Renovation of Built-up Areas: Life Cycle Assessment

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Abstract. This article considers the application of the LCC methods as the best assessment criterion for reconstruction prospects and the justification of the further city-planning strategy in terms of the development of built-up areas. The authors carried out the LCC-assessment of two reconstruction options. 1) the reconstruction of residential buildings erected in the 1970-80-es involving major repairs to prolong their life cycle; 2) the demolition of all buildings and constructing new ones instead. This article presents the inspection results for series 1-464 VM large-panel residential buildings that formed the basis for the calculation of major repairs necessary to prolong their life cycle. These buildings, however, do not comply with the current regulations. The authors conclude that LLC methods can help illustrate the consumer benefits from owning more expensive but power-efficient housing that reduces the heating costs, which is very important in the northern regions.

1. Introduction
The housing stock of Yakutsk includes 269 series 1-464 VM large-panel residential buildings erected in the 1970es. The inspection of these buildings showed that the technical condition of almost all of them is unsatisfactory: there are signs of erosion and defects in stilts, joists, and floor panels, and the wall panels have lost their thermal insulation properties. Today, this “old” stock houses over 50,000 citizens and it requires a radical renovation. Although the Urban Development Code of Russia [1] does not define “renovation”, the main problem, in this case, is whether these houses should be demolished or reconstructed, which option is more economically and socially feasible?

This work aims to justify the type of build-up area renovation using the life-cycle cost methodology for aggregate costs. This methodology is the basic one in the analysis of sustainable development of the structure [2,3] that takes into consideration all actions from the decision to build a structure to its operation and dismantling.

2. Research materials and methods
The subject-matter of this research is Block 136 of Yakutsk where about 7000 people live in 17 series 1-464A large-panel buildings commissioned between 1971 and 1978.

The land area of the block is 30.5 ha, and 56% of it is residential. Public and administrative areas amount to 39%, and utility and warehouse areas to 5%. Series 1-464 residential houses are based on a cross-wall structure. The outer walls are made of 1- and 3-layer concrete panels 21-35 cm thick, depending on the climate zone (Figure 1).
During the inspection, the authors discovered a high physical wear of the houses due to the following defects: the erosion of the concrete cover of the basement panel, reinforcement exposure and corrosion, panel deflection exceeding the maximum permissible value (Figure 2, a); concrete salt-
out and destruction, main reinforcement exposure and corrosion in corbels and stilts (Figure 2, b); foundation girder concrete destruction due to leaks (Figure 2, c); vertical cracks in the span of the foundation girder (Figure 2, d). The authors also found that the outer walls have low thermal insulation, and the interpanel joints have problems with air permeability and thermal insulations (Figure 3).

Figure 3. Thermal images of series 1-464 VM large-panel houses (Slobodchikov E).

Of 17 buildings of this series inspected, the technical condition of 14 is classified as marginally operational and 3 as operational. The physical wear of these buildings calculated according to VSN 53-86(r) Physical Wear Assessment Guidelines for Residential Buildings [4] is 25% or more, and in some of the structures, elements, systems or their components, it reaches 60%. The destruction and deformation of mechanical floor frames, as well as foundation framework and joist cracks can be found in all of the inspected buildings. If the supporting structures of these houses are not reinforced, they can become dangerous. The first dangerous deformation of a series 1-464 building in Yakutsk took place in 2006, and it was an abnormal yielding of a house.

To justify the selection of the best renovation solution for the block, we compared two options based on their associated costs using the full life cycle principles:

1. The calculation of the aggregate value for series 1-464 VM residential buildings in the block after reconstruction (major repairs) of each of them.
2. The calculation of block renovation stipulating the complete demolition of all series 1-464 VM residential buildings and the construction of new 9-storey site-cast buildings.
Table 1. LCC comparison for two reconstruction options.

| Expenses | Option 1 | Option 2 |
|----------|----------|----------|
| Large-panel building, series 464-VM | Aggregate value for 17 site-cast buildings |
| one-time costs: | | |
| renovation costs | in thousands of rubles | 296,203.5 | 5,035,459.5 | 1,271,804 | 5,326,359 |
| construction site preparation, including the demolition of 464-VM large-panel buildings | in thousands of rubles | 296,203.5 | 5,035,459.5 | 1,218,661 | 4,874,646 |
| recurring costs: | | |
| utilities | in thousands of rubles | 610,314 | 10,375,338 | 437,970 | 1,751,880 |
| upkeep | in thousands of rubles | 5,584.6 | 94,938.2 | 10,976.8 | 43,907.2 |
| ongoing repairs | in thousands of rubles | 859.2 | 14,606.4 | 5,082.8 | 20,331.2 |
| major repairs | in thousands of rubles | 801.6 | 13,627.2 | 1,369.9 | 5,479.6 |
| LCC for 20 years | in thousands of rubles | 116276.4056 | 1976698.895 | 413523.4 | 1715893 |
| Overall building area | in square km | 3,467.2 | 58,942.4 | 15,767.9 | 63,071.6 |
| Average aggregate costs over the life cycle of a residential building, in rubles/sq.m/year | in thousands of rubles | 1.7 | 1.7 | 1.3 | 1.4 |

The reconstruction of old residential development can be implemented using various massing solutions [5,6]. After the major repair, however, the building must comply with all technical regulations [7,8]. It is virtually impossible to make series 1-464 VM large-panel buildings compliant to fire safety requirements because of the lack of natural lighting and ventilation in the staircase, and the requirements of safe living because of insufficient ceiling height (2.5 instead of 2.7), noise insulation, and the absence of elevators. To assess the life cycle of a large-panel building, we selected
one residential house with a medium physical wear parameter of 32%. Repair and renovation works will prolong its operational life cycle for another 20 years [9]. The calculation of renovation costs was carried out using the base-and-index method [10] as described in the current guidelines for estimate standards and prices.

The Life Cycle Cost is calculated as an aggregate of all ownership costs for a residential building, including the one-time expenses on construction and assembly works, and temporary and recurring costs for the operation, maintenance, repair and decommissioning [11,12]. The LCC method is based on the selection of the most economically feasible option of the available, i.e. the one with the smallest aggregate cost [13,14]. As an alternative reference object, the authors selected a power-efficient 9-storey site-cast residential building erected in Yakutsk in 2016. The LCC calculations take into consideration the demolition of 464-VM large-panel residential buildings.

3. Discussion
The authors performed the LCC assessment of both renovation options and carried out a comparative analysis. Table 2 shows the comparison of the current values for each life-cycle phase and their variations.

The results of the comparison show that the aggregate cost of the first block renovation option is higher than that of the second one by just 15.7% but the recurring costs are significantly higher, by almost 50% (Figure 4). High costs in the operation period are associated with the high heating consumption of 464-VM large-panel buildings.

![Figure 4. LCC comparison for the 2 renovation options in the built-up area (in rubles).](image)

The calculation of life cycle costs can become an efficient justification method for the comprehensive reconstruction of built-up territories. Despite the simplicity of LLC calculation, it is impossible to determine the exact value of the existing buildings at the initial stage because their market and renovation prices are very different. At this stage, it is necessary to perform a technical inspection of all buildings, determine the actual wear level for each of the buildings, and calculate the possibility of life cycle prolongation without major repairs, taking into consideration the operational conditions. Besides, the heating and water supply systems located in the basements of these buildings cause significant operational problems due to constant leaks and pipe breaks. This leads to the flooding of building base ground, dampening and freezing of stilts and basement panels, which leads
to the rapid erosion of the foundation support structure and, consequently, the reduction of buildings’ life cycle. Today, the owners are responsible for the operational life and the performance characteristics of housing. Owners, in their turn, cannot solve such problems alone. Therefore, regional renovation programs with real cost calculations and life cycle forecasts are necessary for entire residential blocks. The analysis performed shows that the life cycle cost method can be used in practice to justify block renovation.

4. Conclusion
The experience of built-up area renovation program implementation shows that it is a problem of economic and administrative regulation in most countries. Using the LCC method to assess the comprehensive renovation of an area, it is possible to set the engineering and economic parameters of the renovation project and provide valid and open information about all expenses, including the future operational costs, justify investment efficiency, and facilitate the introduction of power-saving solutions. This method also facilitates the selection of the best reconstruction option based on the mitigation of aggregate costs at all stages of the project’s life cycle.

5. References
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