as value added, number of locations, complexity of the product line and rate of change in products or production technologies. Consequently, the model offers five stages: conception/existence, survival, profitability and stabilization/growth, take-off and maturity. Each stage is characterized by an index of size, diversity and complexity, described by five management factors: management style, organizational structure, the extent of formal systems, the main strategic objectives and the owner's involvement in the business. The model focuses on small businesses. To grow and increase in size and profitability, firms must adapt to the environment [12].

Not all the models reviewed are technically fully applicable to real estate lifecycle, but their ideas are applicable to the creation of conceptual model. The generalized life cycle shows a consistent set of time periods, on each of which the object is in a certain state, has different efficiency and manifests itself differently in relation to the external environment. For many types of technical objects, moral aging vs. physical wear and tear as the end of the life cycle are distinguished. The life cycle of a real estate object and many other objects significantly depends on the intensity of the object's operation. The link between the functioning efficiency of an object and its life cycle stages determines the importance of life cycle (LC) management and the importance of analyzing and constructing its models.

Any organization is concerned about LC increase. Its support and modification are carried out for this purpose. Modification can mean modernization, repair or repurposing. For example, an old one-story academic building can be converted into a garage or a training workshop.

Management and support of a real estate object's life cycle in education can be external and internal. Internal LC support typical for commercial educational institutions. It focuses on the survival of the university. External LC support is typical for state universities and state real estate.

There are typical life cycle models. The most common is the trapezoidal model. This LC model includes four stages. A more complex model is the “quality loop” (ISO 9001), which encompasses 11 stages. Cascade spiral models of LC are also used. The cascade model relies on additional external resources that increase the life cycle duration. The spiral model is based on the development of an additional resource in the process of cyclic functioning of a system or object. In this paper, we propose a mechanism for constructing the life cycle of a real estate object based on the concept of resource use. In addition, the initial stage of the creation of a real estate object and the final stage of its termination are considered separately.

Resources as the LC model basis. The resource consumption life cycle model [4] (RCLCM) is based on the fact that the rate of resource consumption during the creation of an object and the rate of their consumption by the object define the initial phase of growth and the final phase of degradation of most objects, including living systems as well as regional ones.

As a mathematical basis to construct a life cycle model, it is advisable to use the Verhulst (Pierre Francois Verhulst) equation, which he formulated to describe the growth model [13, 14]:

$$\varphi \frac{dR}{dt} = vR\left(1-\frac{R}{K}\right). \qquad (1)$$

Expression (1) shows the initial correlation of resource changes to the rate of their expenditure and the resources volume required to complete the growth process. In expression (1), parameter *v* characterizes the rate or intensity of external resources consumption (resource unit/time), parameter *K* is the resource capacity of the property, that is, the maximum possible number of resources for the creation of a real estate object (construction and functioning). The indicator φ is a dynamics indicator, that is, the phase of growth or degradation. It has two values +1 and –1. The value of φ reflects two opposite in essence processes following the same functional correlation.

The positive indicator φ value corresponds to the development of the real estate. It consumes an external resource and accumulates its own. The negative value of the dynamics indicator corresponds to the degradation of the system due to the consumption of its own resource and loss of the object sustainability. The exact solution of the equation (1) is an *R*(*t*) sigmoid or an *S*-shaped curve:

$$R(t)=\frac{KR_0e^{vt}}{K+R_0\left(e^{vt}-1\right)}. \tag{2}$$

The *R*(*t*) function has a limit due to the resource capacity of the real estate object:

$$\lim_{t\to\infty}R(t)=K. \tag{3}$$

This means that if *R*(*t*) > *K*, then there is a waste of resources. For comparability of different life cycles, the values of *R*(*t*) and *K* are measured in relative units: either as a percentage or in the range [0; 1]. The latter option is preferable, since it allows the use of probabilistic characteristics and probabilistic models. Fig. 1 shows a graphical representation of the solution of equation (2) or the growth phase *S* of the real estate object. This solution describes an ascending sigmoid. The symbols indicate different periods: *C* — the period of conceptual design, *D* — design, *B* — construction, *E* — operation.

Operation corresponds to the maturity period (normal functioning) of R_{con}. Depending on the rate of resource consumption, the slope or straight-line section of the curve changes. Fig. 2 shows a graphical representation of solution (2) at different resource consumption rates.

In Fig. 2, the curves represent three situations. Standard construction S_1 corresponds to the standard delivery date t_1. Accelerated construction S_2 *corresponds* to an earlier delivery date t_2. Delayed construction S_3 corresponds to the delayed delivery t_3. For the rates of external resources consumption (Fig. 2) $v_2 > v_1 > v_3$ takes place, respectively, the commissioning time $t_2 < t_1 < t_3$.

Thus, the rate or intensity of consumption of *v* resources within certain limits changes the growth phase of the life cycle of the real estate asset. This mechanism is a lifecycle management tool. The shelf "R_{con}" is the period of operation of the facility.

If the object is operated, it is characterized by tear&wear and destructive effects of the external environment. In this case, the dynamics indicator φ = –1 and the solution takes the following form in expression (4):

$$R(t)=\frac{KR_0e^{-wt}}{K+R_0(e^{vt}-1)}. \tag{4}$$

In expression (4) there is a parameter *w*, which shows the internal resources' consumption rate. This solution corresponds to the descending curve presented in Fig. 3.

Fig. 3 illustrates the maturity R_{con} phase and the next degradation *Q* phase (dissipation). The degradation phase is caused by physical wear and tear or external impacts. It is obvious that the internal resources rate of expenditure at this stage determines the degradation time period. This situation is demonstrated in

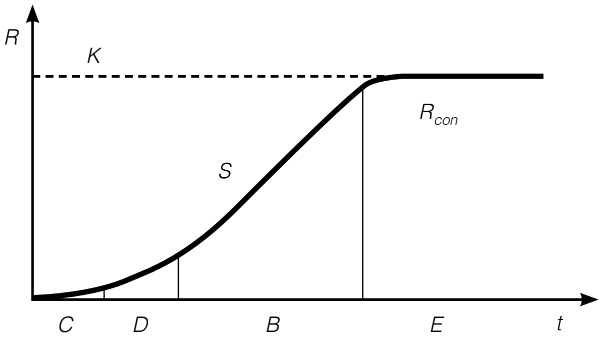

Fig. 1. Growth S phase of the real estate

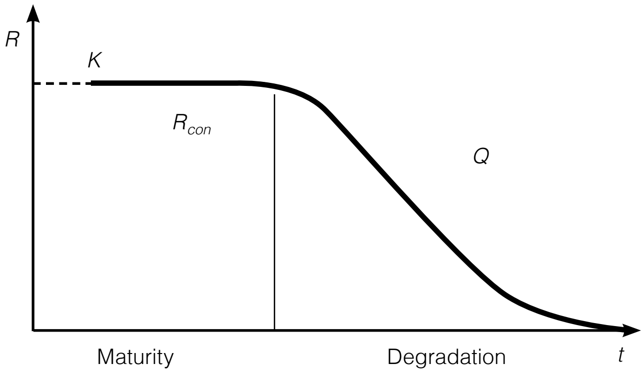

Fig. 3. Degradation phase Q of the lifecycle of the real estate object

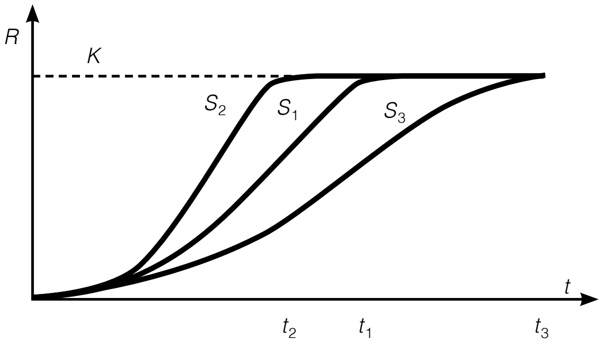

Fig. 2. Three variants of external resource consumption

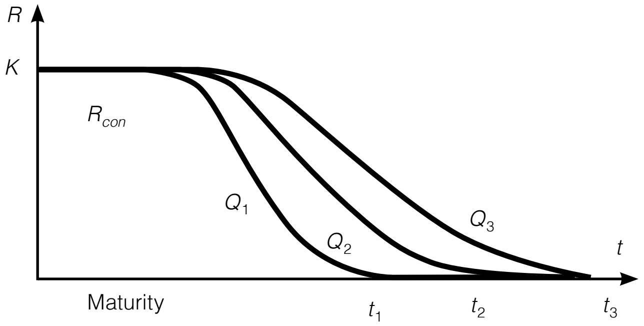

Fig. 4. Three options of the internal resources' consumption

Fig. 4. For the situation illustrated in Fig. 4, $w_1 > w_2 > w_3$, respectively $t_1 < t_2 < t_3$. Conclusion: the faster internal resources are consumed, the shorter the facility's service life.

The Verhulst equation proves it. Consequently, the patterns that this equation describes can be taken as the basis for constructing the lifecycle of a real estate object for the phases of growth and termination of operation.

The model in Fig. 3 comprises part of the maturity process R_{con} and the degradation process Q. The general model of the lifecycle of real estate (LCRE) is defined as the sum of the processes of growth S, maturity R_{con} and degradation Q, that is, the combination of expression (2) and expression (4):

$$\mathrm{LCRE} = S + R_{con} + Q. \tag{5}$$

The degradation or dissipation often starts under the impact of external destructive forces. This situation is shown in Fig. 5. As a normal condition, destructive forces can have an impact on the real estate object.

An external negative impact entails the consumption of internal resources of the real estate object and generates a dissipation Q process (Fig. 3, Fig. 4). In order to support the LCRE, it is necessary to reduce or stop the Q degradation. For this purpose, an additional external reserve resource R^* is introduced, on which the condition $R^* = -Q$ is imposed. Under this condition, the additional resource neutralizes the Q degradation and modifies the lifecycle LCRE*:

$$\begin{aligned} &\mathrm{LCRE}^* = \mathrm{LCRE} + R^*_{con}, \\ &\mathrm{LCRE}^* = \mathrm{LCRE}. \end{aligned} \tag{6}$$

Degradation occurs due to wear&tear, internal failures, or external impacts. When the factors driving the Q degradation appear, it is necessary to use new resources R^*. The recursive use of expression (6) allows us to increase the lifecycle of the real estate object as long as there are resources to neutralize degradation or dissipation.

Synchronous and asynchronous LC management. We can talk about a modified and ordinary lifecycle model. The ordinary model is described by the expression (7):

$$\mathrm{LCRE} = S + R_{con} + Q. \tag{7}$$

Modified model relates to the expression (6) and takes the form:

$$\mathrm{LCRE} = S + R_{con} + Q + R^*. \tag{8}$$

The peculiarity of expression (8) is that the R^* value can be used repeatedly and thereby continuously increase the lifecycle of a real estate object. In transport, this corresponds to the regular track repair. In fact, repeated use of R^* means cyclic lifecycle management. We can talk about a modified R^* con maturity period or functioning of real estate.

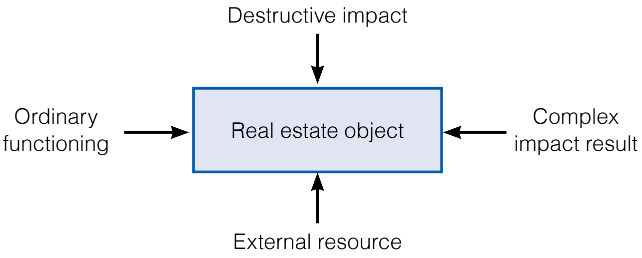

Fig. 5. A model of the resulting impact of destructive forces and external resources on a real estate object

The total value of R^* will depend on the number of management acts (repair and restoration work). Fig. 5 shows that an increase in LCRE is possible due to the use of external resource that compensates for external destructive effects. In theory, n number of such interactions are allowed. Their number cannot be large, since the amount of work and the cost of repairs increases over time, and the efficiency of the facility decreases. At a certain point it is more feasible to create a new object compared to the operation and repair of the old one. However, while it is possible, it is advisable to repair the old object instead of creating a new one. For the lifecycle repair or modification, two types of LC modification are possible: synchronous and asynchronous. Fig. 6 shows asynchronous LC correction.

Based on observations or monitoring, the presence of Q or its signs is detected. The rate of resource consumption w is estimated. Predicated on the experimental data, the appropriate rate of resource consumption v is selected under the condition:

$$v \approx w. \tag{9}$$

The process of correcting the S state begins. Fig. 6 illustrates the processes of Q degradation and S_i correction. The semi-bold line DR denotes the resulting process:

$$DR = S_i(v) + Q(w). \tag{10}$$

The time of the destruction initiation is indicated by t_q, the time of the correction initiation is indicated by t_s. There is a time gap between them Δt — the period of asynchrony. This is a typical situation when a destructive process begins, while the manager is not ready for it and did not expect its beginning. The shorter the asynchrony time, the faster the LC recovery, that is, regular operation.

Fig.7 illustrates the asynchronous correction.

In case of synchronous correction:

$$DR = R_{con}. \tag{11}$$

What makes synchronous correction possible? Its basis is spatial monitoring and forecasting. The costs of monitoring and forecasting compensate for the costs of synchronous correction and losses during the period of asynchrony. Thus, additional resources (reserve), monitoring and forecasting are needed for synchronous LC correction. Monitoring and forecasting can be considered as a support system for real estate lifecycle management.

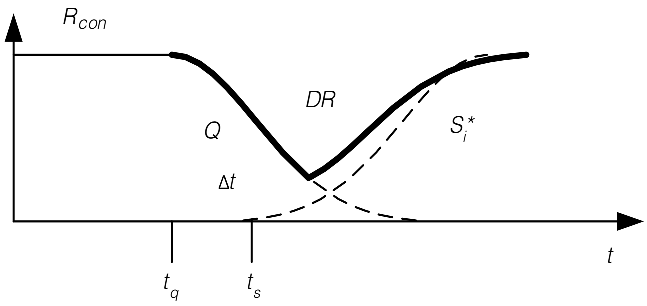

Fig. 6. Asynchronous LC correction

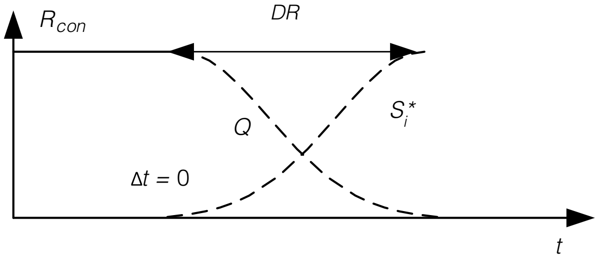

Fig. 7. The asynchronous LC correction

CONCLUSION

The fundamental difference between the phases of growth and degradation of real estate is that its growth is provided by a person, and degradation is caused by the impact of "nature". Therefore, this model of life cycle management is based on creation on the "man – nature" interaction. The parameters *v* and *w* are defined empirically. It varies for different types of objects. Usually, the standard construction time is estimated, for which *v* is assumed to be equal to 1. Resource consumption is estimated based on the standards of physical wear. In general, this model is comparative, which allows it to be used for various situations. The proposed LC model consists of qualitatively different processes but is described by similar mathematical equations. In the first case, the consumption of external resources is considered. In the second, the expenditure of internal resources. The analysis shows that the RCLCM offers a deterministic path of organizational development, demonstrating limited explanatory strength when faced with the issues of the real business environment. Therefore, it is proposed to consider RCLCM as a process "driven" by the resources reacting on the external environment behaviour. In response to these changes in the environment, companies spend resources from the reserve fund to ensure the functioning and development sustainability. It is proved that monitoring and forecasting are components of synchronous lifecycle management.

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Управление жизненным циклом объекта недвижимости с использованием уравнения Ферхюльста

Управление жизненным циклом объекта недвижимости является важной составной частью воспроизводственного процесса. Дается краткий анализ моделей жизненных циклов организации. В качестве гипотезы научного исследования предполагается, что жизненный цикл на начальном этапе строится на потреблении внешних ресурсов, а на завершающем этапе расходует внутренние ресурсы. Вводятся понятия «модель жизненного цикла расхода ресурсов» и «скорость расхода ресурсов». Именно скорость расхода ресурсов определяет окончание жизненного цикла объекта недвижимости. В качестве математической основы используется дифференциальное уравнение Ферхюльста, применяемое для модели роста популяций. Модель жизненного цикла включает три фазы: роста, стабильности, деградации. Показана возможность модификации жизненного цикла при использовании такой модели. Описано синхронное и асинхронное управление. Доказано, что мониторинг и прогнозирование являются компонентами синхронного управления жизненным циклом недвижимости.

Ключевые слова: *управление недвижимым имуществом, жизненный цикл, ресурсы, модель жизненного цикла расхода ресурсов, синхронное управление*

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