Sensitivity analysis of facilities life cycle costs

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SENSITIVITY ANALYSIS OF FACILITIES LIFE CYCLE COSTS

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Preliminary notes

Life cycle cost analysis of the constructed facilities provides insight into the planning, design, construction, operation, maintenance and disposal costs of the facilities. By applying this method during the early design phase it is possible to reduce maintenance and operating costs, plan future costs of ownership and prevent or reduce the impact of business interruption due to the maintenance and functional usability. The results of the life cycle cost analysis of facilities depend considerably on the period of life cycle cost analysis and the applied discount rate once net present values are populated. This paper presents life cycle costs case study analysis of the public facility for two different analysis periods, one of 30 and another of 50 years. Facility life cycle costs for both analyzed periods have been discounted to net present value using five different discount rate factors. Predicted construction costs are calculated based on Croatian construction standards, and operation and maintenance costs are based on analysis of historical data of similar constructed facilities in Croatia.

Key words: *facility management, facilities life cycle costs, sensitivity analysis.*

Analiza osjetljivosti ukupnih životnih troškova građevina

Prethodno priopćenje

Postupak proračuna ukupnih životnih troškova građevine daje uvid u troškove planiranja, projektiranja, građenja, uporabe i uklanjanja građevine. Uporabom ove metode u ranoj fazi projektiranja moguće je smanjiti troškove uporabe, planirati buduće troškove te spriječiti ili umanjiti utjecaj prekida poslovanja uslijed potreba održavanja i funkcionalne uporabivosti. Rezultati proračuna ukupnih životnih troškova građevine znatno ovise o duljini vremenskog razdoblja za koje se radi proračun i primijenjenoj diskontnoj stopi pri svođenju troškova na neto sadašnju vrijednost. U ovom radu napravljena je analiza ukupnih životnih troškova jedne javne građevine za vremensko razdoblje od 30 i 50 godina. Ukupni životni troškovi građevine oba vremenska razdoblja svedeni su na neto sadašnju vrijednost uz pomoć pet različitih diskontnih stopa. Predviđeni troškovi izvedbe građevine izračunati su na temelju podatka o etalonskoj cijeni građenja i korisnoj površini zgrade, a troškovi uporabe i održavanja na osnovi analize povijesnih podataka sličnih građevina.

Ključne riječi: *analiza osjetljivosti, održavanje građevina, ukupni životni troškovi građevina*

1 Introduction
Uvod

Until recently, the attention of clients, architects and contractors was directed mainly to the reduction of construction costs, and only few participants paid attention to the reduction of maintenance and operating costs of buildings and, as more important, to the reduction of the life cycle costs [1]. Maintenance costs are costs of statutory periodic inspections, costs of replacing degraded materials and elements and costs of periodic works and repairs. The law specifies the building owner as a responsible party for building maintenance. The Law on Physical Planning and Construction in Croatia defines the building owner as one responsible for:

- building maintenance in a way of preserving essential requirements of building during its life time period,
- promoting the fulfillment of essential building requirements,
- building maintenance without violating building properties [2].

Traditionally, operating and maintenance costs of construction were not taken into account. However, the relationship of capital and maintenance costs can take the ratio of, for example, up to 1:5 [3] and therefore it is extremely important to design new facilities in a way to reduce the overall life cycle cost without reduction of the quality of construction. On the contrary, installation of quality elements should provide better functionality and lower building maintenance costs during its life time period [4].

2 Service life of a facility
Uporabni vijek građevine

Service life of a facility is defined as the period during which the behavior and properties of structures remain preserved at the level which fulfills essential requirements (mechanical resistance and stability, safety in case of fire, hygiene, health and the environment, safety in the use, protection against noise, energy saving and heat preservation) [2].

Service life planning is part of the design which ensures that service life of the facility is equal to or greater than the designed service life, where facility life cycle costs are taken into account, and if it is possible, cost optimization is also performed. Planning of service life reduces the facility owner's costs and allows lifetime assessment of certain parts of facility which helps defining the appropriate specification and construction details. Once service life time of facility and its parts is determined it is possible to plan maintenance cost and to assess facility value.

The service life of a product will end at the moment the product reaches its end of life, which can happen in many ways. Some authors mention up to six different ways of obsolescence for consumer products (e.g. technical, economical, ecological, esthetical, functional and psychological) [5]. ISO standards define three different ends of life: technical, economical and functional.

Fig. 1 shows different facilities' service lives depending on the criteria of defining the service life. The technical service life is over when the component can no longer fulfill the performance it is designed for. Economical service life ends when another component can fulfill the same or better function but with lower costs. Functional service life ends

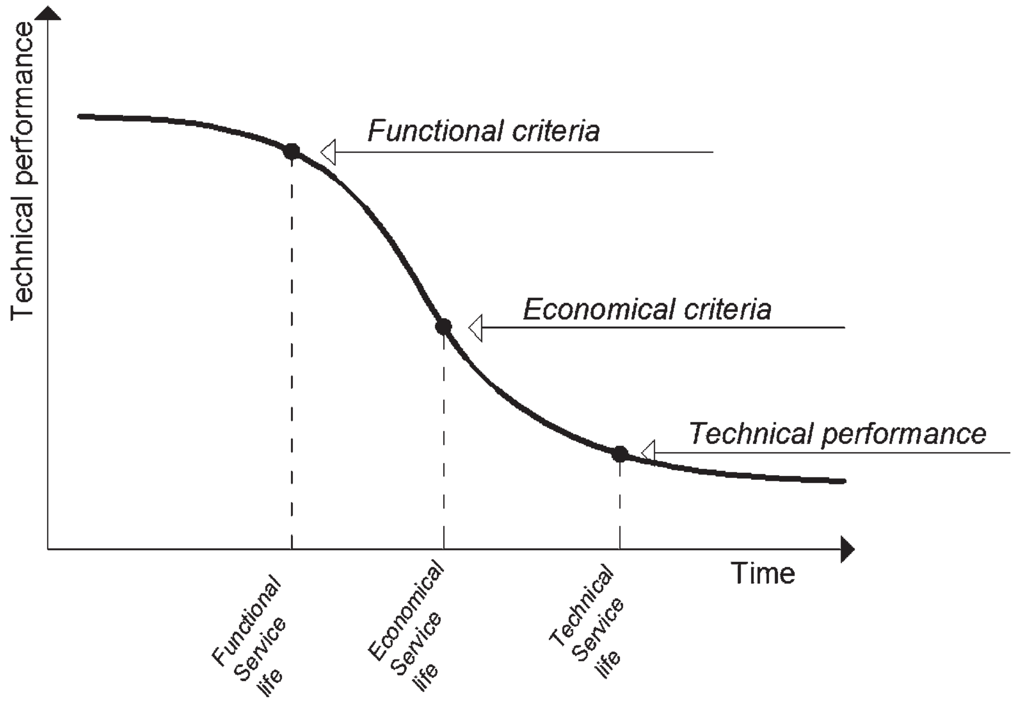

Figure 1 *Different types of a building service life* [5]
Slika 1. *Različite vrste životnog vijeka građevine* [5]

when the component does not fulfill the user demands or this function is not needed any more. These three ways of ending service life define the period of analysis for life cycle cost [5].

3 Facilities life cycle cost analysis
Elementi proračuna troškova životnog ciklusa građevina

There are two ways of calculating the life cycle costs. The first one is based on historical data of costs (e.g. per square meter for facilities of similar type), which gives very questionable results due to a number of factors (e.g., utilization, level of maintenance, operating scenarios etc.) and the second one is based on making a detailed model which predicts costs depending on predicting the durability, and thus the repairs, maintenance and reconstruction of structure or its part together with energy costs. The second method allows the cost optimization of the construction and the usage of sensitivity analysis to determine which elements of the analysis are most sensitive to changes.

Key elements of the construction life cycle cost analysis are:

- estimated service life of facilities and their elements,
- the period of life cycle cost analysis,
- discount rate and costs.

ISO standards (ISO 15686-2:2001) differ the following periods of life cycle cost analysis:

- foreseeable usage period of a good (life cycle),
- the period specified by contractual obligations,
- standard period of investment that is applied within an organization,
- period longer than 100 years, where the period of 100 years is applied because it is considered that the results are not significantly altered for longer period.

There are several cost categories that should be taken into account when budgeting life cycle costs. Those costs are costs of acquisition, maintenance, operation, management, disposal and demolition, and eventual residual value of the facility at the end of life. Since the life-cycle costs are discounted to present value the selection of appropriate discount rate is extremely important. Higher discount rates will tend to favor alternatives with lower capital costs, shorter service life and high maintenance costs and lower discount rates have reversed effect [20].

Public facilities have certain peculiarities when comparing to public ones and those peculiarities are:

- low or zero discount rate reflects the unique nature of public facilities which are often seen as social, rather than capital projects,
- long life cycle,
- low or zero income during life cycle.

The subject of the research presented in this paper is to determine the influence of the analysis period and discount rates when budgeting life cycle costs of public facilities. Life cycle costs case study analysis of the public facility was made for two different analysis periods, one of 30 and another of 50 years. Life cycle costs of the facility are calculated for both analysis periods and five different discount rates (e.g. 3,50 %, 5 %, 6,50 %, 8,0 % i 9,0 %) in order to determine their impact on life cycle costs. Net present value method will be used in order to determine the facilities' life cycle cost.

4 Case study analysis of the facility's life cycle costs
Studija slučaja ukupnih životnih troškova građevine

Life cycle cost analysis is made for public facility which is used for educational and scientific purposes with net area of 2374,67 m^2. Operation and maintenance costs are taken into account for analysis periods of 30 and 50 years. The facility has a closed quadratic ground plan with the entrance on the south side. The facility has basement, ground floor, one storey and attic. The storey height is approximately 3,80 m. Horizontal communication takes place in wide well lit corridors connected by vertical, massive concrete double staircase. Classrooms, library, reading room and toilet facilities are located on the ground floor. Bearing and partition walls are made 38 cm and 12 cm thick. Floor construction is 15 cm thick slab made of reinforced concrete. The roof is made of wood, mostly with one eave and in one corner of the building two eaves are covered with galvanized eaves flashing. Staircase is massive made of reinforced concrete, covered with terrazzo. Ceilings and walls in the attic are made of gypsum cardboard plates [9]. The facility regions and their corresponding surfaces are shown in Tab. 1.

***Table 1** Facility regions and their corresponding surfaces*
***Tablica 1.** Sadržaji građevine s pripadajućim površinama*

N°	Facility regions	Surfaces, m^2
1.	Classrooms	383,5
2.	Informatical classrooms	131,23
3.	Hallways	466,74
4.	Sanitary facilities	72,33
5.	Thermal station	35,56
6.	Repository	68,4
7.	Cabinets	223,2
8.	Atrium	250,14
9.	Offices	233,62
10.	Laboratory	219,08
11.	Canteen	57,65
12.	Library and reading room	93,85
13.	Archive room	54,35
14.	Apartments	63,38
	Total	**2.374,67**

Facility life-cycle costs consist of the following costs groups:

- acquisition cost (Tender and bidding),
- capital facility cost,
- maintenance and operation cost and
- demolition and disposal cost.

The facility life cycle cost structure is taken from the ISO standard 15686-5:2008 and it is shown in Fig. 2. For this research purpose the tendering and bidding costs are neglected since they are identical regardless of the facility service life and discount rate applied and therefore irrelevant in the sensitivity analysis.

Facility capital costs are analyzed based on the construction cost and facility usable area.

Operation and maintenance costs include costs of statutory periodic inspections, costs of replacing degraded materials and elements, costs of periodic works and repairs, costs of reactive maintenance and usage costs. Statutory periodic inspections are various activities that are regulated by relevant laws and regulations in order to take measures necessary for safety, health and life of people. Tab. 2 shows some Statutory required inspections on the facility.

***Table 2** Statutory periodic inspections activities*
***Tablica 2.** Aktivnosti zakonom propisanih periodičnih pregleda*

N°	ACTIVITIES
1.	Inspection of thermal station
2.	Inspection of lighting installation
3.	Inspection and maintenance of fire pumps
4.	Inspection of panic lighting
5.	Inspection and testing of protection against electric shock
6.	Inspection of fire alarm
7.	Inspection of internal hydrant network
8.	Inspection of external hydrant network
9.	Inspection of fire extinguishers
10.	Inspection of fire detection systems
11.	Inspection of air conditioning systems

Facility inspection defines maintenance works and requires knowledge of the causes of failures and proposals of measures that should suit the circumstances, order and frequency of certain maintaining activities. When making facility maintenance plan for replacing degraded materials and elements the information provided in the Engineering Yearbook 2003/2004 [4] is used (Facility service life planning, page 241. -247. Zagreb, 2004). Tab. 3 shows some of the Life Cycle replacement activities.

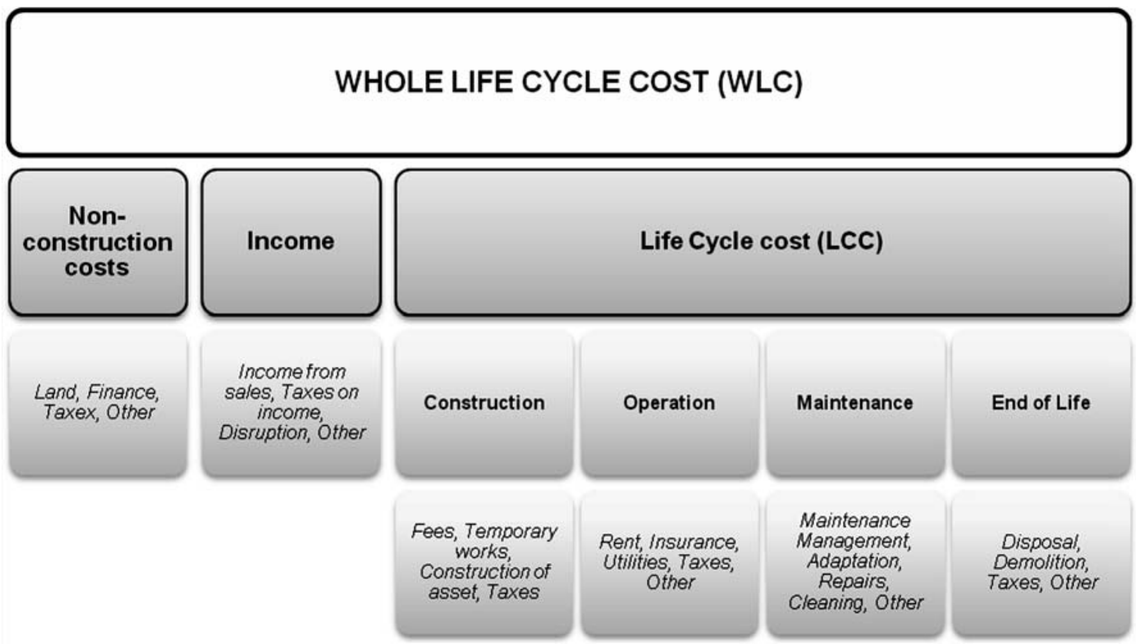

***Figure 2** Facility life cycle cost structure* [21]
***Slika 2.** Struktura ukupnih troškova građevine* [21]

Table 3 *Life cycle replacement activities*
Tablica 3. *Aktivnosti na zamjeni istrošenih materijala i elemenata građevine*

N°	ACTIVITIES
1.	Replacment of metal sheet covering
2.	Replacement of external wooden windows
3.	Replacement of external wooden doors
4.	Replacement of vertical and horizontal rain drainage
5.	Replacement of snow fence
6.	Replacement of electrical installations
7.	Replacement of telephone installations
8.	Replacement of water supply and sewage installation
9.	Replacement of heating equipment
10.	Replacement of plastic shutters
11.	Replacement of plastic external covering

Periodic works and repairs are planned activities that are repeated in approximately same time intervals depending on service life of facility or construction element. Tab. 4 shows some of the planned preventive activities.

Table 4 *Periodic works and repairs activities*
Tablica 4. *Aktivnosti periodičnih radova i popravaka*

N°	ACTIVITIES
1.	Painting of walls and ceilings
2.	Varnishing parquet
3.	Grinding staircases, corridors and platforms
4.	Painting of radiators
5.	Painting of eaves
6.	Painting of walls with oil paint
7.	Painting of metal constructions
8.	Painting of external
9.	Impregnation of the facade
10.	Painting of facade
11.	Painting of plinth
12.	Painting of fire stairs and protective grids
13.	Painting of internal joinery
14.	Mortars repairs and cementitious topping
15.	Costs of staging

Reactive maintenance activities are hardest to predict, but there are techniques, such as Integrated Logistic Support (ILS) technique, which are based on reliability analysis, sustainability and logistics support. In this case study analysis some of the reactive maintenance activities are analyzed and shown in Tab. 5.

Table 5 *Reactive maintenance activities*
Tablica 5. *Planirane aktivnosti reaktivnog održavanja*

N°	ACTIVITIES
1.	Glazing shattered glass surfaces
2.	Repairs of fire detection repairs
3.	Replacement of lighting fixtures - light bulbs and lamps
4.	Repairs of windows and doors
5.	Repair or replacement of chains, locks, door handles

Operational facility costs are very significant in life cycle costs. Operational costs are the costs of all utilities, such as electricity, heating, water supply, waste disposal, IT services and cleaning costs of facility and its environment (e.g. cleaning materials, maids, janitor, etc.). Some of the operational costs are shown in Tab. 6.

In cases where the land price exceeds the current value of the facility it is economically justified to remove old facility and convert the land mostly for the construction of new facilities, whose value typically exceeds the value of removed facility by several times [10]. Predicted building

Table 6 *Operational activities*
Tablica 6. *Troškovi uporabe građevina*

N°	ACTIVITIES
1.	Water supply
2.	Electricity
3.	Heat supply
4.	IT services
5.	Waste disposal

costs of new facility are calculated based on the data of budgeted facility construction cost of similar facilities in the Osijek area. The costs of building such a facility are about 5015,91 kn/m^2 (687,11 €/m^2) [11]. From the above data and the facility area of 2 374,67 m^2 it is possible to calculate the construction costs of the facility which are approximately 11 911 131,00 kn (1 631 661,78 €).

5 Maintenance costs of the facility
Troškovi održavanja građevine

Net present value (*NPV*) of the facility life cycle cost is calculated for two analysis periods of 30 and 50 years where five different discount rates were applied (3,50 %, 5 %, 6,50 %, 8,0 % and 9,0 %) in order to determine their impact on life cycle cost. Net present value of the facility life cycle cost is calculated according to expression [12]:

$$NPV = \sum_{i=1}^{n} \frac{FMC_i}{(1+r)^i} ,$$

where:
FMC_i – facility management cost at time i
r – discount rate
n – number of years.

Discount rate represents the time value of money. It is a technique used for comparing costs and revenues occurring at different points of time on a common basis, normally the present time. Discounting the costs to net present value, the discount rate has a key role. A high discount rate will tend to favor options with low capital cost, short life and high recurring cost, whilst a low discount rate will have the opposite effect [13]. The discount rate may reflect the effect of only the real earning power of the money invested over time or it may also reflect the effects of inflation.

The most popular methodologies when choosing proper discount rate appear to be [13]:

- at the current or expected rate the organization must pay for the use of its borrowed funds,
- at the rate of return that could be expected from the loaning of money, but which is denied to the organization by the need to fund its own projects (sometimes referred to as the opportunity cost),
- at the lowest rate of industrial borrowing for a financially sound, well-established company and
- investments in long-term treasury bonds can be assumed to have no risk.

Tab. 7 shows net present value of facility life cycle cost for time period of 30 years and five different discount rates (3,50 %, 5 %, 6,50 %, 8,0 % and 9,0 %). It shows net present value of the following facility costs, net present value of capital costs, net present value of operation and

Table 7 *Net present value of facility life cycle cost for time period of 30 years; Costs are expressed in Euros*
Tablica 7. *Neto sadašnja vrijednost troškova održavanja građevine za vremensko razdoblje od 30 godine; Troškovi izraženi u eurima*

TYPE OF COSTS		*NPV* (*r*=3,50 %)	*NPV* (*r*=5,00 %)	*NPV* (*r*=6,50 %)	*NPV* (*r*=8,00 %)	*NPV* (*r*=9,50 %)
Net present value of capital costs (1)		1 620 562,0	1 620 562,0	1 620 562,0	1 620 562,0	1 620 562,0
NPV of operation and maintenance costs	Statutory periodic inspections	50 747,7	42 416,2	36 032,1	31 063,2	27 136,7
	Life Cycle replacement	48 547,5	36 535,4	27 919,1	21 643,7	17 005,2
	Periodic works and repairs	73 484,6	58 466,1	47 338,9	38 951,7	32 523,1
	Reactive maintenance	41 814,3	34 949,3	29 688,9	25 594,6	22 359,2
	Operational costs	1 194 030,8	997 995,6	847 782,9	730 867,1	638 480,3
NPV of operation and maintenance costs (2)		1 408 624,9	1 170 362,5	988 761,9	848 120,2	737 504,5
NPV of disposal and demolition costs (3)		36 839,7	23 924,7	15 632,8	10 275,8	6 793,6
TOTAL NPV OF FACILITY LIFE CYCLE COSTS (1)+(2)+(3):		**3 066 026,7**	**2 814 849,3**	**2 624 956,8**	**2 478 958,0**	**2 364 860,2**

Table 8 *Net present value of facility life cycle costs for time period of 50 years; Costs are expressed in Euros*
Tablica 8. *Neto sadašnja vrijednost troškova održavanja građevine za vremensko razdoblje od 50 godina; Troškovi izraženi u kunama*

TYPE OF COSTS		*NPV* (*r*=3,50 %)	*NPV* (*r*=5,00 %)	*NPV* (*r*=6,50 %)	*NPV* (*r*=8,00 %)	*NPV* (*r*=9,50 %)
Net present value of capital costs (1)		1 620 562,0	1 620 562,0	1 620 562,0	1 620 562,0	1 620 562,0
NPV of operation and maintenance costs	Statutory periodic inspections	64 719,2	50 372,4	40 628,6	33 755,4	28 734,3
	Life Cycle replacement	101 908,4	64 815,7	43 095,4	29 886,2	21 533,8
	Periodic works and repairs	94 628,1	70 114,0	53 844,2	42 632,6	34 632,0
	Reactive maintenance	53 326,3	41 504,8	33 476,2	27 812,8	23 675,6
	Operational costs	1 522 763,3	1 185 193,8	955 931,3	794 210,6	676 068,8
NPV of operation and maintenance costs (2)		1 837 345,3	1 412 000,6	1 126 975,6	928 297,7	784 644,4
NPV of disposal and demolition costs (3)		18 514,4	9 017,0	4 436,6	2 204,6	1 106,2
TOTAL NPV OF FACILITY LIFE CYCLE COSTS (1)+(2)+(3):		**3 476 421,8**	**3 041 579,7**	**2 751 974,2**	**2 551 064,4**	**2 406 312,6**

maintenance costs and net present value of disposal and demolition costs where net present value of operation and maintenance costs is given as a sum of:

- net present value of statutory periodic inspections cost,
- net present value of replacement costs,
- net present value of periodic works and repairs costs,
- net present value of reactive maintenance cost,
- net present value of operational costs.

Analogous to the above the facility life cycle costs for time period of 50 years are calculated and they are shown in Tab. 8.

6 Sensitivity analysis
Analiza osjetljivosti

Sensitivity analysis is the calculating procedure used for prediction of effect of changes of the key input data on output results. In this procedure input parameters are altered one by one from initial values(s) in order to determine their impact on the analysis outcome(s) [16]. This, if necessary, prevents unwanted alterations of outcome variables. This procedure is often used in investment decision making related with the investment project evaluation under conditions of uncertainty.

In order to determine impact of discount rate on facility life cycle costs discount rate is varied in five steps from 3,50 % to 9,5 % with step of 1,50 %. For this case analysis purposes it is assumed that the facility life cycle costs occur as scheduled, without limitation.

Fig. 3 shows the development of facility life cycle cost net present value depending on the analysis period and the discount rate applied when calculating the net present value costs. The figure shows that increasing the discount rate reduces the differences of facility life cycle costs net present values for two selected analysis periods of 30 and 50 years. At discount rate of 9,50 % there is almost no difference in the facility life cycle cost net present value for those two observed time periods.

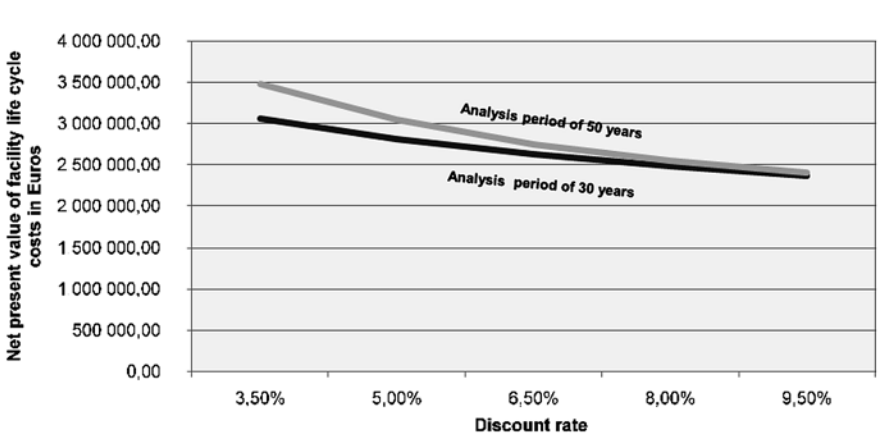

Figure 3 *Net present value of facility life cycle cost*
Slika 3. *Neto sadašnja vrijednost troškova održavanja građevine*

Table 9 *Discount rates alterations and the corresponding changes of life cycle costs net present value*
Tablica 9. *Prikaz promjene diskontne stope i pripadajuće promjene NSV troškova održavanja*

	Percentage of alteration								
DISCOUNT RATE	*r*=3,50 %	30,00 %	*r*=5,00 %	23,08 %	*r*=6,50 %	18,75 %	*r*=8,00 %	15,79 %	*r*=9,50 %
NPV VALUE OF FACILITY LIFE CYCLE COST FOR TIME PERIOD OF 30 YEARS, €	3 066 027	8,19 %	2 814 849	6,75 %	2 624 957	5,56 %	2 478 958	4,60 %	2 364 860
	Percentage of alteration								
DISCOUNT RATE	*r*=3,50 %	30,00 %	*r*=5,00 %	23,08 %	*r*=6,50 %	18,75 %	*r*=8,00 %	15,79 %	*r*=9,50 %
NPV VALUE OF FACILITY LIFE CYCLE COST FOR TIME PERIOD OF 50 YEARS, €	3 476 422	12,51 %	3 041 580	9,52 %	2 751 974	7,30 %	2 551 064	5,67 %	2 406 313

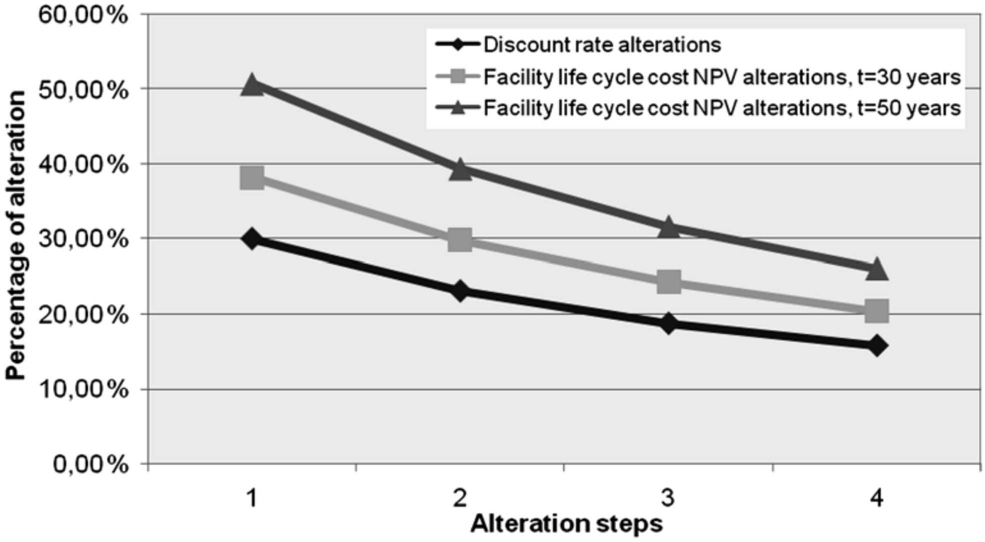

Figure 4 *NPV sensitivity analysis and facility life cycle costs*
Slika 4. *Grafički prikaz analize osjetljivosti NSV ukupnih troškova održavanja građevine*

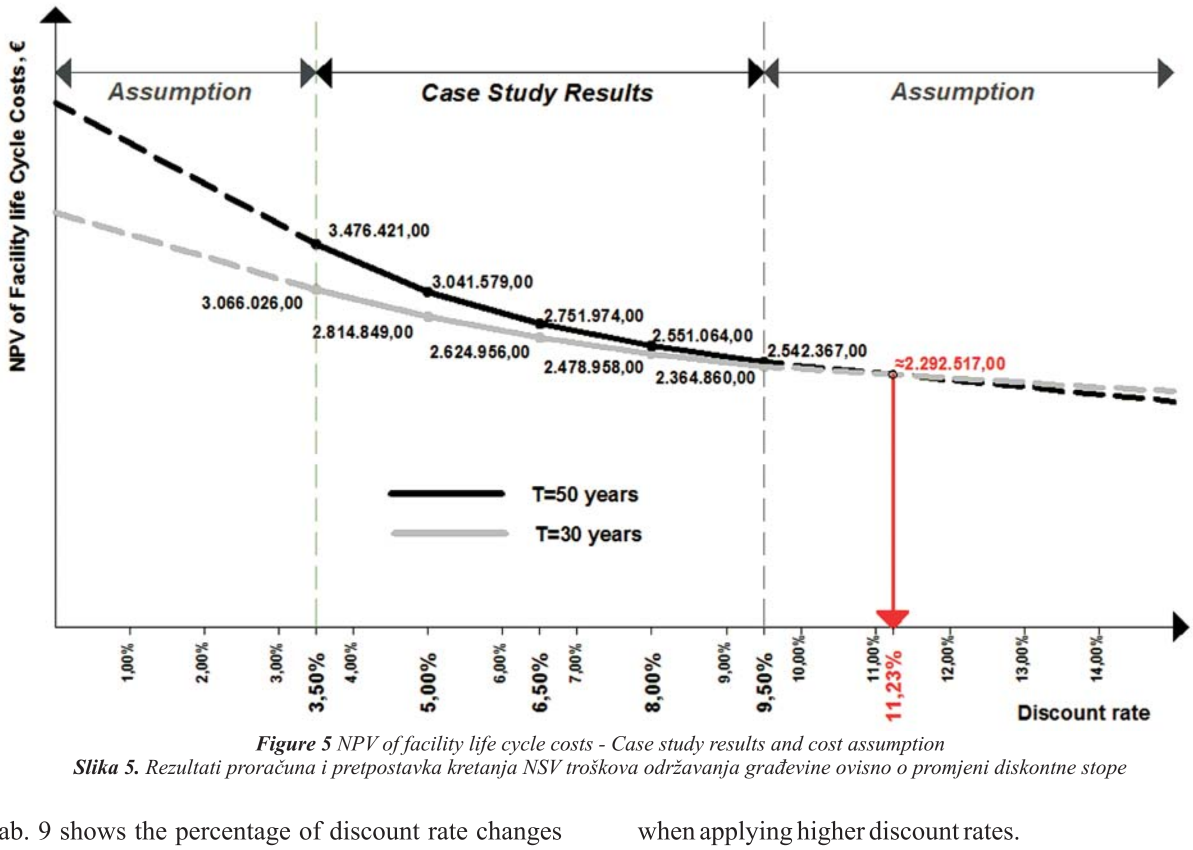

Figure 5 *NPV of facility life cycle costs - Case study results and cost assumption*
Slika 5. *Rezultati proračuna i pretpostavka kretanja NSV troškova održavanja građevine ovisno o promjeni diskontne stope*

Tab. 9 shows the percentage of discount rate changes and facility life cycle cost net present value changes depending on discount rate value and analysis period applied. As expected, lower percentage of discount rate alteration causes smaller alterations of net present value costs (Fig. 4). When observing the impact of discount rate and the analysis periods alterations it is observed that the same alteration of discount rate has a greater impact on longer time period life cycle cost and decreasing of impact when applying higher discount rates.

NPV of facility life cycle cost for applied discount rates from 3,50 % to 9,50 % are shown in Fig. 5. According to the assumed development of facility life cycle costs they would be the same for both analysis periods at discount rate of 11,23 %. By further increase of discount rate facility life cycle costs for analysis period of 30 years would become greater than facility life cycle costs for analysis period of 50 years.

7 Conclusion
Zaključak

In this paper, the facilities life cycle cost case study analysis was made where the facility maintenance and operation costs were analyzed for two different time periods, 30 and 50 years. The facility life cycle costs were discounted to the net present value using five different discount rates (3,50 %, 5,0 %, 6,50 %, 8,0 % and 9,50 %).

The purpose of this case study was to determine the influence of changing discount rates on net present value of life cycle costs and dependence of these costs on two different time periods.

Previous research has found that the high discount rate will tend to favor options with low capital cost, short life and high recurring cost, whilst a low discount rate will have the opposite effect.

In this case study it was found that the same rate of discount rate changes has much greater influence on the change of the facility life cycle costs. However, further increasing of discount rate reduces this influence and the difference between net present values of facility life cycle cost for those two time periods decreases. Further discount rate increasing would lead to the assumption that facility life cycle costs are bigger for time period of 30 years. At discount rate of 11,23 % net present value of facility life cycle costs for both time periods is approximately the same. From all the above it can be concluded that the choice of higher discount rates favor projects with higher life cycle costs or projects with longer service life.

Further, the selection of longer service life and higher discount rates makes it possible to get results that could easily lead to wrong conclusions unless a detailed analysis of all significant factors affecting facility life cycle costs is performed.

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