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Impact of the Selected Building Maintenance Strategy on Costs and Service Life

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ABSTRACT

Purpose - to determine the impact of selected materials and maintenance strategies at the building exploitation stage on the building's service life and to present the influence of LCCA analyzes and the decision making process on future building durability.

Design/methodology/approach - the authors conducted a variant analysis of the estimated service life and building construction and maintenance costs under different scenarios for the selected residential building with the commercial part; the estimated service life (ESL) indicator method and a simple approach to the life cycle costs analysis (LCCA) were used in the research.

Findings - the results indicate the following suggestion for the investor – if he (at the decision-making stage) considered more expensive material solutions and then took into account the service time and costs of future renovations, would probably choose variant II - high quality of the materials building; the variant II has the longest estimated service life of 60 years (together with III), but significantly lower construction and maintenance costs; the analyzed variants were also intended to show the necessity to carry out cost-time analyzes at the initial stage of construction of the facility.

Research limitations - the research was limited to an example building and three different construction and service life scenarios

Research implications - there is a need to carry out cost-time analyzes at the initial stage of construction of the facility - the investor at the decision-making stage must consider material solutions and then took into account the service time and costs of future renovations etc.

Keywords:	maintenance strategies; service life; life cycle cost analysis; exploitation process; buildings durability
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INTRODUCTION

The decision-making process regarding the implementation of a construction project must be preceded by many multi-variant economic analyzes, optimization of technological and material solutions both at the planning stage and later throughout the entire life cycle of the building. For the user of the object, it is important not only to be able to minimize the costs of both construction and subsequent exploitation, but also the service life of the building.

After the industrial revolution, the role of precise calculation of the number of works for the purpose of calculating the costs of construction or modernization of construction works began to be appreciated (Lendo et al., 2019). Therefore, building life-cycle analysis (LCA) in the decision-making process, and especially life-cycle cost analysis (LCCA), are increasingly used in construction projects. LCA and LCCA are similar analyzes and it is usually assumed that LCA is LCCA plus quantified environmental analyzes. The essence of these assessments is to apply a broad approach to the subject being investigated, which may cover the entire life cycle of the building, from planning and construction through exploitation to demolition.

Thanks to the LCCA results, we have the opportunity to choose the right solution to minimize operating costs, as well as the environmental impact of not only the products used, but also the facility itself. Frequently higher initial costs lead to lower costs related to repairs, product damage and service (Dziadosz, Kapliński & Rejment, 2015). According to (Rogalska & Żelazna-Pawlicka, 2019) and (Grzyl et al., 2017), the LCCA calculations for the period of durability of building’s structural elements seem to be advisable. In turn, the authors in (Galiano-Garrigós & Andújar-Montoya, 2018) argue on the example of the analysis of the University of Alicante building that it is possible to improve the efficiency of the maintenance process through the integration, standardization and centralization of computerized information, the ubiquity and accessibility to information, and the automation of some phases of the process.

In the article, the authors focused on determining the impact of selected materials and maintenance strategies at the building exploitation stage on the building's service life. The influence of LCCA analyzes and the decision making process on future building durability is presented in the paper. The essence of the problem was shown on the examples of a factory and a residential building with a commercial and service part. The authors used the ESL (Estimated Service Life) analysis to calculate the service life of the analyzed residential building with the commercial part for three selected decision variants considered in the whole life cycle of the facility.

LITERATURE REVIEW

Exploitation models and their impact on the functional properties of the building

The operation phase is the most important in the building lifecycle both from the point of view of its impact on the environment and man, as well as from the perspective of the impact on the amount of the building lifecycle costs (Belniak, 2018). The exploitation process is a set of ordered activities carried out within the object participation and in relation to the technical object at the time of exploitation. Exploitation is related to the activities of users and is also shaped by external factors associated with nature activities. The exploitation process itself may consist of intentional and unintentional events that are measurable, difficult to measure or immeasurable. Course of individual operations is determined by individual characteristics of objects and their organizational and technical environment, resulting in uniqueness of individual exploitation processes (Loska, 2012).

The exploitation process can be modeled in several ways, but two approaches in particular are important and fully reflect the approach to the exploitation process:

• exploitation process presented as a sequence of events,
• exploitation process presented as a series of states.

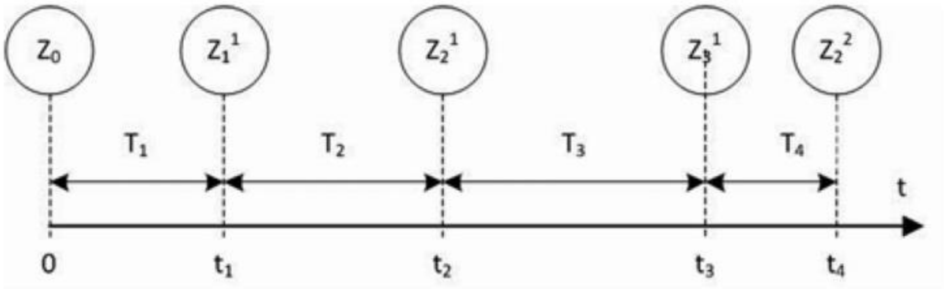

Figure 1. The exploitation process model as a sequence of events.
Source: (Kaźmierczak, 2000).

Figure 1 shows an exemplary model of the exploitation process imagined as a sequence of specific events (Z_{ij} - exploitation events), under which some tasks are carried out on the basis of information about events occurring at different moments on the timeline (t_i - moments in which events occur), where T_i means time interval between events.

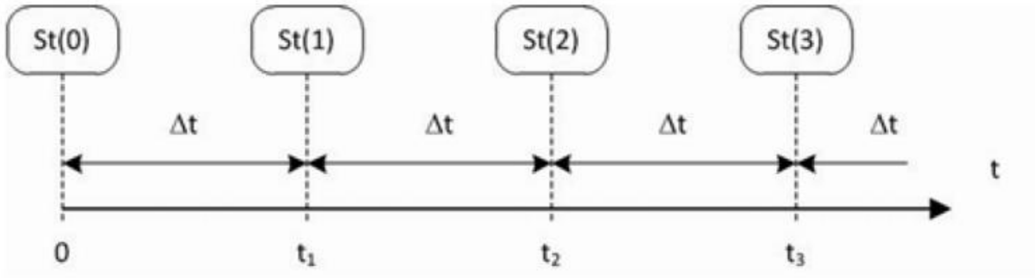

Figure 2. The exploitation process model as a series of states.
Source: (Kaźmierczak, 2000).

Figure 2 shows a model of the exploitation process presented as a series of states in which maintenance tasks are undertaken and implemented based on the momentary conditions of the object (t_i - moments of identification of the technical condition), identified at equal intervals (Δt - time interval between the moments of identification of the technical condition).

The exploitation process models shown define the procedure depending on the type of exploitation events - intentional or unintentional. In practice, moments of identification of the technical condition and those with event sequences often occur simultaneously or interchangeably. Therefore, identifying the right model and adopting the right procedures requires periodic building inspection to make the most appropriate exploitation decision. It should also be noted that the models show cause and effect relationships, and their one-dimensionality does not take into account non-technical aspects occurring in the environment. The lack of a comprehensive approach in the presented exploitation process models suggests that modeling methods should be enriched by the actual current state of the object with a simultaneous attempt to predict the potential scenario of future events. Therefore, the duration of the facility's service life should also be considered. The considerations should specify the reliability of individual building elements. The predicted service life should be equal to the period of use, i.e. the average time for breakdown-free work of the facility (Tymiński, 2011). The exploitation phase is also associated with the largest costs during the building’s life cycle, as shown in Figure 3.

Exploitation according to the Polish standard PN-93/N 50191 is a set of all technical and organizational activities aimed at enabling the building to fulfill the required functions, including the necessary adaptation to changes in respect to external conditions. There is no concept of exploitation in the Construction Law, however, art. 5 and chapter 6 of this Act speaks of the use and maintenance of buildings. The maintenance of a building according to (Kasprowicz, 2005) is a subset of activities related to enabling the building to perform the required functions, including the necessary adaptation to changes in external conditions. When defining the maintenance and use, it is also necessary to specify what the service life is, how it is understood. The service life should be defined by the time starting from the construction performance until the performance properties reach the minimum permissible level.

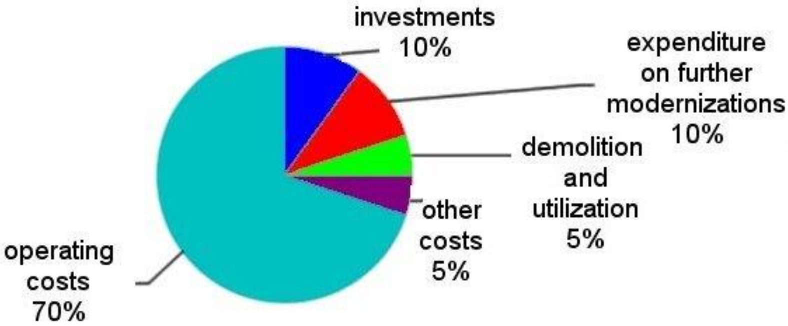

Figure 3. Percentage share of the building's life cycle costs chart
Source: (Plebankiewicz, 2014).

The designed durability of the structure and the use of appropriate repair or maintenance works during the exploitation of the facility may affect the change in the length of the service life.

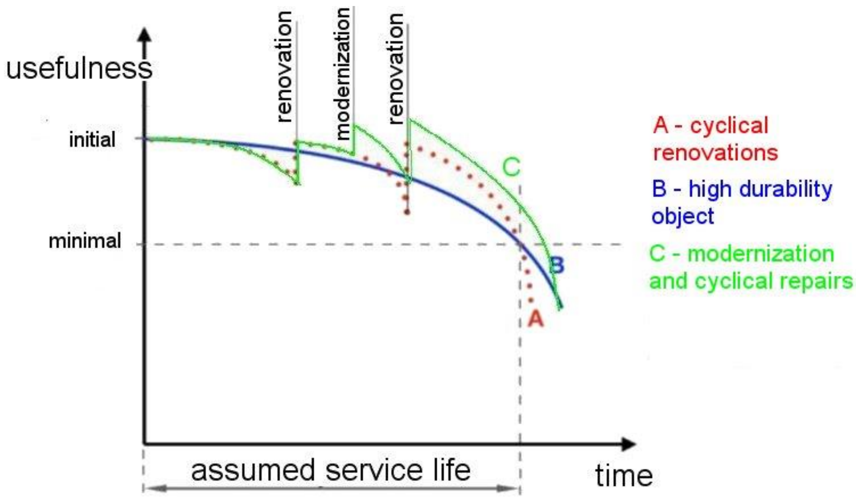

Figure 4. Changes in the usefulness properties of the building during the service life depending on the decision solution adopted
Source: own study.

Figure 4 is a graph showing changes in the performance of a building during its service life depending on the adopted decision solution. Usefulness is the assessment of whether the object fulfills the required functions. Minimal usefulness means a value below which the building ceases to fulfill its basic utility functions and should not be used. Graph A shows the usability behavior over time for a building subjected to periodic renovation. In contrast, Chart B describes a building with high durability associated with the high quality of the materials and / or components used. Additionally, Chart C presents a building subjected to cyclical renovation works, but also modernization works. It can be seen that it is possible to extend the life of the facility by repeated repair, maintenance and modernization work. As the external conditions change, the building's ability to perform the required functions could be reduced and a need to adapt to the changes may occur.

Renovation work can be further divided into:

- ad hoc repairs, i.e. construction works consisting only in the elimination of damages and restoring the possibility of fulfilling the assumed functions by the element,
- planned repairs, i.e. maintenance works planned in advance and carried out in accordance with the prepared schedule, having a specific scope of work and periodicity,
- necessary repairs, meaning treatments resulting from specific conditions of exploitation, i.e. conducting specific works based on research and ongoing observation of the object.

Exemplary types of maintenance strategies were presented by (Kelly, 2006). The author presents the strategies in a graphical form showing the change in costs over time on the example of a factory where actions were taken to change the maintenance strategy from reactive to proactive. It should be noted that reactive maintenance means taking action only when such necessity arises, and therefore corresponds to carrying out ad hoc or high necessity repairs. Proactive strategy is an alternative to traditional reactive strategy. It involves overtaking degenerative activities, planning renovation strategies, monitoring the current state of the building.

Due to the fact that the considered factory already exists for some time, it is planned to change the strategy over a period of 4 years to one that is focused on actions taken at specific intervals, is consistent with the assumptions made and aims to reduce the likelihood of failure or significant deterioration of the element.

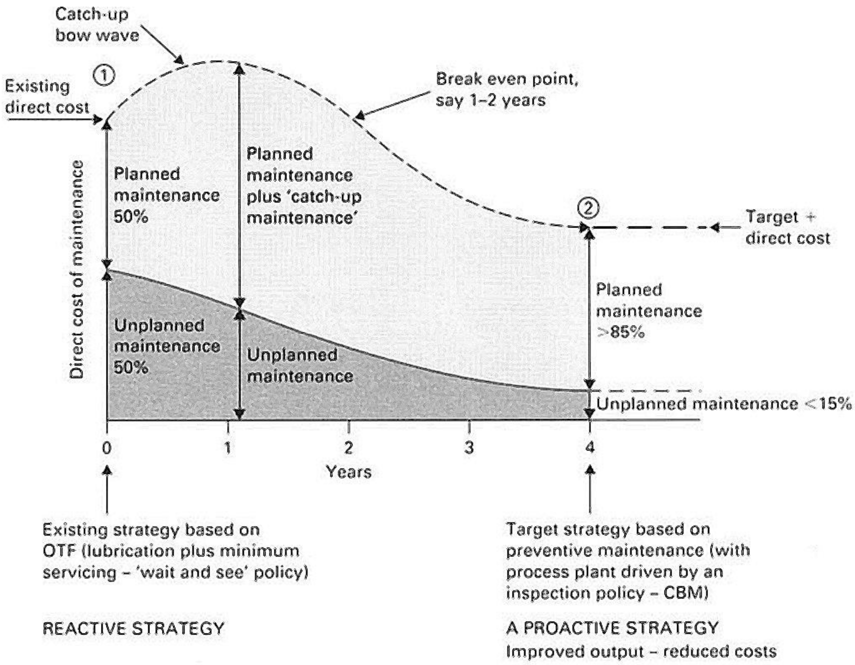

Figure 5. Change of factory maintenance strategy - cost change over the years

Source: (Kelly, 2006).

The graph in Figure 5 shows that up to the point the changes in the maintenance of the plant were introduced, the adopted strategy of the factory was the so-called "wait and see", which is a reactive strategy. Therefore, no preventive actions were taken and the moment of failure or the moment when deteriorated element required replacement was awaited. At the time of starting the gradual change of the strategy, it was assumed that the planned and unplanned maintenance would be one to another in a 50% / 50% relationship. It should be understood that there was a 50% probability of defects, irregularities that were not planned in any way during the operation of the plant, but at the same time actions were taken to counteract half of the defects that could have occurred in the developed scenario. According toKelly (2006), the change in strategy resulted in an initial increase in maintenance costs (dashed line) after a period of about a year, as some remedial and supplementary work could be required to restore the durability of the exploited elements. Analyzing the graph further, it can be seen that the turning point causes a gradual decrease in maintenance costs, and thus it should be noted that approaching the end of the maintenance strategy transformation deadline, the unscheduled maintenance of the facility was significantly reduced, and the maintenance costs significantly decreased compared to the "zero" stage of taking action to change the strategy . In the case of a factory for which the above graphic maintenance plan transformation graph was created, this change has a positive effect on the service of the facility - production is improved and costs are reduced.

Maintenance strategies similar to those presented above are presented in ISO 15686-5: 2017 (ISO 15686-5, 2017). Maintenance according to this ISO standard includes conducting corrective, responsive and preventative maintenance on a building or its parts and all associated management, cleaning, services, repainting, repairing or replacing of parts as needed for the building to be used for its intended purpose.

By analyzing the types of maintenance scenarios precisely presented in the literature, they can be grouped into three leading categories that differ in terms of scope and repair planning:

- I Preventive maintenance - predictive,
- II Condition based maintenance - corrective,
- III Deferred maintenance - reactive.

Preventive maintenance means taking specific corrective actions at pre-specified and planned intervals. The purpose of such maintenance is to reduce the probability of a failure or deterioration of an object's condition. This maintenance should plan the scope of necessary maintenance works and eliminate faults that may appear in the service process, and therefore it requires the preparation of some kind of an action plan.

Condition based maintenance also involves taking repair actions according to a set plan, but also requires monitoring of the facility. This maintenance focuses on keeping the building in a good technical condition, but it does not prevent major accidents, but only delays their occurrence. This scenario may also include preventive measures, but to a large extent depend on the needs of the facility user.

Deferred maintenance comes down to taking action only when the necessity arises. It does not include maintenance or monitoring of the condition of the facility. It assumes a high degree of deterioration of individual elements that are subjected to repeated repairs until reaching the durability limit. The building is not subjected to scheduled works, and in the event of a breakdown, the cost of repair may be much higher than in the case of constant care of the facility.

The durability of the building and its elements as a factor influencing the service life

The durability of a building structure is described as the ability to meet the user's requirements for a specified period of time under the influence of certain factors. The measure of durability is the time during which the object retains its properties (Nowogońska, 2011). Durability also depends on the initial assumptions, such as the parameters and properties of the materials used, the quality of the building and the quality of the project preparation. The exploitation conditions also have a great influence – the way how building is used and the ability to resist the influence of the external and internal environment. The durability of a building is related to the durability of individual building elements, which may be more or less susceptible to certain factors.

The most important factors influencing the durability of the building are (Celińska-Mysław & Wiatr, 2017): location and position of the object in relation to the directions of the world, water and soil conditions, solutions used in the project, parameters of the materials used: quality, structure, properties, external environment, internal environment, construction execution standard and quality control, method of exploitation.

The durability of the facility may vary due to the designed service life, which may be 10 years for temporary structures, 50 years for residential, public utilities or even 100 years for monumental engineering structures. During this time, the structure of the facility should ensure an appropriate level of reliability, take over all actions and influences, and remain usable (Broniewicz, 2013). In technical terms, the service life of a building must vary depending on the intended use of the structure. This is determined by the components selection, including materials that will reach their end of durability at different times and conditions. Thus, the problem of durability is directly related to exploitation, i.e. a decrease in utility values over the years.
Building components (i.e. products made as separate entities fulfilling specific functions) and their sets, due to the assumed service life, are divided into permanent - non-exchangeable and exchangeable (Orłowski, 2011). Fixed components, i.e. non-replaceable elements, are the main elements of the building, such as foundations, load-bearing walls, etc. Replaceable components are elements that are completely replaceable, often with a shorter service life, such as windows, coverings, plasters, partition walls, installations. The service life of the entire building is therefore practically limited by the degradation of its permanent components, the replacement of which is not possible.

In Orłowski (2011) the basic elements influencing the assessment of the building exploitation are described as:

- processes occurring during the use of the facility,
- increased requirements of building users,
- deterioration of functional properties during its exploitation.

By analyzing these elements, it can be concluded that the way of use itself and the duration of use of the building have a large impact on the durability of the building. It should be noted that the factor related to the increased requirements of building users sometimes entail the need to modernize the building during its exploitation. The authors took into account such a scenario in the analyzes and showed it also in Figure 4.

RESEARCH METHODOLOGY

Description of the analyzed building

The case study was prepared on the example of an existing commercial and service building with a residential part on the upper floor in a terraced development, erected around 2000. The facility is located in Cracow. The building was built on a slope and consists of 4 floors, one of which is partially in the ground. In July 1998, an architectural and construction design for a complex of commercial pavilions with residential parts was prepared, according to which the list of areas for the analyzed building is as follows:

- basement 50.70 m^2
- ground floor 45.35 m^2
- first floor: 51.20 m^2
- attic of 46.55 m^2.

The building is founded on continuous concrete footings with variable widths. External walls are made of reinforced concrete (20 cm) and MAX brick, insulated with 12 cm of polystyrene, and internal load-bearing and partition walls are made of checkered bricks of various thicknesses. The slabs are made of 14cm thick reinforced concrete. The stairs leading to the basement / garage and to the first overground storey are made of reinforced concrete, while the stairs leading to the attic have wooden open structure. The building has a gable roof with a collar beam structure covered with metal tiles. The building has horizontal and vertical hydro-insulation, thermal and acoustic insulation. Cement-lime plasters were made inside and outside. Windows and door are made of PVC or wood, depending on the storey. External blinds were installed on the first floor. Figure 6 shows the location of the analysed residential building in relation to adjacent buildings.

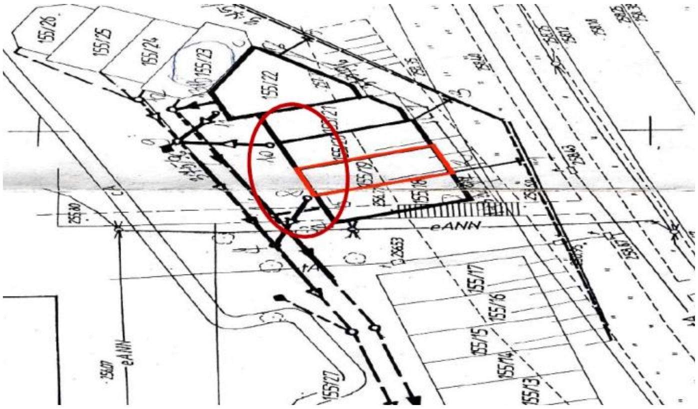

Figure 6. Analysed residential building with the commercial part location
Source: own study.

On-site inspection of damages and defects

The age of the facility, around 20 years, may also suggest that the pavilion has hidden defects, which will be noticed, for instance, only during renovation works of a larger extent. The building has not been completely renovated or modernized so far. Table 1 shows the scope of damage or defects noticed during the on-site inspection. Data was collected based on visual assessment.

Table 1. Defects of estimated building elements

i	Element	Defects
1	Basement / ground floor walls (level -1)	Moisture, cracks, cavities
2	Above ground walls (level 0, +1)	Cracks, cavities, mold foci
3	Attic walls (level +2)	Cracks, loose plaster, water stains in the area of joining the roof surfaces of adjacent structures
4	Slabs	Cracks, mold on bathroom ceiling
5	Attic	Cracks, visible plasterboard joints
6	Roof - external elements	The risk of leakage is justified by stains on the attic walls, poor fixing of the soffit
7	Stairs	Non-uniform step heights, relatively low height between the flight of stairs and the attic ceiling
8	Vestibule (residential part, level 0)	Cracks, loose plaster, lack of acoustic insulation in the wall separating the living area from the service part
9	Elevations	Cracks, plaster detachments, dirt
10	Drainage	Poor permeability, linear drain grate is loose
11	Ventilation	Gravity ventilation, in bathrooms exhaust fans installed in the residential part - poor draft, ineffective ventilation - high humidity and mold
12	Windows	Leakages, roof windows deterioration due to water

		ingress, improper construction of roof windows, the occurrence of condensation
13	Doors	Leakage, visual damages
14	Electrical installations	Malfunction of several wires, circuit overload

Source: own study.

Estimation of ESL (Estimated Service Life)

The authors conducted a variant analysis of the estimated service life under different scenarios for the abovementioned building. The analysis used the ESL (Estimated Service Life) indicator. Estimated service lifetime ESL is formulated as the ratio of the following determined values:

$$ESL = RSL \times f_A \times f_B \times f_C \times f_D \times f_E \times f_F \times f_G \quad (1)$$

where:

RSL − reference service lifetime,
f_A – quality of used materials and / or building components
f_B – level of design
f_C – work execution level
f_D – internal environment
f_E – external environment
f_F – in use conditions
f_G – level of maintenance
wherein the influence of the given factor is negative, then f is 0.8, 1.0 for neutral and 1.2 for positive influence.

To make the estimation of ESL possible, it is necessary to conduct a two-stage analysis made up of (PN-ISO 15686-1:2005):

a) determining the reference service lifetime RSL,
b) allocating values to factors influencing durability (factors from A to G).

The reference service lifetime (RSL) of a building should be understood as a period expressed in years, in which a component or a set of components making up a building or a constructed asset will stay at the reference level in precisely defined conditions (PN-ISO 15686-1:2005). RSL can be adopted for calculations based on (according to (Belniak, 2018) and (Wieczorek, 2015)):

• data provided by the producer of a building component,
• experiences or observations of similar structures or materials working
• in similar conditions,

- assessments of the product durability made by acceptance committees operating at the European Commission, which are included in national reports,
- available technical literature,
- construction regulations which can give typical service lifetimes of components, buildings, constructed, assets, etc.,
- table of standards coming from PN- 1990:2004 Eurocode and PN-ISO 15686-1:2005.

RESULTS & DISCUSSION

The variants considered by the authors are in line with the scenarios A, B, C shown in Fig. 4 and described in exploitation models and their impact on the functional properties of the building chapter:

- variant I assumes thus maintaining the usability in time for the analyzed object, which is subjected to periodic renovations.
- on the other hand, variant II was determined for a hypothetical object of high durability associated with the high quality of the materials and / or components used. However, the facility has the same performance parameters, only the materials used differ. Therefore, it was assumed that reinforced concrete strip foundation would be made instead of concrete ones and load-bearing walls as monolithic reinforced concrete, insulated with polystyrene with stone cladding, additionally the roof is covered with a copper sheet, instead of the standard steel roof tiles.
- whereas variant III presents the analyzed facility, without any modifications, subjected to periodic renovation works, similarly to the facility in variant I, but additionally also modernized.

For the variants characterized above, the authors adopted the reference service lifetime (RSL) of a building at the level of 50 years, which corresponds to the standards coming from PN-1990: 2004 Eurocode for the design lifetime of building (DLB) category four. For variants I and III, impact of factors influencing the durability from f_A to f_G was determined at a neutral (average) level of 1.0 for each of them. Because for variant II, it was decided to use improved material solutions in the field of building components, including the ones that cannot be replaced (foundations and load-bearing walls), the authors recognized the positive impact of these solutions application and thus determined the value of the factor f_A at 1.2 level. The remaining factor values (from f_B to f_G) were also assumed for variant II at a neutral level (1.0). The factor values comparison for the service life estimation is shown in Table 2.

Table 2. The factor values for the estimation of the service life

Factor	Variant I		Variant II		Variant III	
	Condition	Factor value	Condition	Factor value	Condition	Factor value
f_A – quality of used materials and / or building components	Normal quality	1,0	Good quality	1,2	Normal quality	1,0
f_B – level of design	Normal design	1,0	Normal design	1,0	Normal design	1,0
f_C – work execution level	Normal	1,0	Normal	1,0	Normal	1,0
f_D – internal environment	Average risk	1,0	Average risk	1,0	Average risk	1,0
f_E – external environment	Average risk	1,0	Average risk	1,0	Average risk	1,0
f_F – in use conditions	Residential use	1,0	Residential use	1,0	Residential use	1,0
f_G – level of maintenance	Normal maintenance	1,0	Normal maintenance	1,0	Good maintenance	1,2

Source: (own study).

Calculations of estimated service life (ESL) for all three variants are presented in Table 3.

Table 3. Estimated service lives (ESL) for variants I – III

Variant	RSL in years	Values of factors affecting the durability of the analyzed building							ESL in years
		f_A	f_B	f_C	f_D	f_E	f_F	f_G	
I	50	1.0	1.0	1.0	1.0	1.0	1.0	1.0	50
II	50	1.2	1.0	1.0	1.0	1.0	1.0	1.0	60
III	50	1.0	1.0	1.0	1.0	1.0	1.0	1.2	60

Source: own study.

Table 4 shows the costs related to the construction as well as renovation and modernization of the building carried out in the following years. The construction costs were estimated for the third quarter of year 2000 using the cost estimate program BIMestiMate. Cost of renovations - every 5 years is the cost of narrow-scope renovation works aimed at restoring the original standard of the residential part (e.g. interior painting, windows), and every 10 years it is renovation work of the installation and replacement of broken equipment. Renovation costs (every 20 years) are the costs of a major renovation using cheap materials. In the case of variant II, the costs of more expensive, higher-quality materials were estimated, ensuring longer durability. According to the description of variant II, the estimated were the costs of reinforced concrete strip foundations instead of concrete ones, stone cladding instead of the MAX brick cladding, and the roof covering with copper sheet instead of steel roof tiles. The calculations assume an estimated service life of 50 years. Modernization is a permanent improvement of an existing building structure leading to an increase in its value in use. Exemplary modernization costs in variant III concerned attic insulation, modernization of heating installations, installation of new telecommunication devices, etc.

Table 4. Building construction and maintenance costs according to selected variants

Element	Variant I	Variant II	Variant III
Construction costs	€ 72 111.63	€ 89 320.93	€ 72 111.63
Cost of renovations - every 5 years	€ 1 511.63	€ 1 511.63	€ 1 511.63
Cost of renovations - every 10 years	€ 2 325.58	€ 2 325.58	€ 2 325.58
Renovation costs - major renovation every 20 years	€ 16 279.07	€ -	€ 16 279.07
Cost of modernization	€ -	€ -	€ 6 976.74
SUM	**€ 127 576.74**	**€ 112 227.91**	**€ 134 553.49**

Source: own study.

The most expensive variant in terms of construction costs is, of course, variant II, which required the use of more expensive building materials. The choice of more expensive solutions, however, was compensated by the lack of the necessity to perform major repairs, which resulted in the fact that variant II turned out to be the cheapest solution. The most expensive solution, on the other hand, is variant III due to the additional costs devoted to modernization.

CONCLUSION

The analyzed variants were intended to show the necessity to carry out cost-time analyzes at the initial stage of construction of the facility. Authors in Ruiz et al. (2019) argue that, there is evidence that preventive maintenance is much more efficient than corrective maintenance, since severe deteriorations that may represent danger to people are avoided, and also money is saved. If the investor at the decision-making stage considered more expensive material solutions and then took into account the service time and costs of future renovations, he would probably choose variant II. Variant II has the longest Estimated Service Life of 60 years - together with variant III, but significantly lower construction and maintenance costs. In the III case, carried out modernization, resulted in an increase in the service life which was included in the analysis, however the calculation of ESL and construction and exploitation costs does not take into account the increase in the functionality of the object and at the same time its value increasement. Variant I is, on the other hand, the safe one and the most frequently used one that implements a typical predictive strategy - preventive maintenance.

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