Saimaa University of Applied Sciences
Faculty of Technology, Lappeenranta
Double Degree Program in Civil and Construction Engineering

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Analysis of the construction of an open multi-storey parking and evaluation of its profitability

Bachelor's Thesis 2018

Abstract

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The study was commissioned by YIT Saint-Petersburg. The main purpose of the thesis was to analyse the Finnish project of an open multistorey parking with sloping floors and to find out if it is possible to build the same parking lot in Saint-Petersburg, Russia according to required norms and regulations. Also, the aim of the study was to estimate the profitability of such a parking solution. In addition, the thesis considers different types of parking lots that are commonly used in Saint-Petersburg for residential housing.

The data for this study was gathered from Russian and Finnish norms and regulations, guides for parking design, articles taken from the Internet and by interviewing civil engineers working at YIT Saint-Petersburg.

As a result of this study the Russian project of the parking with inclined floors was developed. The profitability of the parking lot was estimated and compared to other typical parking solutions. It appears that construction of sloped parkings is not suitable for residential complexes due to its great dimensions and not the highest economic efficiency. The advantages and disadvantages of different types of parking lots were presented.

Keywords: parking lot, parking space, multistorey ground parking, car place, efficiency

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1 Introduction

1.1 Problem statement

The number of cars grows fast every year. In 2017 the sales of new cars in Russia increased on the average by 12 % compared with the previous year according to the AEB (Association of European Businesses) statistics (1). The level of motorization in the country is almost 300 cars per thousand people what is 3 times more than 20 years ago. Each automobile needs to be parked what becomes a problem in big cities – in the absence of land and its high cost.

Returning home on private vehicles, residents are increasingly faced with the issue of parking in walking distance from the entrance of their own house. Searches for a free car space take time and nerves. The situation is critical in high-rise residential areas of cities with a great population density, and it becomes worse with the growth of motorization. Parking on lawns, playgrounds, roads in several rows became common (Figure 1). All of this prevents the passage of transport and, most importantly, a normal and comfortable life.

To make the problem mentioned above less acute, standards for the number of parking spaces were introduced in Saint-Petersburg (2). In the project of an apartment complex developers must provide parking of any type that would cover the need of residents in the parking lot. Otherwise, the project will not be approved by higher authorities.

More than often that is not an easy task for construction companies. One must either sacrifice "residential" square meters leaving free territory for the storage of cars within the boundaries of the existing land area or spend money on building an underground or surface multistorey parking.

On the one hand, the second option is preferable as there is an opportunity to return the incurred costs by selling car places or renting them out to tenants. More, it seems that for car owners the best way to store the vehicle is at an indoor parking lot. However, not everyone is ready to spend money on the private place for the car. The advantages of such an option are mainly appreciated by buyers

of expensive housing. While in the mass segment, preference is given to keeping the car on the street, even if sometimes it is hard to find a free place in the yard.

According to experts, about half of the existing parking spaces in the comfort class houses are unclaimed. In economy class projects, this figure is even higher – up to 75 % of the area of the parking is empty by the moment the house is put in operation. Only in the elite and business-class houses there are fewer problems with selling car spaces – they are sold at the early construction stages.

The situation is quite understandable, as the construction of parking lots requires financial investments from developers. Therefore, the price of each place for the vehicle is high. It often exceeds the cost of the car itself for clients of the mass segment housing. Future residents having limited resources available prefer to spend money on apartments of larger size or with a large number of rooms.

As a result, the companies build parking lots according to the mandatory provision of parking spaces but are forced to reduce their prices, since supply exceeds demand. A more balanced approach to the parking lot construction is needed, and developers are constantly looking for new effective solutions with investment appeal.

Figure 1. Examples of the wrong parking (11)

1.2 Task description

The purpose of the company YIT Saint-Petersburg is to build more profitable parking lots that are able to accommodate more cars on less area. Looking for a better decision, an example of the ground multistorey parking project in Finland

is taken into account (Appendix 1). The parking structure has an efficient space planning solution without separate ramps. The building consists of sloping floors appropriate for internal car movement and for locating storage places on them.

The objectives of the thesis are:

- to study the Finnish parking structure;
- to find out if it is possible to build a similar parking lot in Russia in accordance with the required rules and regulations;
- to compare the Russian and Finnish norms (space-planning solutions) for parking design;
- to estimate the need and profitability of the construction of such parking lots for the company.

Also, the thesis considers different types of parking lots that are commonly used in Saint-Petersburg, and what type of parking is a better solution for different residential estate objects.

2 Typical parking lots in Saint-Petersburg

2.1 Parkings classification

The construction of parking lots begins with the definition of their type – each with its own design features. The choice of a particular type is determined by the financial capabilities of the investor, in compliance with the legislative requirements and marketing considerations.

According to the set of rules SP 113.13330.2016 applied in Russia, parking lots are classified concerning objects of other purpose and by the ground level as presented in Table 1 below.

Table 1. Parkings classification

<table>
<tr><td rowspan="2">1 Flat car parking</td><td colspan="3" rowspan="2">1.1 Ground level</td><td colspan="2">1.1.1 Open storage</td></tr>
<tr><td colspan="2">1.1.2 Closed storage (awnings)</td></tr>
<tr><td rowspan="5">2 Buildings, structures of parkings</td><td rowspan="2">2.1 Detached</td><td colspan="2">2.1.1 Ground level</td><td rowspan="2">2.1.2 Underground</td></tr>
<tr><td>Open type</td><td>Close type</td></tr>
<tr><td rowspan="2">2.2 Attached</td><td colspan="2">2.2.1 Ground level</td><td rowspan="2">2.2.2 Underground</td></tr>
<tr><td>Open type</td><td>Close type</td></tr>
<tr><td>2.3 Build-in</td><td colspan="2">2.3.1 Ground level</td><td>2.3.2 Underground</td></tr>
<tr><td rowspan="2">3 Mechanized parking</td><td colspan="3" rowspan="2">3.1 Ground mechanized parking</td><td colspan="2">3.1.1 Detached multistorey structure for loading cars to storage platforms</td></tr>
<tr><td colspan="2">3.1.2 Car lifts attached to buildings</td></tr>
</table>

Also, classification can be given by the following criteria (3):

- Duration of storage – permanent, temporary or seasonal;
- The number of levels – one- and multi-storey;
- The degree of automation – partial or full;
- Heating conditions – heated or unheated car parkings;
- Movement of a vehicle:
  - with driver's participation – ramps or using freight elevators
  - without driver’s participation – by mechanized structures
- Movement of a vehicle between levels – ramps, mechanized or automated.

2.2 Surface parking

It is the simplest way of organizing car places. Surface parking is not enclosed or created by a structure and is allocated an area on ground level. The territory for vehicles is limited only by markings and signs. Some parking lots are surrounded by a fence and equipped with a security system, time tracking facilities, and other improvements.

Well-designed open flat parking should be integrated into the overall building and landscape design of the site so to avoid a dominance of cars. The use of trees and other planting improves the visual appearance of the territory, as well as provides shading.

There are different parking layout solutions (Figure 2): 1 – with continuous entrance and exit; 2 – separate entrance and exit; 3 – at an angle to the driveway 30°; 4 – at an angle to the driveway 60°; 5 – at an angle to the driveway 45°; 6 – at an angle to the driveway 90°.

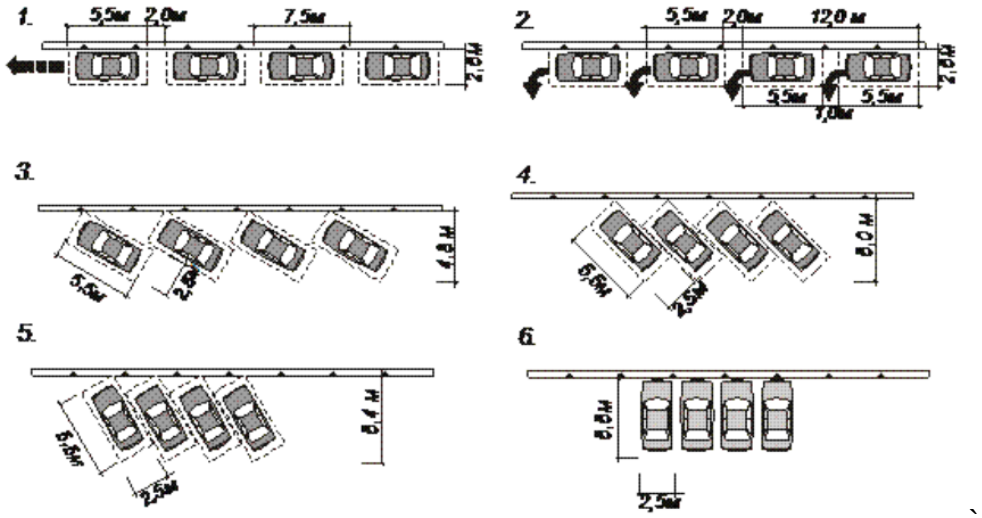

Figure 2. Layout of cars in open parking lots (12)

A parking layout solution depends on how much free space there is left for the parking lot itself and for the normal car movement.

- Parallel parking takes up less space. It is usually located near sidewalks. It may cause difficulties for inexperienced drivers.
- Parking at an angle to the driveway, as shown in Figure 2 (pictures number 3, 4, 5), is convenient to use as it is much easier to leave the area at a smooth angle than under a sharp one. Width requirements are reduced for such a layout. Among the disadvantages of this solution is taking more pavement per vehicle than the perpendicular configuration.
- Parking at an angle 90° is the most efficient and economical since it accommodates the most vehicles per linear meter. However, it requires more skills than putting a car at a smaller angle. In order to put the car, it is needed as much space as possible around, and it is controlled by the set of rules (3).

Open flat parking lots are widespread in all cities but have significant shortcomings. They use the land extremely inefficiently. Parked cars reduce the areas reserved for lawns and playgrounds. Even though large areas are occupied, not so

many vehicles can be placed there compared to the multistorey type of parking. There is no protection from weather conditions, and that is the reason for the cheap cost of space in such car parking.

Sometimes, to solve the problem of lawns eco-parkings (Figure 3) are created with the help of lawn grids which strengthen the soil and the root system of the grass. The result is a neat lawn made of live grass, on which the car can safely be driven without damaging the plants.

Figure 3. Eco-parking (13)

Surface parkings are typical for economy class houses as the cost of their organization is minimal and does not require large financial investments. However, despite of the cheapness of the equipment of such parking lots, in the projects of economy and comfort class houses the most common are ground multi-level parking spaces, on which it is possible to accommodate tens of times more cars.

2.3 Multistorey ground level parking

Nowadays, multistorey parking is the optimal solution to the problem of a large amount of vehicles: with the same area, it can take in times more cars than flat parking. Multistorey ground parking lots use the urban space much more efficiently. They can be found in districts with complex development.

A multi-level parking is considered to consist of two or more levels connected by ramps or elevator lifts. There are a lot of variations of such parking lots – with straight or curved ramps, inclined floors, half-ramps, mechanized and automated lifts, elevator lifts. They can be in a stand-alone structure (Figure 6) or attached to the deaf end walls of a building.

Ramps are classified according to several characteristics: the location relative to the storage area and the building, the number of lanes, the outline in the plan, the nature of the traffic, the spatial construction, the degree of isolation from the storage room (4).

Table 2. Parking ramps classification (4)

Parking ramps	
Build-in	Attached
Single lane	Double lane
Straight	Curved
Full-storey	Half-storey
One-way traffic	Two-way traffic

Depending on the number of lanes, ramps can be single-track or double-track. Single-track ramps have a lane, the width of the carriageway of which ensures the passage of only one car. Double-track ramps have two lanes with the width enough for the movement of two cars. On double-track ramps, traffic can occur in one direction along both lanes or in different directions – one lane up and one down. The type and the number of lanes of the ramps is chosen according to the project.

By the outline in the plan, there are straight or curved ramps. On straight ramps, the movement of cars occurs only on a straight line for ascent or descent, and turns are made on the horizontal plane of intermediate platforms and floors. On curved ramps, the movement up and down happens at the same time with the rotation on the inclined plane of the ramp along the trajectory defined by its generatrix. A variety of curved ramps are circular, elliptical and concentric.

Ramps are divided into full-storey or half-storey by the height or the length of an ascent. Half-storey ramps provide an ascent or descent between two consecutive floors with the help of two slopes.

Types of ramps mostly used in practice in Russia are shown in Figure 4. They are distinguished by the simplicity of the constructive solution and the minimum dimensions of the horizontal projection:

- Straight ramps “*а*” are easy to use (clearway ramp system), but more territory for the parking lot is required;
- Half-storey ramps *“б”*, *“в”* are recommended for the parking lots built in narrow areas, mostly for long-storage of cars;
- Half-storey ramps with one-way traffic “*е*” have the advantageous system of movement of cars inside the building – short sections are obtained for moving vehicles, a relatively short rise time, and, therefore, less exhaust emissions.

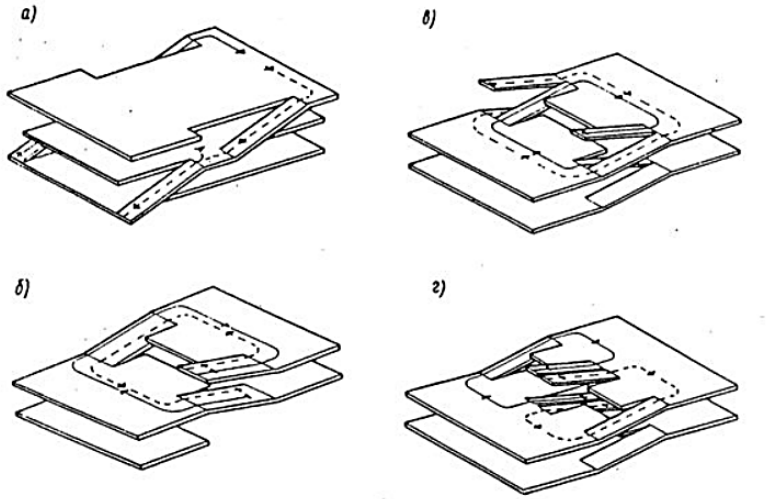

Figure 4. Types of ramps mostly used in practice in Russia (4)

Besides multistorey parking lots mentioned above, there are "**sloped parkings**" without separate ramp structures (Figure 5). The entire car-parking consists of sloping floors, through which vehicles move between levels, and at the same time storage places are located across the floors, the slope of which should not exceed 6 % (3). This is supposed to be an efficient space saving system.

Sloped parking is characterized by the continuous traffic through all the lower levels. In order to reduce the way of the car's internal movement from the entrance-exit to the storage place, various methods are used in the design: the installation of additional driveways with ramps, the design of cylindrical volume parking or the use of freight elevators for lifting cars.

Benefits of different design decisions for sloped parkings (Figure 5):

- “sloping floors – two-way” – very economical, 90° parking recommended
- “sloping floors with helical down ramp” – angle parking and express exit recommended for short-term parking use

- “sloping floors – one-way” – economical and suited to long sites.

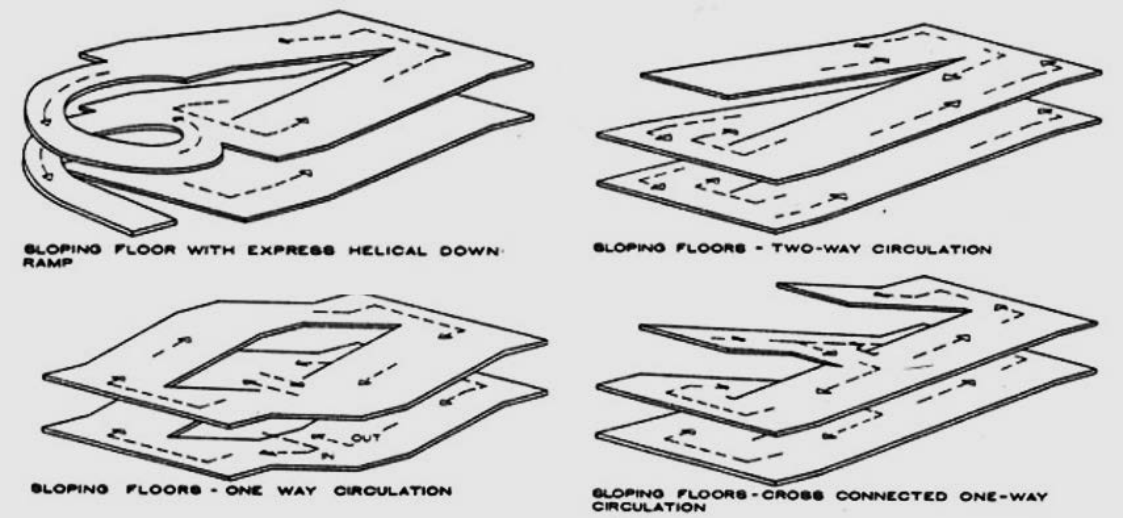

Figure 5. Parking lots with sloping floors (6)

Ground level parking structure can be of an “open” or “closed” type. The set of rules (3) use the term **open parking lot** (Figure 6) to refer to a structure designed for car storage that has openings along at least 50 % of the perimeter, as opposed to an **enclosed parking lot** (often heated) that requires mechanical ventilation. Natural or mechanical ventilation provides fresh air flow to disperse car exhaust in normal conditions, or hot gas and smoke in case of fire.

Figure 6. Open multistorey parking with half-storey ramps (Novoorlovsky, YIT SPb)

To make the multistorey parking lot “open” or “close”, heated or unheated is the decision made by developers. There are benefits and disadvantages of each type.

- Benefits of the heated enclosed parking lot:
  - comfortable car storage conditions;
  - better for ecology – reduces exhaust emissions into the atmosphere;
  - the size of the sanitary protection zone can be significantly reduced (5);
  - allows to spend less time and fuel on preparing the car for the trip.

  Disadvantages:
  - cost – around 20 % of costs go to building services systems, connection to heat supply network.
- Benefits of the unheated open parking lot:
  - the cheapest;
  - easier in construction;
  - easier to maintain.

  Disadvantages:
  - greater sanitary protection zone (5);
  - less comfortable storage conditions especially during seasons with the low temperature outside.

2.4 Underground parking

An underground parking is structured parking built below ground level. Such a parking lot is equipped with engineering systems for heating, ventilation and smoke removal, lighting, firefighting and communications. All this is necessary to ensure the normal functioning of the underground area and create a comfortable microclimate in it. Security is provided by security and video surveillance systems.

Underground parkings should be preferred for a number of reasons. First, it deals with several environmental problems – such as environmental pollution, noise, crowding out the living space of neighborhoods, it does not distort the landscape and architectural integrity of the city. Free space is used by the builder to improve the comfort of the tenants, as well as to create attractive and non-ordinary elements (for example, gazebos or fountains). Underground parking lots make it possible to save energy, decreasing its consumption by constant underground air temperature (in case of good heat insulation of the building). Moreover, sanitary and hygienic requirements to their location are much softer compared to the norms for above-ground parking lots and garages (5).

Among the disadvantages of underground parking lots is the large investment of time and money in the construction of them. On average, the arrangement of underground space increases the project implementation period by 6 - 8 months. The cost of the construction of underground parkings is 30 - 40 % more expensive than the construction of ground level garages.

Also, as underground parking lots are technically complex structures the following rerquirements should be met during the design:

- take into account loads on supporting structures during the construction of a parking lot under a building;
- examination of soil condition, hydrogeological condition of the land;
- examination of the foundations of the nearby development.

The construction of underground parking lots is especially difficult and expensive at Saint-Petersburg for the reason that the ground water lies very close, which requires the use of complex engineering solutions. The presence of such parking is typical for complexes of comfort and business class, whose tenants mostly can afford an expensive car place.

2.5 Mechanized parking

Recently, traditional methods of locating cars do not meet modern requirements. More and more machines, while the area is still the same or even less. One of the ways to reduce the losses in the areas is to place cars closer to each other. This is only possible if the driver does not participate in the process of parking the car.

To solve this problem, mechanized parking appeared. It reduces or eliminates the required room for vehicle maneuvering, standard floor heights, and access in and out of vehicles that are needed in normal parking structures. Cars are handed over for storage, then they are automatically moved to the storage location. Issuance of cars occurs in reverse order.

Mechanized parking is a multi-level structure with an elevator and parking spaces for cars. The system is fully automated and controlled by a single operator. The driver is only required to put the car in the elevator and hand the magnetic card

to the operator. Then the elevator will lift the car to the desired tier, then move it to the cell corresponding to the card code.

Many structural and functional types of automated systems exist, such as:

- underground systems as part of the building foundation;
- above ground where they can match neighboring buildings in architectural appearance;
- horizontal and vertical.

If the building is a rectangular parking (Figure 7), then there are two vehicle delivery systems in the box: a system of vertical and horizontal movement. The process of placing cars in boxes and their issuance last a long time.

If the building is in the form of a multistorey cylinder (Figure 7), then on each floor there is a fixed annular platform, in which there are radially located cells for storing cars. In the center of the cylinder, rotary elevator platforms are made, which move cars vertically and install them in storage cells, as well as in the opposite direction. It is one of the fastest ways for delivering the car.

The building of the parking lot is made of a metal skeleton. Its outer lining can be different for metal structures: reinforced concrete box, profile sheet, sandwich panels, tinted and mirror glass. It can be covered with pretty much whatever is needed for it to fit the city landscape.

Figure 7. Mechanized parkings (7)

Also, there is an opportunity to increase the capacity of existing regular parking lots with the help of specially designed devices.

In those places of the underground garage, where the ceiling height is more than 3,5 m, a special hydraulic lift is installed with an individual electric drive and a platform for the car (Figure 8). Such a lift may be used for cars of bigger size. If the ceiling height is less than 3,5 m, then a system with adjustable angle of the platform is provided (Figure 8). Two cars are put in one parking place. The disadvantage of this solution is that for lifting and lowering the top car you must first roll out the bottom one from under the lift platform.

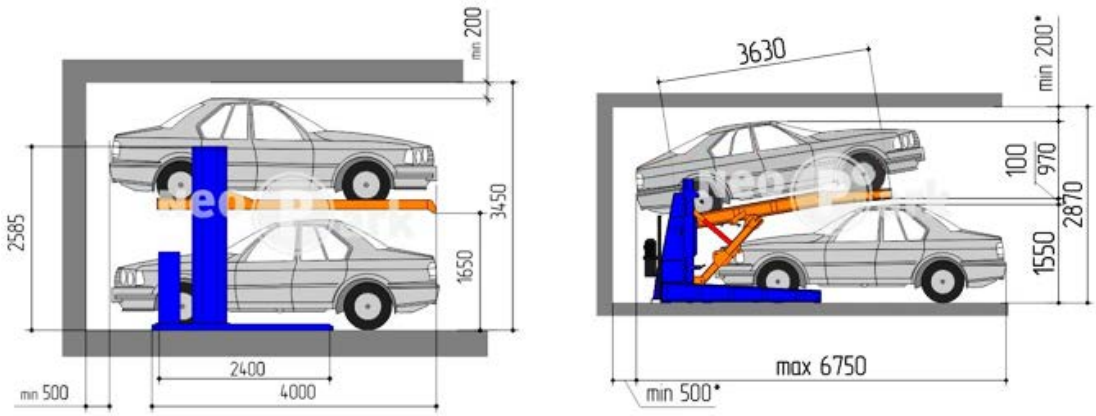

Figure 8. Hydraulic parking lifts (8)

Mechanized parking is an innovative and efficient car storage system. Nonetheless, few developers apply the technology in residential real estate projects in Saint-Petersburg. The complex and expensive equipment of automated garages, designed for the frequent use of the car by the owner, does not justify the effect obtained from mechanization.

2.6 Comparison of the different types of parking

The main advantages and disadvantages of each parking solution are presented in Table 3.

Table 3. Comparison of the different types of parking

Type of parking lot	Advantages	Disadvantages
Surface parking	simple in organization; cheap	require large territories; areas for lawns are reduced; lack of protection from weather conditions

Multistorey ground level	possible to accommodate large number of vehicles; more efficiently use the territory; construction is relatively simple; better storage conditions	financial investments; takes away some land area; sanitary protection zones; depending on the type - organization of the heating system, etc.
Underground	no loss of the land area; high capacity; environmentally friendly; fine storage conditions	expensive; impact on the foundations of the surrounding buildings; complex geological conditions in the area of Saint-Petersburg
Mechanized	increase capacity; eliminates stairs, elevators and fire exits; requires less building volume and less ground area than a conventional facility with the same capacity; no CO2 emission and fuel consumption while the car is moved through the building	cost; operation and maintenance; waiting for a car to be issued; equipment failure

3 Norms and regulations

3.1 Parking capacity

One of the main characteristics of parking is the number of car places it can provide. In Russia as in many countries, the minimum number of places for different estate objects is regulated by the state norms. According to the Rules of land use and development of St. Petersburg, it is necessary to build at least one car place for every 80 square meters of living space of an apartment building (2). However, when agreeing the project, the required number of places in the parking lot may increase, if the construction of a new house is conducted in a densely populated urban area. On the other hand, it is possible to reduce the mandatory number of parking spaces, if parking near the housing complex under construction is already in place.

In practice, the capacity of a parking lot directly depends on the class of new buildings, and the higher the comfort of housing, the more parking spaces are provided:

- about 20 parking spaces for every 100 apartments – in economy class;
- about 60 parking spaces for every 100 apartments – in comfort class;
- 1-2 parking spaces for each apartment – in business and elite class.

On average, in Saint-Petersburg, there are 25 - 30 parking spaces for every hundred apartments.

3.2 Russian and Finnish norms for parking design

Russian requirements for parking lots are determined by SP 113.13330.2016 and depend on the type of parking, its volume and location. This document takes into account the requirements of most regulations (for heating, ventilation systems, fire protection and so on).

The Finnish guidance for parking facilities design is RT 98-11237 (9).

According to the goal of the thesis the main norms for space-planning solutions of the parking are considered in the chapter. To see the difference between the norms of two different countries, the table of comparison was made (Table 4). Mostly, the norms are quite similar.

The sizes of the typical parking space and an example of the parking layout solution are shown in Figure 9 (9).

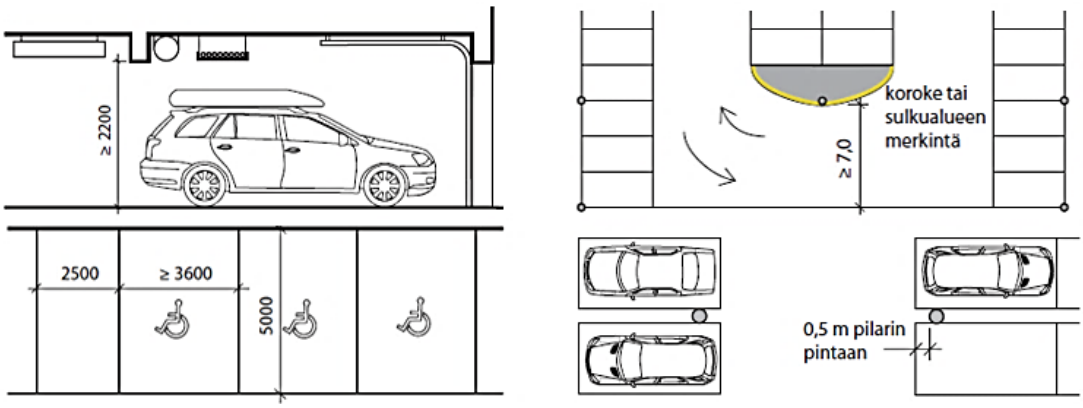

Figure 9. Finnish sizes of the parking space and a column placement example

Table 4. Comparison of norms for space-planning and design solutions of parking facilities

<table>
<tr><th>Characteristics</th><th>SP 113.13330.2016</th><th>RT 98-11237
KH 91-00607
Infra 64-710166</th></tr>
<tr><td>Parking space width</td><td>2,5 m</td><td>2,5 m</td></tr>
<tr><td>Parking space length</td><td>5,3 m</td><td>5,0 m</td></tr>
<tr><td>The height of the storage of cars (the distance from the floor to the bottom of the protruding building structures or utilities and hanging equipment)</td><td>Must be 0.2 m more than the height of the highest car, but not less than 2 m</td><td>≥ 2,2 m
<table><tr><td>Height, m</td><td></td></tr><tr><td>2,2...2,3</td><td>tight</td></tr><tr><td>2,4...2,5</td><td>normal</td></tr><tr><td>≥ 2,5</td><td>spacious</td></tr></table></td></tr>
<tr><td>The minimum width of the carriageway</td><td>3,5 m</td><td>3,5 - 3,8 m (depending on the ramp type)</td></tr>
<tr><td>Inclined floors should have a slope not more than</td><td>6 %</td><td>4 % (5 % for a reason)
≤ 1:25</td></tr>
<tr><td>The longitudinal slope

- of straight open (not protected from atmospheric precipitation) ramps

- of straight ramps inside the building

- of curved ramps</td><td>

< 10 %

< 18 %

< 13 %</td><td>

10 %

12,5 %
14% (half-storey ramps)

8,3 %</td></tr>
<tr><td rowspan="2">The size of the extended parking space for people with limited mobility</td><td>6,0×3,6 m</td><td>5,0×3,6 m</td></tr>
<tr><td colspan="2">Maximum allowable floor slope is 2 %</td></tr>
<tr><td>Number of parking places for people with disabilities</td><td>10% of regular parking spaces including at least one extended parking space for wheelchair users (10)</td><td>2 parking spaces on 50 spaces, then one extra space for every new 50 car places</td></tr>
</table>

Russian one parking space width and length, shown at the table above, are calculated for medium cars (Table 5) according to Appendix A “Classification of vehicles used to determine the dimensions of parking spaces in parking lots” of the set of rules.

Table 5. The dimensions of parking spaces for medium size cars (3)

Type of the car	Dimensions max, mm			Minimum overall radius, mm	European classification
	Length, mm	Width, mm	Height, mm		
Medium	4300	1700	1800	6000	Class B, C

The size of the parking space is determined considering the minimum allowable safety clearances for not less:

- 0,8 m – between the longitudinal side of the car and the wall;
- 0,8 m – between the longitudinal sides of cars;
- 0,5 m – between the longitudinal side of the car and the column;
- 0,7 m – between the front or back of the car and the wall.

Other main points for designing a **ground multistorey parking lot** in Russia are considered in section 5 of SP 113.13330.2016. (3.)

1. Ground parking lots can be no more than nine floors high.

2. The number of ramps and the number of required exits and entrances of parking lots should be taken depending on the number of cars located on all floors except the first, taking into account the mode of operation of parking, the design flow and planning decisions on its organization.

The type and the number of ramps should be taken when the number of cars:

- up to 100 – one single-track ramp with the use of appropriate signaling;
- up to 1000 – one double-track ramp or two single-track ramps;
- over 1000 – two double-track ramps.

3. Ramps must meet the following requirements:

- The minimum width of the carriageway of the ramps: straight and curved – 3,5 m, the minimum width of the entrance and exit lanes – 3,2 m, and on a curved section – 4,2 m;
- Minimum outer radius of curved sections – 7,4 m.

4. At parking lots with 50 or more parking places for permanent and temporary storage of vehicles, there should be a checkpoint at the main entrance-exit, and there should be rooms for cleaning equipment, maintenance staff, toilet, etc., a platform for placing primary means of fire extinguishing equipment, personal protective equipment, and fire equipment.

Special requirements for open multistorey parkings:

- The width of the building (between open apertures in opposite walls) of open parking lots with natural (without forced draft) ventilation and without smoke protection during a fire should not exceed 40 m.
- At least two emergency exits should be provided from each floor.

What also affects the size of the parking lot building is the amount of remaining space on the plot for it. Distances from the parkings to buildings and territories for various purposes are regulated by SanPiN (Sanitary Regulations and Norms) 2.2.1/2.1.1.1200-03 in Russia (Table 6). A sanitary zone with the landscaping of the territory adjacent to the rationing objects is established from the ground parking lots (5). Sanitary zones can be reduced by 25 % for enclosed ground parkings with complete wall fences, in the absence of opening windows in them, as well as entrances-exits oriented towards residential buildings.

Table 6. Distances from parkings to buildings and territories for various purposes

Objects to which the distance is calculated	Distance, m				
	Parking capacity, number of parking spaces				
	< 10	11-50	51-100	101-300	> 300
Walls of houses with windows	10	15	25	35	50
Walls of houses without windows	10	10	15	25	35
Schools, children's institutions, technical schools, playgrounds for recreation, games and sport	25	50	50	50	50

Therefore, developers must provide the distance of at least 35 - 50 m from the parking lot to residential buildings.

4 Analysis of open multistorey parking lots

4.1 Finnish parking lot general information

The parking lot that was analyzed located in Jyväskylä, Finland. It is the ground level unheated open multistorey parking with sloping floors. The floor plans and the section of the building are shown in Appendix 1.

At first, general dimensions and characteristics of the parking were studied. They are presented in the table below:

Table 7. General dimensions and characteristics of the Finnish parking

1. Number of floors	7 floors (2 floors are located below ground level)
2. Number of parking spaces	634
3. Dimensions Length of the parking lot Width of the parking lot Height of the parking lot Height of one typical floor (the distance from the floor to the bottom of the protruding building structures)	 76,82 m (axes 1-11) 37,62 m (axes A-C) 27,245 m (on axis 11) 2,6 m (floors K1, 1); 2,4 m (floors 2, 3, 4, 5)
4. Total area of the parking lot	19897 m^2
5. Area of one typical floor	2913 m^2
6. Area of one car place	5,0 × 2,7 = 13,5 m^2
7. Type of the ramp	Sloping floor with two-way circulation
8. The width of the carriageway	4,0×2 m
9. Inclined floors slope	~ 3,44 % (1:29)
10. Number of lifts and stairwells	3 lifts with load capacity 630 kg; 3 heated stairwells (the area of each is around 35 m^2)
11. Additional rooms	Rooms for cleaning equipment and for maintenance staff, toilet located at the floor K2

Then, constructive parking solutions were studied:

- cast-in-place and precast floor slab on prestressed cast-in-place beams (900 mm width)

- underground floors outer walls are made from reinforced concrete; other floors – perforated steel sheets (openings ~ 35 %)
- foundation – ground reinforced concrete slab, thermal covering, waterproofing
- roof structure – reinforced concrete slab TT3000-180/600, thermal covering, membrane waterproofing.

The main advantage of the Finnish parking is sloping floors which allow not to use separate ramp structures for internal car movement. Thus, the total area of the parking lot can be reduced, or more parking spaces can be added.

4.2 Developed parking project in Russia

Taking the Finnish parking as an example, the project of the parking lot with sloping floors was developed according to the Russian set of rules.

The size of the Finnish parking is too big for integrating into Russian conditions as there is not much free space in the plot. Land plots within the city are usually small, and the project's economy forces the developer to use every meter of the plot for housing construction as efficiently as possible. More, there must be certain distances from facilities for the storage of passenger cars to building objects what leaves even less space for the parking building (5). Therefore, the length of the Russian variant of the parking was reduced. The slope of the floors was chosen close to the maximum allowed and it was 5 %.

As a result, two variants of parking lots were made.

At least two dispersed emergency exits should be provided from each floor of garages directly to the outside, into the stairwells, or onto a type 3 staircase (a staircase fixed to the external facade of the building) (3). The first designed parking lot is with two stairwells and two lifts inside the building (Figures 10, 11, 12). The second one has one stairwell and a lift inside, and the other stairwell outside, what allows to create more parking spaces (Figure 11).

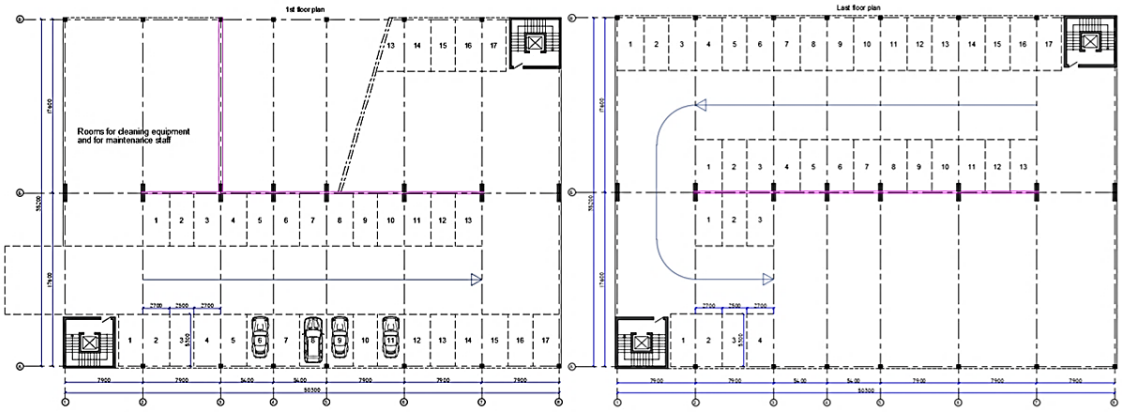

Figure 10. 1st floor and last floor plans of the Russian parking 1

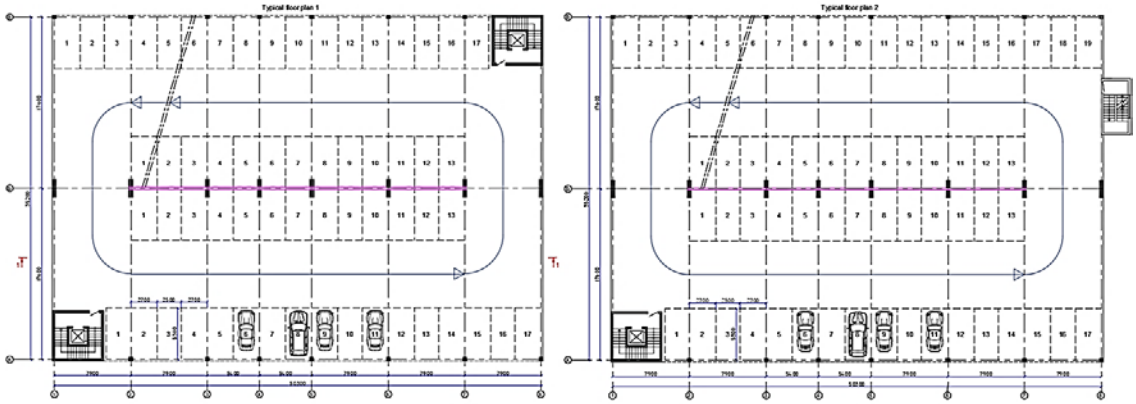

Figure 11. Typical floor plans of the developed Russian parking projects

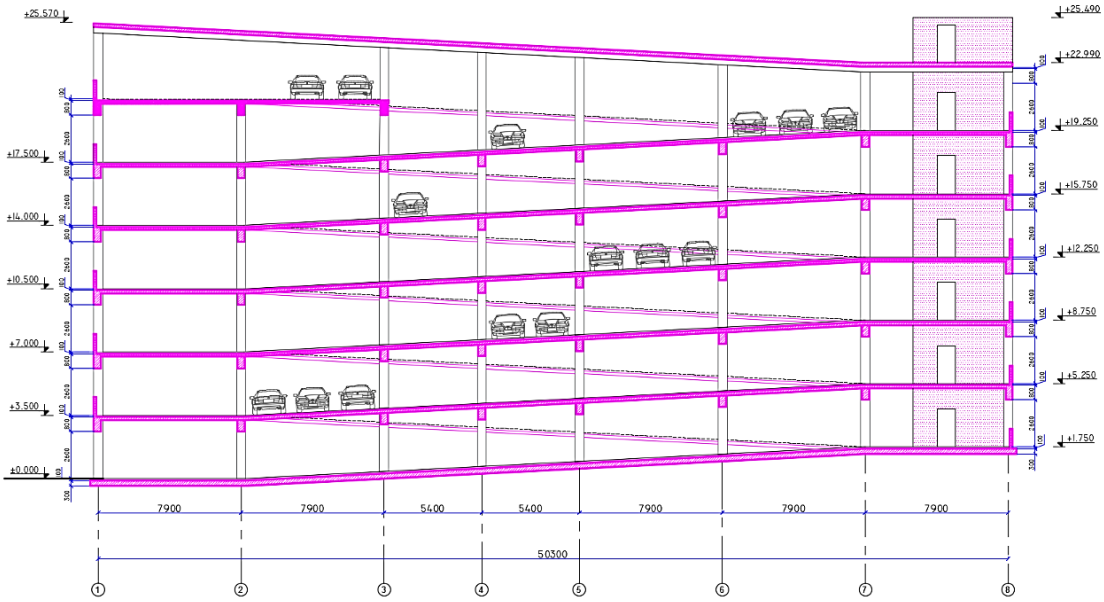

Figure 12. Section drawing 1-1 of the Russian parking 1

The size of the parking lot in axes is 50,3 × 35,2 m. It is of six levels high – 25,57 m, with the fool height of one floor – 3,5 m and the distance from the floor to the

bottom of the protruding building structures – 2,6 m. There are 367 and 379 parking spaces of different sizes: 5,3×2,5 m and 5,3×2,7 m. Storage rooms and a toilet are located on the first floor.

4.3 Economic efficiency of parking

4.3.1 Definition of the efficiency of parking

The efficiency of the space-planning solution of the parking lot is characterized by two indicators:

1) the reduced area of the car place S_r (formula 1)

$$S_r = \frac{S_{tot}}{N} \quad (1)$$

N – number of parking places

S_{tot} – total area of the parking lot, m^2

2) coefficient of efficiency K_e of using the parking area (formula 2)

$$K_e = \frac{N \cdot s}{S_{tot}} \quad (2)$$

s – area of one car place, m^2

$N \cdot s$ – total storage area, m^2

Values of these indicators depend on the rationality of the chosen space-planning solution, the greatest approximation of its parameters to the minimum possible dimensions (according to current standards) of car places, driveways, ramps, engineering support facilities and operational services. With the decrease in S_r and the increase in K_e, the reduction in the future cost of one car place will be provided.

4.3.2 Calculation of the economic efficiency

To evaluate the profitability of the selected parking solutions with sloping floors their efficiency was calculated. For comparison, there are typical Russian multi-storey parking solutions with half-storey ramps.

1. Finnish parking lot

$$S_r = \frac{19897}{634} = 31{,}38\ m^2$$
$$K_e = \frac{634 \cdot 13{,}5}{19897} = 0{,}430$$

2. Russian parking lot variant 1

$$S_r = \frac{11406{,}24}{367} = 31{,}08\ m^2$$
$$K_e = \frac{99 \cdot 13{,}25 + 268 \cdot 14{,}31}{11406{,}24} = 0{,}451$$

3. Russian parking lot variant 2

$$S_r = \frac{11503{,}56}{379} = 30{,}35\ m^2$$
$$K_e = \frac{99 \cdot 13{,}25 + 280 \cdot 14{,}31}{11503{,}56} = 0{,}462$$

4. Open multistorey parking for residential complex Novoorlovsky (buildings 1.3.3/1, 1.3.3/2, 1.4.2), YIT Saint-Petersburg (Figures 6, 13, 14). The size of the parking lot in axes is 34,4 × 30,1 m. It is 7 floors high (including the operated roof). The total area of the parking does not include the area of the operated roof. There are regular parking spaces 5,3×2,5 m and two extended car places for people with limited mobility 6,0×3,8 m.

$$S_r = \frac{6096{,}96}{207} = 29{,}45\ m^2$$
$$K_e = \frac{205 \cdot 13{,}25 + 2 \cdot 23{,}1}{6096{,}96} = 0{,}453$$

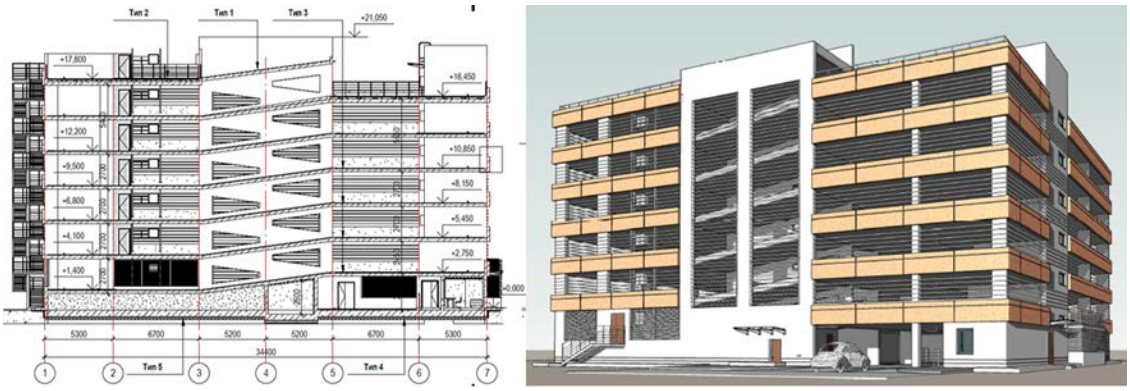

Figure 13. Section drawing 1-1 and the general view of the Novoorlovsky parking

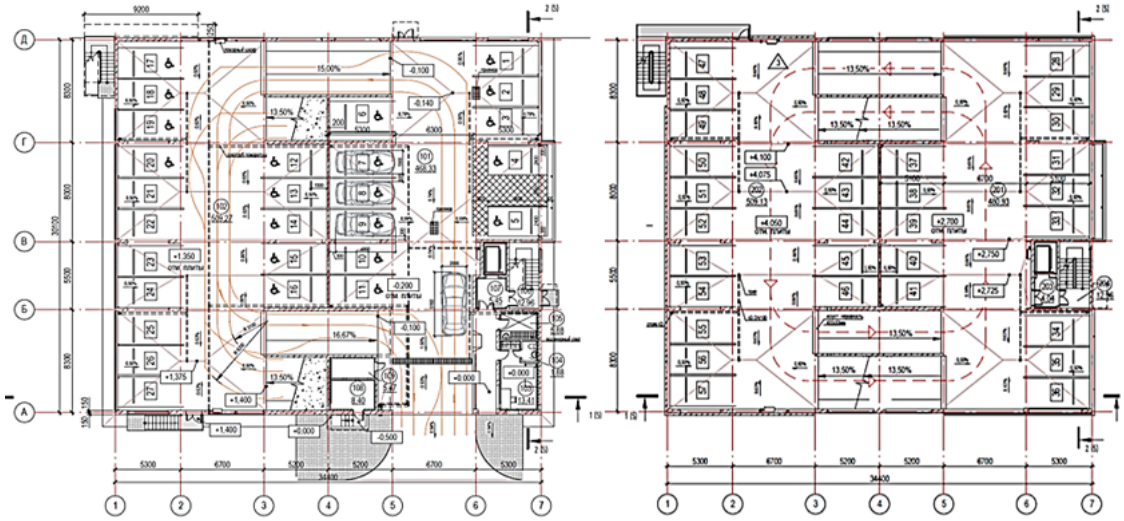

Figure 14. 1st floor and typical floor plans of the Novoorlovsky parking

5. Enclosed unheated multistorey parking for residential complex Tarmo, YIT Saint-Petersburg (Figure 15). The size of the parking lot in axes is 49,6 × 35,1 m. It is 8 floors high (including the basement storey). There are regular parking spaces 5,3×2,5 m and ten extended car places for people with limited mobility 6,0×3,6 m.

$$S_r = \frac{12713{,}46}{440} = 28{,}89\ m^2$$

$$K_e = \frac{430\ \cdot 13{,}25 + 10 \cdot 21{,}6}{12713{,}46} = 0{,}465$$

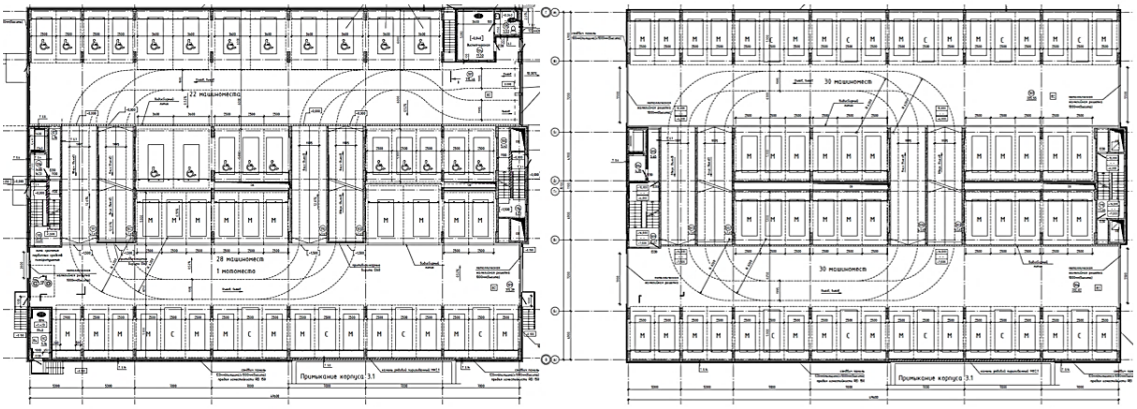

Figure 15. 1st floor and typical floor plans of the Tarmo parking

4.3.3 Analysis of the results

Calculations from the previous chapter are summarized in Table 8.

Table 8. Results of the economic efficiency calculations for different parkings

Type of parking lot	Finnish parking	Russian parking 1	Russian parking 2	Novoor-lovsky	Tarmo
Length of the parking, m	76,8	50,3	50,3	34,4	49,6
Number of parking places	634	367	379	207	440
Total area of the parking, m^2	19897	11406,24	11503,56	6096,96	12713,46
Area of one typical floor, m^2	2913	1804,92	1821,14	1035,44	1681,03
S_r, m^2	31,38	31,08	30,35	29,45	30,11
K_e	**0,430**	**0,451**	**0,462**	**0,453**	**0,465**

It turns out that sloped parkings are not much more efficient than the regular ones, and the most effective solution of all is parking Tarmo. The next effective parking is the developed project with sloping floors and one stairwell outside the building.

By the efficiency indicators, it is obvious that typical parkings with half-storey ramps have appropriate and profitable space-planning solutions. The construction of sloped parkings is suitable mostly for big plots. It is not the best decision for residential complexes.

Besides big dimensions in the plan of the parking with inclined floors, there is also a problem with the cost of its construction. Usually, multistorey parkings are made from reinforced concrete, as of all the structural materials, the requirements of strength, durability, resistance to chemical attack and fire resistance are most fully met by it. Currently, most parkings are designed and built using typical structures of industrial and civil buildings with a grid of columns with the bay around 7 m. For the sloped parkings, a complex structure of cast-in-place and precast floor slabs on prestressed cast-in-place beams without intermediate internal supports is used. According to the economic calculations made by the company YIT Saint-Petersburg, the cost of such a structure is at least 30 % more than the classical one.

5 Conclusion

Parking is an important part of any property, which largely determines its class and market attractiveness. Own parking today is one of the components of the project for a significant part of housing complexes under construction in Saint-Petersburg. Compared to the different types of parking lots, multistorey ground parking is one of the cheapest, simplest and efficient ways for accommodation of cars near residential buildings.

Multistorey parking with inclined floors is an effective solution for large areas. In conditions of dense urban development, parking lots with half-storey ramps are more suitable. The half-storey ramp layout represents simple and profitable parking design.

Theoretically, the use of sloped parkings is possible on perspective real estate objects. However, there is no such need, since their economic efficiency is not much bigger than the efficiency of other typical multistorey parking lots. What is more, there are other disadvantages of the solution:

- complex structure;
- more expensive than typical multistorey parkings;
- great dimensions of the building;

- due to the maximum allowable slope (5 %) of the floors – not very comfortable car storage conditions, no possibility for organizing extended car places for people with limited mobility (wheelchair users);
- floor-to-floor travel distance is greater than in other types of ramp garages.

Generally, the main points should be considered during developing a space-planning solution of the parking:

- maximum use of the area allocated for the construction site;
- easy storage;
- safety, convenience and minimum time spent moving the car inside the garage;
- minimum operating costs;
- the minimum specific indicator characterized by the ratio of the total area of the parking garage to its capacity;
- low cost of the parking space.

Figures

Tables

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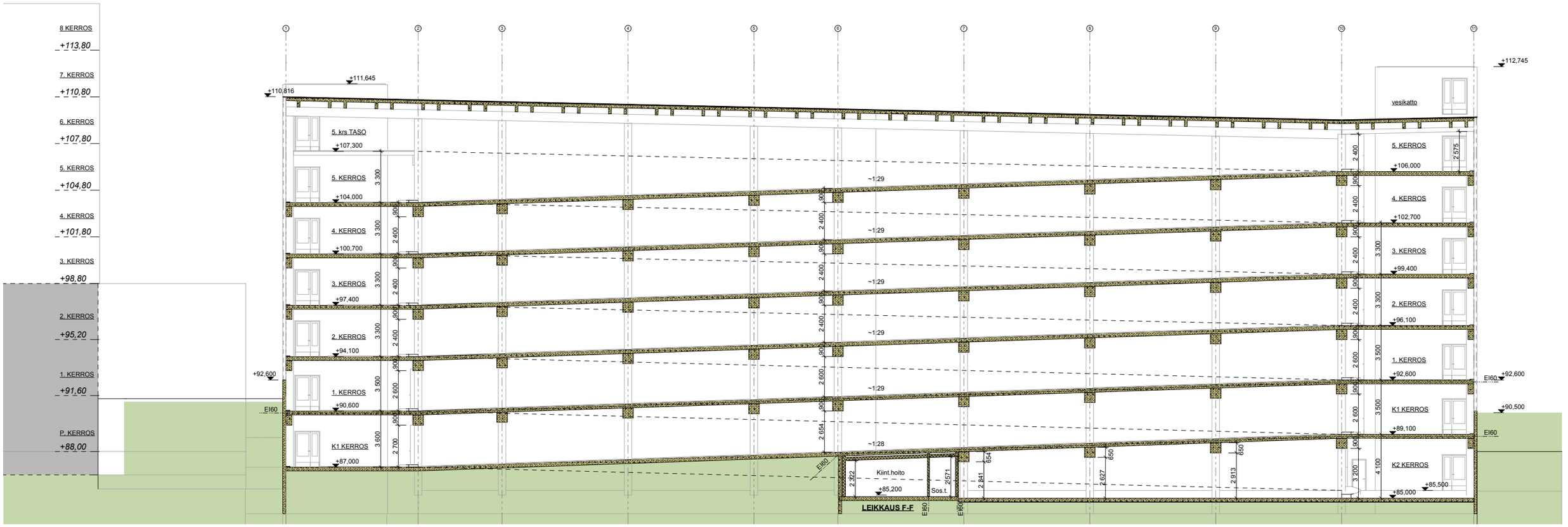
Appendix 1. The drawings of the Finnish parking lot



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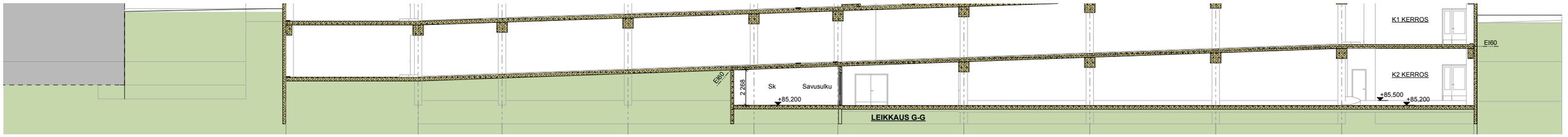

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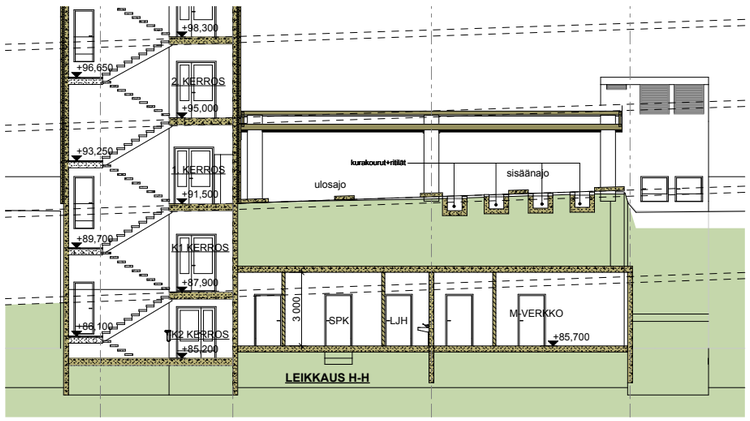

H — Leikkaus H-H — 1:250

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	Päiväys: **30.11.2016**	Projek nro: **03-066**	Piirustuksen nro: **T2.3.6**	Suunnielija: Jaska **ARK**

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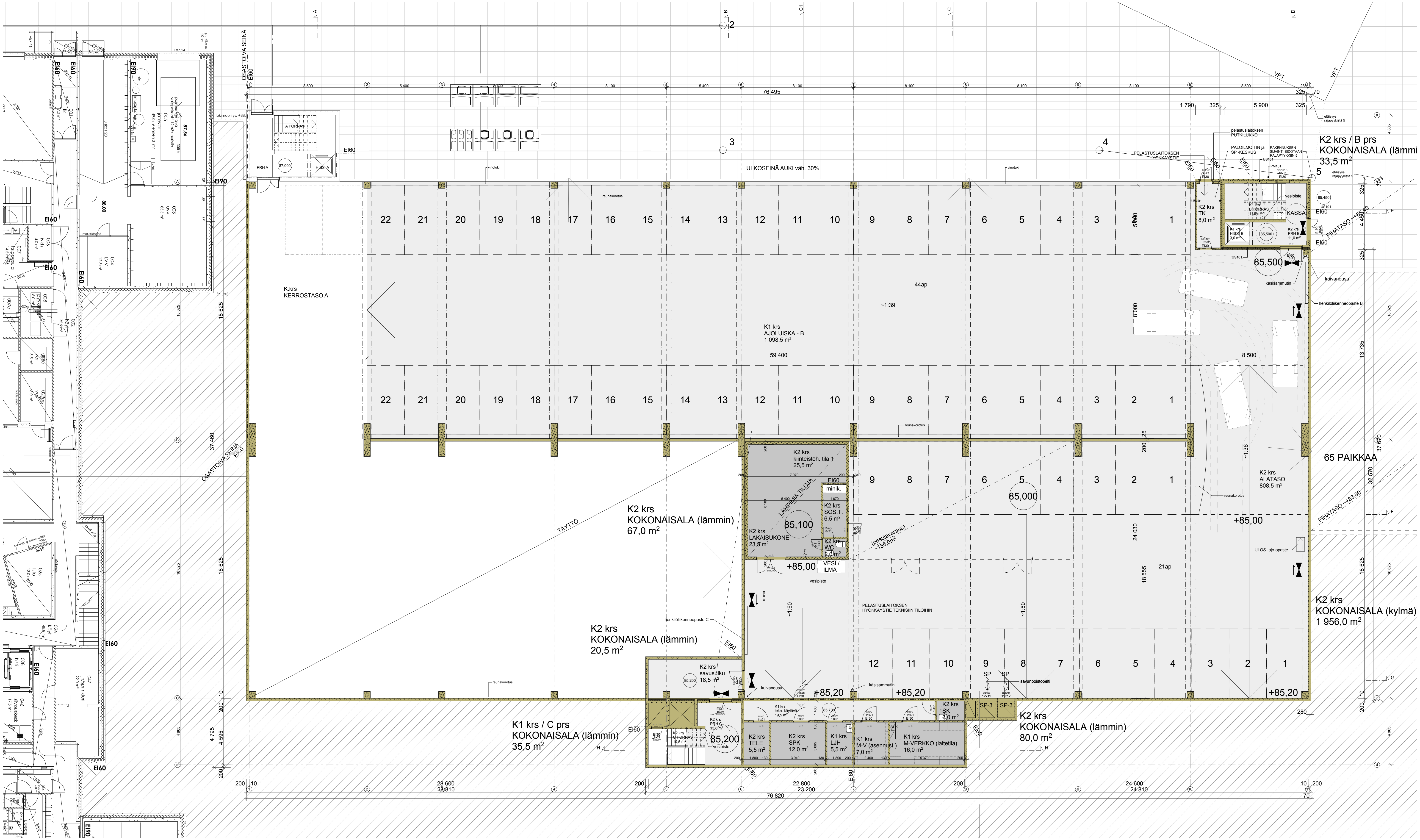

L2_

K2 KERROS

1:250

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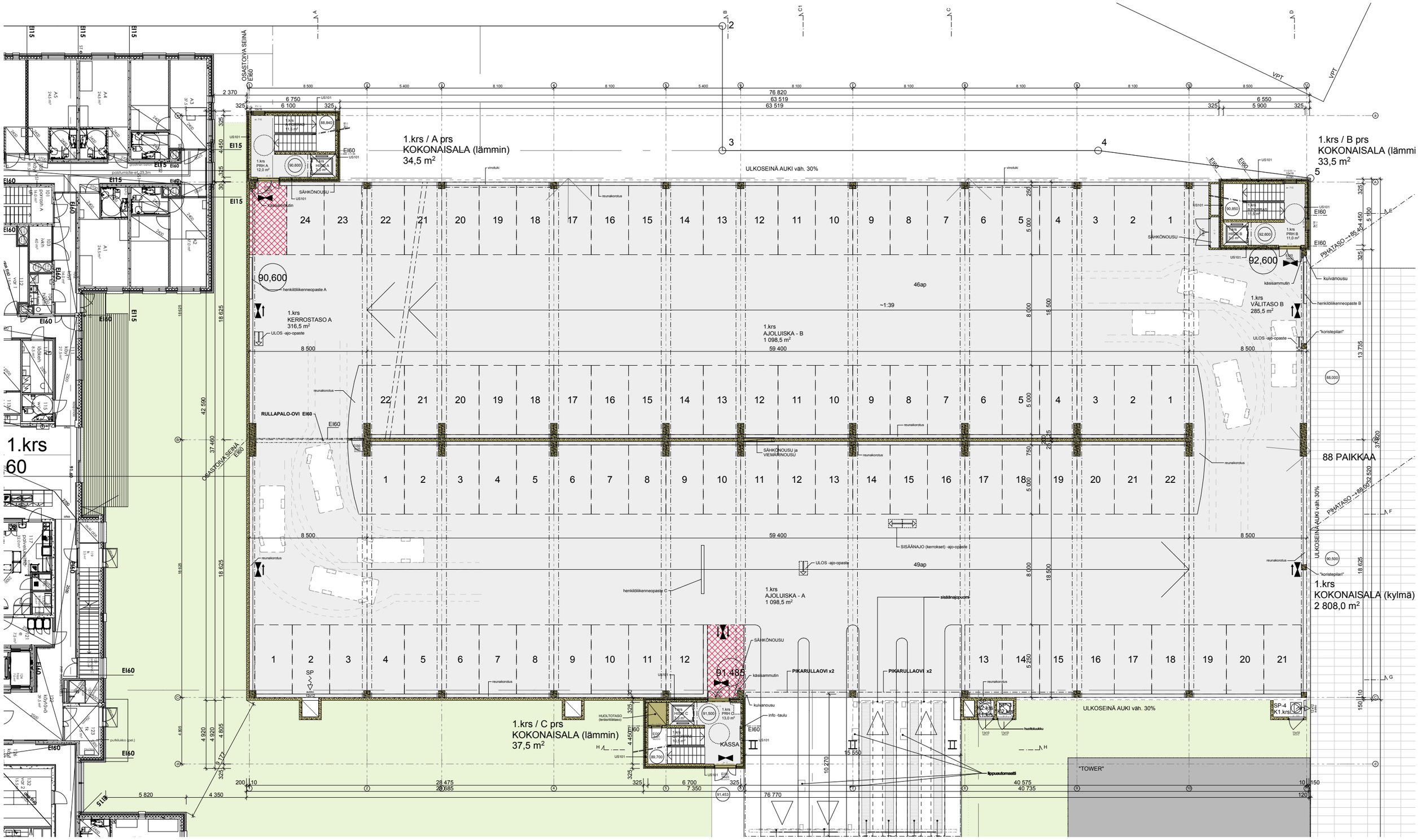

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ARKKITEHTIPALVELU.fi

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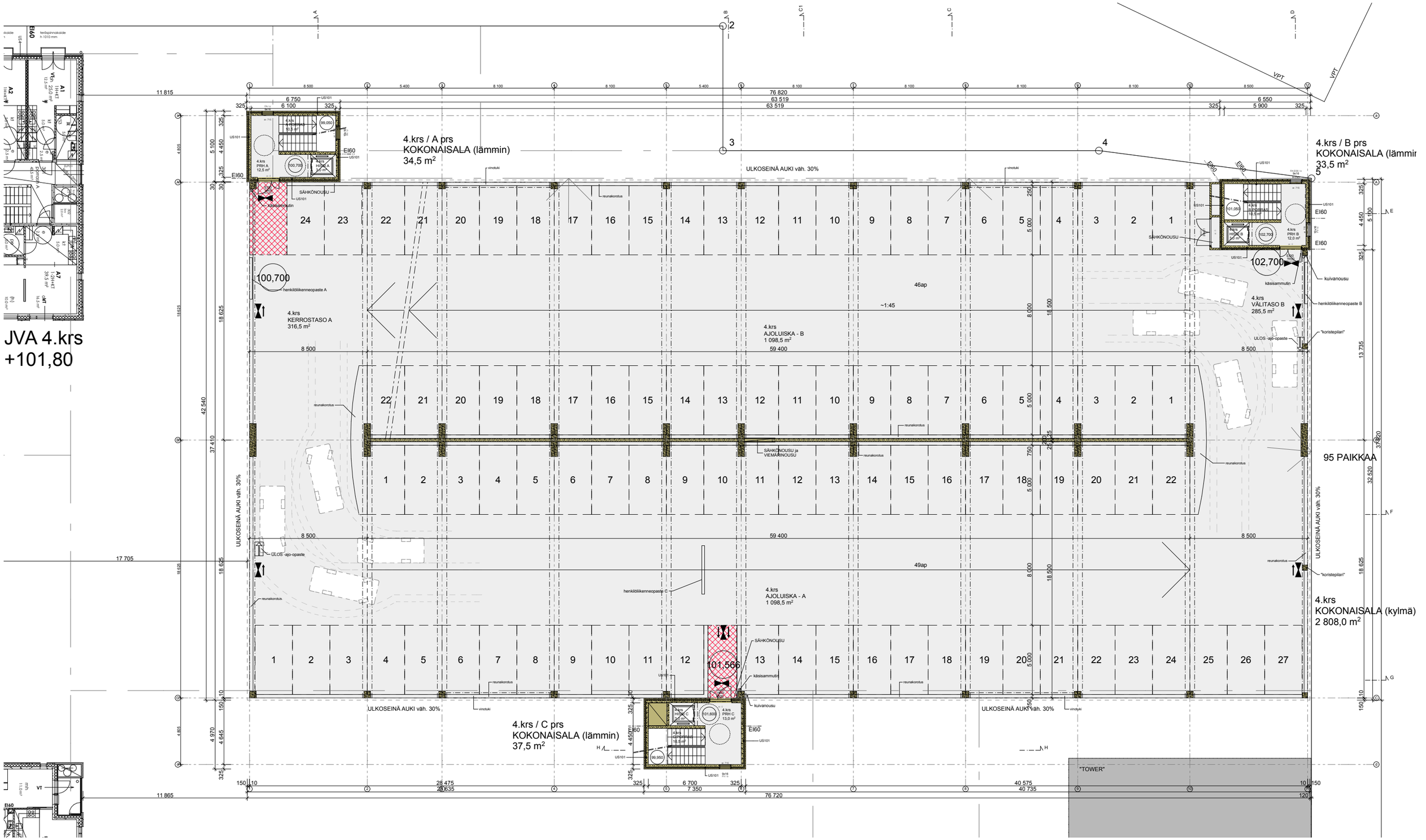

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