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MODEL FOR ASSESSING THE UTILITY PROPERTIES OF A BUILDING

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Abstract

This article considers the changes of the utility properties of the building, which arise from the moment of putting it to use to the so-called out of use time. Two independent processes that occur during the operation of buildings were distinguished: the deterioration of the utility properties of the object and the growth of users requirements. The authors present a mathematical model to evaluate the utility properties of the building. The knowledge of utility properties is necessary for the valuation of the real estate, as well as for planning of the size and scope of repairs and refurbishment of buildings. As is known, the model is a simplified implementation of the phenomenon (process) that captures the basic features associated with the analyzed problem. The authors identified four groups of factors determining the utility properties of the building: technical factor (showing the construction safety, fire safety, utility safety); functional factor (including the ability to change the function of a building, access to the building, health and comfort of users, in particular thermal and acoustic comfort, Visual Comfort, etc.); object‘s aesthetic factor; economic factor, including the entire life cycle of the object.
The usage of a mathematical model gives a lot of advantages: explores the relationship between various aspects of the problem; allows to compare the many possible solutions and helps to choose the best one; allows to forecast future events (e.g. reliability, durability, etc.).

Key words

Service life, utility properties; basic works requirements; social performance; reference object; sustainability

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1 INTRODUCTION

In the life cycle (service life) of each building object we are dealing with two types of processes [1]:

- a constant decline in the performance of the building, the process starts with the completion of the facility, and
- the constant increase in the requirements of the users of the building, this process starts from the moment of completion of the design phase.

Mileage of both processes in a function of time is shown in Figure 1 and Figure 2.

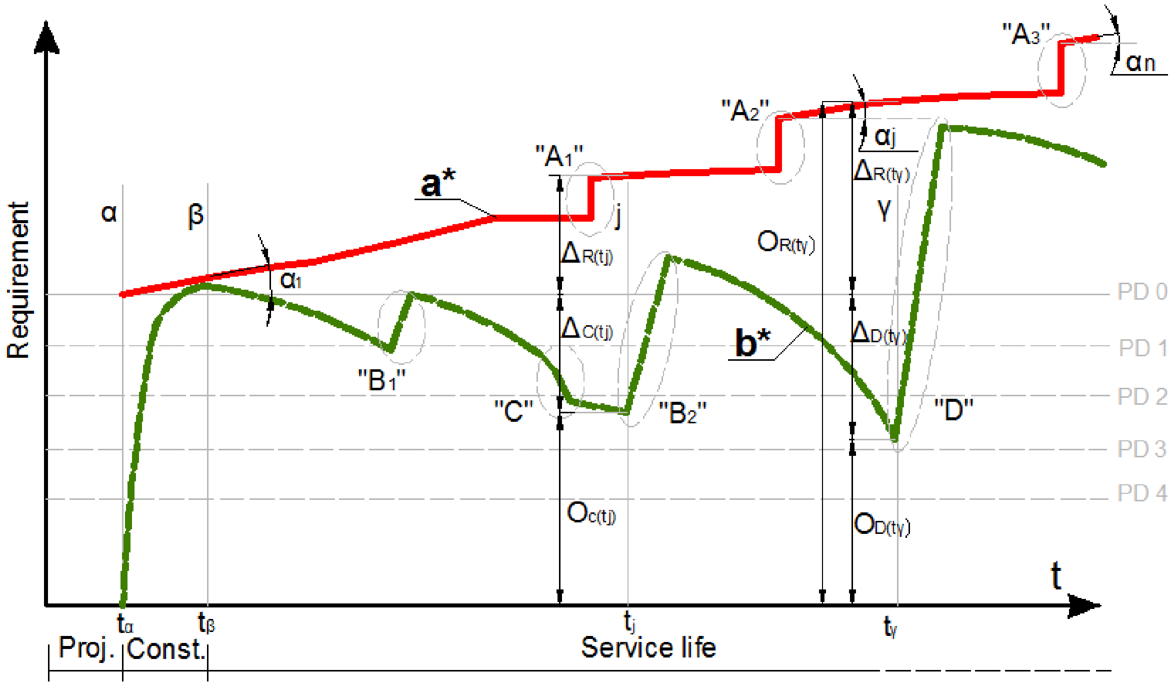

Fig. 1: The performance of building in a function of time; a – added together reference functions (social aspects and technical/legal aspects) $O_R(t)$; b* –performance function $O_U(t)$ (according to [1])*

The differences between real performance properties of the building and user requirements increase over time. It was assumed that the building degree of consumption will be determined by comparing the current characteristics of the testing building with the characteristics of the so-called reference object. Line PD 0 in Figure 1. presents an assessment of the performance in time t_α, i.e. at the time when the building enter into service. It is assumed that the building was designed and constructed in accordance with the relevant standards (Eurocodes) [2, 3] in the application of the required procedures for the supervision and control throughout the construction process. Line PD 3 defines the minimum level of user requirements, which should comply with the building. If the assessment of the performance will be located below the PD 3, the further use of the building is unacceptable. Levels of assessment, to which we refer building performance may vary over time.

Knowledge of the waveforms of these phenomena is important in the course of use of the building - in the process of management. Parametric assessment of the performance of a building is a complex and difficult proceeding. The purpose of this article is to identify the tool of owner (manager) of the object which allows reasonably assess the current, and with some probability the future state of utility building. This will allow make decisions regarding further use of the building: the scope of the renovation, refurbishment or even the time out of use.

2 INCREASED REQUIREMENTS OF UTILITY PROPERTIES OF THE BUILDING (CURVE "a*")

The authors consider the performance of the building in the aspect of the basic requirements and social performance (comfort of using building).

According to the bill - Construction Law [4] the owner or manager of a building is required to use it in accordance with its purpose and the requirements of environmental protection. He should maintain the object in proper technical and aesthetic condition, not allowing for excessive deterioration of its performance and the technical efficiency, guaranteeing in particular the fulfilment of the so-called basic requirements (Basic Works Requirements). They are expressed in terms of the following requirements:

(BWR 1) Strength and Stability
(BWR 2) Safety in case of Fire
(BWR 3) Hygiene, Health and the Environment
(BWR 4) Safety in Use
(BWR 5) Protection against Noise
(BWR 6) Energy Economy and Heat Retention

BWR1 – BWR 6 requirements were determined by directive 89/106/EWG [5] and are commonly known for many years. BWR 7 requirement, on the other hand, was introduced by regulation No 305/2011 PE and CPR [6]; it is valid from 1 July 2013. According to this requirement, the building should be designed, constructed and deconstruction assuming the sustainable use of natural resources and in a manner that [7]:

- Use of materials, products and components with durability adapted to the design life of the building,
- Use of environmentally friendly raw materials and materials, including the secondary products
- Recycling of the building after deconstruction, including materials and products, from which it is made.

The new regulation CPR completes certain requirements of directive 89/106/EWG. In BWR 3 requirement was added the environment and climate impact in the service life of the product, BWR 4 requirement was supplemented with the necessity to take into account the risk of intrusion and accessibility for people with additional needs / disabled people, while BWR 6 was supplemented with the necessity to take into account the energy consumption in the use phase and the deconstruction of the object. On the basis of years of analyzing the changes (additions) of basic requirements it can be stated that the scope of these requirements is increasing with the passage of time. There are several causes of this phenomenon. The most important are: increasing environmental threats (terrorism, vandalism), increased pollution, the need to protect the environment. BWR requirements are implemented through regulation or resolution of the appropriate state offices.

Social performance of builidng (comfort of using the building) are the second group of factors causing the increase of a reference curve a*. They are considered in the context of BS EN 16309: 2014 – *Sustainability of construction works – Assessment of social performance of* *buildings – Calculation methodology* [7]. In this standard, following factors affecting the functionality of a building are taken into account:

- Accessibility to building - in particular approach and entrance to the building and moving inside, and access to buidling services;
- Adaptability;
- Health and comfort – in particulat indoor air quality, acoustic comfort, visual comfort, spatial comfort, the electromagnetic interaction;
- Impacts on the neighbourhood – in particular noise, emissions, glare/overshadowing, shocks/vibrations;
- Operational management (i.e. BMS (Building Management System));
- Safety and security - in particular adaptation to consequences of climate change, resistance to accidental actions, personal safety and sacurity against intruders and vandalism, security against interryptions of utility supply. [8]

The scope and size of social performance mainly depends on requirements of the investor (owner), it is often associated with wealth of society. In simplification, it can be assume that a measure of the increase comfort of using of the building in the community is an increase in the GDP of the country. Of course, the talent and skills of the designer should also be apperciated here.

In Figure 2 there is a chart formation of the growth requirements curve of the **a *.**

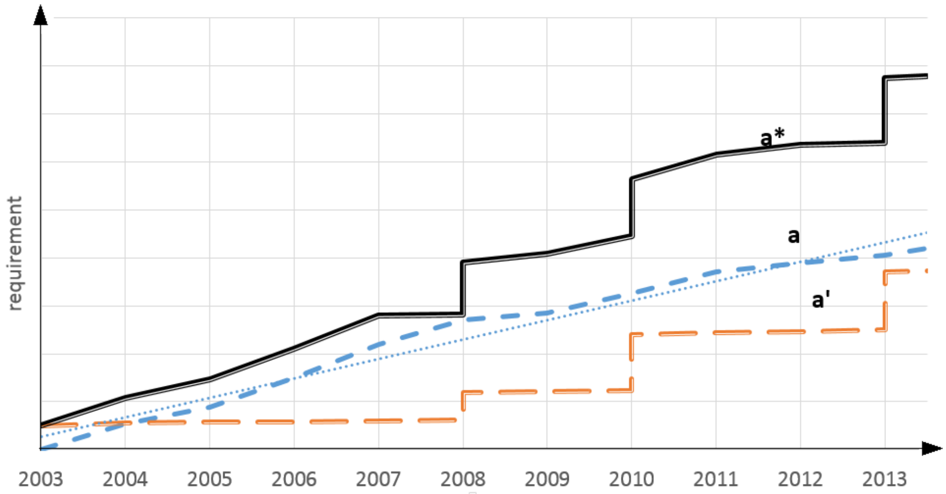

Fig. 2: Reference functions for buildings a – reference function for social aspects with linear trend function y = 4,2064x - 8423,1 R² = 0,9747; a' – reference function for technical/legal aspects; a – added together reference functions (social aspects and technical/legal aspects) (according to [9]).*

It is formed by two member functions; function a and a‘ “. The "staircase" function „a‘ “ with sudden increases in vertical compliance is the result of legislation, to which the owner is obligated with separate decrees and regulations. In general, they are valid from a certain date. For example *„Technical conditions to be met by buildings and their location*“ in Appendix 2, the regulation of the Minister of Spatial Development which is in force since 01.01.2014 *„Thermal insulation requirements regarding partitions and any other requirement involved in energy-efficiency and saving“*[10] introduces new requirements for the heat transfer coefficient $U_{C(max)}$ [W/(m^2·K)], whose value for external walls is expected to be 0.25 and subsequently has to change in 2017 to 0.23 in 2012 to 0.20.

Curve „a“ illustrates the growth of social requirements of the performance (comfort). Function:

$$y = 4{,}2064x - 8423{,}1 \qquad R^2 = 0{,}9747 \qquad (1)$$

(x - statistical data; R^2 - coefficient of determination) was prepared (according to the above assumption) on the basis of data on GDP (gross domestic product) growth in Poland in the years 2003-2013. The curve, in the services life of an object can have different values of the seat-back angle. During the period of economic prosperity, when the research programs and innovative projects are carried out; industry uses scientific developments and society lives better, the requirements of building users are clearly rising; therefore, this curve increases the seat-back angle.

3 PROCESS OF LOWERING THE PERFORMANCE OF A BUILDING (CURVE "b*")

From the moment of putting the building to service its properties deteriorate. It is a natural process; the change of these properties is, among others, the consequence of consume the building during the operation, the negative impact of the environment as well as aging of used materials. The **b*** describing the current degree of fulfillment of the performance decreases its value over time t - Fig.1.

Neither the entire object nor all its components are equally degraded. The same environment factors have a different impact on elements made of concrete and a different on those made of wood or steel. For this reason, the building and its components should subject to periodic review. Components and elements of the object, in which the consumption symptoms were stated, should be subjected to repairs and maintenance. These activities, according to PN-ISO 15686-7 – are divided into active and forced [11, 12].

Active actions are planned, in most cases they consist in the maintenance elements of the building as well as the repairs.

Corrective forced actions - according to the definition, are the result of damage or failure. Unfortunately it is the most common form of actions required to maintain the performance of the building. As a result of refurbishment the performance of the building increases, approaching the level of "0". These event related to the refurbishment is marked in figure 1 the symbol "B".

Line PD 3 provides minimum acceptable performance level of the building. During the performance of the building (to the moment of refurbishment) the function b* describes the current degree of fulfillment of the performance and it is between the level of PD 0 - defining properties of the building at the time of entry into service and the minimum level - PD 3.

$$PD\ 3 < b^* < PD\ 0 \qquad (2)$$

With the passage of time the use of the building, the intensity of consumption of the object increases faster than observed in the initial period of operation. The process of ageing of materials and degradation of components accelerates. The slope of the curve b* describing the properties of the building at time t increases and after a few years of operation, the utility state of the object can reach the level of PD 3. Simultaneously, the increase in the user's requirements $\Delta_R(t)$ (increment the reference building [13,14]) at the time - t_γ increased to the point that the process of carrying out the repair does not satisfy the user; it is not sufficient.

4 ASSUMPTIONS TO MODEL DESCRIBING THE PERFORMANCE OF THE BUILDING

The residential building is seen as a dynamic system, consisting of a set of various elements and components which are selected in a targeted manner and which have to meet certain requirements set by the owners with a different purpose and fulfill various functional performance such as safety, durability, comfort, etc. These elements are purposely one oriented whole; they have certain properties and are located in specific relations to each other. Over the time, due to various impacts, the building looses its ability, or a part of it, to perform the required functions - the relations between the elements are loosened.

Determining the use value of the building is of paramount importance for their owners and managers. On that basis, plans for further use of the building and costs that are connected with this can be developed [15,16].

The use value of the building is the main criterion (gauge) to assess the state of the building. It applies to existing buildings. It significantly expresses the subjective assessment determined by an expert. This assessment usually covers the basic elements of the system, which are required to be fulfilled regardless of the operating environment of the building. The aim of the assessment of the building value is to decide about the further fate of the object, it relates to the costs associated with (generally speaking) possession of the building. The utility value of the building determines the actual condition of the different components of the building, and social performance of the building.

Analyses of the system (such as a building object) entails the need for certain simplifications; insignificant (in the opinion of an expert) interrelationships between the two groups of factors are omitted.

Assessment of the use value of an object belongs to so-called multi-criteria decision problems. Requirements to be met by building are estimated on the basis of the following criteria: building safety, energy saving and heat insulation, etc. Number of criteria can be variable, depending on the design of the object, purpose, surroundings, and other special features: - in general, we assume that the evaluation of the building is based on i-criteria (i = 1,2, ..., m). In the model proposed by the authors, 8 criteria are considered (BWR 1 ÷ BWR 7 + social performance of the building). In each of the criterion we distinguish j sections (parts, classes) (j = 1,2, ..., n); for example, in criterion (BWR 1) " Strength and Stability" distinguish among other sections (classes): ultimate limit state, serviceability limit state, the state of the monitoring equipment in public buildings with rooms accomodating large number of people, such as entertainment venues and sports halls.

The notation o_{ij} represents an assessment of the j-th section in the i-th criterion - it is a partial measure of the i-th criterion.

Expert knowledge translates into sets of numbers using a digital estimated assessment scale. Estimate scales are tools that enable experts to assign to their judgments qualitative numerical values and record the estimated size or atribute of the object. Using the estimated scale, experts should know the definition of the parameter and its unambiguous interpretation, and indicators that assign to a parameter a determination of the parameter‘s intensity. In practice estimated discrete numerical scale is used. It is basically arbitrary and depends only on its creator. Introduction insufficient number of points leads to a reduction in discrimination power scale. On the other hand, too many points may exceed the ability of differentiation by experts who use the scale. For most criteria, you can determine the minimum or maximum value, constituting a kind of critical value. In the standard BS EN ISO 15686-1 a concept critical property is applied (and defined). Here is the definition: critical property - acceptable value of the building or his part, subject to compliance by the required functions. During the analyzed model a five-point scale was assumed. As the maximum value - the highest, 5 was accepted, while the lowest (the worst condition) – 1. Of course, there are still three intermediate scale values: 4, 3, 2.

In the multicriteria analyses, the unequal importance of the adopted criteria (sections, classes) and including this in the evaluation algorithm is a significant problem. To this end, the so-called weights (coefficients hierarchical) are introduced, which correct values of criteria according to preferences expressed by the expert. Individual assessments oij should be attributed to different numerical weights λij (i=1,2, …, m) (j=1,2, …, n); wherein:

$$\sum_{i=1}^{j=n} \lambda_{ij} = 1 \quad \text{dla } i=1,2, \ldots, m \tag{3}$$

5 MODEL CONSTRUCTION

Assume the following code:

To the assessment of the utility value, we assume a finite set of criteria:

O = {O_i i=1,2,3, ..., m}. Each criterion consists of a set of sections (parts, classes) D = {D_j j = 1,2,3, ..., n). In the model set criterion is a stimulant (an advantage), when its higher value causes more favorable global assessment.

Matrix of assesment values of criteria is as follows:

$$[O]_{ij} = \begin{bmatrix} o_{11} & o_{12} & \cdots & o_{1j} & \cdots & o_{1n} \\ o_{21} & o_{22} & \cdots & o_{2j} & \cdots & o_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ o_{i1} & o_{i2} & \vdots & o_{ij} & \vdots & o_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ o_{m1} & o_{m2} & \cdots & o_{mj} & \cdots & o_{mn} \end{bmatrix} \tag{4}$$

Matrix of weights assigned to the various sections of the criteria is as follows:

$$[\Lambda]_{ij} = \begin{bmatrix} \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1j} & \cdots & \lambda_{1n} \\ \lambda_{21} & \lambda_{22} & \cdots & \lambda_{2j} & \cdots & \lambda_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \lambda_{i1} & \lambda_{i2} & \vdots & \lambda_{ij} & \vdots & \lambda_{in} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \lambda_{m1} & \lambda_{m2} & \cdots & \lambda_{mj} & \cdots & \lambda_{mn} \end{bmatrix} \tag{5}$$

Vector of weights assigned to individual criteria:

$$L = \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_i \\ \vdots \\ L_m \end{bmatrix} \qquad (6)$$

The assessment of the use value E of a building is obtained by using the so-called summation index revised.

$$E = \sum_{i=1}^{m} E_i L_i \qquad (7)$$

where: E_i - adjusted assessment of the use value of the i-th criterion, L_i - the weight of the i-th criterion.

Assessment of performance of building for i-th criterion is calculated the sum of the scalar multiplication assessment matrix with weights matrix of the sections (subcriteria) in this way we get the corrected vector i-th criteria.

$$E_i = \sum_{j=1}^{n} o_{ij} \ \lambda_{ij} \qquad (8)$$

Adjusted vector criteria can be written as:

$$E_i = \begin{bmatrix} e_{i1} \\ e_{i2} \\ \vdots \\ e_{ij} \\ \vdots \\ e_{in} \\ \end{bmatrix} i = 1,.., m \qquad (9)$$

while the weights of the criteria are written in the form (6).

By multiplying these vectors by themselves we get corrected system evaluation vector. Its components are assessments the following categories (criteria):

$$O = \begin{bmatrix} O_1 \\ O_2 \\ \vdots \\ O_i \\ \vdots \\ O_m \end{bmatrix} \qquad (10)$$

Assessment of the use value $O_R(t_\gamma)$ for reference building in the examined time t_γ is calculated from the formula:

$$O_R(t_\gamma) = \sum_{i=1}^{m}(E_i L_i) \qquad (11)$$

The use value $O_D(t_\gamma)$ of the analyzed building in t_γ time is calculated from the formula:

$$O_D(t_\gamma) = \sum_{i=1}^{m}(E_i L_i) \qquad (12)$$

The difference $\Delta_{R+D}(t_\gamma)$ between the use value of a reference building and the use value of (real, analyzed) building in the examined time - t_γ is:

$$\Delta_{R+D}(t_\gamma) = O_R(t_\gamma) - O_D(t_\gamma) \qquad (13)$$

Where:

$O_R(t_\gamma)$ - the utility value of the reference building at the time t_γ,

$O_D(t_\gamma)$ - the utility value of the analyzed building at the time t_γ.

The degree of wear of the object in the test time t_γ calculated from the formula:

$$S_t = \frac{(O_R - O_D)}{O_R} \qquad (14)$$

In a situation where the degree of wear increased by such a value that the repair (reconstruction of the original state) is not satisfactory, the building should be refurbished. This case is marked with the symbol "D" in Figure 1.

Refurbishment of the building occurs in the following circumstances:

a) If the degree of wear of the building has exceeded a certain limit value $S_M(t)$ when the repair does not comply the manager expectations of the property:

$$S(t) \geq S_M(t) \qquad (15)$$

The object should be subjected to refurbishment, in order to extend its service life,. Otherwise, the building is undergoing the so-called exiting from use state [11, 17].

b) When the degree of wear of the building has not reached the limit value:

$$S(t) \leq S_M(t) \qquad (16)$$

but the user has adequate means and wants to raise through the current performance of the building through the refurbishment (often this will also increase the value of the object).

6 COMPLETION

Presented in Chapter 5 the model for assessing the performance of the building and the analysis showed how complex the process of determining the performance of a building is. The progressing difference between the degrees of fulfillment of performance of the building (PD) and the requirements of users during the operation of the facility is a permanent and natural process. Lack of theoretical models allowing for a reliable determination of the performance value and estimation of the behavior of the object in the future makes the condition of the buildings be assessed mostly on the basis of visual sensations, as well as applications of periodic maintenance intervals. As a result of the lack of thorough analysis of the performance of building, it is often the effects of the damage that are removed, not the causes. This article is a fragment (theoretical part) from research work carried out in the Department of Geomechanics, Civil Engineering and Geotechnics of Faculty of Mining and Geoengineering.

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