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Planowanie budowlanych przedsięwzięć inwestycyjnych w ujęciu zrównoważonym

Streszczenie

Budownictwo, jako istotny dział gospodarki, wymaga wdrożenia strategii zrównoważonego rozwoju opartego na trzech filarach: ekonomicznym, społecznym, środowiskowym. Konieczna jest obecnie zmiana podejścia do planowania przedsięwzięć budowlanych, w tym szczególnie projektowania obiektów budowlanych z uwzględnieniem uwarunkowań cyklu ich życia. W artykule przedstawiono metodykę szacowania kosztów w cyklu życia (LCC) na przykładzie budynku mieszkalnego, dokonując analizy rozwiązań wariantowych. Szczególną uwagę zwrócono na przydział składników kosztów do poszczególnych faz cyklu życia, uwypuklając problematykę trwałości elementów obiektu budowlanego i konsekwencji z tego wynikających. W celu przeprowadzenia analizy LCC z wykorzystaniem dyskontowania posłużono się programem Primavera Pertmaster wspomagającym planowanie przedsięwzięć. Podjęcie tak sformułowanego problemu jest szczególnie ważne ze względu na konieczność dostosowania standardów dokumentacji projektowo-kosztorysowej w budownictwie do potrzeb analizy w ujęciu LCC. Na mocy nowego ustawodawstwa prawa zamówień publicznych w Polsce podejście LCC stało się obowiązujące, jednakże o formie implementacji zadecydują dopiero szczegółowe rozporządzenia wykonawcze.

Słowa kluczowe: budownictwo zrównoważone, koszty w cyklu życia, trwałość budynku

Planning of construction investment projects in a sustainable approach

Abstract

Construction, as an important branch of the economy, requires the implementation of sustainable development strategy based on three pillars: economic, social and environmental. It is necessary to change the current approach to the planning of construction works, including in particular the design of buildings taking into account the conditions of their life cycle. This article presents a methodology of life cycle costing (LCC) through the example of a residential building and analyzes alternative solutions. Particular attention was paid to the allocation of the cost elements for different phases of the life cycle, highlighting the issue of the durability of the building elements and the consequences resulting from this fact. The Primavera Pertmaster project planning tool was used for LCC with discounting. The attempts to resolve such problems are especially significant because of the necessity of adapting the design and estimation standards in construction industry to the needs of LCC analysis. Under new legislation on public procurement law in Poland, an LCC approach has been mandatory, but the form of implementation is to be decided by detail executive regulations.

Keywords: sustainable construction, lifecycle costs, building durability

JEL CODE: L74, M11, O22

Introduction

In the light of the sustainable development strategy, it is now necessary to update the approach to the planning of construction works, including the design of buildings and the associated construction costing. This article presents the life cycle costing methodology, abbreviated as LCC, using a residential building as an example and it reviews Polish legal standards relevant to the presented problem.

The example at hand focuses on the costs of investment works and on the costs of repair works, as well as the implications of the assumed scope of repairs and their location in the life cycle of the building based on their predicted frequencies.

Costs were calculated by means of detailed calculation using a general-purpose costing software, whereas the LCC analysis was based on network scheduling and discounting using a specialized software program to assist project planning and analysis.

Six cases were investigated with different material solutions of individual building elements and necessary maintenance work based on the assumed durability in the two boundary test cases of the facility. It was important to determine the impact of the time horizon on the results of the LCC analysis.

Construction sustainability

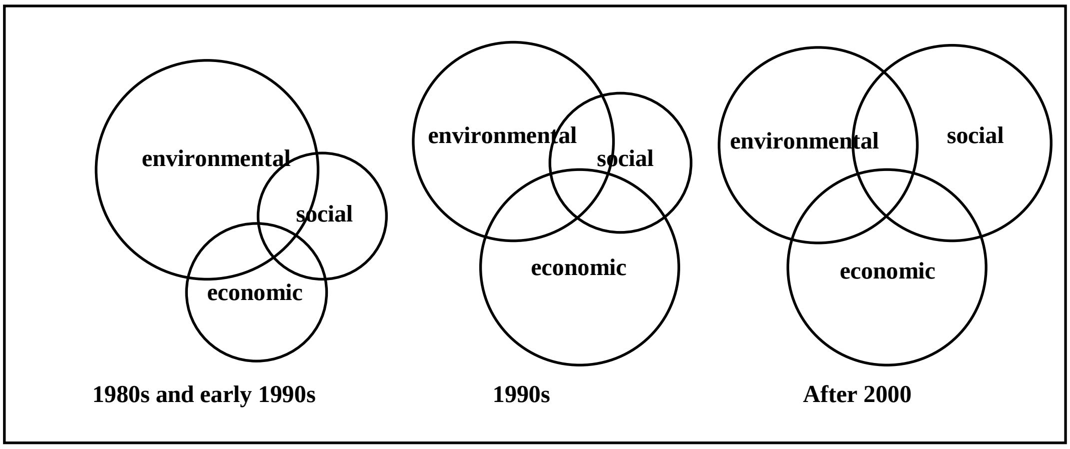
The main purpose of construction is to design and erect buildings that should meet a number of requirements, including, in particular, the so-called basic requirements (*Act* 1994) on the safety of construction, fire safety, occupational safety, hygienic and health conditions, environmental protection and protection from noise, vibration, energy savings and thermal insulation, and the recently introduced requirement for sustainable use of natural resources. These requirements are an expression of the alignment of Polish national law with the EU directives as a manifestation of the adopted sustainable development strategy, which was also described in the context of standardization (Wall 2011).

This strategy assumes the management of resources in the present circumstances, which will safeguard the needs of future generations. It rests on three pillars: economic, social and environmental, with the initial objectives focused on the proper management of limited resources, especially energy, and aimed at finding solutions that would reduce the impact of the production of building materials and construction products on the environment. The transition from the leading role of the aspects identified as environmental towards those economic over time has recently led to the social aspects being highlighted. The change in approach in terms of sustainability is shown in Figure 1, especially in the context of global trends.

Currently, implementation of the sustainable development strategy with respect to environmental aspects includes solutions related to the entire life cycle of buildings that could have an adverse impact on the environment. The main focus is on energy conditions, rational use of natural resources (or, more broadly, ecology), material solutions, the use of appropriate building technologies and design processes that take into account the phase of use, deconstruction and waste disposal. An interesting cognitive approach is the design approach that directly accounts for future deconstruction, known as DfD ("Design for Deconstruction"). So far it has been developed in several centers and has prompted interesting detailed solutions.

It should be emphasized that both the building materials industry and the building operation generate significant energy consumption (over 40% worldwide (Czarnecki *et al.* 2012)) and harmful emissions (35% worldwide (Czarnecki *et al.* 2012)). The importance attached to the environmental requirements is presently underlined by environmental product declarations (*Standard* 2014) and building environmental assessment (*Standard* 2012), although their proper implementation remains crucial.

Figure 1. Concept of sustainability across time



Source: Marghescu 2005: as cited in Ibrahim 2015.

One should stress that a well-designed and well-constructed building is a solution that should be accepted from the social perspective throughout the life cycle. Among the key characteristics of this aspect are: microclimate, accessibility for people with disabilities, efficient use of space, building friendliness for both users and the environment, acoustic comfort and visual comfort. The proposal for a way of assessing social qualities is contained in PN-EN 16309 + A1: 2014-12 (*Standard* 2014).

The economic aspect of construction, meanwhile, is expressed by the cost of the building. So far, evaluations focus on the cost of obtaining materials, i.e. construction costs, including design, while the balanced approach requires the inclusion of costs throughout the life cycle. In addition, the economic efficiency of the investment and the value of the building can be assessed in this respect. The full range of evaluation measures for this aspect is included in EN 16627 (*Standard* 2015) for the assessment of economic performance and the corresponding features of the building.

Building life cycle phases

In relation to a building, life cycle involves consecutive, interrelated phases (stages), whose outset is investment planning and scope planning. The subsequent phases of the cycle are: design (preliminary, basic and executive documentation), commissioning, maintenance and use, and final elimination.

Preventive maintenance work is carried out in the use phase and replacement work is performed on the basis of wear and tear. The elimination phase should take into account the deconstruction or disassembly of the building including the planned ecological disposal of the resulting waste or its recycling. Similar indications also apply to waste generated through repairs, which is a condition of a sustainable approach in both cases.

According to Art. 3 of the Construction Law Act (*Act* 1994), the concept of a building includes both buildings and landscape objects. The scope of activities undertaken in the various phases of the life cycle of construction works may vary due to their complex and specific nature, with the most extensive applying to buildings. The next phases in the life cycle of the building are shown in Table 1 where the ranges of corresponding activities are identified.

The design phase of the building should be considered fundamental. The solutions adopted during that stage, including materials and construction products, components and installation systems plus technical equipment, and more broadly the construction technology, determine the amount of costs generated during the use phase. The choice of design solutions, especially the type of building materials, should take into account not only their negative environmental impacts but also the sustainability of the solutions and the possibilities of recycling. Therefore, variant solutions are of particular importance in the design phase and their economic effectiveness can be assessed using the LCC methodology, which is the key element of the analysis below.

Building life cycle costs

As far as definition is concerned, LCC is about determining the costs associated with a product life cycle directly incurred by one or more participants in the cycle. In the world literature, the methodology for constructing LCC models is very diverse, being linked to various industries and referring to either all or only selected life cycle phases, either in general or in great detail.

General guidelines for costing in the building life cycle are indicated in the Standard (*Standard* 2008). This standard has not been translated into Polish, as opposed to other European Union countries where it was introduced with adaptations to existing national guidelines and regulations. The last amendment of the procurement law (*Act* 2004) indicates the necessity of setting costs in the life cycle of construction works in the area of public procurement in Poland.

The very analysis of costs in a building life cycle can be performed under a deterministic or non-deterministic approach that takes into account risk and even uncertainty. In cost-related issues, the non-deterministic approach is more complex because of the many factors that are difficult to predict or analyze using probabilistic methods. These factors include variable prices of inputs, and in consequence, the value of future repair and maintenance costs.

The procedure of analyzing building life cycle costs can be contained in six steps (*Efektywność* 2015):

- determining analysis scope, including adoption of variants,
- identifying cost components,
- cost estimation,
- calculation of key financial ratios,
- risk and uncertainty analysis,
- choosing solution.

In the case of LCC analyses for construction works, the length of the time horizon is of particular importance in the initial phase. It can reflect the life of an object or it may be a time estimate of the cost of a given model. Another very important step is the identification of the individual cost components adopted in the analyzed LCC model. A summary of the basic cost-generating activities attributed to life-cycle phases is presented in Table 1.

The first, and therefore approximate, cost estimate should be made without taking into account the effect of time at cost level, i.e. inflation and discounting. This approach enables the weighting of individual cost components to be emphasized, allowing the key costs of the model to be emphasized. Only in the next step should the value of individual cost components be estimated in detail and should one proceed to model analysis accounting for the influence of time on the values obtained.

Table 1. Cost components in relation to building life cycle phases

Building life cycle phases				
Design	**Construction works**	**Operation and maintenance**	**Use (operational costs)**	**Deconstruction and disassembly**
- design works (feasibility study and analysis, preliminary, basic and executive documentation) - costs projections - fees, permits - geotechnical research	- temporary works - site preparation - infrastructure works - erecting objects - works related to equipment - small architecture - construction management - taxes - waste disposal - unspent costs - unforeseen costs	- adaptation, maintenance, replacement, refurbishment - design and execution of the above - maintenance of green areas	- media, including fuel, energy, water - sewage disposal - cleaning and maintenance of the object - cleanliness and patency of electric cables - taxes and insurance premiums - pest control - cleaning fee - management fee - other operating costs	- inspections, checks for disassembly, - demolition, disassembly, deconstruction - fees and charges, - preparation for recycling and actual recycling

Source: own study.

Durability as an important factor in sustainability

The length of the time horizon adopted in the LCC model generates a variety of scenarios for the use phase, including the extent of the necessary repair works, replacement of building elements and, above all, their location in time. In the use phase, the durability of buildings and their components should be considered as a basic operational characteristic in addition to the previously specified basic requirements. Normally, it expresses the ability to fulfill the intended function of buildings and their components, and is expressed numerically as time (Ajdukiewicz 2011).

In reference to buildings and their components, durability is determined by a number of factors, but mostly:

- building location, including location in relation to cardinal points,
- groundwater conditions,
- accepted design solutions,
- type of materials used, their composition and properties,
- environmental conditions,
- production quality and control level
- usage.

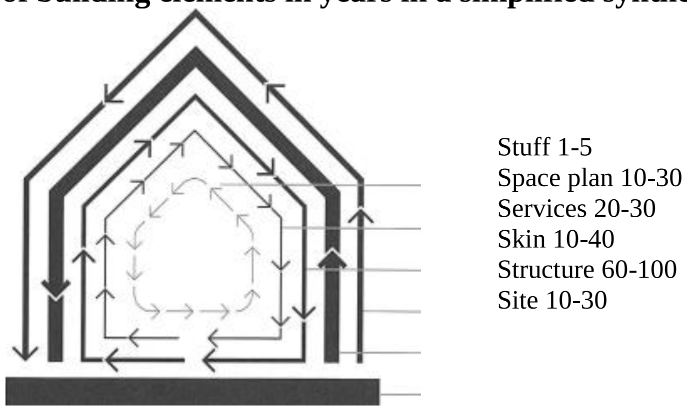
A construction work, and in particular a building, consists of a number of structural elements, i.e. layered bearing and non-bearing sections made of different materials. Consequently, the life cycle of individual elements and their layers and components are very different, usually with longer time horizons for the main load carriers and shorter, plus very distinct, for different types of finishing works, installation systems and components. The process of technical wear of the building as a whole and its components is related to the physical and chemical processes occurring in the building during its use and is conditioned by the influence of the previously mentioned factors.

In the contemporary integrated view, the problem of durability is expressed in what is known as the period of use. In this context, there are two concepts, namely the life-cycle planning within the meaning of international standards (*Standard* 2005) and life-cycle design within the meaning of Eurocode standards, including (*Standard* 2004) for various types of construction works. In the case of buildings, i.e. Category 4 objects according to (*Standard* 2004), the period of use assumed by the designer at 50 years is the time span in which the structure, or its part, is to be used for its intended purpose and within intended maintenance, i.e. it does not require extensive repair (Ajdukiewicz 2011).

In the LCC, there is a need to project the life span as a parameter that reflects the sustainability of a building and its individual components. With a large number of determinants influencing the various building life cycle phases, it is one of the major design problems. This issue is also important in the context of planning the frequency of repair works and their scope during the use phase. The scope of these works can be actively influenced by proper design, including optimized selection of solutions for individual baffles, their layers and components.

In general, the durability of the various elements varies, as schematically shown in Figure 2, indicating different durability times and constituting the basis of many publications, among others by J. Bochen (2014) and A. Pieniążek *et al.* (2015).

Figure 2. Durability of building elements in years in a simplified synthetic view



Source: Brand 1994.

Cost analysis in the life cycle of a residential building

The analysis conducted in this article was to determine the life cycle cost of a construction work for the given model. The LCC model was designed to estimate the design phase, including the purchase of a building plot, the construction of the facility and its use, excluding the deconstruction phase. In the use phase, the costs of repair works were taken into account, while the operating costs incurred from taxes, fees, media and current maintenance of the building were excluded.

The cost estimate was made for a single-family detached house with a usable attic and a usable floor area of approximately 150m2 total. The construction site designed in traditional technology is characterized by external baffles that meet the requirements of thermal protection as at January 1, 2014.

Large material differentiation of particular elements of the building influences the considerable variability of the scope of refurbishment works planned during the period of use of the building, which were included in the analysis.

Based on the blueprints of the works and the accepted basis of calculations, the costs of the construction work was estimated, along with the arising repair costs (Cicha, Jędrzejak

2014). Cost estimation of investment and repair construction works was performed based on the detailed method using the Norma Pro computer software supporting cost estimation.

Three time horizons – 30, 50 and 85 years - were adopted for further analyses, and so were two extreme use scenarios and consequently life-cycle patterns:

- *scenario I* with the least durability, i.e. the quickest wear and tear resulting from the lack on the side of the care of the owner of the building for its technical condition,
- *scenario II* with the most durability resulting from the provision of appropriate repairs and maintenance in the time required for these activities.

The adoption of the largest time horizon in the analysis, i.e. 85 years, was dictated by the software application limitations and was also consistent with the maximum duration of sustainability in practice for traditional single-family buildings. The 50-year period reflects the most commonly accepted test case in the world literature for determining the life cycle costs of buildings, and is currently used for reference in the design of such structures. The shortest period of 30 years was established in order to verify the impact on the final results of the time horizon and the frequency of repair works. In both scenarios, the different life cycle of individual components was adopted, and consequently the frequency of work varied.

Based on this data, six time-cost schedules were developed using the Primavera Pertmaster software, although in practice no such plan is developed in such a broad perspective. The analysis with the use of the scheduling method involves the traditional planning of phases of preparation and implementation of the project without the subsequent phases. For the purpose of LCC analysis, the repair processes, their duration, and the logical links with analysis-derived terms were modeled against dynamic cost analysis.

LCC calculations were first performed without taking into account the effect of time on their values and then taking into account that effect with discounting. A fixed discount rate of 4% was assumed. The results of the analyses for the individual scenarios are presented in a synthetic view in Table 2 (a-f), with Column 2 listing the elements of the structure or the type of work performed.

In the case of repair works, the adopted durability in years and sizes are given in parentheses. Determination of proposed durability for individual building components was made on the basis of the analysis of available data, including (Michalik 2014) and technical expertise. The third column lists the planned costs, which for the repair works cover the costs of these works taking into account their multiplicity in the planned life cycle.

The total cost for particular scenarios demonstrates very large variations from PLN 1,417, 776 to PLN 813,752. The comparison of these costs without discounting shows that the costs of life-cycle repairs approach the cost of production in the analyzed case. This case is illustrated by the analysis for the largest time horizon, where these costs accounted for 193% of the production cost.

With the change in the time horizon, these relationships significantly decrease, so that, e.g., they were just 111% for the shortest test case in the second scenario. The LCC costs with discounting show different relationships with the distribution of individual amounts in time. They accounted for 118%, and 104% for the longest and shortest time horizon, respectively.

Table 2. LCC analysis reports

a) analysis time 85 years, minimum durability values

Task id.	Building elements or types of works	Netcost [PLN]
0	Project preparation	205 900
A	Ground acquisition and terrain fence	180 000
B	Building design documentation	25 900
1	Earthworks and preparation works	16 402
C	Earthworks and land development	16 402
2	Raw state works	305 472
D	Load-bearing structures of building	252 845
E	Roof refurbishment works [50]	52 627
3	Instalation systems works	260 219
F	Instalations and external connections	64 719
G	Sanitary instalation refurbishments [25]	93 600
H	Electric instalation refurbishments [25]	44 400
I	Instalation equipment upgrades [15]	57 500
4	Finishing state works	629 783
J	Finishing of building	194 567
K	Platers ans walls claddings [40]	30 916
L	Floor panels [20]	44 400
M	Ceramic plates [15]	66 095
N	Doors and internal woodworks [50]	30 400
O	Painting and wallpapers [5]	65 808
P	Insulations and facades [25]	107 775
R	Gutters, pipes and flashings [15]	61 240

LCC = PLN 835,770 (PLN 1,417,776 zł)

b) analysis time 85 years, maximum durability values

Task id.	Building elements or types of works	Netcost [PLN]
0	Project preparation	205 900
A	Ground acquisition and terrain fence	180 000
B	Building design documentation	25 900
1	Earthworks and preparation works	16 402
C	Earthworks and land development	16 402
2	Raw state works	305 472
D	Load-bearing structures of building	252 845
E	Roof refurbishment works [50]	52 627
3	Instalation systems works	179 719
F	Instalations and external connections	64 719
G	Sanitary instalation refurbishments [40]	62 400
H	Electric instalation refurbishments [30]	29 600
I	Instalation equipment upgrades [30]	23 000
4	Finishing state works	511 090
J	Finishing of building	194 567
K	Platers ans walls claddings [60]	15 458
L	Floor panels [25]	33 300
M	Ceramic plates [20]	52 876
N	Doors and internal woodworks [60]	30 400
O	Painting and wallpapers [7]	49 356
P	Insulations and facades [40]	71 850

LCC = PLN 782,365 (PLN 1,218,583)

c) analysis time 50 years, minimum durability values

Task id.	Building elements or types of works	Netcost [PLN]
0	Project preparation	205 900
A	Ground acquisition and terrain fence	180 000
B	Building design documentation	25 900
1	Earthworks and preparation works	16 402
C	Earthworks and land development	16 402
2	Raw state works	305 472
D	Load-bearing structures of building	252 845
E	Roof refurbishment works [50]	52 627
3	Instalation systems works	191 219
F	Instalations and external connections	64 719
G	Sanitary instalation refurbishments [25]	62 400
H	Electric instalation refurbishments [25]	29 600
I	Instalation equipment upgrades [15]	34 500
4	Finishing state works	462 184
J	Finishing of building	194 567
K	Platers ans walls claddings [40]	15 458
L	Floor panels [20]	22 200
M	Ceramic plates [15]	39 657
N	Doors and internal woodworks [50]	30 400
O	Painting and wallpapers [5]	37 017
P	Insulations and facades [25]	71 850
R	Gutters, pipes and flashings [15]	36 744

LCC = PLN 821,434 (PLN 1,181,177)

d) analysis time 50 years, maximum durability values

Task id.	Building elements or types of works	Netcost [PLN]
0	Project preparation	205 900
A	Ground acquisition and terrain fence	180 000
B	Building design documentation	25 900
1	Earthworks and preparation works	16 402
C	Earthworks and land development	16 402
2	Raw state works	305 472
D	Load-bearing structures of building	252 845
E	Roof refurbishment works [50]	52 627
3	Instalation systems works	122 219
F	Instalations and external connections	64 719
G	Sanitary instalation refurbishments [40]	31 200
H	Electric instalation refurbishments [30]	14 800
I	Instalation equipment upgrades [30]	11 500
4	Finishing state works	335 608
J	Finishing of building	194 567
K	Platers ans walls claddings [60]	0
L	Floor panels [25]	11 100
M	Ceramic plates [20]	26 438
N	Doors and internal woodworks [60]	0
O	Painting and wallpapers [7]	28 791
P	Insulations and facades [40]	35 925
R	Gutters, pipes and flashings [20]	24 496

LCC = PLN 766,628 (PLN 985,601)

e) analysis time 30 years, minimum durability values

Task id.	Building elements or types of works	Netcost [PLN]
0	Project preparation	205 900
A	Ground acquisition and terrain fence	180 000
B	Building design documentation	25 900
1	Earthworks and preparation works	16 402
C	Earthworks and land development	16 402
2	Raw state works	252 845
D	Load-bearing structures of building	252 845
E	Roof refurbishment works [50]	0
3	Instalation systems works	133 719
F	Instalations and external connections	64 719
G	Sanitary instalation refurbishments [25]	31 200
H	Electric instalation refurbishments [25]	14 800
I	Instalation equipment upgrades [15]	23 000
4	Finishing state works	318 024
J	Finishing of building	194 567
K	Platers ans walls claddings [40]	0
L	Floor panels [20]	11 100
M	Ceramic plates [15]	13 219
N	Doors and internal woodworks [50]	30 400
O	Painting and wallpapers [5]	20 565
P	Insulations and facades [25]	35 925
R	Gutters, pipes and flashings [15]	12 248

LCC = PLN 778,190 (PLN 926,890)

f) analysis time 30 years, maximum durability values

Task id.	Building elements or types of works	Netcost [PLN]
0	Project preparation	205 900
A	Ground acquisition and terrain fence	180 000
B	Building design documentation	25 900
1	Earthworks and preparation works	16 402
C	Earthworks and land development	16 402
2	Raw state works	252 845
D	Load-bearing structures of building	252 845
E	Roof refurbishment works [50]	0
3	Instalation systems works	91 019
F	Instalations and external connections	64 719
G	Sanitary instalation refurbishments [40]	0
H	Electric instalation refurbishments [30]	14 800
I	Instalation equipment upgrades [30]	11 500
4	Finishing state works	247 586
J	Finishing of building	194 567
K	Platers ans walls claddings [60]	0
L	Floor panels [25]	11 100
M	Ceramic plates [20]	13 219
N	Doors and internal woodworks [60]	0
O	Painting and wallpapers [7]	16 452
P	Insulations and facades [40]	0
R	Gutters, pipes and flashings [20]	12 248

LCC = PLN 737,324 (PLN 813,752)

Source: own study.

The percentage values for all the scenarios illustrating the relationship of lifecycle costs to production costs are summarized in Table 3 (the values given in parentheses refer to the amounts without discounting).

Table 3. Lifecycle costs to production costs

Use scenario	Time horizon		
	85 years	**50 years**	**30 years**
I	118% (193%)	116% (161%)	110% (126%)
II	111% (166%)	108% (134%)	104% (111%)

Source: own study.

The differentiation of these relations does not allow to determine the average size apart from the time horizon due to the breakdown of the costs of individual refurbishments. It is crucial to adopt the length of the horizon. The insufficiently long 30-year horizon is not reliable and should be omitted in LCC analyses as it does not properly account for the wear and tear factor of a construction work and its components.

Conclusions

Implementing a sustainable development strategy in the construction industry requires general changes in the planning of construction works, including the design of the structures and consequently the cost estimation. Full analysis of LCCs for building structures requires identification of life cycle components, determination of the durability of construction elements and their components, projection of repair works and their positioning in time, determination of operational expenses and determination of the costs of deconstruction and material recycling. Preparing data for this type of analysis is very laborious.

The analysis of the adopted LCC model for a single-family residential building allowed to set the costs for the assumed scenarios. They are closely related to the technical solutions adopted in this structure (which differ for each structure) and can also be differentiated in terms of costs incurred during the use phase. During the design of the building, targeted changes can be made with regard to the conscious development of the wear pattern. A sustainable approach tends to opt for solutions that are more durable, being usually associated with higher production costs.

The authors chose to tackle the problem due to the recent changes in construction law and public procurement law, which, so far, have affected only those legal acts without the relevant executive regulations. Under the new legislation on public procurement in Poland, the LCC approach has become mandatory, but the form of its implementation is likely to be decided by detailed executive regulations, although the statutory provisions are already marking the direction of change and this article follows them in identifying potential problems that need to be investigated.

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