Reconstruction of the gray belt objects based on energy efficiency clusters

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Abstract. Objects redevelopment methods of the "gray belt" - industrial areas surrounding the historical district of St. Petersburg, Russia - have been considered. Information about 45 objects located in different administrative districts of the city was collected. Factors of physical wear (wear of floors, walls, roofs, types of building structural system) have been chosen as a criteria for clustering. As a result of the study, SOMs with different learning parameters were created as a result of the study. Energy efficiency calculations for two clusters were made with the selection of modern materials. Recommendations for the reconstruction according to the parameters of physical wear are given.

1 Introduction

The issue of the development of old industrial zones is relevant today. The reorganization of industrial buildings and their territories can create new places of attraction for visitors and citizens. This will help to stimulate the economics, disperse the tourist centre and reduce the traffic load [1-5]. Also the reorganization of this area will expand the network of polycentres with a developed horizontal infrastructure. This will contribute to improving the quality of life thanks to a reasonable and comfortable arrangement of the territory, creating an attractive, balanced environment for work, living and recreation of the citizens [6-11].

The industrial zone of St. Petersburg, Russia or the "gray belt", is the largest reserve for urban development near the historic centre of the city. The area of industrial buildings in St. Petersburg is about 50 million m^2. According to various estimates, this zone occupies about 40% of the total area of the city.

Industrial territories are located in 12 administrative districts of St. Petersburg. The gray belt is outlined by the coast of the Neva Bay, it includes a port complex in the southern part of Kanonersky Island. It includes industrial and public business buildings in Kirovsky, Moskovsky, Frunzensky and Nevsky districts, within the territory outlined by the Obvodny Canal and Leninsky Prospekt, Tipanova Street and Slavy Prospekt. Also there are industrial buildings remained on the right bank of the Neva from Narodnaya Street to Energetikov

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Prospekt in the southern part of Krasnogvardeisky district. At the moment, most of the objects of the «Gray belt» are in need of reconstruction.

Achieving the level of quality and comfort of buildings, the standards of thermal protection during the reconstruction is much more difficult than with new construction. For example, it is difficult to significantly change the planning decisions, the material of the building envelope, etc.

From the point of view of architectural and construction solutions, the main indicator of energy efficiency of a building is resistance to heat transfer of building envelope. This parameter determines the temperature of the surfaces of the building envelope, affecting the feeling of comfort.

The method of calculating this indicator has changed significantly since the 1970s. In 2003, amendments appeared in the thermotechnical standard, which consider the climatic features of various regions of the country.

The purpose of this work is to create clusters according to the characteristics of physical wear and type of construction, to provide each cluster with calculation of energy efficiency during the reconstruction [12 - 14].

Tasks:

- to identify gray belt objects;
- to determine the types of structures for each object;
- to determine the wear of structures for each object;
- to group the gray belt objects into clusters;
- to carry out the calculation of energy efficiency during the reconstruction of each cluster.

2 Materials and Methods

To determine the effective strategy of redevelopment of gray belt objects, it is necessary to develop an approach for classifying objects included in these zones. In this article, it is proposed to use self-organizing maps for clustering objects.

A self-organizing map (SOM) or self-organizing feature map (SOFM) – is a type of artificial neural network (ANN), that is trained using uncontrollable learning to produce a low-dimensional (typically two-dimensional) discretized representation of the input space of the training samples, called a map, and therefore it is a method of reducing the dimension. They were developed in 1982 by Tuevo Kohonen, an honorable professor of the Academy of Finland [15]. Self-organizing map (SOM) – is an efficient tool for neural network modelling for visualization and generalization of multidimensional data. It is suitable for solving complex problems like process analysis, machine perception, control and information transfer [16].

The Self-Organizing Map algorithm can be divided into 6 steps [15]:

1. The weights of each node are determined.
2. The input vector is randomly selected from the training data set and presented to the network.
3. Each node of the network tests for matching to the input vector. Winning node becomes «Best Matching Unit» (BMU).
4. The range of the BMU is calculated. This value starts with the highest one. It is usually set as the network radius, decreasing with each iteration.
5. All nodes found in the radius of the «Best Matching Unit» neuron, calculated in the item 4, are configured so that they are more similar to the input vector. His weights change more if it's closer to the BMU.
6. Repeat item 2 for N iterations.

45 buildings of the gray belt located in different parts of the city were selected as objects of research [17]. 4-5 objects were selected from each district for further research. The distribution of the researched objects by districts is shown in Figure 1.

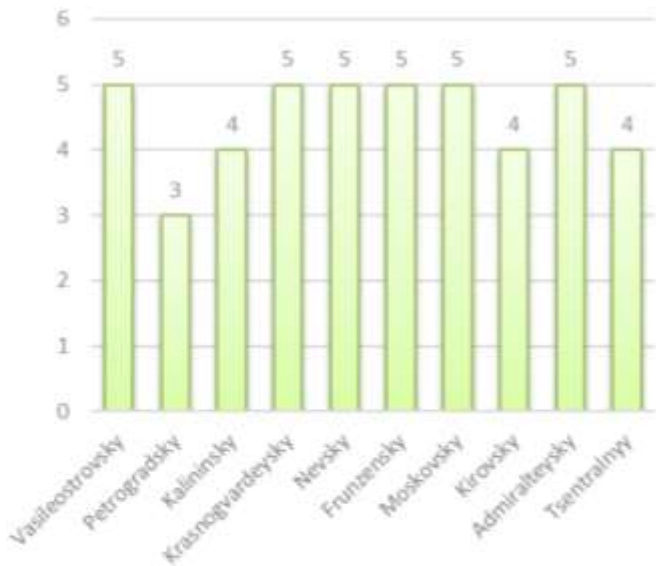

Fig. 1. Number of research objects by districts

The following information was collected for each object:

1. Physical wear characteristics (roof wear, floor wear, wall wear).
2. Type of construction (roof materials, floor materials and wall materials).

These characteristics are shown in Table 1.

Table 1. Types of constructions and physical wear

№	Symbol	District	Roof	Wear of roof, %	Floors	Wear of floors, %	Walls	Wear of walls, %
1	V-1	Vasileostrovsky	Bitumen felt with sealant compound	75	Reinforced concrete shell	60	Brick wall	55
2	V-2	Vasileostrovsky	Roofing steel on timber rafters	50	Timber floor, brick arches	50	Brick wall	40
3	V-3	Vasileostrovsky	Roofing steel on timber rafters	60	Precast reinforced concrete floor slabs on steel beams	70	Brick wall with timber partitions	60
4	V-4	Vasileostrovsky	Bitumen felt with sealant compound	15	Precast reinforced concrete floor slabs on steel truss	15	Brick wall	10
5	V-5	Vasileostrovsky	Bitumen felt with sealant compound on	15	Precast reinforced concrete floor	15	Brick wall	10

№	Symbol	District	Roof	Wear of roof, %	Floors	Wear of floors, %	Walls	Wear of walls, %
			reinforced concrete roof slab, metal roof		slabs			
6	P-1	Petrogradsky	Built-up roofing; bitumen felt with sealant compound, metal roof	50	Brick arches on steel beams; cast reinforced concrete slab	45	Brick wall; reinforced concrete and steel columns	45
7	P-2	Petrogradsky	Iron roof	30	Timber floor on timber beams	40	Plastered brick wall	30
8	P-3	Petrogradsky	Metal roof	10	Plastered timber floor on steel beams	35	Plastered brick wall	30
9	K-1	Kalininsky	Roofing steel on timber rafters	40	Steel beams with timber beams; cast reinforced concrete slab	40	Brick wall with ceramic wall tile and timber partitions	30
10	K-2	Kalininsky	Roofing steel on timber rafters	45	Timber floor	45	Plastered brick wall with timber partitions	35
11	K-3	Kalininsky	Roll roofing	50	Cast reinforced concrete slab and steel beams	50	Plastered brick wall; reinforced concrete and steel columns	50
12	K-4	Kalininsky	Steel sheet	25	Precast reinforced concrete floor slabs	30	Plastered brick wall, coated with paint	40
13	Kr-1	Krasnogvardeysky	Metal roof	15	Metal	15	Metal walls	15
14	Kr-2	Krasnogvardeysky	Iron roof on timber rafters	45	Precast reinforced concrete floor slabs	35	Brick wall	35
15	Kr-3	Krasnogvardeysky	Iron roof on timber rafters	40	Reinforced concrete beams with slag block	40	Brick wall	40
16	Kr-4	Krasnogvardeysky	Bitumen felt with sealant compound on reinforced concrete roof	35	Precast reinforced concrete floor slabs	20	Brick wall with reinforced concrete	20

№	Symbol	District	Roof	Wear of roof, %	Floors	Wear of floors, %	Walls	Wear of walls, %
			slab				columns	
17	Kr-5	Krasnogvardeysky	Bitumen felt with sealant compound on reinforced concrete roof slab	40	Precast reinforced concrete floor slabs	30	Brick wall with timber partitions	65
18	N-1	Nevsky	Roll roofing	30	Precast reinforced concrete floor slabs	15	Brick wall	15
19	N-2	Nevsky	Roll roofing	20	Precast reinforced concrete floor slabs	15	Brick wall with reinforced concrete panel	15
20	N-3	Nevsky	Bitumen felt with sealant compound on reinforced concrete roof slab; metal roof	40	Precast reinforced concrete floor slabs on steel truss	25	Brick wall with drywall partitions	25
21	N-4	Nevsky	Metal roof	25	Precast reinforced concrete floor slabs	15	Precast steel structures	15
22	N-5	Nevsky	Roll roofing	20	Precast reinforced concrete floor slabs	15	Claydite concrete blocks; brick wall	15
23	F-1	Frunzensky	Iron roof on timber rafters/on reinforced concrete roof slab	10	Precast reinforced concrete floor slabs	10	Plastered brick wall	10
24	F-2	Frunzensky	Roll roofing	40	Timber rafters; concrete arches on steel beams	40	Plastered brick wall	40
25	F-3	Frunzensky	Bitumen felt with sealant compound on reinforced concrete roof slab	15	Precast reinforced concrete floor slabs	15	Brick wall	15

№	Symbol	District	Roof	Wear of roof, %	Floors	Wear of floors, %	Walls	Wear of walls, %
26	F-4	Frunzensky	Bitumen felt with sealant compound on reinforced concrete roof slab	25	Precast reinforced concrete floor slabs	20	Brick wall with face brick; reinforced concrete columns	20
27	F-5	Frunzensky	Iron roof on timber rafters	40	Precast reinforced concrete floor slabs	35	Brick wall with timber partitions	45
28	M-1	Moskovsky	Roll roofing	35	Precast reinforced concrete floor slabs	25	Brick wall	50
29	M-2	Moskovsky	Galvanized steel sheet on timber rafters	35	Timber floor on steel beams	40	Brick wall with timber partitions	40
30	M-3	Moskovsky	Metal roof on timber rafters	30	Timber floor on timber beams	40	Brick wall	40
31	M-4	Moskovsky	Roll roofing	15	Precast reinforced concrete floor slabs	10	Brick wall, wall panel	15
32	M-5	Moskovsky	Steel on timber rafters	30	Steel beams with concrete beams	30	Brick wall with timber partitions	30
33	Kir-1	Kirovsky	Bitumen felt with sealant compound	35	Precast reinforced concrete floor slabs	25	Brick wall	25
34	Kir-2	Kirovsky	Bitumen felt with sealant compound on reinforced concrete roof slab	40	Precast reinforced concrete floor slabs	35	Brick wall	45
35	Kir-3	Kirovsky	Bitumen felt with sealant compound on reinforced concrete roof slab	30	Precast reinforced concrete floor slabs	20	Claydite concrete blocks; brick wall with ceramic wall tile	20
36	Kir-4	Kirovsky	Bitumen felt with sealant compound	25	Precast reinforced concrete floor slabs	30	Brick wall; reinforced concrete columns	25
37	A-1	Admiralteysky	Slate on timber rafters	40	Timber floor on timber beams	45	Plastered brick wall	45

№	Symbol	District	Roof	Wear of roof, %	Floors	Wear of floors, %	Walls	Wear of walls, %
38	A-2	Admiraltsky	Metal roof	40	Reinforced concrete floor	40	Brick wall	40
39	A-3	Admiraltsky	Roll roofing	45	Reinforced concrete floor	45	Brick wall	50
40	A-4	Admiraltsky	Iron roof	40	Reinforced concrete floor	40	Concrete wall with reinforced concrete frame	40
41	A-5	Admiraltsky	Iron roof on timber rafters	40	Steel beams with timber beams	30	Brick wall with timber partitions	30
42	T-1	Tsentralny	Metall roof on timber rafters	20	Timber floor, reinforced concrete floor	30	Brick wall	25
43	T-2	Tsentralny	Built-up roofing	30	Reinforced concrete floor	20	Brick wall	25
44	T-3	Tsentralny	Built-up roofing	30	Reinforced concrete floor	20	Brick wall	25
45	T-4	Tsentralny	Galvanized steel sheet on timber rafters	30	Plastered timber floor	40	Brick wall with timber partitions	40

3 Results

Total selection of the objects were 30 buildings of Saint-Petersburg industrial areas after pre-processing of the data and evaluation of their quality in the software named Deductor. The indicators of physical wear and types of structures with the extreme values and emissions were considered. Objects with extreme values were excluded from research.

The program Deductor analyzed the factors of physical wear. The results of the analysis are shown in Figure 2. The x-axis shows the values of each test criteria. The total number of clusters is seven (Table 2).

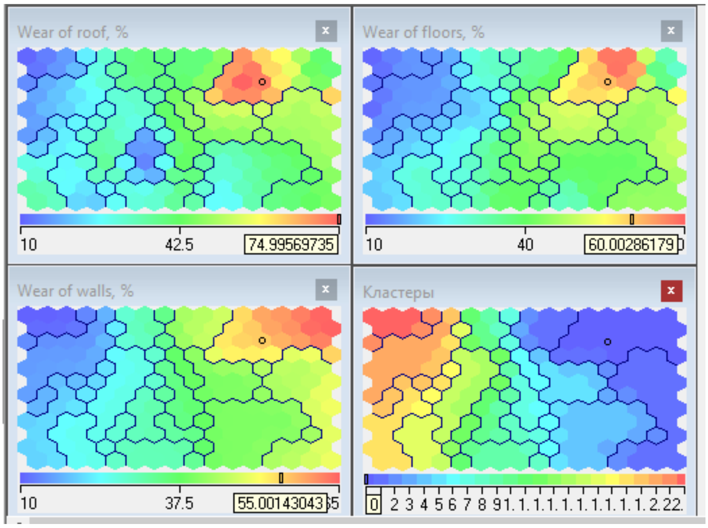

Fig. 2. Self-organizing map for physical wear characteristics

Table 2. Characteristics of physical wear clusters

Cluster	Symbol	Average roof wear, %	Average floor wear, %	Average wall wear, %
7	Kr-1	20	15	15
	N-1			
	N-2			
	N-4			
	N-5			
6	N-3	35	23	25
	Kir-2			
	T-2			
	T-3			
5	Kir-4	23	30	25
	T-1			
	P-3			
4	K-4	33	40	40
	Kr-3			
	F-2			
	M-2			
	M-3			
3	P-2	35	35	30
	K-1			
	V-5			
	A-5			
2	P-1	40	40	47
	K-3			
	F-5			
	M-1			
1	V-1	60	60	60
	V-3			
	Kr-5			

Types of construction were also considered. During the research, the data were divided into two clusters (Table 3).

Table 3. Types of construction clusters

Cluster	Symbol	Roof	Floor	Wall
1	P-2	Iron roof	Timber floor	Brick wall
	M-2			
	M-3			
2	N-4	Roll roofing	Cast reinforced concrete slab	Brick wall
	N-5			
	N-3			
	Kir-2			
	T-2			
	T-3			
	Kir-4			
	T-1			
	P-3			
	K-4			
	Kr-3			
	F-2			
	N-1			
	N-2			
	Kr-1			
	K-1			
	V-5			
	A-5			
	P-1			
	K-3			
	F-5			
	M-1			
	V-1			
	V-3			
	Kr-5			

4 Discussion

The program has divided the objects into 7 clusters depending on the indicators of physical deterioration of structural elements of buildings. With the increase of the cluster number, the indicators of physical wear decrease. Characteristics of physical wear clusters received in the program Deductor can be reduced thus it will reduce their number. Recommendations can be made for follow-up actions based on the results (Table 4).

Table 4. Recommendations

Cluster	Symbol	Technical condition	Recommendations
4	Kr-1	Satisfactory	Requires minor repairs with elimination of local damage without strengthening of the constructions
	N-1		
	N-2		
	N-4		
	N-5		
	N-3		
	Kir-2		
	T-2		
	T-3		
3	Kir-4	Unsatisfactory	Major repairs with strengthening and restoring the capacity are required to ensure normal operation
	T-1		
	P-3		
2	K-4	Pre-emergency	The buildings in this cluster belong to the objects of cultural heritage. Immediate safety measures are required (unloading of structures, temporary support, etc.). Operation of the building
	Kr-3		
	F-2		

	M-2 M-3 P-2 K-1 V-5 A-5 P-1 K-3 F-5 M-1		must be stopped for major repairs (reconstruction) with the restoration (strengthening) of damaged structures.
1	V-1 V-3 Kr-5	Emergency	It is required to conduct security and support activities. These buildings are the object of cultural heritage and need to be reconstructed

Two clusters were identified according to the design characteristics. Then the thermotechnical calculation of the wall and selection of insulation were made for the reconstruction. Composition of the existing outer wall is shown in Table 5.

Table 5. Composition of the existing outer wall

№	**Layer**	**Layer name**	**Specific gravity t, kg/m³**	**Thicknes s δ, m**	**Thermal conduction λ, W/(m·°C)**	**δ/λ m²·° C/W**
1	Load-bearing	Brick wall	1400	0.51	0.64	0.797
	TOTALS:			0.51		0.797

Heating degree-day:

$$HDD = (t_{int} - t_{ext}) \cdot z_{\alpha} \quad (1)$$

According to SP 50.133330.2012 «Building heat insulation» HDD = 4749.9 °C·day

Normalized heat transfer resistance of the outer wall:

$$Rn = \alpha \cdot HDD + \beta \quad (2)$$

where α, β - design factors, according to SP 50.133330.2012 «Building heat insulation»: α = 0,00035; β = 1,4.

$$Rn = 0.00035 \cdot 4749.9 + 1.4 = 3.063 \text{ m}^2\cdot°\text{C/W}$$

Design heat transfer resistance of the outer wall:

$$R = 1 / \alpha_{int} + \Sigma\, (\delta/\lambda) + 1 / \alpha_{ext} \quad (3)$$

$$R = 0.115 + 0.797 + 0.044 = 0.956 \text{ m}^2\cdot°\text{C/W}$$

Considering the factor of homogeneity of the solid brick wall made of hollow bricks we get:

$$R = 0.956 \cdot 0.97 = 0.927 \text{ m}^2\cdot°\text{C/W}$$

Conclusion:

$$R = 0.927 \text{ m}^2\cdot°\text{C/W} < Rn = 3.063 \text{ m}^2\cdot°\text{C/W}$$

The calculation value of the surface heat exchange resistance is significantly lower than normalized value. Consequently, the existing design of the outer wall does not meet modern requirements for thermal protection of buildings.

Composition of the outer wall. Selection of the insulation is shown in Table 6.

Table 6. Composition of the outer wall. Selection of insulation material

№	Layer	Layer name	Specific gravity t, kg/m³	Thickness δ, m	Thermal conduction λ, W/(m·°C)	δ/λ m²·°C/W
1	Load-bearing	Brick wall	1400	0.51	0.64	0.797
2	Insulation	Mineral wool	90	0.10	0.035	2.857
	TOTALS:			0.61		3.654

Normalized heat transfer resistance of the outer wall:

$$Rn = \alpha \cdot HDD + \beta = 3{,}063 \text{ m}^2{\cdot}°\text{C/W}$$

where α, β - design factors: $\alpha = 0.00035$; $\beta = 1.4$.

Design heat transfer resistance of the outer wall:

$$R = 1 / \alpha_{int} + \Sigma\ (\delta/\lambda) + 1 / \alpha_{ext} = 0{,}115 + 3.654 + 0.044 = 3.812 \text{ m}^2{\cdot}°\text{C/W}$$

Considering the factor of homogeneity we get:

$$R = 3.812 \cdot 0.97 = 3.698 \text{ m}^2{\cdot}°\text{C/W}$$

Conclusion:

$$R = 3.698 \text{ m}^2{\cdot}°\text{C/W} > Rn = 3.063 \text{ m}^2{\cdot}°\text{C/W}$$

The calculation value of the surface heat exchange resistance is significantly above normalized value. Consequently, the existing design of the outer meets modern requirements for thermal protection of buildings and can be used in the buildings reconstruction.

Composition of the outer wall is shown in Table 7.

Table 7. Composition of the outer wall. Selection of insulation material

№	Layer	Layer name	Specific gravity t, kg/m³	Thickness δ, m	Thermal conduction λ, W/(m·°C)	δ/λ m²·°C/W
1	Load-bearing	Brick wall	1400	0.51	0.64	0.797
2	Insulation	Aerogel based thermal insulation	150	0.04	0.014	2.857
	TOTALS:			0.55		3.654

Normalized heat transfer resistance of the outer wall:

$$Rn = \alpha \cdot HDD + \beta = 3.063 \text{ m}^2{\cdot}°\text{C/W}$$

where α, β - design factors, according to SP 50.133330.2012 « Building heat insulation»: $\alpha = 0.00035$; $\beta = 1.4$.

Design heat transfer resistance of the outer wall:

$$R = 1 / \alpha_{int} + \Sigma (\delta/\lambda) + 1 / \alpha_{ext} = 0.115 + 3.654 + 0.044 = 3.812 \text{ m}^2\cdot°\text{C/W}$$

Considering the factor of homogeneity:

$$R = 3.812 \cdot 0.97 = 3.698 \text{ m}^2\cdot°\text{C/W}$$

Conclusion:

$$R = 3.698 \text{ м}^2\cdot°\text{C/W} > Rn = 3.063 \text{ m}^2\cdot°\text{C/W}$$

The calculation value of the surface heat exchange resistance is above normalized value. It is equal to the results obtained for mineral wool boards 100 mm thick. Consequently, the existing design of the outer meets modern requirements for thermal protection of buildings and can be used in the buildings reconstruction.

4 Conclusion

The research identified objects of the gray belt - industrial areas surrounding the historical district of St. Petersburg, Russia, defined building dilapidation for each object; were created clusters according to the characteristics of the physical wear and types of construction.

Recommendations were given for the reconstruction considering the parameter of physical wear, selected insulation for external load-bearing walls that meets the requirements for energy efficiency of buildings.

The method of object clustering is based on the fact that it is possible to consider typical methods when making a decision on reconstruction. Standard solutions will allow to make the reconstruction process with minimal costs.

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