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INTEGRISANO PROJEKTOVANJE, EKSPLOATACIONI VEK I ODRŽAVANJE BETONSKIH ZGRADA – ODRŽIVOST

***Rezime**: U radu je dat osvrt na termine koji se koriste u oblasti održavanja i eksploatacionog veka betonskih zgrada saglasno novim međunarodnim dokumentima. Komentarisane su i analizirane neke Preporuke za integrisano projektovanje eksploatacionog veka i održavanja kao novog pristupa koji doprinosi održivosti konstrukcija betonskih zgrada (društveni, ekonomski i ekološki aspekti). Obuhvaćena je metodologija pregleda i procene stanja zgrada. Prikazana je internacionalna i naša regulativa u ovoj oblasti (Pravilnik za konstrukcije) i Zakon o održavanju zgrada. Komentarisane su metode održavanja (korektivno, preventivno, prema stanju i kombinovano).*

***Ključne reči**: Integrisano projektovanje, eksploatacioni vek, pregled, procena stanja, održavanje, održivost betonskih konstrukcija*

INTEGRATED DESIGN, SERVICE LIFE AND MAINTENANCE OF CONCRETE BUILDINGS – SUSTENABILTY

***Summary**: The paper reviews the terms used in the field of maintenance and operational life of concrete buildings in compliance with new international documents. Some Recommendations for integrated design of service life and maintenance as a new approach that contributes to the sustainability of concrete building structures (social, economic and ecological aspects) are commented and analyzed. The methodology of inspection and assessment of the condition of buildings is covered. Some of International and our regulations in this area (Regulations for Structures) and the Building Maintenance Act are presented. Maintenance methods (corrective, preventive, according to condition and combined maintenance) are commented on.*

***Key words**: Integrated design, service life, survey, condition assessment, concrete structures sustainability*

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1. INTRODUCTORY NOTES

Building and civil engineering structures are the longest lasting products in societies. The design service life of structures is usually 50 – 100 y [5]. Service life depends on structural design and detailing, mixture proportioning, concrete production and placement, construction methods and maintenance. Changes in the properties of buildings during their use require careful monitoring, damage registration and appropriate repairs. That is why the quality of housing and work depends to a large extent on the quality of their maintenance. We have mainly used the concept of corrective maintenance [12]. In the new conditions of the ownership transformation of the housing stock, the maintenance of these buildings becomes a major social problem due to difficulties in collecting funds to finance repairs. The paper analyzes the most common damage to building elements. Some classifications of damages and their causes have been commented on, and correlated to the degree of necessary interventions for their elimination. The introduction of protective coatings of concrete structures is also significant [21].

Common maintenance methods in the industry and their specificities when applied to buildings are analyzed. Their characteristics and costs are compared. It has been shown that it is inexpedient to apply only the concept of corrective maintenance, which is common in our country. The modern concept of maintenance is based on a probabilistic approach, i.e. registration of damages and their frequency, on the basis of which the time and level of necessary interventions are determined. That is why it is suggested to introduce preventive and combined maintenance [25].

Depending on the building, its condition, the timing of maintenance works and the type of those works, in addition to the term "maintenance", the terms "regular maintenance", "normal maintenance", "enhanced maintenance" and "investment maintenance" are also used. Method and procedure of maintenance of certain buildings or structures or equipment may be regulated by a technical regulation [22].

The goal of building management is to ensure their uninterrupted use in a certain time interval with minimal investments in behavior monitoring and repairs. For this purpose, it is necessary to define requirements for the condition of the building and of its components during the service period. As opposed to the maintenance method of other technical systems, where periodic replacement of parts is planned for, buildings are composed of elements that, once joined and connected, work as a spatial unit. Their parts cannot be dismantled, without consequences for the rest of the building.

The problem is further complicated by the fact that many elements have different durability. Life expectancy requirements, i.e. durability of buildings, in differ in many countries. Thus, 80 years were required for large-panel buildings in the former Czechoslovakia, and 150 years in the USSR; for buildings with mixed structure in Czechoslovakia 70 years, and in the USSR 120 years [9]. For prediction and realization service life of buildings and construction assets [17], and environmental management related to principles and framework [16] are given. Also, very important topic is adopting of the structures to climate change [15].

This paper analyzed the problem of sustainability of concrete structures with an emphasis on the operational life and maintenance of concrete buildings. Some significant documents of international organizations in the subject area were analyzed, as well as our regulations related to building maintenance [19], [20] and [23].

2. TERMS IN THE DISCUSSED SUBJECT MATTER

The experience acquired in the management of structures shows that during the **service life (SL)** without large investments for the maintenance of individual elements, serviceability properties (performance) cannot be ensured [6]. **SL** depends, on the one hand, on the properties of the materials of which the building is built, and on the other hand, on the exposure to the actions. It can be different, although for buildings it is fixed at 50 years [5]. For concrete, the age of the material at the time of the action of certain aggressive media, absorption, diffusivity and permeability to liquids and gases is important. **Operational service life** is the expected time of use, for the determination of which mathematical statistical data about the actual service life are used. The actual service life must not be less than the normative one [25].

At a certain moment of use of the facility, intervention is carried out on the facility and its condition is assessed. For this purpose, it is important to carry out monitoring operations. Monitoring includes a set of measures that are taken on the building during its service in order to determine the need for performing various interventions during maintenance. Depending on the type and level of detail, an appropriate monitoring report is drawn up. Continuous monitoring ensures the monitoring of phenomena on the building and in its surroundings during the operation of the building as well as of various effects to which it may be exposed. In order for the information to be more readable and to avoid misunderstandings in its transmission, it is necessary that each part of the building is unambiguously defined. For this purpose, it is recommended to use the terminology from the design of the constructed building [13].

Periodic monitoring is carried out at certain time intervals and is specific for groups of buildings and even for each building. ***Damage*** is considered a change in elements or parts of buildings during their use or a significant change in their reliability compared to the initial state. Exceeding of some limit values of cracks or deflections in the supporting elements or the reduction of the cross-sections of the elements are some of these. In the general approach to maintenance, an important feature - ***maintainability*** is defined as the ability of an element or building to provide the ability to detect-find and eliminate "failures" and prevent malfunctions during interventions carried out during maintenance. This feature also includes the convenience of adequate maintenance organization and the probability that the component or building are restored to their correct condition within the set (planned) downtime.

The term **deterioration** is used for the decline of physical and mechanical properties due to freezing and thawing, erosion, metal corrosion, silicate-aggregate reaction and sulfate effects. There are many definitions for maintenance. One of them is the combination of all technical and other activities carried out in order to restore one component or building to the state in which it performs its function. **Remodeling** refers to reconstruction or repairs that change the purpose of a part. **Retrofitting** includes repairs, strengthening and remodeling, and the term **structural intervention** is also used. Adjusting to new functional requirements is called **adaptation**, and **rehabilitation** is restoring the building to its original state; **Reconstruction** are radical interventions that include: replacement of severely damaged elements, addition of new elements, etc. These include addition of new floors and extension; **Conservation** is a measure that preserves the existing state of a building object or entity. The term is used in the protection of architectural heritage for preservation of the cultural monuments from further deterioration [13].

3. SUSTAINABILITY AND STATE ASSESSMENT INSPECTIONS

Stochastic **durability** analysis does not refer only to the target service life, but to the determination of the maximum allowable probability that the target durability will not be reached [11]. Durability of structures depends primarily on the mechanism of action of the environment and the rate of the degradation process, i.e. it is conditioned, on the one hand, by temporal changes in the material's internal properties and external effects. This value is called the probability of failure. Previously, multi-family buildings were taken care of by housing companies. And despite that, there was a lot of spontaneous instead of planned and systematic approach. After the ownership transformation of housing, the maintenance of buildings becomes a serious social problem, in addition to the fact that the service life of residential buildings in our area is significantly shorter than in other countries. The reason for this is negligence and failure to carry out inspection, control and timely removal of the causes and the damages themselves, which impair safe and comfortable housing.

The environmental design [7] system of buildings and civil engineering structures, in which the selection of materials and structural shape, construction work, maintenance, and demolition and recycling, should be established in aim to minimized the used and resources and energy, to decrease hazardous substances, and control construction and demolition waste [14]. The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and provide reuse or recyclability of the construction works after demolition; durability of the structures; (c) use of environmentally compatible materials in the construction works. There is the harmonization between environmental criteria and structural criteria in the design of buildings: reduction of waste, provide durability (minimize maintenance); resilience, design for deconstruction and disassembly; reuse of structural components.

Sustainability has become an important factor in the design of reinforced concrete buildings, and concrete can contribute to a sustainable design, especially when the material properties are understood and used to their maximum. Concrete can contribute to a sustainable building [23] in the following ways that Concrete is: a local material reducing travel; is long lasting; can be exposed – reducing the need for other materials to cover it; is fire resistant; can be used to minimise energy through the use of its thermal mass; can be recycled at the end of its life.

The building is part of the environment in constant interaction with the environment. This aspect is analyzed and treated under the term **sustainability**. A sustainable construction is built in such a way that the environmental impact on the construction during its service life is reduced to a minimum. It represents the optimum of the requirements of the defined service life (SL), effects, environmental impact and maintenance strategy. A sustainable concrete structure should be built in such a way as to ensure minimal impact of the environment on the building and the building on the environment for the duration of the expected SL. An analysis of sustainability comprises the achievement of durable concrete and adequate maintenance of facilities.

For the analysis of the reliability of structures, the basic criterion is that failure occurs when the resistance of the structure is less than the effect on it, i.e.:

$$\text{"failure"} = R < S \quad \text{or} \quad \text{" failure "} = R - S < 0 \qquad (1)$$

where: R and S have a number of meanings, in the structures R is resistance - the limit of yielding, and S is the function of effects that cause stresses in the construction. Both R and S are functions of multiple stochastic variables [11].

A simplified model for determining the durability of structural buildings introduces the dependence of the corresponding reliability parameters (eg strength, deformations, etc.), depending on the time t. If K marks any parameter, and K_0 marks its initial value, the following expression can be written:

$$K = K_0 \cdot e^{-\lambda \cdot t} \quad t.j. \quad \frac{K}{K_0} = e^{-\lambda \cdot t} \tag{2}$$

There is the λ constant which can be determined experimentally, treating it not as a stochastically distributed parameter by as a mean value of the stochastic set.

The lifespan of residential buildings is, in our country, significantly shorter than in developed countries, as a result of negligence and small investments in inspections and their maintenance, which is also reflected in the condition of the buildings, which deteriorates over time, so their lifespan is getting shorter, and economic losses are increasing. If damages are noticed immediately after their appearance and appropriate repair measures are taken, the required level of comfort and cheaper maintenance can be provided. The percentage of dilapidation S is the mean value of all, for uninterrupted use, essential elements and serves as an indicator of the serviceability of the building. If S is up to 15%, it is considered tolerable (safe), and over 60% the condition is considered as damaged. Aging of buildings - the moral depreciation of buildings represents a social category and it requires large funds to extend the use of the building, because for this it is necessary to carry out extensive works on modernization. This is the reason why integral design with sustainability performance and environmental design has been introduced in recent years Figure 1 [8].Three pillars of sustainability: environmental, social and economic issues. The concept of sustainability assessment of civil engineering work is shown in Fig. 2.

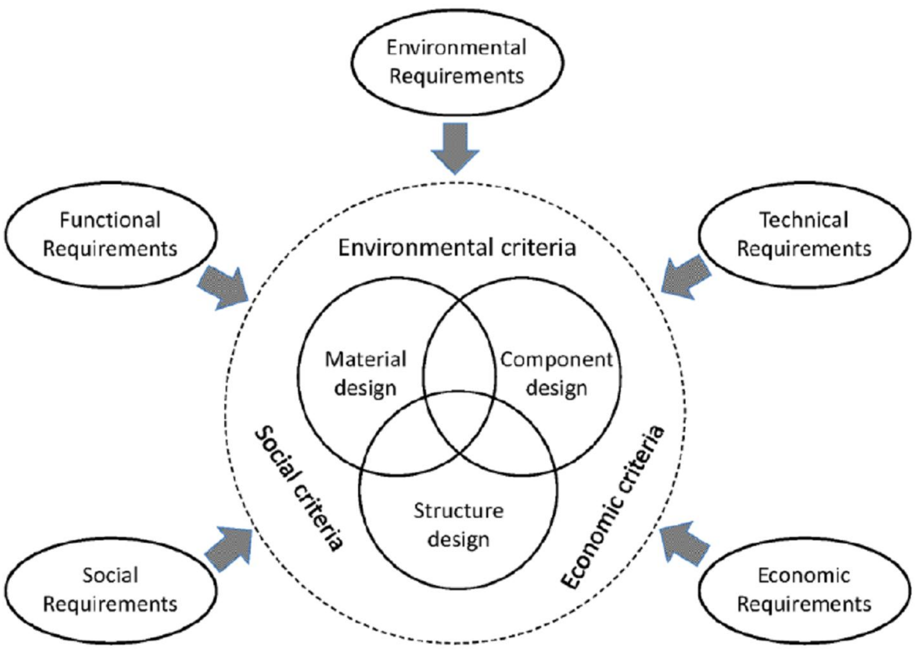

Figure 1. Basic principle of integrated design approach

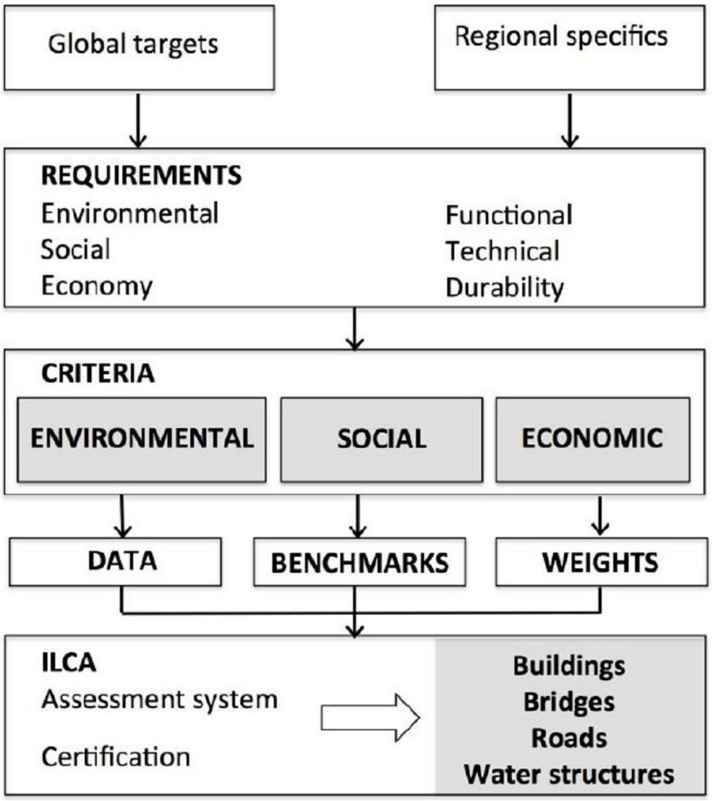

Figure 2. Concept of sustainability assessment, after [8]

Prefabricated buildings represent a complex technical system in which each element fulfills its function with a certain safety coefficient, but individual elements have different duration times. These buildings contain elements with a service life of between 100 and 150 years, when foundations, walls, and floor structures are considered. On the other hand, there are parts that need to be changed more often. Façade elements and balconies are especially important in multi-story buildings. In this sense, it is necessary to inspect buildings older than 50 years and, according to their condition, renovate them [10] and [18].

The quality and comfort of living in multi-story buildings are affected by the regime of temperature and humidity, sound insulation, lighting and air cleanliness. Functionality is assessed on the basis of the dimensions and structure of the rooms and their connection, equipment with installations and with aesthetic values. In addition to the resistance of its construction, the safety of the building is also assessed by its fire resistance. Cost effectiveness is related not only to the cost of construction, but also to the costs of use and maintenance.

Chemical actions are more complex than physical ones and develop so that their effects are more difficult to monitor during the examination. Therefore, in order to increase durability in aggressive environments, protective measures must be used. Since 1992, the aggressive effect of water, environment according to the type of gases and their concentration and humidity of the gas (three groups) and/or liquid chemically aggressive environments (five classes) have been introduced. Weather effects on concrete and reinforcement are also classified, according to air temperature, number of temperature transitions above 0°C and air humidity. Aggressive environments that act chemically or physically on concrete and reinforcement are classified in connection with the requirements for the quality of construction materials and protective measures, which will be exposed to the aggressive effects of the environment during service [21].

Apart from the bearing function and sound proofing, the walls should provide protection from weather effects (external walls), thermal insulation, heat accumulation and equalization of humidity. Therefore, the number of layers of walls and their insulating properties are determined according to the climatic conditions in which it is built [15].

In Japan, an inspection system is applied, standardized in such a manner that there are only slight differences in the evaluation of various inspectors, based on the following three types:

- control inspections with specific time intervals, e.g. after several months or after some unforeseen events (stormy wind, minor earthquakes, etc.),
- periodic inspections of the facility, between one and five years, and -special inspections after fires, earthquakes and the like.
- special inspections after fires, earthquakes, etc.

Basic parameters for the control of the building condition are:

- general and local resistance of the structure,
- spatial stiffness and deformations,
- foundations, underground parts, waterproofing and other elements sensitive to moisture,
- condition of expansion joints and facades,
- thermal properties of facade parts,
- moisture and air permeability of the joints of panel buildings, as well as around windows and balcony doors on facade panels,
- corrosion of metal connectors of structural elements and equipment,
- the condition of the roof, balcony, downpipes, etc.
- proper installation of sanitary devices, heat regime installations, electrical and other installations.

The inspection should include staircases, elevator shafts, loggias, balconies, etc.

The most common classifications of damage are according to [9]:

- the rate of occurrence (gradual and sudden),
- affected area and hazard (higher – critical and lower, i.e. total or partial),
- manner of manifestation (visible – predictable and sudden and hidden),
- type, possibility and economic justifiability of rehabilitation,
- the causes and time when the damage occurred, e.g. low quality of survey works and foundations, design, construction, use and maintenance, or due to unforeseen events (fire, earthquake),
- elements on which they appear (pillars, walls, panels, beams, roof, insulation, cladding, installations, etc.)

In Germany, damage is assessed based on the:

- potential for repair,
- limited serviceability and service life of the building,
- severity and extent of damage.

4. MAINTENANCE STRATEGIES

The following maintenance strategies are used for civil engineering buildings:

1. Basic maintenance with repairs after registering damage.

2. Repairs after a certain period of operation of the facility.

3. Interventions according to the condition of more important components after some unforeseen circumstances or due to exceeding some departure limits established by regular inspection.

It boils down to the division into: corrective maintenance (repair after failure), preventive maintenance and combined maintenance. After each inspection, the condition is compared with that of the previous inspection [22], and [25].

The first method is implemented on all parts and components of the building. The second can be used if the frequency of damage during the period of operation is known, which can result in preventive maintenance, as well as in the third method, which can be implemented only if the conditions are measurable. In practice, these strategies - methods are not strictly separated. Minor damage or lower performance should be understood as a sign that, on building components, intervention should be done without waiting for major damage to occur. Nevertheless, a number of elements that correspond, more or less, to the mentioned maintenance methods can be distinguished.

Basic maintenance corresponds to the maintenance of some installations in buildings, e.g. elevators and repairs of breakdowns on pipelines, etc. For parts that are easy to replace, it is justified to use corrective maintenance. The part that caused the malfunction (failure) is replaced with a new one. Despite the fact that this type of maintenance fully uses the reserve of serviceability of individual parts, the stochastic nature of failures can cause a stochastic duration of failure time. At the same time, precious time is sometimes lost due to a downtime in the functioning of the installations or major damage occurs (sewage overflow, flooding due to a failure of pipe installations). In order to overcome these weaknesses, for the maintenance of technical equipment and installations in high-rise buildings, preventive maintenance is applied, which consists in the replacement of equipment parts after established time intervals. In this way, the performance of the components, which are intervened on, is brought to a satisfactory level and major downtimes are prevented.

Preventive maintenance-periodic model is justified to implement when the rate of degradation starts to increase. These are interventions that, in a "quiet" period of use with minor breakdowns, can be performed at a constant date or with a constant level of functionality and/or durability, during the building's aging period. The choice of the maintenance system depends on the level of total costs achieved and the degree of influence of the chosen maintenance method on the efficiency of the invested funds, i.e. level of comfort and reliability. The economic analysis indicates that in the case when the total replacement costs after the occurrence of the failure are less than or equal to the costs before the occurrence of the failure, it is not advisable to apply preventive maintenance.

Condition maintenance relies on the monitoring of parts of technical components in order to define their condition, i.e. to establish an adequate diagnosis. It should serve as a basis for decisions on the scope of maintenance work. This method is suitable for components for which it is possible to realistically define the condition. In addition, it is necessary to establish criteria for determining the limits of serviceability of individual parts. For this purpose, procedures based on techno-economic criteria and experience are used.

For the ***first*** method, the cost of maintenance is the sum of the cost of repairs and consequences of damage divided by the average lifetime of the building. For the ***second*** method, it is the sum of some repair and risk of damage, during the given time to take action, divided by the given lifetime. For the ***third*** method, the price determination is the most complicated, not only the interval between inspections is observed, but also the level of rejected impacts in the observed lifetime and residual risk. The total cost is the sum of the cost of repairs, expected inspections plus the total risk of damage divided by the lifetime of the building.

Maintenance plan/design should contain:

- data on the owner of the building, the designer and the contractor, the start and end of construction,
- a brief description of the building with an indication of its dimensions, surface area, purpose, materials from which it was built, etc., for which purposes the building was designed,
- notes on possible accidents during construction (overloading, settlement of scaffolding and formwork deformation, very low temperatures, possible breakdowns, etc.)
- notes on possible delays in construction, data on sensitive areas of the structure of the building,
- data on construction tests, if available,
- data on built-in referential points (position and zero measurement results).

The frequency of inspections and their scope, the composition and qualifications of the team members, the method of keeping maintenance logs and criteria for assessing the condition, and the assessment of the condition of the constructed structure are also defined. When creating the maintenance design, keep in mind that the external factors of deterioration are moisture, water, high and low temperatures, climatic conditions of the environment or its aggressiveness.

5. NATIONAL REGULATIONS

In our country, building maintenance is regulated by the Law on the Maintenance of Residential Buildings and the Decree on the Maintenance of Residential Buildings (Official Gazette of the Republic of Serbia 43/93). Maintenance includes work on routine and investment maintenance of housing. They include regular performance of works on the protection of the building and its common and special parts, devices, installations and equipment, repair of damaged and worn-out parts to ensure their working order, serviceability and durability. The law provides for the following groups of works: routine maintenance; investment maintenance, and emergency intervention.

Routine and investment maintenance works are classified according to the nature and dynamics of execution, and emergency interventions include works that eliminate immediate danger to life and health of people or the environment. The law prescribes in detail certain groups of maintenance works. Rules [20] and [23] regulate the way of inspection and maintenance of buildings and the way of drawing up maintenance programs [19].

For the overall maintenance organization, it is important to predict the type of the deterioration process. Sometimes the building is viewed as a technical system, so the consequences of a component's failure to function are studied. Probability functions of behavior over time can be used for individual components. Only in case of low risk can the first maintenance method be used. The risk is defined as the product of the consequences of damage and the probability of their occurrence. As the building ages, the risk increases, so the first strategy is transformed into preventive maintenance.

When determining the scope and priority of works/interventions on individual elements and structures, they are correlated to the condition of the elements and the building itself. For structural damage, four levels are usually introduced, according to the impact on the load-bearing capacity and resistance of the structure and on the operational characteristics (light, moderate, heavy and breakdown). Their frequency is important. This affects the time and type of rehabilitation. based on the results of the inspection, remediation is planned in case of moderate damage, or only regular maintenance work is carried out in case of the light damage.

Before interventions on the building, it is necessary to evaluate the condition of the structure, and then check the requirements for the repair and rehabilitation of the concrete structure [1], [2], and [4].

6. FINAL NOTES AND CONCLUSIONS

During the operation of the building, it is important to spot damages in a timely manner, limit their negative effects and eliminate and/or rehabilitate them during regular or enhanced maintenance of the building. If damages are not taken into account, after their appearance and during maintenance, they can lead to serious disturbances in use and sometimes even to the breakdown of the structure. Therefore, for the overall economy of the building stock, it is necessary to choose an adequate management-maintenance strategy of the buildings. In most cases, the best results are achieved by combining the corrective and preventive maintenance.

The goal of the management organization is to ensure optimal cost-effectiveness for all investments during a certain period of time. The required degree of reliability is determined on the basis of the economic balance according to external requirements and requirements based on a socially acceptable level, i.e. lifetime. The following conditions must be met:

- reliability with sufficient probability that the building and its components will fulfill their intended function during the given period,
- accessibility-availability as a percentage of time in which the building is able to fulfill its function.
- serviceability as a measure that expresses how serviceable the building is
- durability – capacity of the building to fulfill its function during a certain period of time,
- appearance.

For the overall maintenance organization, it is important to predict the type of degradation process of the building and its components. Statistical processing of data of similar building can be very useful in this. Therefore, it is important to create databases on groups of buildings and use them in the management of the housing stock, which is now neglected.

In order to ensure smooth operation and optimal maintenance, serviceability and durability of the buildings, it is necessary to regularly monitor their behavior and register all damages and irregularities. This makes it possible to realistically assess the state of the buildings in all phases of maintenance at a given moment.

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