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VI Faculty of Engineering
Polo Regionale di Lecco

Master of Science in Architectural Engineering

Master's Thesis

SUBURBAN RESIDENTIAL SETTLEMENT «BETWEEN TWO RIVERS»

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CHAPTER 1. INTRODUCTION

The thesis is based on the competition proposed by private organization in Tver' region with the aim of creating a concept of planning and three-dimensional solution of the new suburban residential settlement "Between 2 rivers" at high quality level.

The main goals:

- Development of proposals for zoning and functional use of the territory, taking into account:
  - allocation of zones for different purposes in planning structure of the settlement
  - structure of the residential zones by type and number of storeys
  - public and business zones
  - industrial and commercial zones
  - facilities of transport and engineering infrastructure
  - recreational zones
- Establishment of characteristics of proposed development;
- Creation of clean, safe environment;
- Ensuring the future residents of all types of engineering and social infrastructure;
- Application of energy-saving technologies, use of solar energy both in passive and active variant, use of wind energy;
- Providing for the establishment of a certain number of jobs in the service, trade, education, health, etc.
- Use of the favorable landscape for recreational areas, sports;
- Providing of high quality habitat with the optimal level of costs for the construction as well as for operation.

Supposed use of the site:

- Residential
- Recreational
- Commercial
- Public and business
- Industrial

CHAPTER 2. URBAN DESIGN

2.1. INSTANCES

2.1.1. About the site

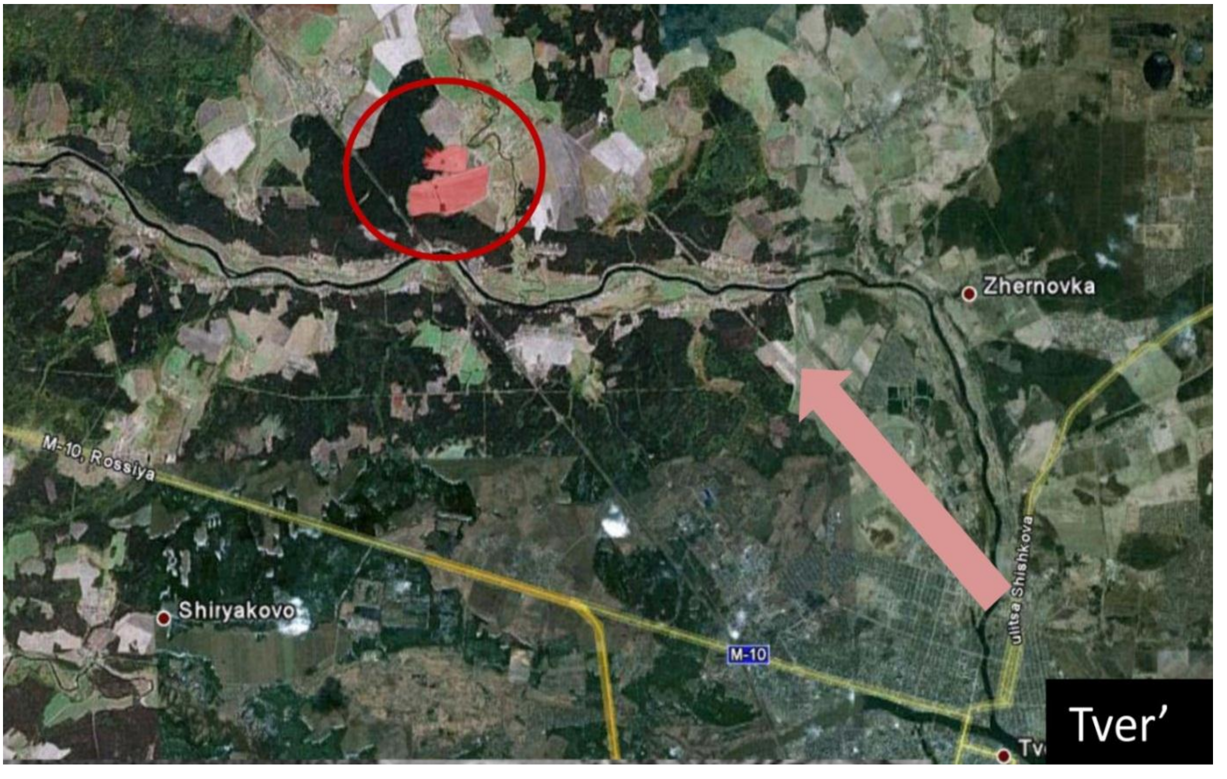


Figure 2.1. Location of the site

Location
The site is situated in *22 km* to the north-west from Tver'.
Area – *164,51 ha*
Allowed use
Low-rise buildings up to 3 storeys with infrastructure
Relief
Almost flat terrain
Geology
Mainly sand

Figure 2.2. Plan of the site

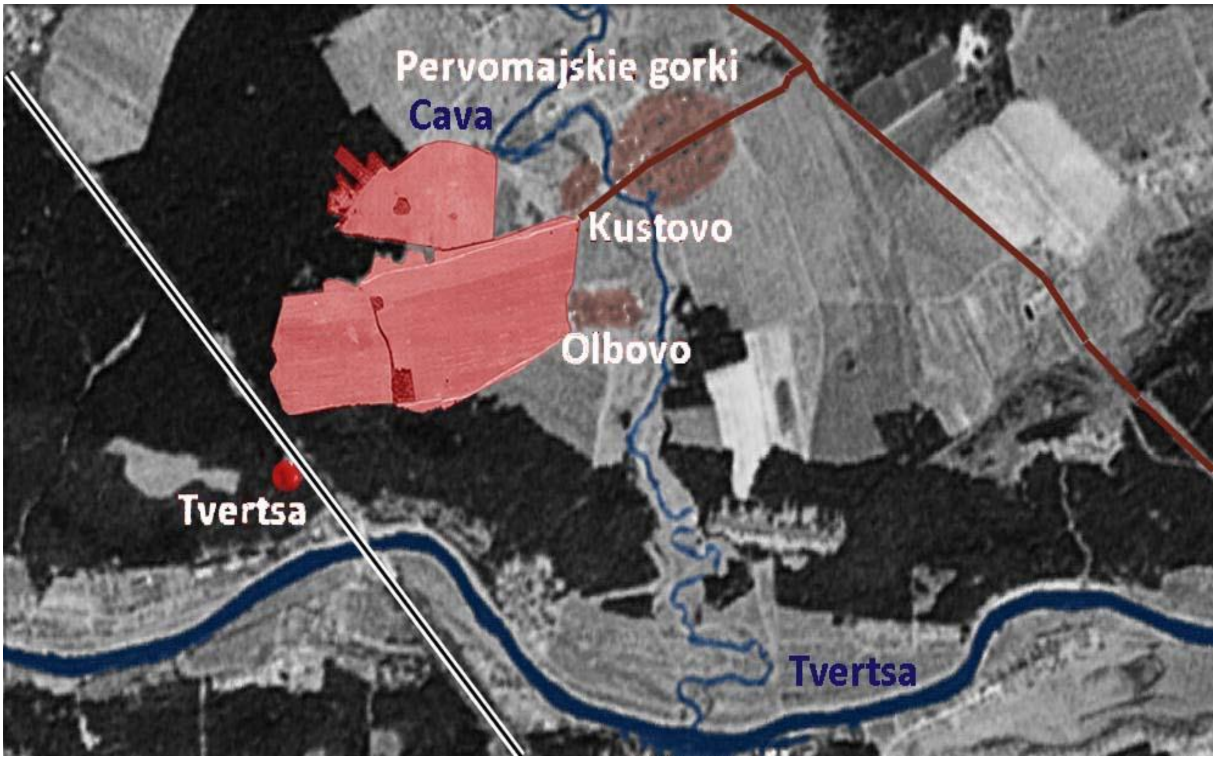


Figure 2.3. Surroundings

Surroundings

Close to the borders of the site there are rivers Tvertsa (*600 m*) and Cava (*300 m*). The site is surrounded by coniferous woodland (magnificent pine forest) from 3 sides. There are villages "Olbovo", "Kustovo" and "Pervomajskie Gorki", adjacent to the site.

Figure 2.4. Panoramic view of the site

Figure 2.6. View of the site

Figure 2.5. Panoramic view of the site

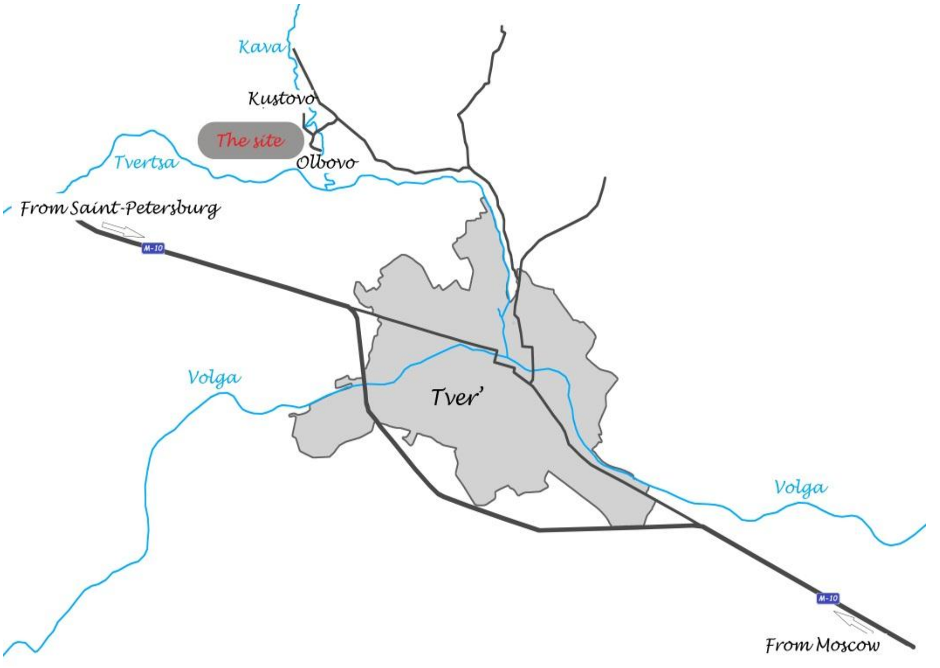


Figure 2.7. Access to the site

Transport

Railway station "Tvertsa" (*150 m*); road with asphalt, that gives the possibility to access the complex all over the year.

Electricity

There electricity lines on the borders of the area

Gas – *500 m*

Figure 2.8. Railway station «Tvertsa»

Figure 2.10. Eastern border of the site

Figure 2.9. View from the railway station

2.1.2. Competition task

On the territory of suburban residential settlement «Between 2 rivers» can be located:

- Individual houses with a total area from 150 to 250 m^2 (2-3 storeys) with plots from 1000 to 3000 m^2;
- Manor complexes with plots from 1 to 10 hectares;
- Access roads and footpaths with asphalt;
- Open recreational areas;
- Parking;
- Buildings and structures for engineering infrastructures;
- Sports facilities (tennis courts, football and basketball fields, a platform for extreme sports, skiing, stands for the bullet shooting, etc.);
- Shops;
- Kindergarten;
- School;
- Hotel;
- Medical center (motherhood and childhood, rehabilitation, medical care for the elderly);
- Training camp;
- Administration;
- Buildings of protection;
- Beach area around natural and artificial reservoirs;
- Territory of children's summer camps.

2.2. KNOWLEDGE

2.2.1. Kalininskij district

Figure 2.11. Russia

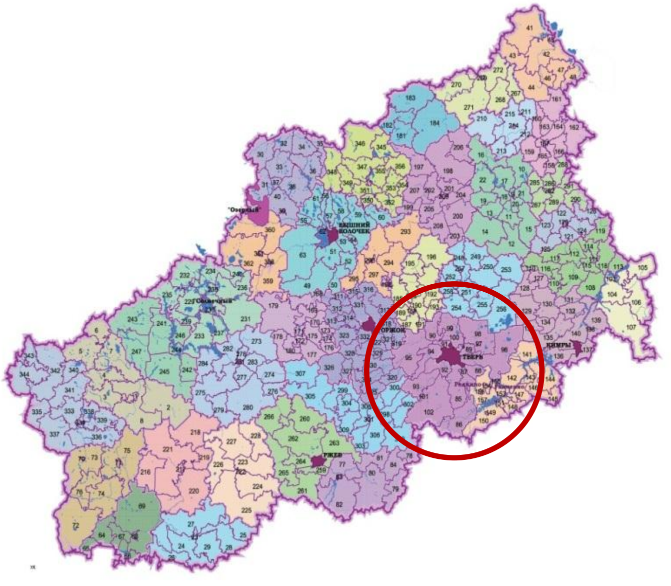


Figure 2.12. Tverskaya region

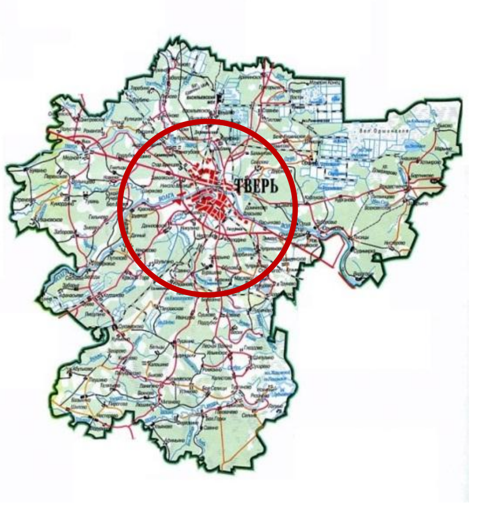


Figure 2.13. Kalininskij district

Kalinin district is an administrative unit in the southeast of the Tverskaya region of Russia.
Administrative center is the city of Tver’.
Its square is *4244,7 km²*. It is the biggest district of the region.
The population of the district on January 1 2009 is *48 610* people.
The main river is Volga, which crosses it from east to west in *95 km* (including Tver’).

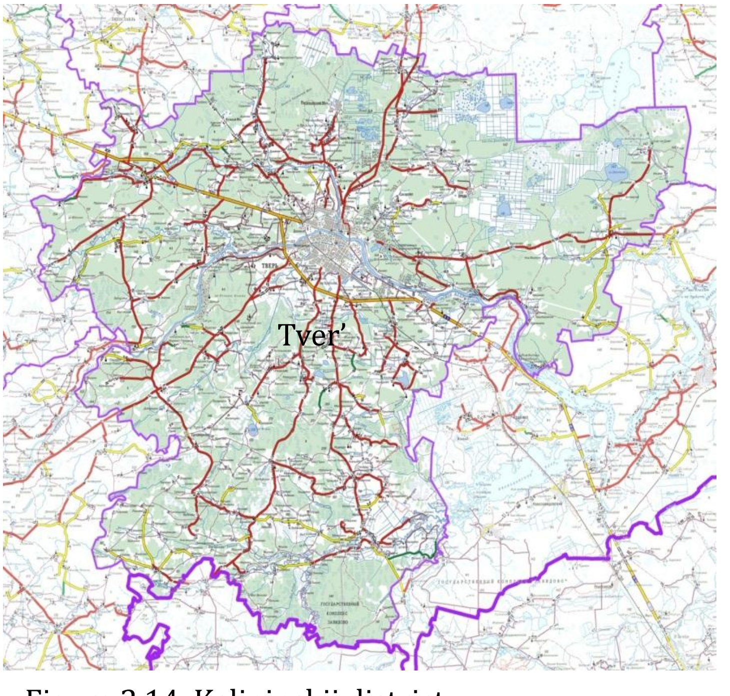


Figure 2.14. Kalininskij district

2.2.1.1. Functional zoning

By predominant type of functional use the territories within the boundaries of the distroct are divided on:

- **Urban zones**
  - **Residential and industrial zones** of towns and settlements, corridors and grounds of engineering and transport communications (transport corridors, electricity transmission lines, transit gas and oil pipelines, domestic waste landfills, industrial waste landfills, airports, river ports)
  - **Special zones** (obkects of defense, security, lands of Ministry of the Interior and other lands of special purpose)
  - **Deposit** of building sand «Hvostovskoe», deposit of silica sand in Tver' restricted zone
- **Zones of forestry**

The zones are located almost all over the district. The highest consentration is in south-western and eastern parts of the district.

- **Agricultural zones**

The zones are concentrated mainly in the central parts of the district in suburban areas of the city of Tver' (in the south, south-west, north and north-western part of the suburban area around Tver'). Also they are located in the area of Sakharovo, Bele-Kushalskoe and in Burashevskoe rural settlement in the area of village Iliinskoe.

- **Resreational zones**

These are the zones in which tourism and recreation facilities are concentrated, including sites of historical and cultural value as well as natural and mineral resources for health and recreational purposes. They include the area of recreational facilities, resorts and tourist complexes.

- **Zones of nature protection**

The zones include protecting forest, protecting strips of forest along roads and railways, forests of sanitary protection of health resorts and specially protected natural areas.

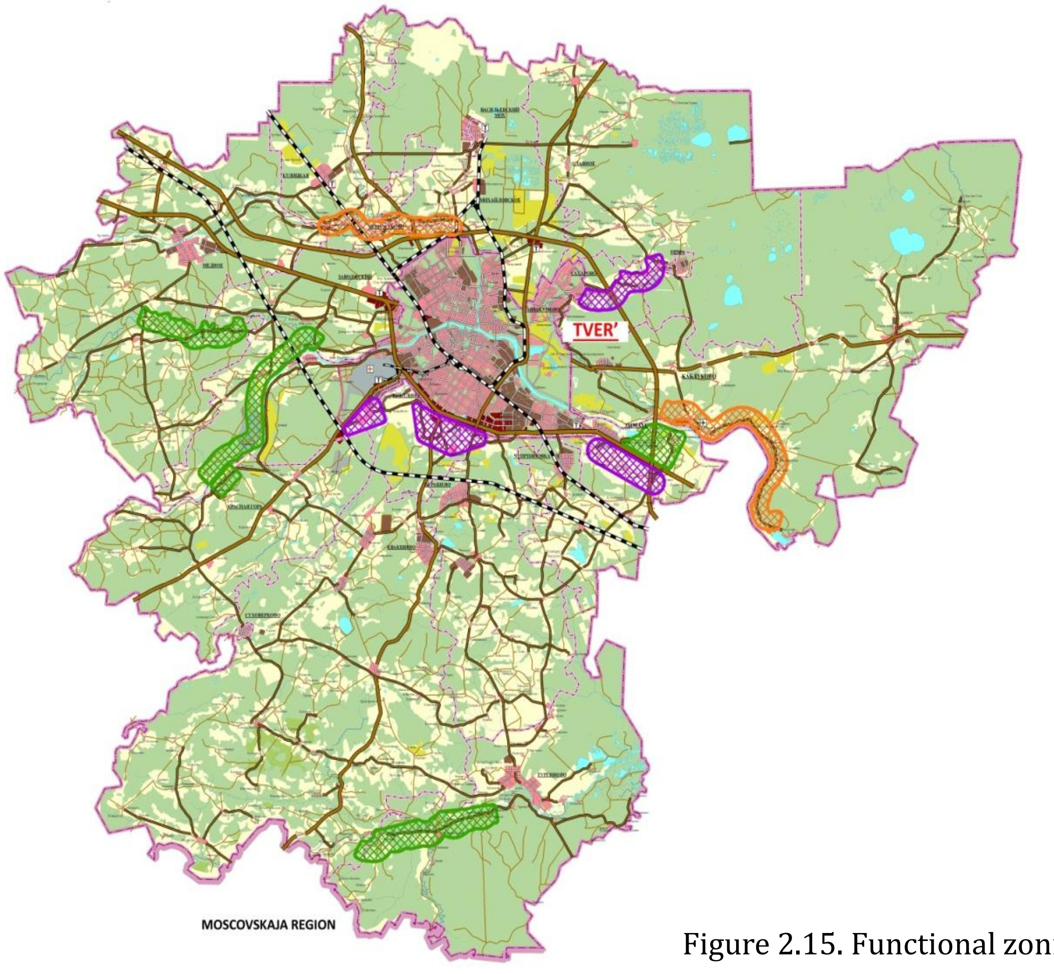
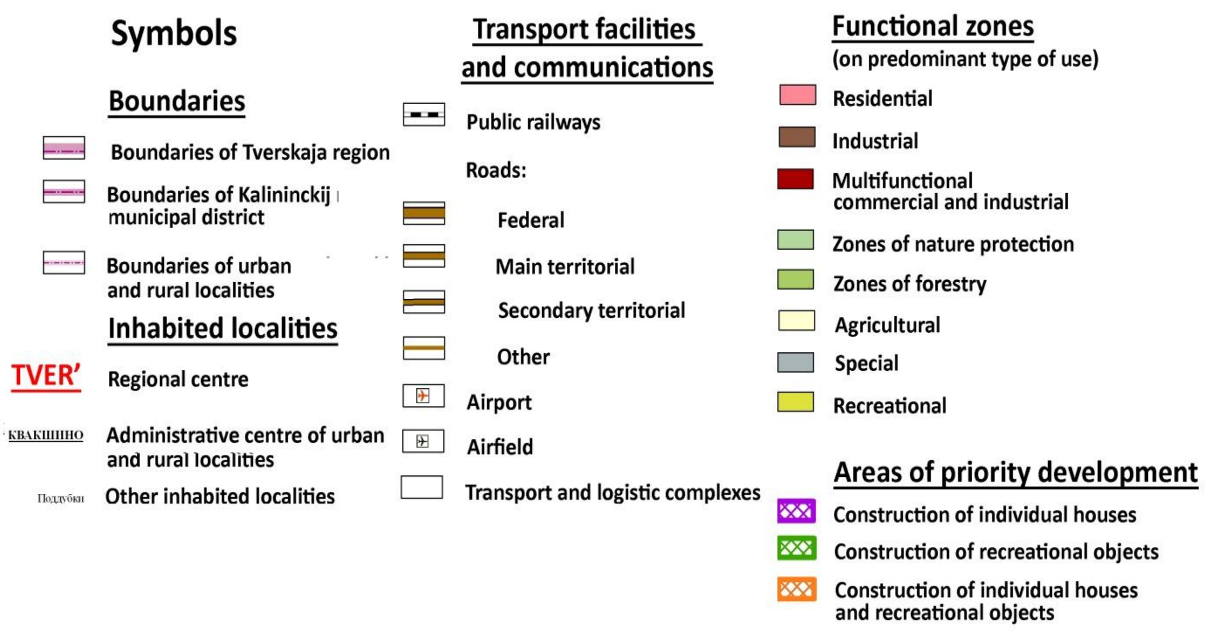


Figure 2.15. Functional zoning



2.2.1.2. Planning restrictions

Landscape planning restrictions

By ease of urban development the territories within the boundaries of the distroct are divided on:

- **Favorable** (not requiring engineering preparation)
  - Hilly watersheds composed of boulder loam and boulder-pebble deposits. Depth to groundwater within these areas is up to *10 m* or more.
  - Gentle slopes of the watersheds are composed loam, gravel and sand deposits. Depth of groundwater with these areas is *2-10 m*.
- **Limitedly favorable** (requiring simple engineering preparation)
  - High terraces formed by alluvial deposits of shallow groundwater
  - Flat plains formed by glacial-lake sediments (loam, clay, loam, sand), with the development of flooding and waterlogging
- **Severe** (requiring complicated engineering preparation)
  - Low terraces formed by alluvial deposits of shallow groundwater, flooded by high water
  - Floodplains of small rivers and streams with shallow groundwater, flooded by high water
  - Wetlands, formed by loam and peat with thickness of *7 m*

Territories favorable and partially favorable for industrial and civil construction are the majority part of the district, about *85%* of the territory. Unfavorable territories for the development are characterized by shallow groundwater level, the risk of flooding and low strength properties of soils. They include the flood plains and low terraces above the flood plains as well as wetlands with peat thickness of *2 m* or more. Peat wetlands in the district occupy considerable area. The largest of them is Orshanskij Moh. Its area is *68 ha*. It is located in the northeastern part of the district. Wetlands with large peat deposits are unsuitable for urban development.

Technogenic planning restrictions

- **Territories, that cannot be the subject of urban development**
  - Sanitary protection zones of underground water intakes of I selt
  - Gas pipeline corridors
  - Sanitary protection zones
- **Territories of mineral deposits**
- **Territories with urban development regulation**
  - Sanitary protection zones of underground water intakes of II selt
  - Zones of air way to the airfield
  - Noise zone from airfield
  - Noise zone from railway

Nature planning restrictions

- **Especially protected natural territories**
  - State complex «Zavidovo»
  - State natural wildlife preserves
  - Monuments of nature
- **Territories with urban development regulation**
  - Protection zones of reservoirs and waterways

Objects of negative impact on environment

- **Territories of industrial factories**
- **Agricultural facilities**
  - Truck-tractor stations
  - Stock-bleeding complexes
- **Waste disposal objects**
  - Animal refuses
  - Dumps
  - Storages
  - Fields of filtration

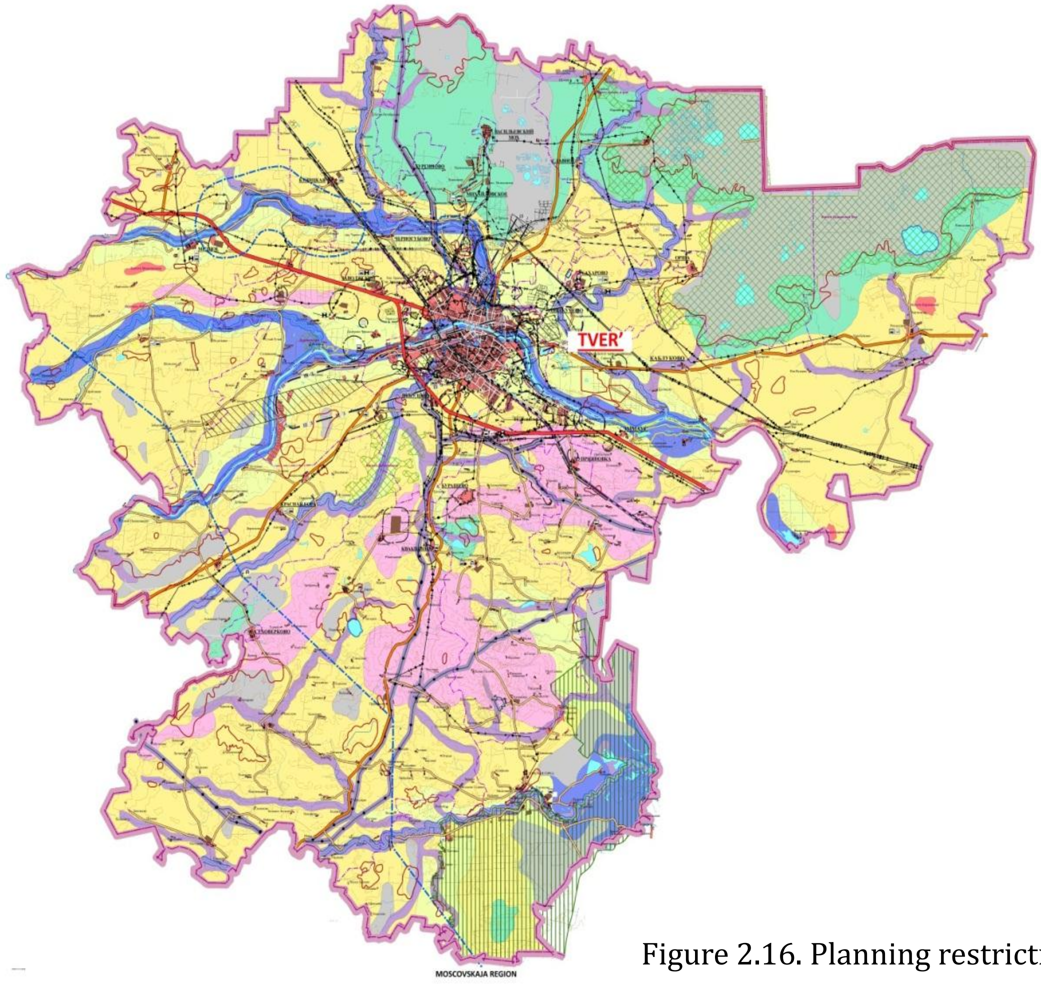


Figure 2.16. Planning restrictions

Symbols

Landscape and construction zoning

(types of relief in the degree of suitability for urban development)

Favorable (not requiring engineering preparation)

- Hilly watersheds formed by boulder loam and boulder-pebble deposits Depth to groundwater within these areas is up to 10m or more
- Gentle slopes of the watershed formed by loam, gravel and sand deposits Depth of groundwater within these areas is 2 - 10m

Limitedly favorable (requiring not difficult engineering preparation)

- High terraces formed by alluvial deposits with shallow groundwater
- Flat plains formed by glacial-lake sediments (loam, clay, loam, sand) with the development of flooding and waterlogging

Not favorable (requiring difficult engineering preparation)

- Low terraces formed by alluvial deposits with shallow groundwater, flooded by high water
- Floodplains of small rivers and streams with shallow groundwater, flooded by high water
- Wetlands, formed by loam and peat with thickness of 7m

Technogenic planning restrictions

Territories that cannot be subject of urban development:

- Sanitary protection zones of underground water intakes of I selt
- Gas pipeline corridors
- Sanitary protection zones

Territories of mineral deposits:

- Clay
- Silica sands
- Building sends
- Sand and gravel materials
- Peat

Territories with urban development regulation:

- Sanitary protection zones of underground water intakes of II selt
- Zones of air way to the airfield
- Noise zone from airfield
- Noise zone from railway

Nature planning restrictions

Territories that cannot be subject of urban development

Especially protected natural territories:

- State complex "Zavidovo"
- State natural wildlife preserve
- Monuments of nature

Territories with urban development regulation:

- Protection zones of reservoirs and waterways

Objects of negative impact on environment

- Territories of industrial factories

Agricultural facilities

- Truck-tractor stations

Stock-breeding complexes

- - Cattle-breeding complexes
- - Pig-breeding complexes
- - Sheep-breeding complexes
- - Horse-breeding complexes
- - Fur-breeding complexes
- Poultry farms

Waste disposal objects

- Burial ground for animal refuse
- Burial ground for anthracic animals refuse
- Dumps
- Mineral fertilizer storages
- Pesticide storages
- Fields of filtration

2.2.1.3. Economic activity organization

Industry

- **Extractive industry**
  - **Peat**

    Tverskaya region has the richest reserves of peat from all regions included in the Central economic region of Russia. By the scale of peat extraction the region takes one of the first places in Russia. Most of the peat resources are concentrated in the Kalininskij region (*14,5%* of total reserves). Peat extraction in the Tverskaya region was carried out in eight peat deposits. Now, only five deposits are developed.
  - **Saproleric resourses**

    Sapropel is used in the treatment (physical therapy) practice for applications, mud baths in mud treatment. In agriculture, the sapropel is used as fertilizer. Most of sapropelic deposits in the Kalininskij region may be associated with the lakes located in the peat deposits. Considerable areas of sapropelic sediments are available in the ecosystem Orshinskij Moh. The development of production is complicated because of weak knowledge and high labour-intensity of extraction. Currently, in the district in the settlement Burashevskoe the company "Tverskaya sapropel“ operates. The company is engaged in sapropel extraction and in production of mineral raw materials for chemical production.
  - **Building materials**

    In the district there are 11 deposits of sand and gravel materials and building sands. Currently, only 2 deposits are developed, Hvastovskoe and Izbizhskoe. There are 2 deposits of brick and tile raw materials (low-melting clays) and 3 deposits of silica sands.

- **Construction industry**

Construction industry is represented by plants "Chupriyanovskaya DPMK" in the settlement Zmeevo and "Kalininavtodor" in the village Strelnikov. Enterprises are engaged in the production of asphalt concrete mixtures of different brands.

- **Metallurgical industry**

Products of metallurgical industry makes up 40% of all industrial products. (39% - processing of metal waste and scrap, and 1% - metallurgical production and production of finished metal products). The industry is represented by the enterprise "KATEL" in the village Pasynkovo, which is engaged in the processing of metal waste and scrap. Also in the settlement Mettallurg there is an enterprise engaged in steel production and production of finished metal products (production of structural steel).

- **Chemical industry**

The enterprise «Vasiljevskij Moh» in the settlement «Vasilijevskij Moh» besides peat extraction is engaged in production of synthetic resins and plastics.

- **Forestry and woodworking industry**

Forestry and woodworking industry is represented by the enterprise «Kalininles» in the settlement Dmitrovo-Cherkassy, which is engaged in transportation of wood. In the villages «Zmeevo» and «Rilovo» there are 2 woodworking enterprises, which deal with cutting of wood. In the settlement «Nikol'skoe» there is woodworking shop.

- **Machinery construction**

Machinery construction is represented by the enterprise «Kulitskij EMZ» , producing electric motors. The sector is only 1% of the total industrial production.

- **Light industry**

Light industry is represented by 6 enterprises, which deal with production of clothing. The sector is only 0,5% of the total industrial production.

Agriculture

- **Plant growing**

Currently, areas under fodder crops make up *68%* of all areas under crops in the district. *16%* of all areas under crops is occupied by grain crops and *12%* is occupied by potatos.

For satisfying the needs of population of the city and the district in potatos at a rate of *110 kg* per person with crop capacity of *300 centners* per hectare it is advisible to have about *1800-2000 ha* of arable lands to the settlement date while *4300 ha* of arable lands are available. So, the district not only fully satisfies its own needs in potatos, but also it can satisfy the needs of neibouring districts of the region.

The main producer of potatos is agro-industrial complex «MIR». 11 farms (*31%)* are engaged in potato growing. Major producers of potatos are also peasant farmers.

The main producer of vegetables is the enterprise «Kalininskoe». In 2007, growers of the enterprise "Kalinin" grew *7,6 thousand tons* of environmentally safe vegetables in a wide range, including tomatoes, cucumbers, peppers, eggplants, marrows, cabbage, carrots, beets. In the farms of inhabitants *29 thousand tons* of vegetables were grown.

- **Animal breeding**

Leaders in animal breeding are pig and poutry industries. The district takes the first place in pig breeding (*90%*). The number of pigs is *62,9 thousand* heads, *97,8%* of which is bred by pedegree plant «Zavolzhskoe». Also the district takes the second place in poutry breeding (*49,7%*).

Currently, in the district there are 35 large and relatively large agricultural enterprises (including 2 state enterprises) with a total area of farmland of *73,3 thousand* hectares, including *50,8 thousand hectares* of arable land, 254 peasant farmers and other enterprises.

In 2007 the number of cattle of all categories was 13.1 thousand heads, including *6,2 thousand* cows, *65,8 thousand* pigs, *800,5 thousand* birds, *3,3 thousand* sheep and goats, *177* horses, *1,152* bees. There is some decline in the number of cattle, including cows, while pigs and poultry population tends to increase.

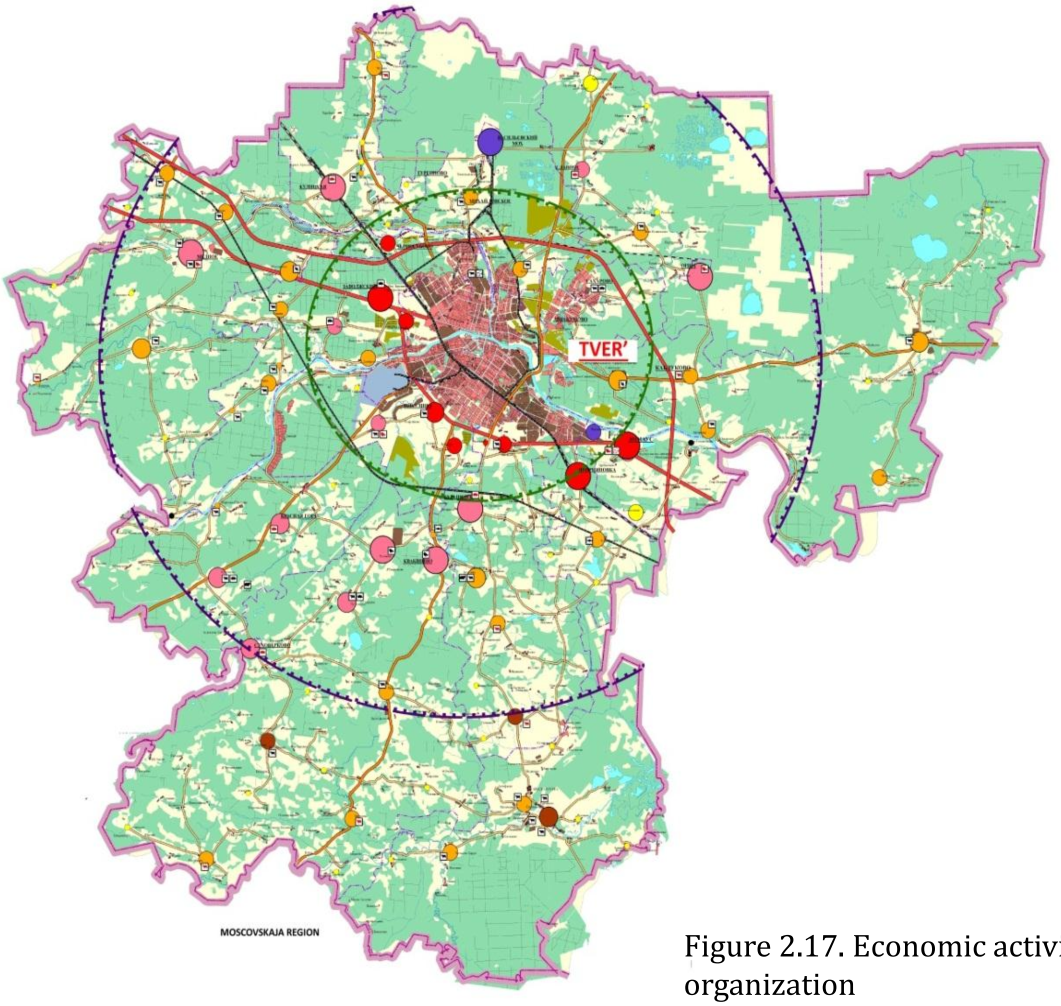
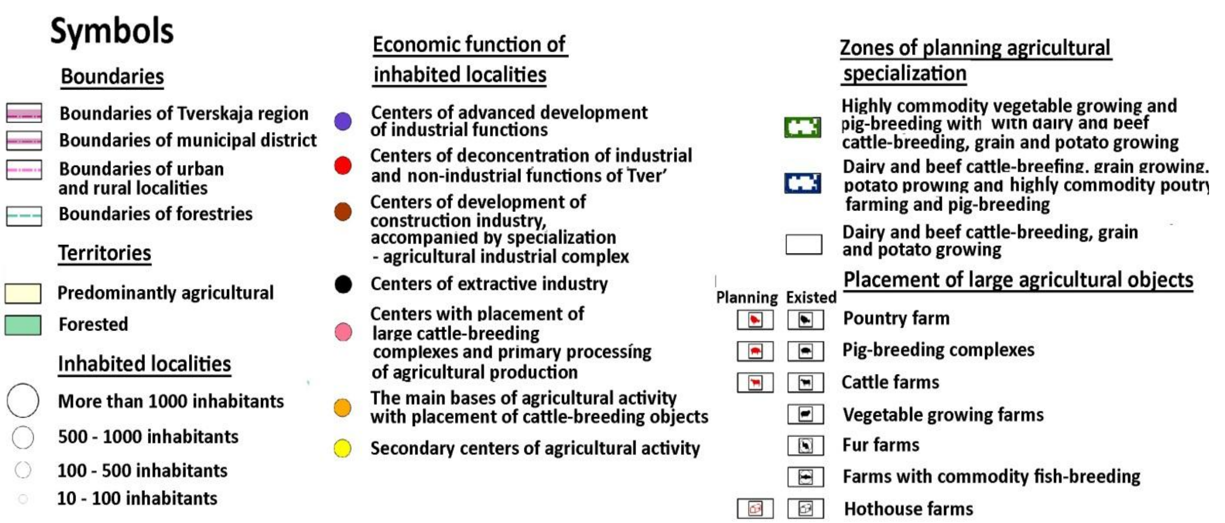


Figure 2.17. Economic activity organization



2.2.1.4. Transport

Rail transport

Octyabr'skay railway (Moscow – Saint-Petersburg) runs through the whole territory of the district. Moscow branch of Octyabr'skaya railway carries transportation of goods and passengers. The size of traffic depending on the season is *80-110* pairs of freight and passenger trains a day.

Motor transport

The total length of regional roads in the district is *861,7 km*, from which *42,5 km* are in the city. Passing through the territory of the district road network includes:

- Federal Highway Moscow - St. Petersburg
- Roads of territorial significance for communication of the district with other districts and the northern part of Moscovskaya region, as well as serving almost all the settlements of the district
- A number of roads in agricultural and forestry enterprises, the Ministry of Defense and recreational facilities

Air transport

Air transport in Kaliniskij district is represented by airfields «Zmeevo» and «Volzhanka». In Tver' there is airfild «Migalova».

Water transport

In Kalininskij district inner water transport functions. Within the boundaries of the district the main shipping route is river Volga. In the water area of river Tvertsa small-size and pleasure fleet is mainly used. The duration of navigation is 200-210 days. Complex of devices of water transport of the district primarily serves freight transportations of the city of Tver' and performs transshipment operations in mixed motor and water communication. The main function is transportation of building cargos. Passenger transportation is carried out within the framework of cruises on the river Volga and for recreational transport in suburban gardening farms. In the area there are a number of passenger piers located on the river Volga, above and below the city of Tver'.

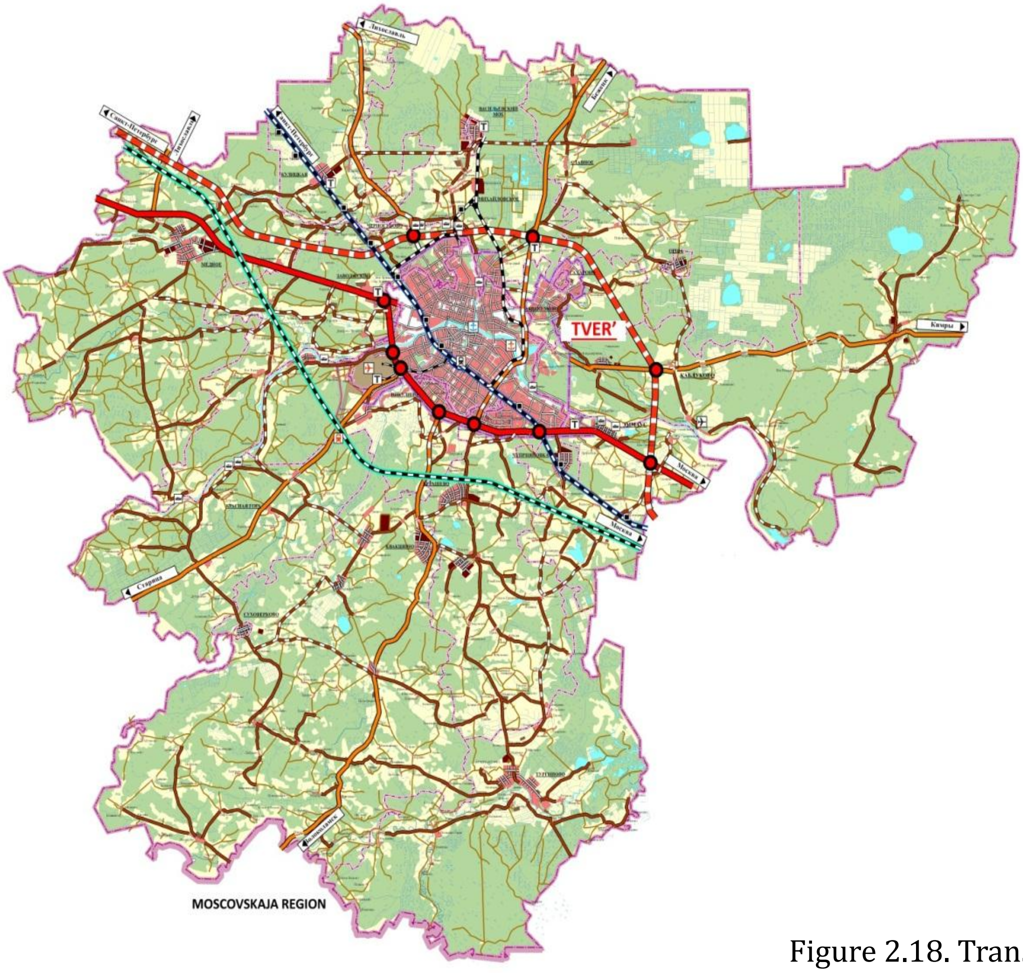


Figure 2.18. Transport

Symbols

Boundaries

- Boundaries of Tverskaja region
- Boundaries of Kalininckij municipal district
- Boundaries of urban and rural localities

Inhabited localities

- TVER' — Regional centre
- КВАКШИНО — Administrative centre of urban and rural localities
- Поддубки — Other inhabited localities

Categories of land

- Agricultural
- Forest
- Inhabited localoties
- Special

Transport facilities and communications

Railways

Public

- High-speed railway
- Electified
- On diesel traction

Departmental

Railway stations

Stopping points

Public roads

- Highway
- Federal
- Main territorial
- Secondary territorial
- Others

Interchange at different levels

Water transport

- Cargo port
- Passanger port
- The main mooring points of water transport

Air transport

- сущ. Airports of federal and international lines
- Airfields of small aircrafts

Interaction of modes of transport

- Transport and logistic complexes

2.2.1.5. Engineering infrastructure

Electric power supply

Electric power supply of consumers of Kalininskij district is carried out by the enterprise «Tver'energo», a member of Conjoint system of center. Currently, electric supply of consumers is carried out from the outer ring of the *110 kW* network, from networks *35, 10* and *6 kW*, as well as from the transit 330 kW network through the substation Kalininskaya.

Heat supply

The main sources of heat in Kalininskij district are gas-fired and coal boilers as well as group industrial and individual heating boilers.

Gas supply

Kalininskij district is crossed by gas pipelines "Serpukhov - St. Petersburg", "Belousovo - St. Petersburg", "Ukhta - Torzhok." The total length of sections of gas pipeline crossing the territory of the district is 104 km.

Since 2005, the Tverskaya Region is part of the Programme of gasification of Russian regions. In order to further the development of gasification of the region and to improve socio-economic conditions of the population Regional Administration adopted Regional target programme "Gasification of Tverskaya region in 2007 - 2009." In the result of implementation of the Programmes construction of a number of inter-settlement gas pipelines of Kalininskij and other districts was carried out. At the expense of means of the region construction of intra-settlement gas networks is carried out.

Natural gas is one of the main fuels used by municipal boilers in gasified settlements. Currently, the level of gasification of the Kalininskij district is *52%.*

The existing transmission system of the district includes trunk gas pipelines, inter-settlement gas pipelines and gas distribution stations. The length of the trunk gas pipelines crossing the territory of the district is *104 km*. On the territory of the Tver' and Kalininskij district there are 7 gas distribution stations.

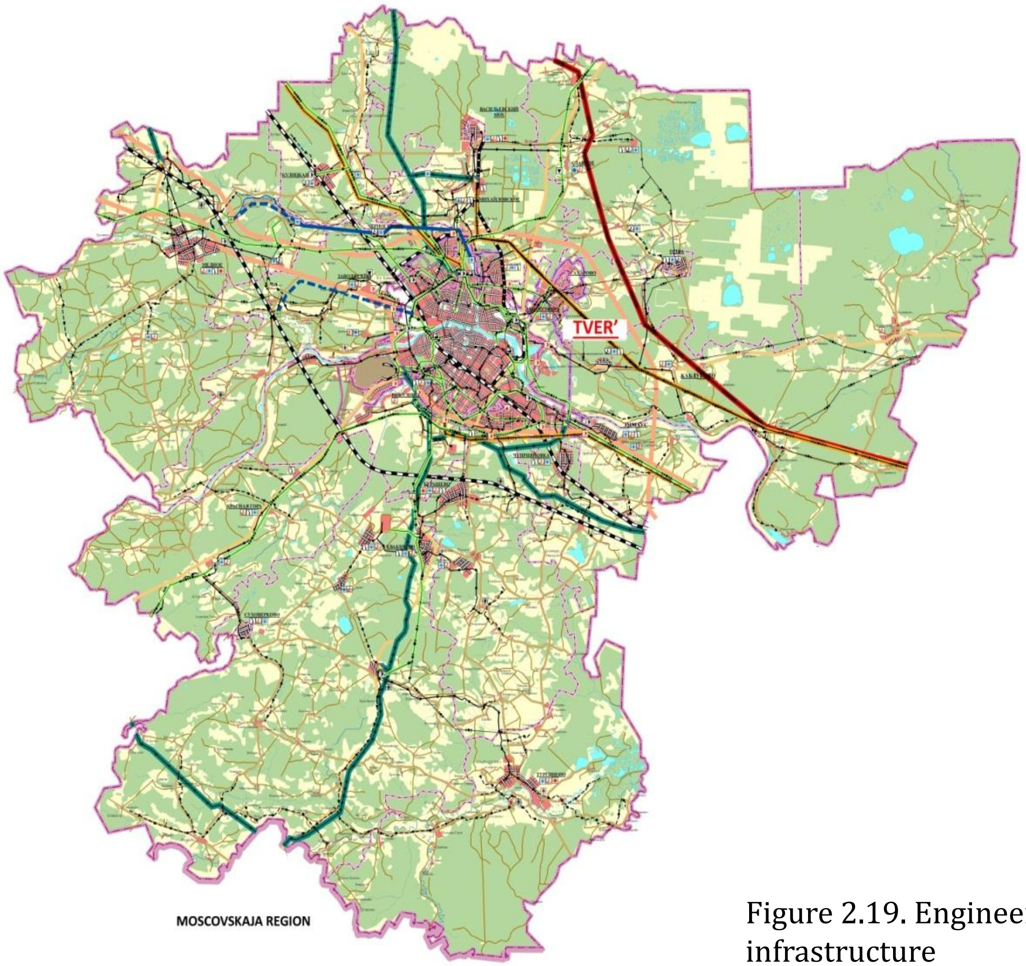
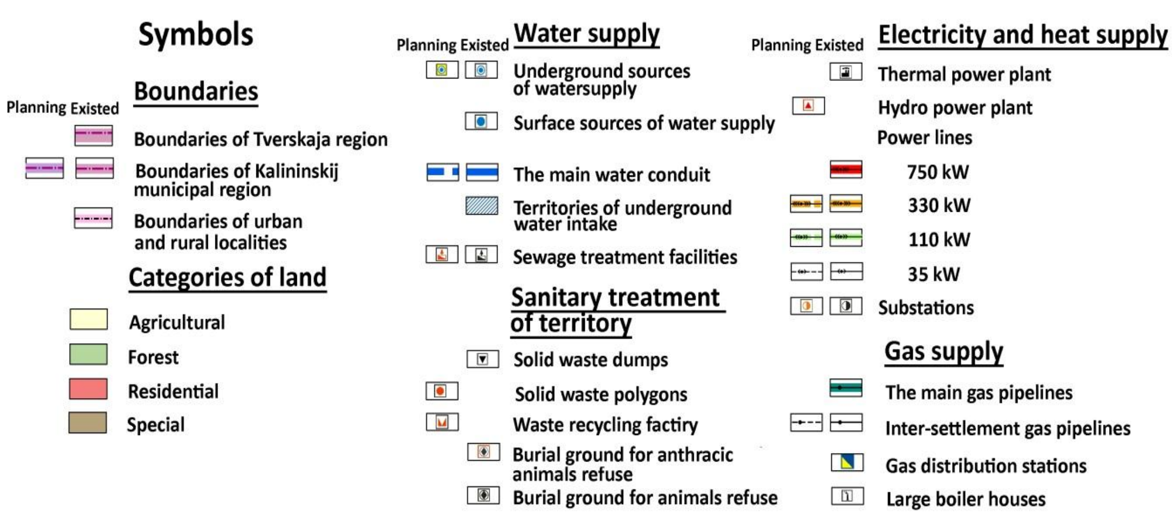


Figure 2.19. Engineering infrastructure



2.2.1.6. Analysis of state of environment

Air pollution

The level of air pollution of Kalininskij district is formed by emissions from industrial and municipal-storage enterprises, motor vehicles. Stationary sources of emissions of harmful substances into the atmosphere are represented by metallurgical, machinery construction and metalworking enterprises, heat source (boiler), chemical and woodworking industry enterprises, construction industry, food and light industry enterprises. The main air pollutants of the district are: the enterprises "KATEL“, "Chupriyanovskaya DPMK“, "Tveravtodor“, objects of heat and power engineering, boilers.

In recent years, there is a tendency to reduce pollutant emissions from stationary sources on the territory of the entire Tverskaya region. It is linked with reduction of production volumes, increase of gas in the fuel balance, implementation of measures for air protection.

Surface water pollution

Water fund of Kalininskij district is represented by 46 rivers, 2 lakes, a large number of wetlands. The largest rivers are Volga, Tvertsa, T’maka, Orsha.

Sources of surface water pollution in the district are:

- Discharges of inadequately treated wastewater of industrial and agricultural enterprises
- Discharges of inadequately treated sewage
- Discharges of storm sewage, not equipped with sewage treatment facilities
- Settlements without sewer system
- Discharges to water bodies in case of accidents on sewer network
- Technogenic fallout of impurities

The main water bodies of the district are characterized as moderately polluted, river T’maka is characterized as polluted.

Groundwater pollution

In the result of anthropogenic impact groundwater change its physical, chemical and biological properties. The main anthropogenic sources of nitrogen compounds in groundwater are mineral and organic fertilizers, gas and smoke emissions of enterprises, the gaseous products of fuel combustion, sewage of industrial and agricultural enterprises, municipal and domestic sewage. Ammonia and nitrates are emitted in groundwater mainly from treatment plants of industrial and agricultural enterprises. Centers of groundwater pollution with nitrites are linked mainly with agricultural objects (fields of filtration, settling tanks).

Soil pollution

Soil is depositing environment, preserving received pollution for a long time. Technogenic and anthropogenic pressures on the soil of the district is significant. The sources of soil pollution are industrial enterprises, utilities, transport, agriculture, solid domestic waste dumps, illegal dumps, disposal facilities of biological waste, including anthracic animal refuse dumps.

The main sources of soil pollution of residential areas are the enterprises of building industry, metallurgy, machine building, food industry, agriculture, transport, industrial and human domestic activities.

Geochemical state of soils is strongly influenced by methods of disposal and storage of solid domestic waste. Storage of solid domestic waste at sites equipped without respect to sanitary and ecological requirements and without preliminary recycling increases the risk of pollution of the surface of the earth with toxic chemicals. Serious environmental threat to soils is industrial waste. Dumps, landfills, setting tanks, etc. carry a significant environmental risk.

In Kalininskij district there is no special facilities of neutralization and recycling of industrial and domestic waste. Also there are no places for storage and burial of industrial waste and for burial of toxic industrial waste. Dispose of domestic and equated with them solid industrial waste is done by burial of solid waste in dumps. Currently in the district there are two legal dumps. In addition to the two legal dumps there is a large amount of illegal waste disposal sites.

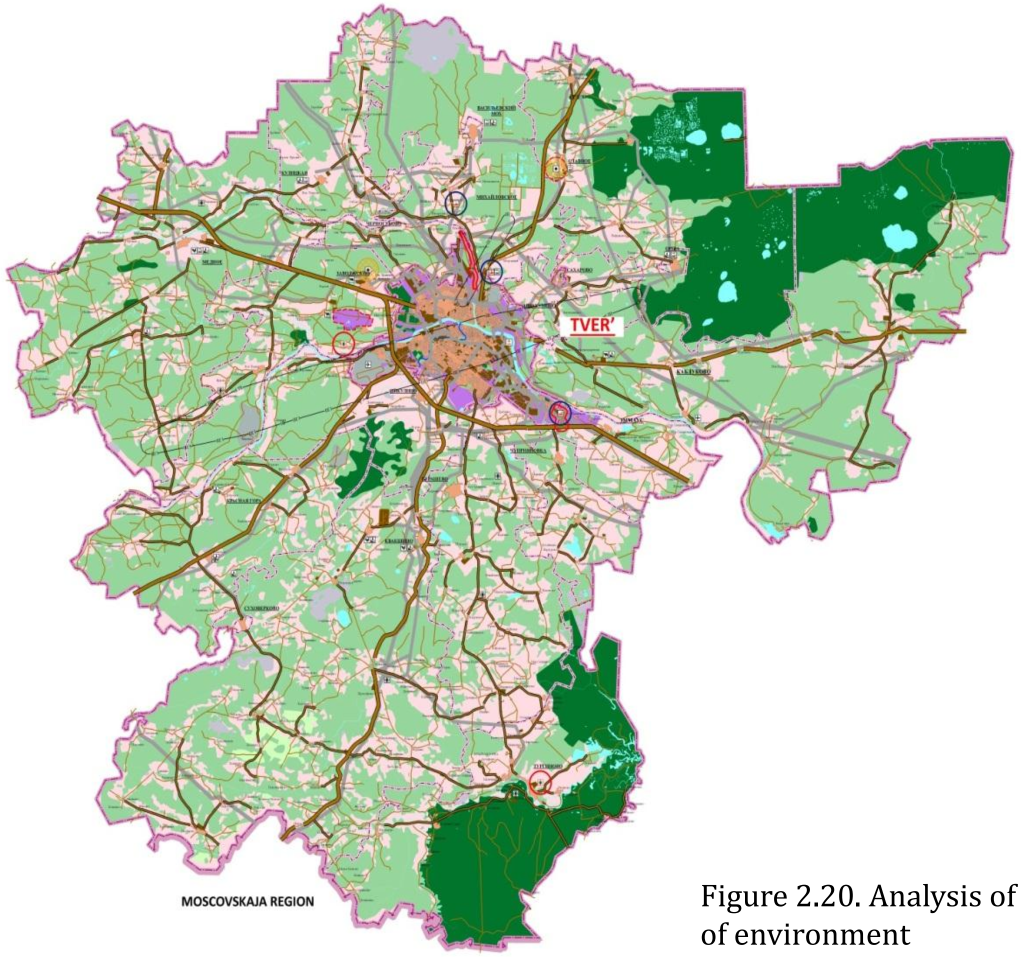


Figure 2.20. Analysis of state of environment

Symbols

Boundaries

- Boundaries of Tverskaja region
- Boundaries of Kalininskij municipal region
- Boundaries of urban and rural localities

The main sources of negative impact on environment

Industrial enterprises of I-II classes of ecological danger

Metallurgy
- Foundry with secondary recycling of copper

Construction industry
- Asphalt and concrete plant

Agriculture
- Animal-breeding complexes
- Poultry farms

- Industrial enterprises of III - V classes of ecological danger
- Noise zones from airfields

Objects of transport and engineering infrastructure
- General railways
- The main roads
- Airfields
- Cargo ports
- Corridors of the main engineriering communications
- The main discharges of industrial wastewater
- Solid waste dumps
- Burial ground for anthracic animals refuse
- Burial ground for animals refuse

State of components of environment

Degree of disturbance of soil cover
- Weakly disturbed
- Moderately disturbed
- Strongly disturbed
- Areas of potential chemical contamination of soils

State of surface and underground waters
- Moderately polluted (III class)
- Polluted (IV class)

State of atmospheric air
- Zones of the highest pollution of atmospheric air

Vegetation and system of protected natural territories

- Especially protected territories

Forested territories:
- Protective forests
- Exploitation forests

Areas with problem landscape ecological and sanitary hygienic state

- Zones of critical state of environment
- Zones of local impact on environment

2.2.2. Tver’

2.2.2.1. About the city

Tver’ is the main city and administrative center of Tverskaja region and Kalininskij district.

Since the time of its foundation for almost nine centuries Tver’ has been and remains a reliable buttress of the Russian statehood, a stronghold of the Russian army, a center of commerce and industry and a concentration of pearls of architecture and spiritual pillars.[1]

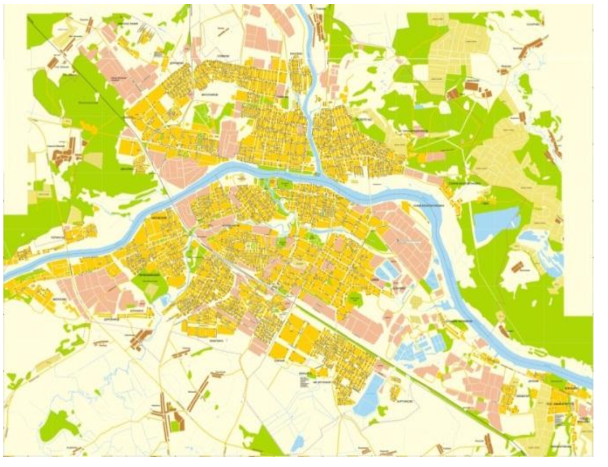


Figure 2.21. Tver’ map

Figure 2.22. Panoramic view of Tver’

Figure 2.23. Panoramic view of Tver’

Figure 2.24. Panoramic view of Tver’

Figure 2.25. Panoramic view of Tver’

[1] http://www.tver.ru

2.2.2.2. Geographical position

Tver' is situated in *167 km* to the northwest from Moscow and in *485 km* to the south from St. Petersburg. It covers an area of *152 km²*. From the south Kalinin moraine ridge rises.

Tver' is located on the banks of the river Volga, Tvertsa, Tmaka, Azure, Sominka. The modern area of the city includes a number of natural parks: Komsomolskaya, Pervomayskaya Bobachevskuyu, Birchwood Park, and Sakharov.

There are many discussions about the question if geographical position of Tver' is advantageous or not. On the one hand, the position of the city between Moscow and St. Petersburg is extremely profitable in economic terms. Tver' unwittingly became a major transportation hub, the intersection of many tourist and tour routes. On the other hand, the proximity to the capitals creates considerable difficulties, since both the metropolis draw off the human, financial, and ultimately, the economic potential of Tver'.

[2]

Figure 2.26. Geographical position of Tver'

[2] http://www.tver.ru

2.2.2.3. Symbols

Tver’ emblem

The emblem has been considered as a symbol of the city from the ancient times. This is a sign approved by the supreme authority, which expresses the history, geography and economic life of the city in strong graphic form.

Tver’ emblem was approved October 10, 1780 and re-enacted May 25, 1999 and December 22, 2000. On dark red field on golden chair without back, covered with green pillow with gold tassels and cord on the edge there is gold crown decorated with green precious stones. Tver’ emblem "chair without a back, a crown on it" is known since the 17th century. It was used in the coats of arms of Russian tzars, depicted on the banners of Tver’ regiments.

Tver’ flag

Tver’ flag is the symbol of its social, historical and administrative status.

It was adopted May 25, 1999. It is a yellow-red-yellow flag. In the center of the red band there is one color contour drawing of Tver’ emblem.[3]

Figure 2.27. Tver’ emblem

Figure 2.28. Tver’ flag

[3] http://ru.wikipedia.org – article «Тверь» («Tver’»)

2.2.2.4. History

XI – XV

XI – Small rural settlement on the right bank of river Volga near river T'mak.

XII – Already small trading settlement.[4]

1135 – The first written record of Tver the handwriting of Prince Vsevolod Mstislavovitch. This date is considered like the date of foundation of the city.

1238 – The city was ravaged by Mongol-Tatars but it was recovered from defeat quickly.

1247 – Tver' became the capital of Tver' principality.

1305 – Tver' Prince Mikhail Yaroslavich became Grand Duke that testified that by the time the Tver' became the most powerful principality in the North-Eastern Russia.

The end of XIII – the first third of XIV – Tver' was the largest center of the national liberation struggle of the Russian people against the Tartar yoke.

1485 – Moscow's armies occupied Tver'. Tver' principality ceased its independent political existence and became a part of Russian centralized state.[5]

Figure 2.29. Ancient Tver'

Figure 2.30. Ancient Tver'

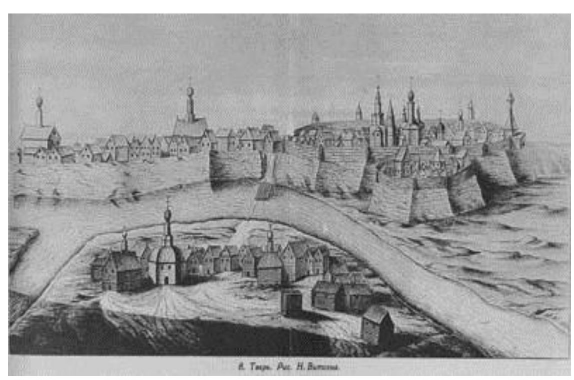


Figure 2.31. Ancient Tver'

[4] http://ru.wikipedia.org – article «Тверь» («Tver'»)
[5] http://www.tverobl.ru

XVIII – XIX

1709 – Construction of Vyshnevolockij water system was completed, connecting river Volga and the Baltic Sea. The economic importance of Tver as a major transit point between rising St. Petersburg and central Russia. Under Peter I Tver' is a member of St. Petersburg region and is the center of Tver province.

XVIII – The first chemical manufacture in Russia was opened in Tver'.

1763 – Large fire destroyed almost the entire city. Catherine II immediately issued an edict for the restoration of Tver', but with the new regular plan. Construction work started in the same year. On the territory of the Kremlin and the adjacent tenements were erected palace Putilovoj, ensembles of Octagonal square, the Volga embankment and the main streets.

The end of XVIII – Tver' was the large industrial city.

1851 – Tver' was connected with Moscow and Saint-Petersburg by Nikolaevskaya railway.[6]

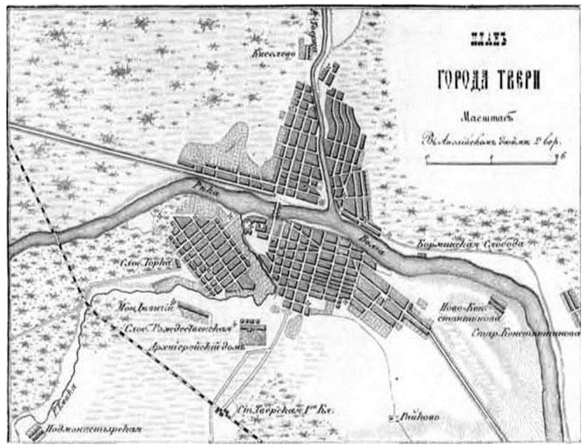


Figure 2.32. Plan of Tver'. XVIII century

Figure 2.33. Tver'. XVIII century

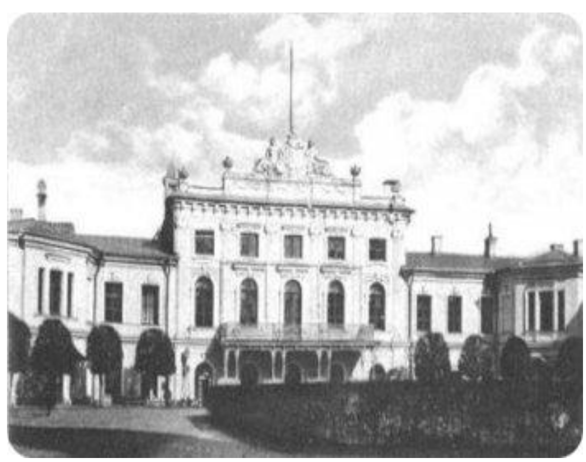


Figure 2.34. Tver'. XVIII century

[6] http://ru.wikipedia.org – article «История Твери» («History of Tver'»)

XX

<u>1920-30s</u> – All the central streets and squares of Tver' were renamed, began the struggle with the church and the confiscation of church valuables. Dozens of churches that were monuments of 17-19 centuries have been closed and demolished.

<u>1931</u> – Tver' was renamed in Kalinin and became the center of Kalinin region in honor of M. I. Kalinin – soviet statesman and party figure.

<u>October 1941</u> – Kalinin was captured by German armies, but in December Russian armies liberated the city.

During the fighting more than half the houses and about seventy factories of Kalinin were destroyed.

<u>1943</u> – Restoration works began.

<u>1990</u> – Kalinin was renamed in Tver' and Kalinin region in Tver' region.[7]

Figure 2.35. Tver'. XX century

Figure 2.36. Tver'. XX century

Figure 2.38. October revolution

Figure 2.37. M.I.Kalinin

[7] http://ru.wikipedia.org – article «История Твери» («History of Tver'»)

2.2.2.5. Administrative division

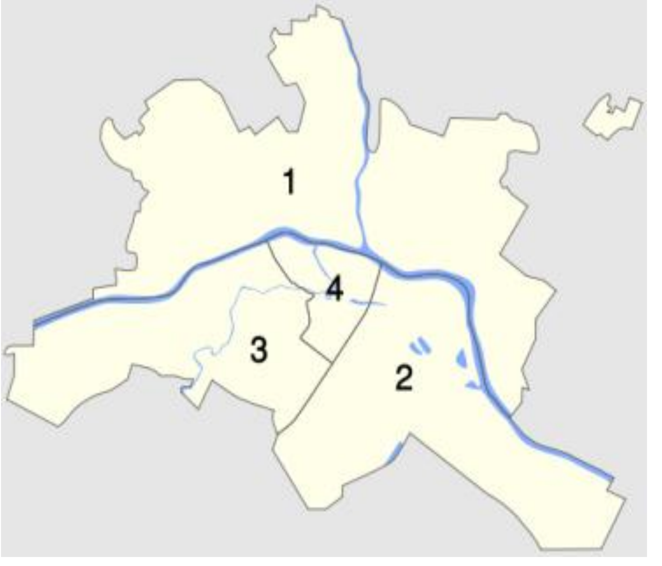


Figure 2.39. Administrative division

1. Zavolgskij district

The district covers the northern, left-bank part of the city. The boundary with the Proletarskij and Central districts is in the center of the river Volga. The northern, western and eastern boundaries of the area are held by the city. The river Tvertsa runs through the area of Zavolzhsky district in its lower current and falls into the Volga.

2. Moscovskij district

The district covers the eastern part of the city in which residential and industrial areas are concentrated and where the road to Moscow begins. The region includes some neighborhoods, as well as settlements and villages included in the boundaries of the city of Tver'.

3. Proletarskij district

The district covers the western, mostly industrial part of city. On the territory of the district key industrial factories of regional economy are located.

Micro-district "Proletarskie Dvori" is the oldest working-class suburb of Tver'. It was built in the architectural pseudo-gothic style in the second half of the XIX century by the owner of the Tver' Manufactory S. T. Morozov, a famous Russian entrepreneur and sponsor, initially for its own factory.

4. Centralnij District

It covers the historical city center and some surrounding areas. In the district administrative buildings, historic monuments, cultural institutions (theaters, museums, libraries), educational institutions, as well as shops, shopping centers, offices, banks and other institutions are concentrated.[8]

[8] http://ru.wikipedia.org – article «Тверь» («Tver'»)

2.2.2.6. Land use

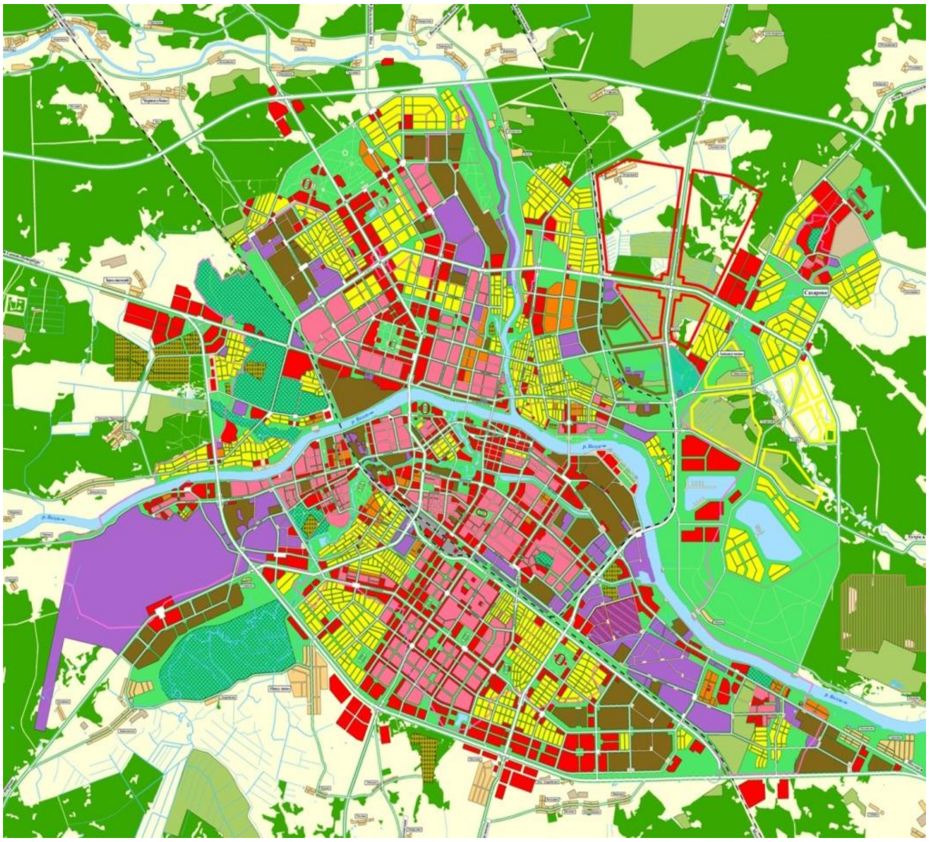
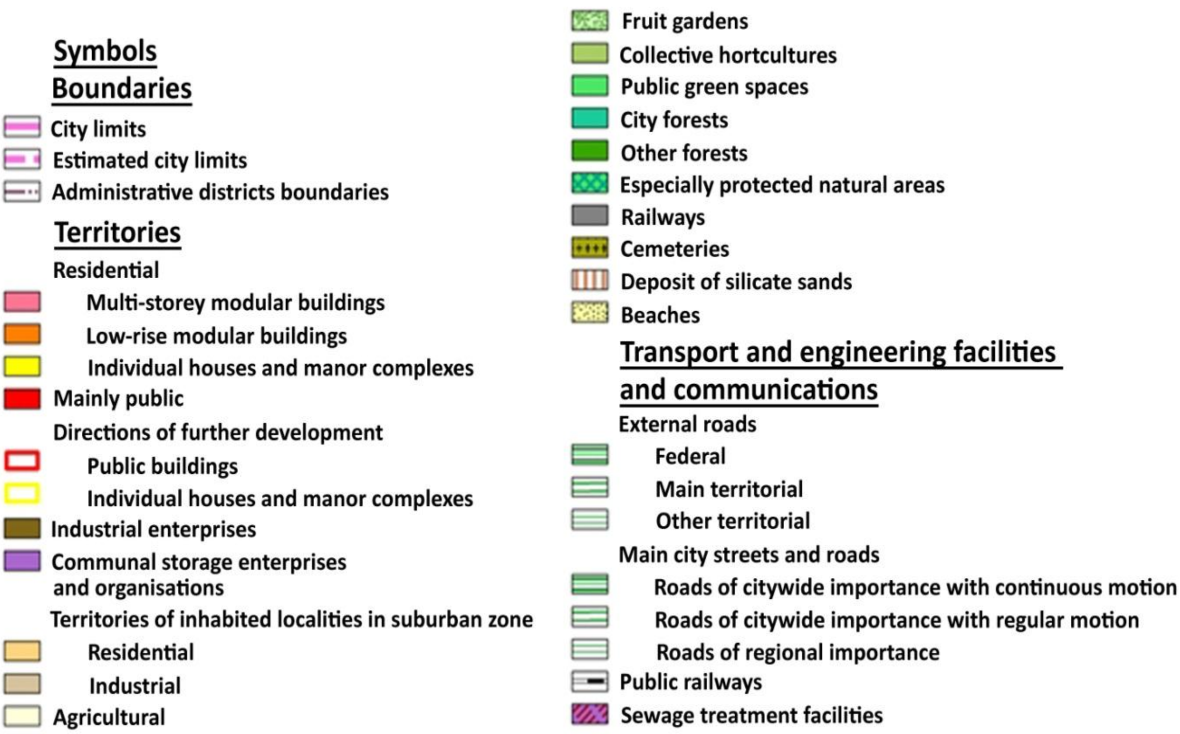


Figure 2.40. Land use



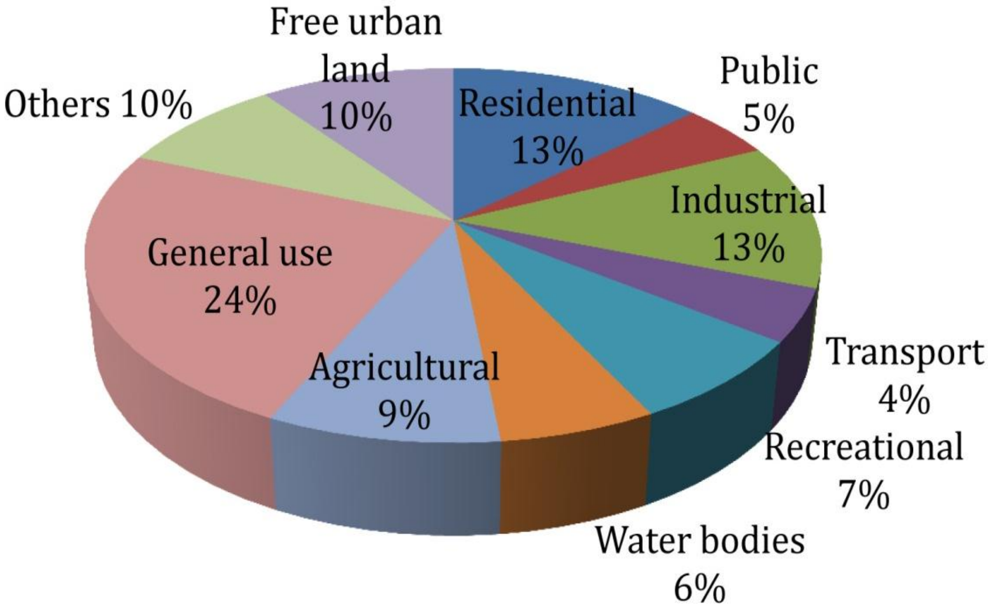


Figure 2.41. Land use

Table 2.1. Land use [9]

Land use	Area, ha
Total area	**15222**
Residential	2019
Public	731
Industrial, storage and municipal	1912
Transport, links and communications	682
Nature preservation, historical, cultural and recreational	1116
Water bodies	888
Agricultural	1302
General use	3682
Others	1327
Free urban land	1563

[9] http://www.tver.ru

2.2.2.7. Population

2.2.2.7.1. General population

In 2011 population of Tver' is 404,2 thousand people. It reached its maximum in 1989, when 449,9 thousand people lived in the city. Singnificant decrease in population occured from 1989 to 2002 – up to 412,8 thousand people. In the subsequent years decline of population has slowed. From 2002 to 2007 the population decreased by 7,3 thousand people. From 2007, when the population was 405,5, gradual increase of population began. From 2007 to 2010 it increased by 4,9 thousand people. In 2011 there was decrease of population on 6,2 thousand people.

Table 2.2. General population[10]

Year	Population Thousand people
1959	261,5
1970	344,8
1979	414,7
1989	449,9
2002	412,8
2005	406,7
2006	405,6
2007	405,5
2008	407,3
2009	409
2010	410,4
2011	404,2

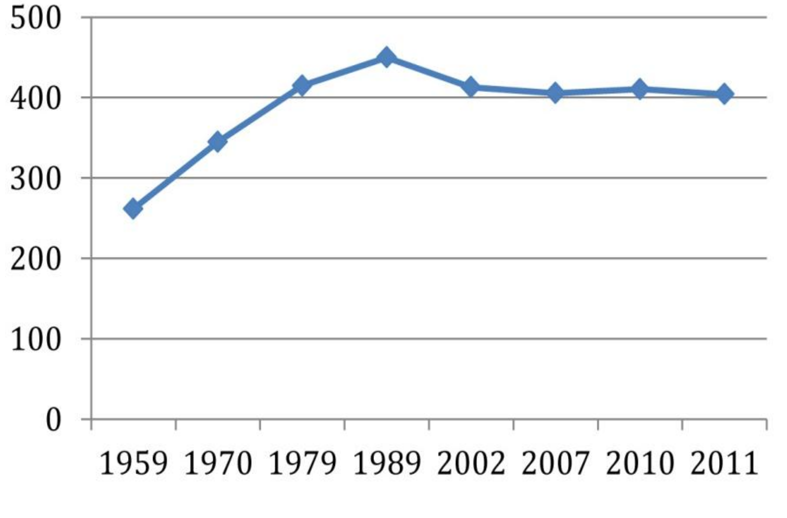


Figure 2.42. General population

[10] http://www.tver.ru

2.2.2.7.2. Population in the districts

Dynamics of population in districts of Tver' is different. Thus, the population of Moskovskij district from 1989 to 2002 decresed only by 7 thousand people or 5,6% from the level of 1989. The population of Central and Proletarskij desctricts decreased much more signifecantly: on 13,3 thousand people or 19,9% and 32,4 thousand people or 26,8% respactively. Zavolzhskij district is the only one where the number of living people has been steadily increasing. In 2002 the population of the region has reached 135,2 thousand people, which is 7% more than in 1989.

Table 2.3. Population in the districts [11]

Year	Zavolzhskij	Moskovskij	Proletarskij	Centralnij
1959	66,7	78,8	76	46
1970	88,9	103,4	100,2	52,3
1979	104,8	123,6	120,4	62,4
1989	126,8	131,2	120,9	66,8
2002	135,2	124,5	92,3	56,9
2005	138,7	123,4	90	54,6
2006	139,2	123,6	89,2	53,6
2007	139,6	123,9	88,5	53,5
2008	140,2	124,4	88,9	53,8
2009	141,1	124,3	89,6	54
2010	141,4	124,5	90,2	54,3
2011	138,3	120,2	91,2	54,5

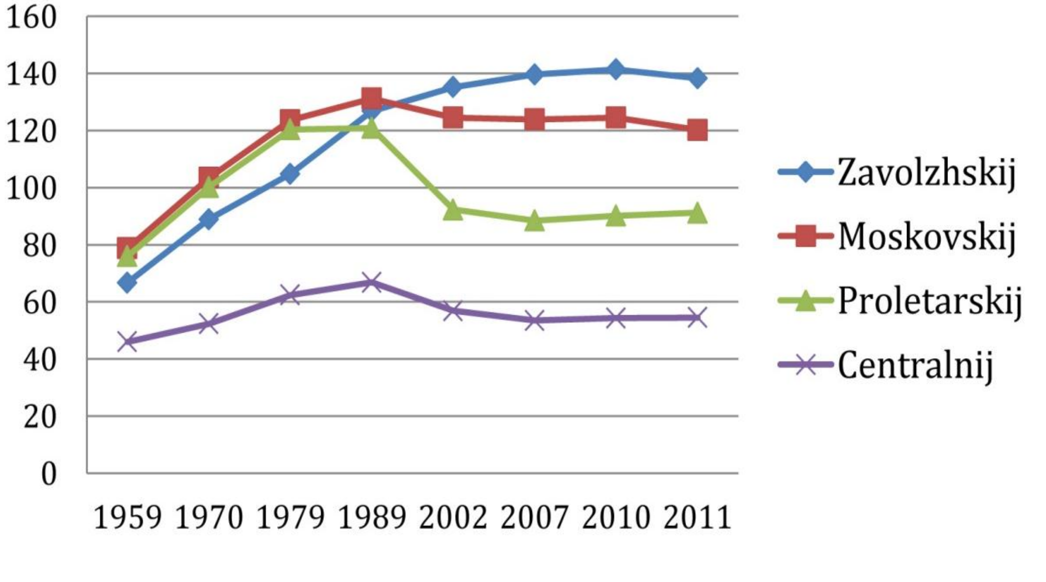


Figure 2.43. Population in the districts

[11] http://www.tver.ru

2.2.2.7.3. Population by the main age groups

Considering structure of population of Tver' by the main age groups there is a tendency of increase of percent of population older than working group. If in 1989 percent of population younger than working group, working group and older than working group was 19,7, 60,3 and 20 respectively, in 2011 the same figures are 13,7, 63,4 and 22,9.

Table 2.4. Population by the main age groups [12]

Year	Younger %	Able to work %	Older %
1979	17,2	67,1	15,7
1989	19,7	60,3	20
2005	14,1	63,7	22,2
2007	13,5	64,2	22,3
2008	13,3	64,2	22,5
2009	13,3	64,1	22,6
2010	13,6	63,6	22,8
2011	13,7	63,4	22,9

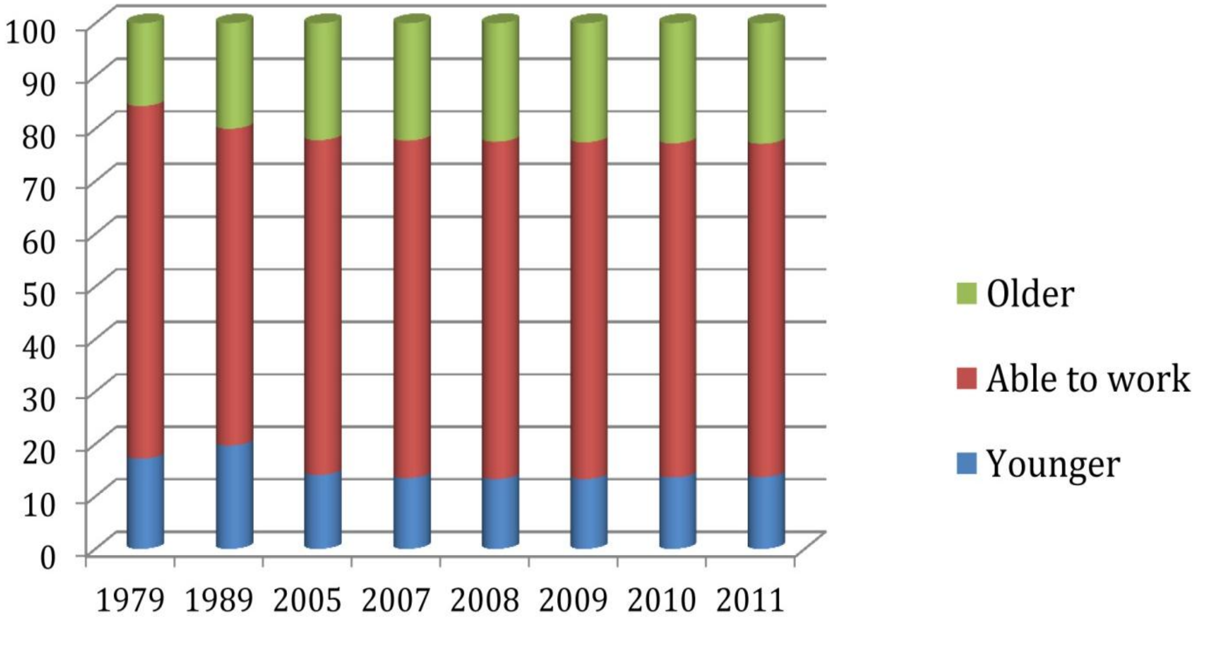


Figure 2.44. Population by the main age groups

[12] http://www.tver.ru

2.2.2.7.4. Population by sex and age

Structure of population of Tver' in different age groups is uneven. On the average, the female part of the population is 56%. Among children and adolescents up to 15 years, males slightly but still dominated. In age group from 10 to 14 years the percent of males and females is 50,7 and 49,3 respectively. After this age the percent of females increses. In age group from 30 to 34 years the percent of males and females is 48,2 and 51,8 respectively. In age group from 50 to 54 years the percent of males and females is 42,1 and 57,9 respectively. Among Tver' citizens older than 70 years the percent of males and females is 25,7 and 74,3 respectively. Apparently, this disbalance will be flatten gradually.

Age	Male Thousand people	Female Thousand people
0_4	10	9,5
5_9	9,2	8,4
10_14	7,7	7,5
15_19	11,5	11,8
20_24	19,7	21,4
25_29	19,1	20,1
30_34	15	16,1
35_39	13,5	14,8
40_44	11,7	13,6
45_49	13,7	17,6
50_54	13,8	19
55_59	12	17,2
60_64	8,5	13,1
65_69	4,2	8,1
70_...	10,9	31,5

Table 2.5. Population by sex and age[13]

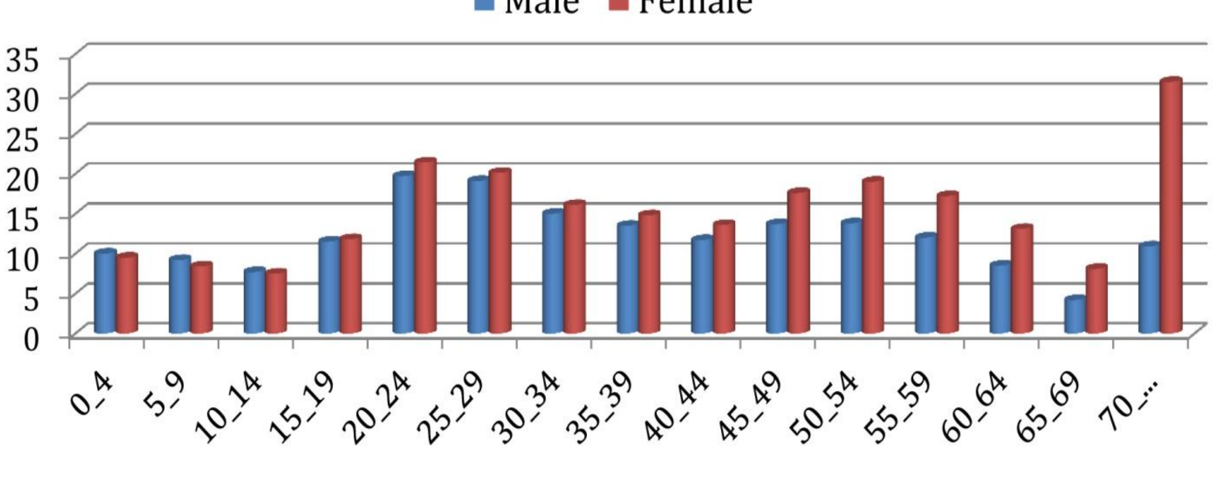


Figure 2.45. Population by sex and age

[13] http://www.tver.ru

2.2.2.7.5. Dynamics of the main demograthic characteristics

Birth and death rates

From 1990 to 1995 in the period of disintegration of USSR, economic reforms and following hyperinflation and mass impoverishment significant decrease in birth rate and increase in death rate occurred. Natural loss in this period increased from 100 people in 1990 to 3,7 thousand people in 1995. It reached its minimum in 2000 - 4 thousand people. Then slow growth began. In 2010 natural loss was 2 thousand people.

Table 2.6. Birth and death rates [14]

Year	Death rate Thousand people	Birth rate Thousand people	Natural loss Thousand people
1990	5	4,8	-0,1
1995	6,9	3,1	-3,7
2000	7,2	3,1	-4
2005	6,9	3,6	-3,3
2007	6,5	3,8	-2,7
2008	6,6	4,1	-2,5
2009	6,4	4,4	-2
2010	6,5	4,5	-2

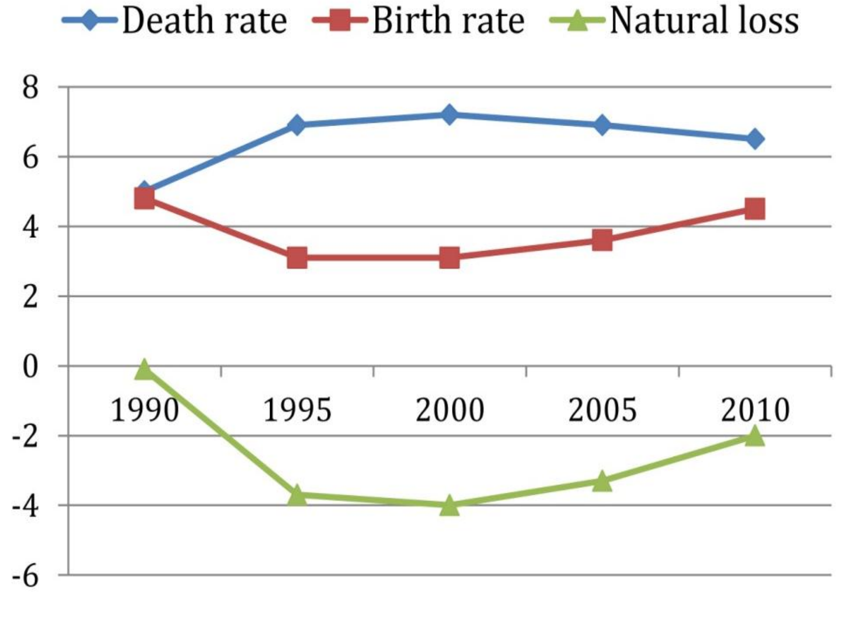


Figure 2.46. Birth and death rates

[14] http://www.tver.ru

Migration

There are **3 types of migration** in Tverskaja Region:

- Migration from other countries (mostly from CIS countries)
- Migration from other regions
- Migration within the region

Reasons of migration:

- The possibility of employment in Tver' enterprises
- Economic activity of Tver' as administrative center of the region
- Migration for study

From 1990 to 1995 in the period of disintegration of USSR, economic reforms and following hyperinflation and mass impoverishment sharp growth of migration occurred. In 1995 it reached its maximum – 5,6 thousand people. In subsequent 5 years there was sharp fall of migration and in 2000 it reached its minimum – 1,6 thousand people. From 2000 to 2007 migration increased up to 4,4 thousand people . Then decrease began. In 2010 growth due to migration was 3,1 thousand people.

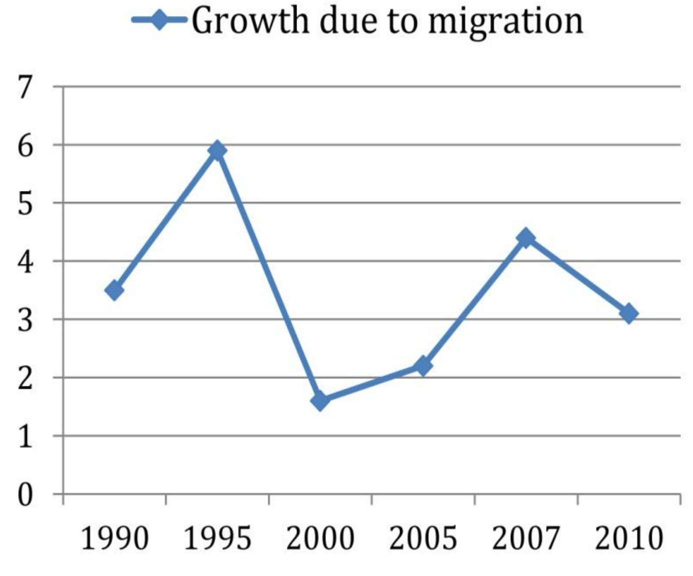


Figure 2.47. Migration

Table 2.7. Migration[15]

Year	Growth due to migration Thousand people
1990	3,5
1995	5,6
2000	1,6
2005	2,2
2007	4,4
2008	4,2
2009	3,4
2010	3,1

15 http://www.tver.ru

Marriages and divorces

From 1990 to 1995 in the period of disintegration of USSR and economic reforms the number of marriages decreased significantly while the number of divorces increased. Then growth of divorces stopped, slow diminution begins and the number reached its minimum in 2005 – 1,82 thousand divorces. In this time fall of the number of marriages continued and reached its minimum in 2000 – 2,9 thousand marriages. Then sharp growth began. From the period from 2000 to 2007 the number of marriages increased by 1,59 thousands. In the period from 2007 to 2009 there was sight decrease of marriage and increase of divorces. Then the tendence changed in both numbers.

Table 2.8. Marriages and divorces[16]

Year	Marriages Thousand	Divorces Thousand
1990	4	1,99
1995	3,35	2,27
2000	2,9	2
2005	3,5	1,82
2007	4,49	2,1
2008	4,32	2,34
2009	4,3	2,42
2010	4,64	2,1

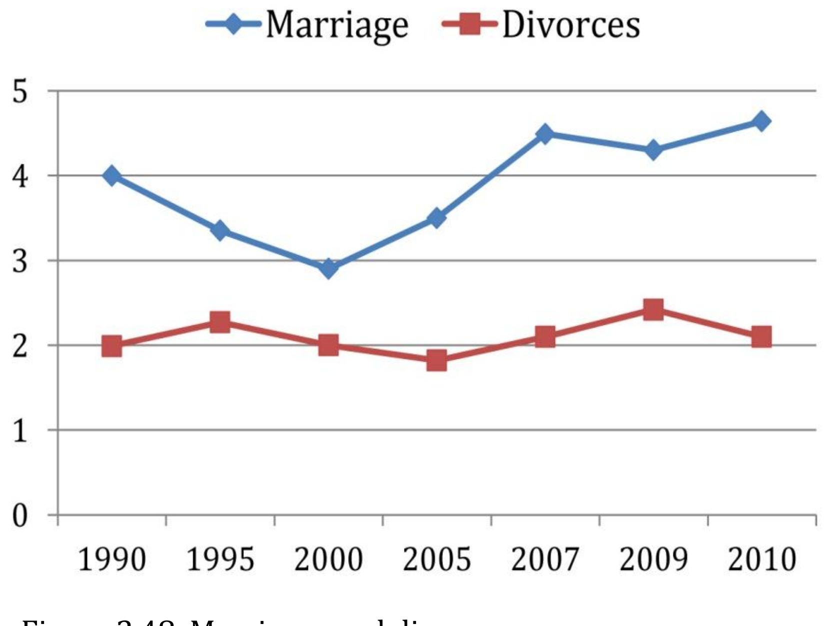


Figure 2.48. Marriages and divorces

[16] http://www.tver.ru

2.2.2.7.6. Social security

Families with many children

In the period from 1995 to 2005 sharp fall of the number of families with many (more than 3) children occurred – from 1,63 thousand families in 1995 to 620 families in 2005, what is minimum number during the peiod from 1995 to 2010. In this time there was decrese in number of children in these families., but not sharp. Then increase began. In 2010 the number of families with many children almost reached the level of 2000 In 2010 in Tver' there was 980 big families with 3,2 thousand children.

Table 2.9. Families with many children [17]

Year	Families with many children Thousand families	Children in these families Thousand children
1995	1,63	5,54
2000	1	3,24
2005	0,62	2
2007	0,72	2,34
2008	0,78	2,55
2009	0,84	2,73
2010	0,98	3,2

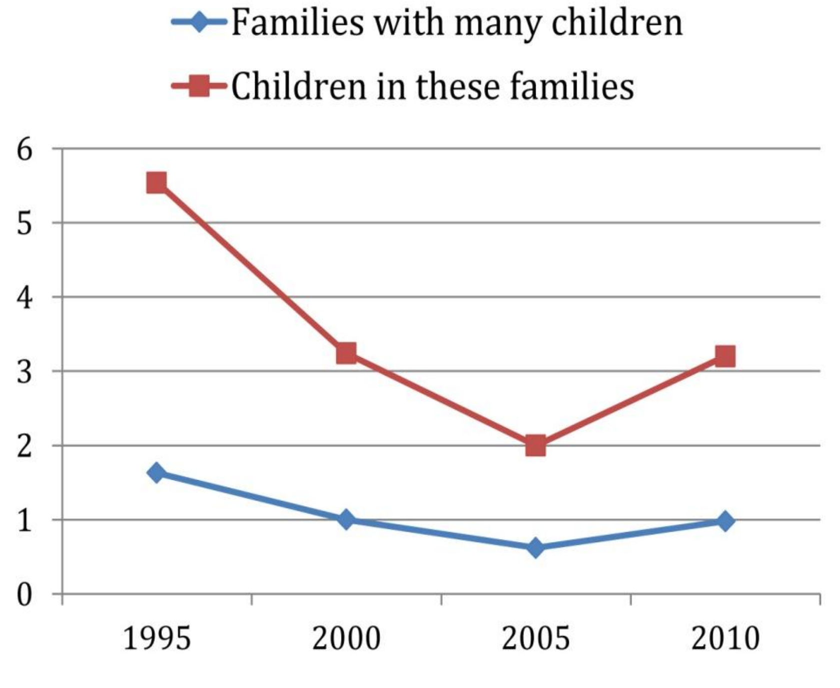


Figure 2.49. Families with many children

[17] http://www.tver.ru

Families with children with disabilities

In the period from 1995 to 2000 there was sharp growth of the number of families with children with disability in Tver'. The number increase from 990 families in 1995 to 1,31 thousand families in 2000. In subsequent 5 years the number of families decreased while the number of children in these families continued growing. In 2005 the number of families reached its minimum – 1,13 thousand families – while the number of children reached its maximum – 1,4 thousand children. Then the number of children decreased significantly while the number of families slightly increased. In 2010 the number of these families was 1,17 thousand, what is 180 families more than in 1995.

Table 2.10. Families with children with disabilities [18]

Year	Families with children with disabilities Thousand people	Children in these families Thousand people
1995	0,99	1,1
2000	1,31	1,35
2005	1,13	1,4
2007	1,16	1,19
2008	1,22	1,24
2009	1,14	
2010	1,17	

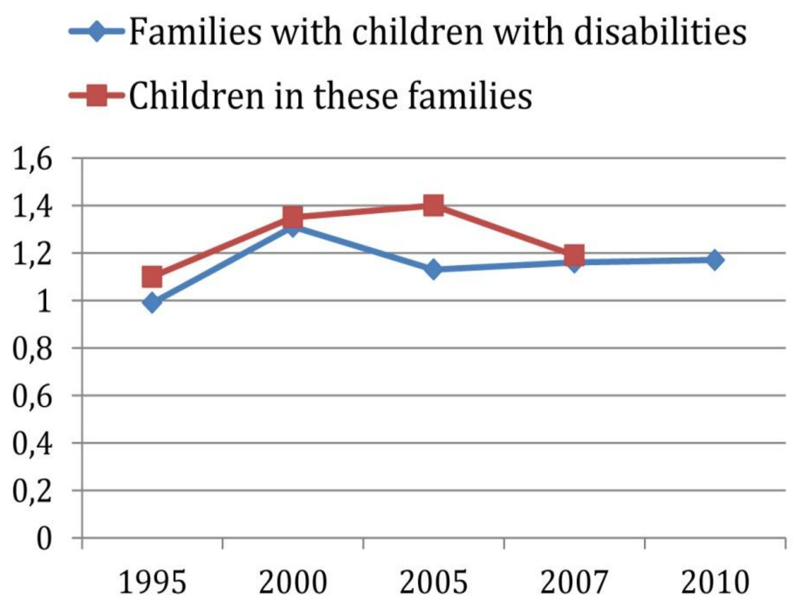


Figure 2.50. Families with children with disabilities

[18] http://www.tver.ru

Single mothers

In the period from 1995 to 2000 there was sharp growth of the number of single mothers, the number increased by 810 people. In 2000 maximum number was reached – 4,57 thousand single mothers. In subsequent period from 2000 to 2005 sharp fall occurred and in 2005 the number of single mothers became less than in 1995. Then there was more gradual decrease, from 2005 to 2010 it decreased by 480 people. In 2010 the number of single mothers was 3,19 thousand people what is less then in 1995 on 570 people.

Table 2.11. Single mothers[19]

Year	Single mothers Thousand people	Children in these families Thousand people
1995	3,76	4,16
2000	4,57	4,96
2005	3,67	3,97
2007	3,6	3,86
2008	3,42	3,69
2009	3,27	3,54
2010	3,19	3,46

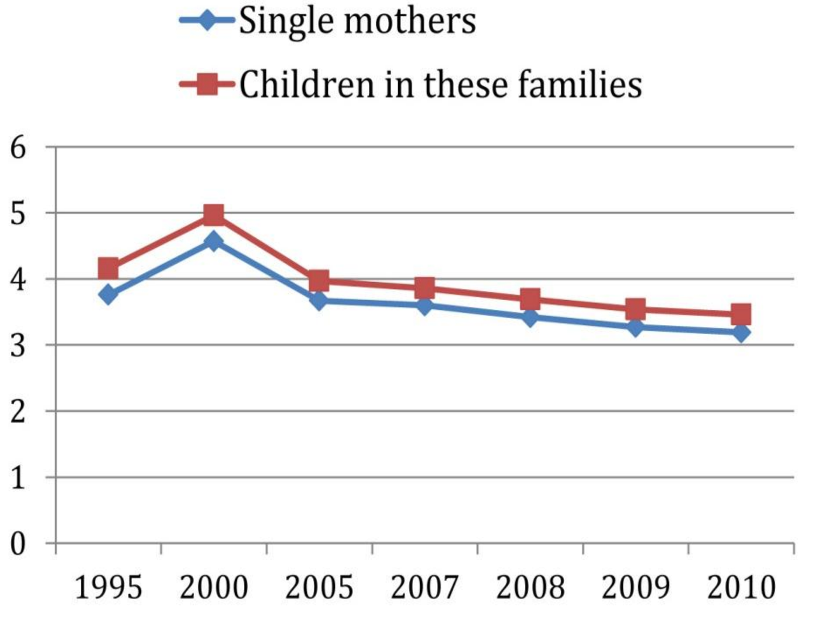


Figure 2.51. Single mothers

[19] http://www.tver.ru

2.2.2.8. Economy

The City of Tver' is justly called one of the most ancient Russian cities. Already in the first third of XII century a fortress appeared in the mouth of the Tvertsa River. It was destined to become a prototype of Tver. In 1246, Tver' became the capital of Tver' Principality. By the end of XIII - beginning of XIV centuries, it was already a big handicraft and trading center. The city started developing especially fast at the end of XIX century: manufactories were built and new plants were opened there. By 1926, Tver' became a city with developed diversified industry.

At present, Tver' is a big administrative, industrial and cultural center of the Upper Volga area and the center of Tverskaya Region.

The leading industries of the city are: machine building and metal processing, food, chemical, electric energy industries and production of construction materials.

In 2010, big and medium industrial enterprises shipped products of their own production, did work and provided their own services worth 61 billion rubles including the products, work and services of enterprises of the processing industry worth 48 billion rubles along with growth by 103% in current prices in comparison to the level of 2009.

Gradual appearance of results of the anti-crisis measures, slowdown of crisis trends in the economy and efforts of the companies for modernization of production facilities, broadening of the sales markets of their products at the end of the year contributed to a slight improvement of dynamic of the volume parameters and creation of preconditions for restoration of the volumes of industrial production in 2011.

Growth of the volumes of shipped products, work done and services provided was registered in 12 kinds of economic activity (of the 13 kinds registered in processing industries) according to results of the year. The biggest companies from the standpoint of production volume are: Tver railway car plant (it accounts for 26.5% of the overall volume of products shipped, work done and services provided by industry of the city), United Bottling Group (6.0%), Melkombinat (5%), Volzhsky Pekar (3.2%), Tverskoy Excavator (2.3%), Khleb (2%), DSK (1.6%), Tsentrosvarmash (1.2%) and Sibur-PETF (1%).[20]

[20] http://www.tver.ru

Tver' occupies a significant place in the regional volume of industrial production still. Tver' produces 37% of the volumes of products shipped, work done and services provided in Tverskaja Region. The volume of the products shipped by processing production facilities accounts for 45% of the regional volume and for 22% according to production and distribution of electric energy, gas and water.

The city has a broad network of general construction, specialized and mounting contractor organizations. Production of construction materials is well developed.

Development of the housing construction sector has a key importance. In 2010, developers of all forms of ownership put into operation 196,600 square meters of housing in the city.

Small and medium businesses play a significant role in the economy of the city. More than 3,000 small businesses of various organizational and legal ownership forms are registered on the territory of the city, as well as about 12,000 sole traders without legal entities. More than 75,000 people or one-third of the people working in the city are employed in this area. Small businesses embrace practically all areas of the economy. The budget of the city receives about 30% of tax incomes from them.

There are 43 commercial banks and their divisions working in Tver'. The market of insurance services, communications and telecommunications is developing actively too.[21]

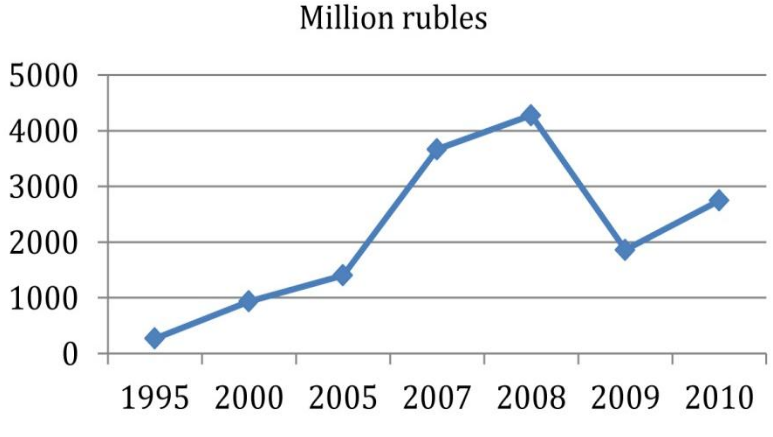


Figure 2.52. Balanced financial results for all activities

[21] http://www.tver.ru

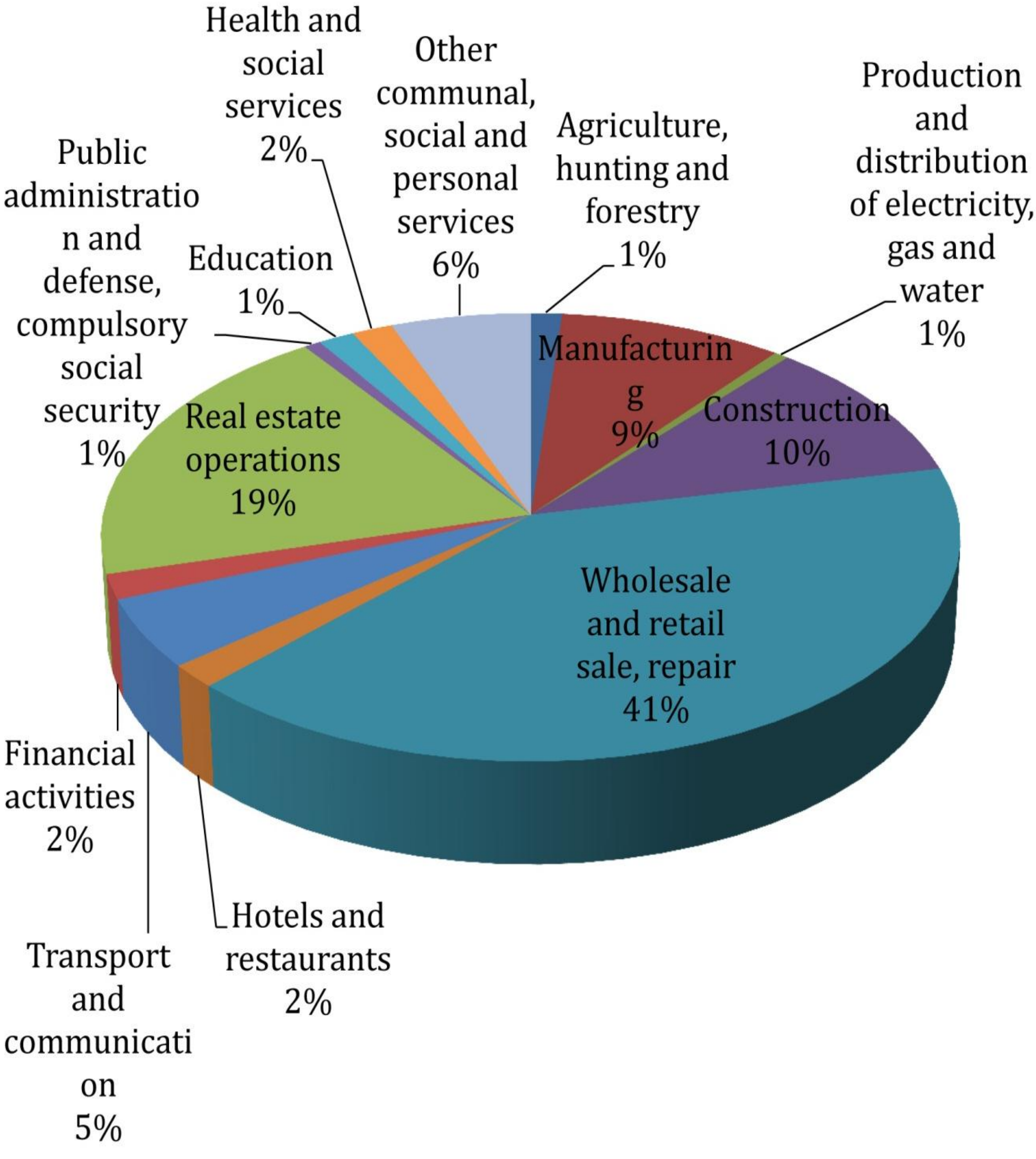


Figure 2.53. Structure of enterprises and organizations by economic activities. Data at the beginning of 2011 [22]

[22] http://www.tver.ru

Table 2.12. Structure of enterprises and organizations by economic activities. Data at the beginning of 2011[23]

Name of activity	Number of organizations	%
Total area	**24197**	**100**
Agriculture, hunting and forestry	323	1,3
Fishing	14	-
Mining and quarrying	50	-
Manufacturing	2243	9,3
Production and distribution of electricity, gas and water	150	0,6
Construction	2510	10,4
Wholesale and retail sale, repair	9848	40,7
Hotels and restaurants	394	1,7
Transport and communication	1191	5
Financial activities	421	1,8
Real estate operations	4718	19,5
Public administration and defense, compulsory social security	175	0,7
Education	353	1,5
Health and social services	412	1,7
Other communal, social and personal services	1395	5,8

[23] http://www.tver.ru

2.2.2.9. Transport

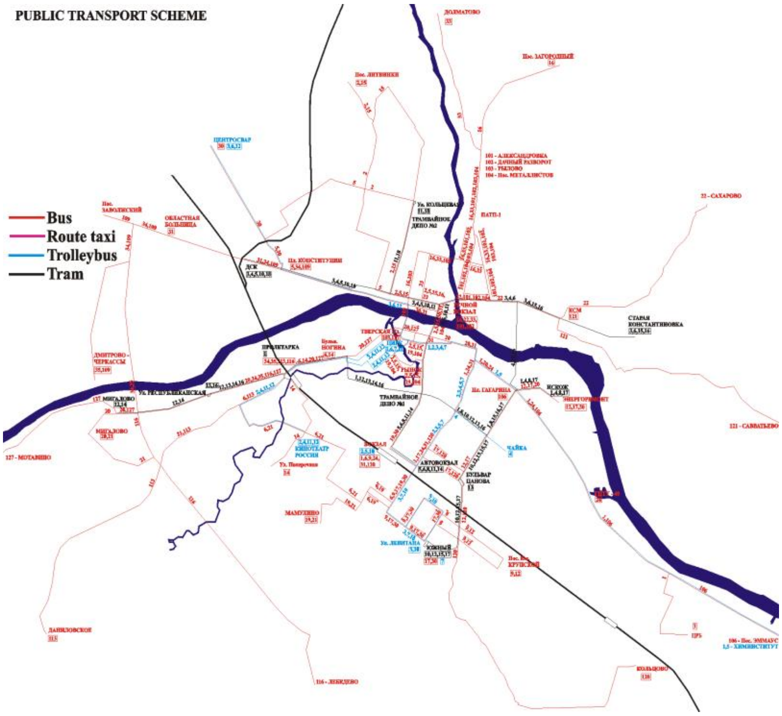


Figure 2.54. Transport

Tver' is a major transportation hub. It is situated at intersection of great number of routs. It is possible to get to Tver' by land, sea and air.

Railway, water mains and highways link Tver' with the capital. There are highways of national importance Moscow – Riga and Moscow – Saint-Petersburg. Octyabr'skaya Railway runs through Tver' and link Moscow and Saint-Petersburg. There are also commuter trains that run from Tver' to Moscow, Torzhok, Bologoe and Vasil'evskij moh. The biggest river port on Upper Volga, located in Tver', is able to receive ships of river-sea type. There is a river port at intersection of rivers Volga and Tvertsa. There are 2 airports – "Migalovo" on western outskirts of Tver ' and "Zmeevo" in Zavolzhskij district.

Transport infrastructure is well developed in Tver. Service is carried out by transport of municipal enterprises as well as by rout taxis of private ownership. In the city, in addition to 19 bus routs, there are 6 trolley routs and 12 tram routes. Their total length is about 550 thousand km, which indicates that the transport service covers all areas and corners of Tver'. Trolleybuses and trams carry 70% of all passengers.[24]

[24] http://www.tverhotels.ru

2.2.2.10. Education

The educational and scientific potential of the city is big. There are 11 state higher educational institutions and their divisions working in Tver, as well as 7 non-state higher educational institutions, Suvorov military school and 12 secondary special educational institutions. The quantity of their students amounts to about 48,000. The specialists are trained in various professions for various sectors of the industry, agriculture, financial and social sectors. There are also eight institutions of basic professional education that train about 3,000 people.[25]

In Tver', there are 2 universities and 3 academies: Tver' state University, Tver' State Technical University, State Medical Academy, State Agricultural Academy and Military Academy of Aerospace Defense named Zhukon.

Tver State University is one of the scientific, educational and cultural centers of the region, the largest university in the region. It was established in 1970.

In Tver', there are five branches of Moscow universities - Moscow State University of Economics, Statistics and Computer Science, Tver' branch of the Moscow Humanitarian-Economic Institute, Tver' branch of the International Institute of Economics and Law, Tver' branch of the Moscow Financial and Law Academy, Tver' branch of Moscow State University of Russian Interior Ministry, as well as Tver' branch of the St. Petersburg State University of Engineering and Economics. [26]

The scientific and technical activity is carried out by 27 research and development and project designing organizations of the most diverse specialties.

The school education system of Tver includes 69 secondary schools (5 of them being non-state ones) that educate more than 36,900 people. The educational sector also includes 85 children's preschool institutions, 77 of them being municipal ones. [27]

25 http://www.tver.ru
26 http://ru.wikipedia.org – article «Тверь» («Tver'»)
27 http://www.tver.ru

2.2.2.11. Culture

Tver’ is a big cultural center with its own cultural traditions and architecture. Its main attraction is Putevoj palace of Catherine II. It was built in 1764-1778 in classical style with baroque elements. It was named Putevoj (Putevoj palace means Road palace), because imperial family rested here on the way from Saint-Petersburg to Moscow.

Church architecture represented widely in Tver’. The city is the center of Tver and Gashinskaya diocese. There are St. Catherine's and the Birth of Christ Monasteries, 4 cathedrals, 15 churches and seven chapels.

Tver’ citizens can become familiar with art of theater. In the city there is Puppet theater, Theater for children and young people, Tver’ State Academic Drama Theatre. Every year 150 thousand people go to the theaters. There is also circus, the State Philharmonic Society, 24 palaces and houses of culture.

Museum institutions of different profile function in the city: the Museum of Saltykov-Shchedrin, Tver’ regional museum and exhibition complex named Lisa Chaikina, United historical, architectural and literary museum. In addition, in some museums it is possible to become familiar with history of communication of Tverskaya region and with characteristics of Tver’ life. Every year museums receive more than 230 thousand visitors. In Tver 3 exhibition halls function: "Union of artists", "Tver’ art salon" and the exhibition hall of the Tver’ regional picture gallery - the oldest one from Russian art museums. There is also children’s artistic school, 3 children’s art schools, choir school.[28]

The library system of the city includes three libraries of regional subordination and municipal library system (22 library divisions united under management of the central city library named after A. I. Gertsen). Higher educational institutions of the city have a rich library stock.[29]

Much attention is paid to physical culture and sport: in Tver’ there are 3 stadiums, 25 swimming pools, more than 230 gyms, as well as 11 youth sports schools, 2 of which are municipal.[30]

28 http://www.tverhotels.ru
29 http://www.tver.ru
30 http://www.tverhotels.ru

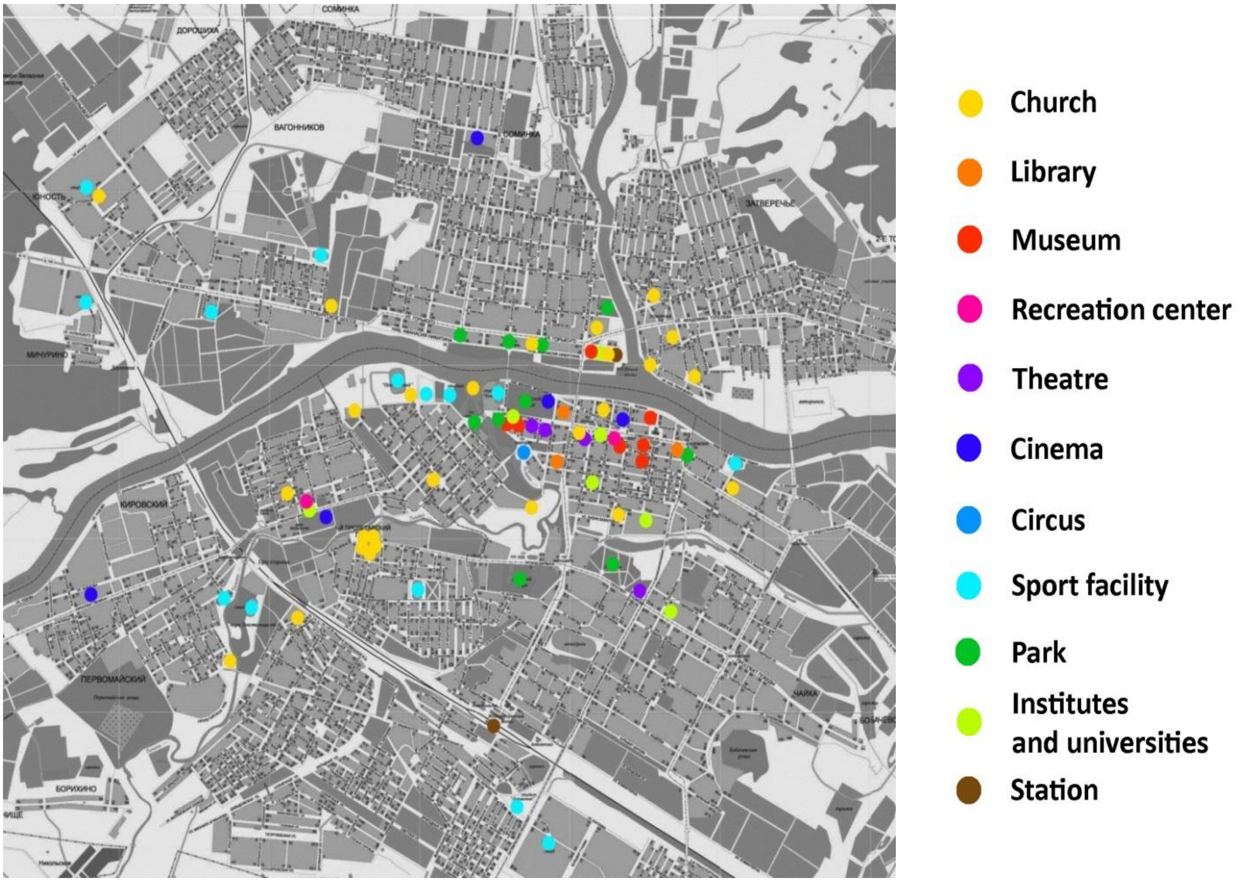
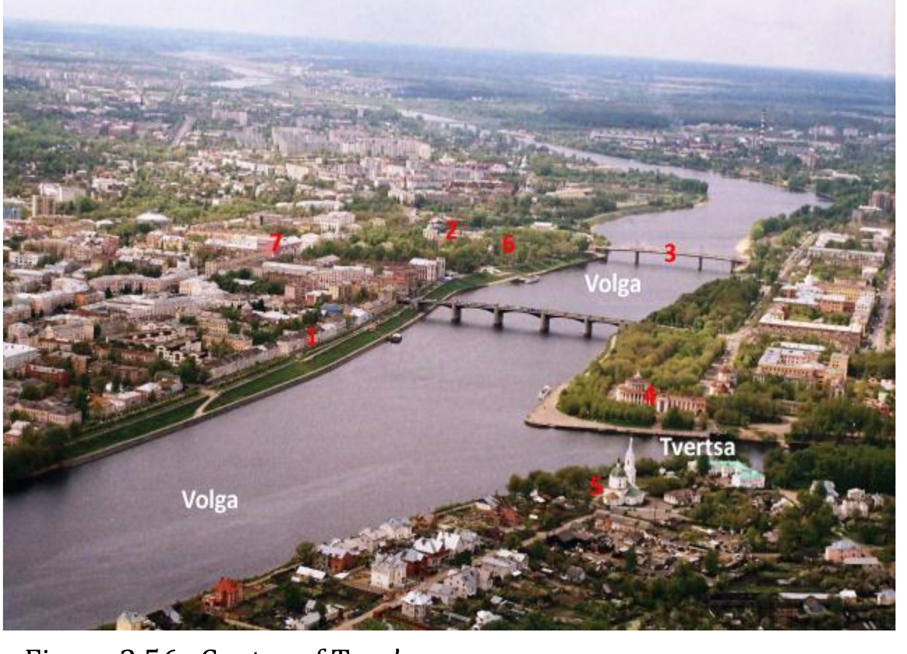


Figure 2.55. The main city sights



1. Stepan Rasin Embarkment
2. Putevoj palace
3. Old bridge
4. River station
5. Church of ancient Otroch Monastery
6. City garden
7. Central street Sovietskaja

Figure 2.56. Center of Tver’

Figure 2.57. Stepan Rasin embarkment

1. Stepan Rasin embankment

Stepan Rasin embankment is situated in Tver’ on the right bank of the river Volga. It was named in honor of Don Cossack Stepan Rasin in 1923. It began to be built in 1760s when there was redevelopment of the city after the great fire of 1763. The houses were built close to each other with principle “single façade”. During the Soviet time with appearance of cargo port and passenger river station embankment became the one for walking of citizens.

Figure 2.58. Putevoj palace

2. Putevoj palace

Putevoj Palace is the main attraction of Tver’. It was built in 1764-1778 in classical style with baroque elements. It was named Putevoj (Putevoj palace means Road palace), because imperial family rested here on the way from Saint-Petersburg to Moscow.

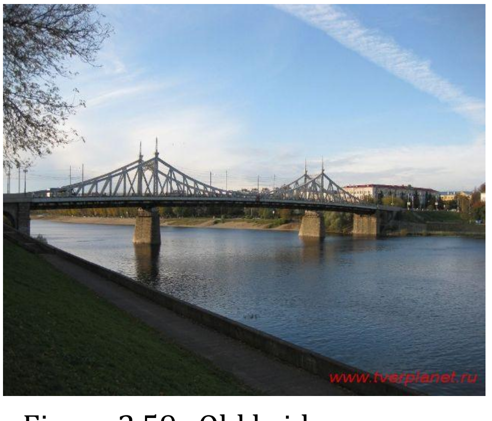


Figure 2.59. Old bridge

3. Old bridge

Old bridge was built in 1931. Firstly one branch for broad-gauge tram was laid, then in 1769 the second one was laid. In 1994-1999 there was reconstruction of the old Tver’ bridge. It became 5 meters wider.[31]

[31] http://www.tverplanet.ru

Figure 2.60. River station

4. River station

River station is situated on the intersection of two rivers, Volga and Tvertsa. It was built in 1935-1938. It is one of the most impressive buildings of Soviet times in Tver'. It is notable for its geometrized composition and original decor.

Figure 2.61. Otroch monastery

5. Church of the ancient Otroch monastery

Otroch Uspenskij monastery was founded in the middle of XIII century. In 1930s all monastery buildings except the Uspenskij Cathedral, were destroyed. The Cathedral was built in 1772 in style of Narishkin baroque.

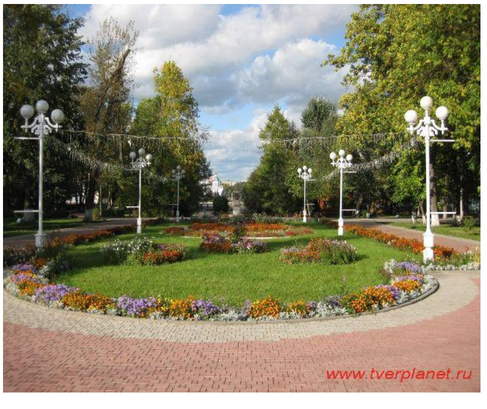


Figure 2.62. Gorodskoj garden

6. Gorodskoj garden on the place of Tver' Kremlin

Gorodskoj garden is situated on the right bank of the river Volga on former territory of Tver' Kremlin. In 1850 governor ordered to plan Znamenskaja square and Gorodskoj garden, the third one after Dvorcovij and Gubernatorskij, situated in the west.

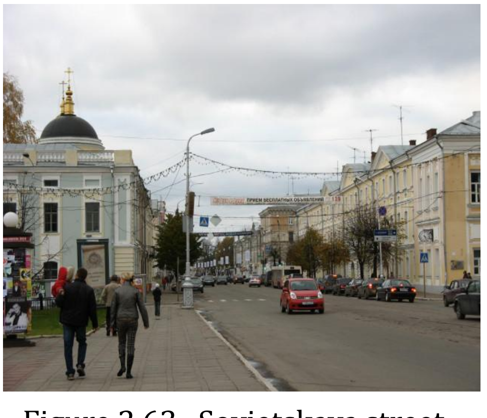


Figure 2.63. Sovietskaya street

7. Central street Sovietskaya

Sovietskaya street is the main street in the city, situated in its historical center. This street together with 2 streets branched off from Sovietskaja square and other squares are outstanding architectural composition which was assumed as basis [32] of the plan of the city of Tver', made in 1763.

[32] http://www.tverplanet.ru

2.2.3. Site analysis

2.2.3.1. Dimensions

The site is divided by forest on 3 parts. The western part is the smallest one, its area is 39,37 ha. Its length in the longest place is 697 m, its width is near 635 m. The eastern part is the largest one, its area is 82,33 ha. The length of its longest side is 1,229 km. The length of its smallest side is 967 m. Its width is near 739 m. The area of the northern part is 42,81 ha. Its length in the longest place is 958 m. Its width in the widest place is 569 m. Total area of the site is 164,51 ha.

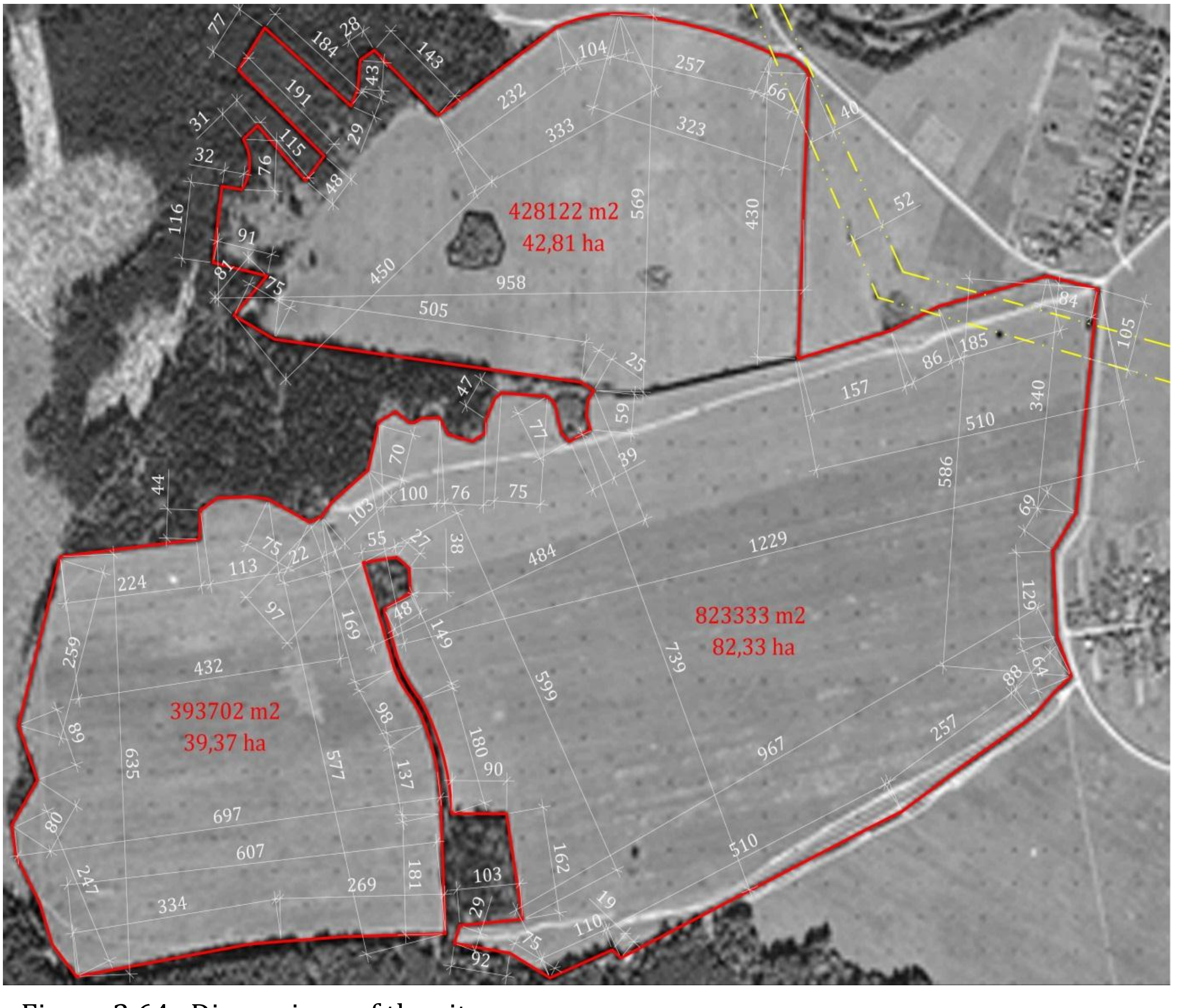


Figure 2.64. Dimensions of the site

2.2.3.2. Relief analysis

The highest altitude mark is 144,8 m. It is situated in the northen part of the site. The lowest altitude mark is 139,5 m. It is situated in the northern, eastern and south-eastern angles. The difference between the highest and the lowest altitude marks is 5,3 m. The difference between the highest and the lowest altitude marks in the western part is 3,5 m, in the eastern part it is 4,5 m and in the northern part is 5,3 m. Taking into consideration that length of the site is near 2 km and width is near 1,3 km, relief of the site can be considered as flat.

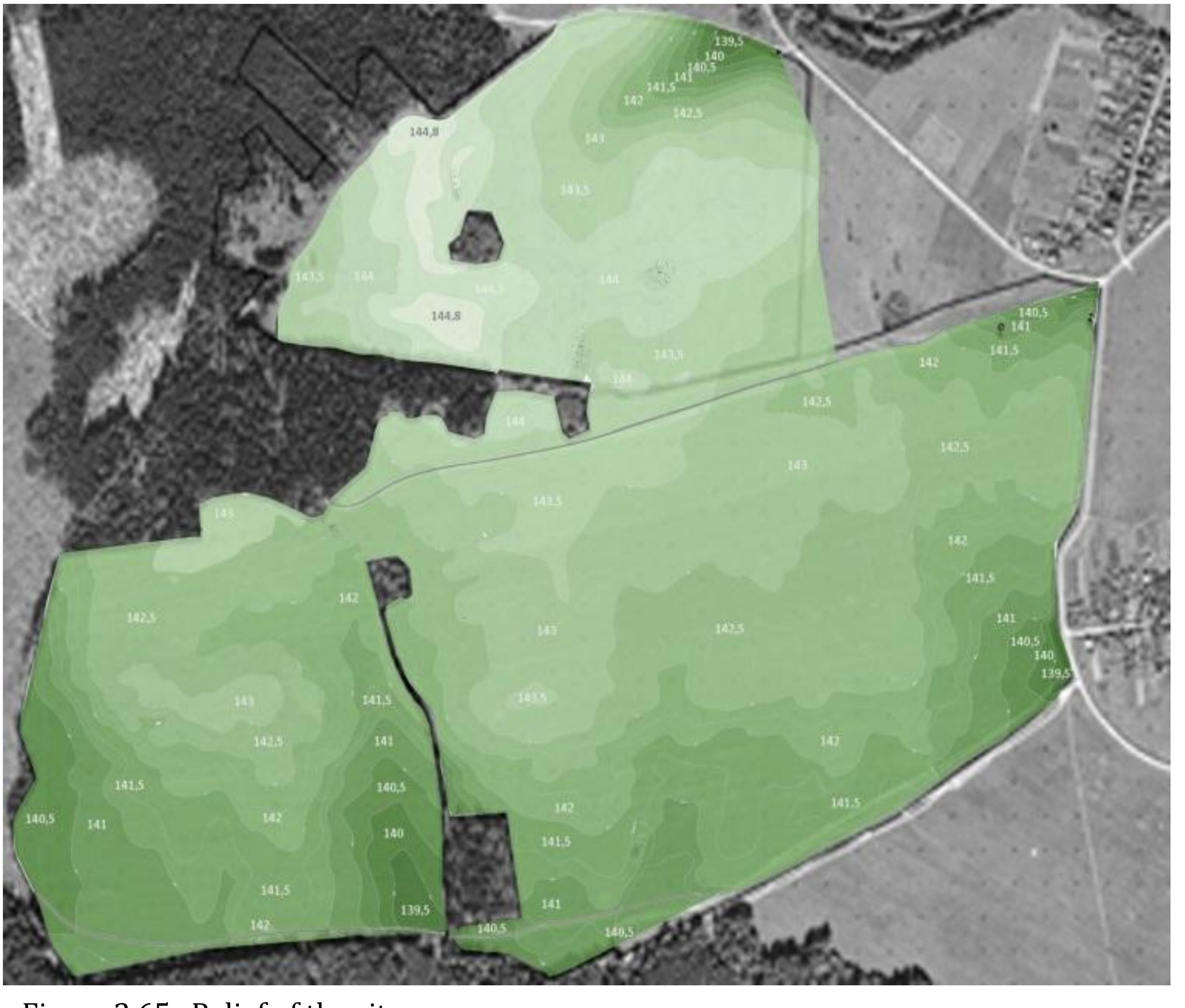


Figure 2.65. Relief of the site

2.2.3.3. Slops analysis

The main aim of slops analysis is to determine the lowest places of the site and directions of water flows in periods of rains and during thawing of snow. The lowest places can accumulate water and provoke bogginess of the territory. Such territories are unfavorable for agricultural development. This circumstance is an obstacle for individual construction as in most cases gardening is a necessary part of people's life in the settlements.

In the site the lowest parts are determined in almost all southern and western boundaries of the site, in the eastern entrance zone and in the northern zone close to the river.

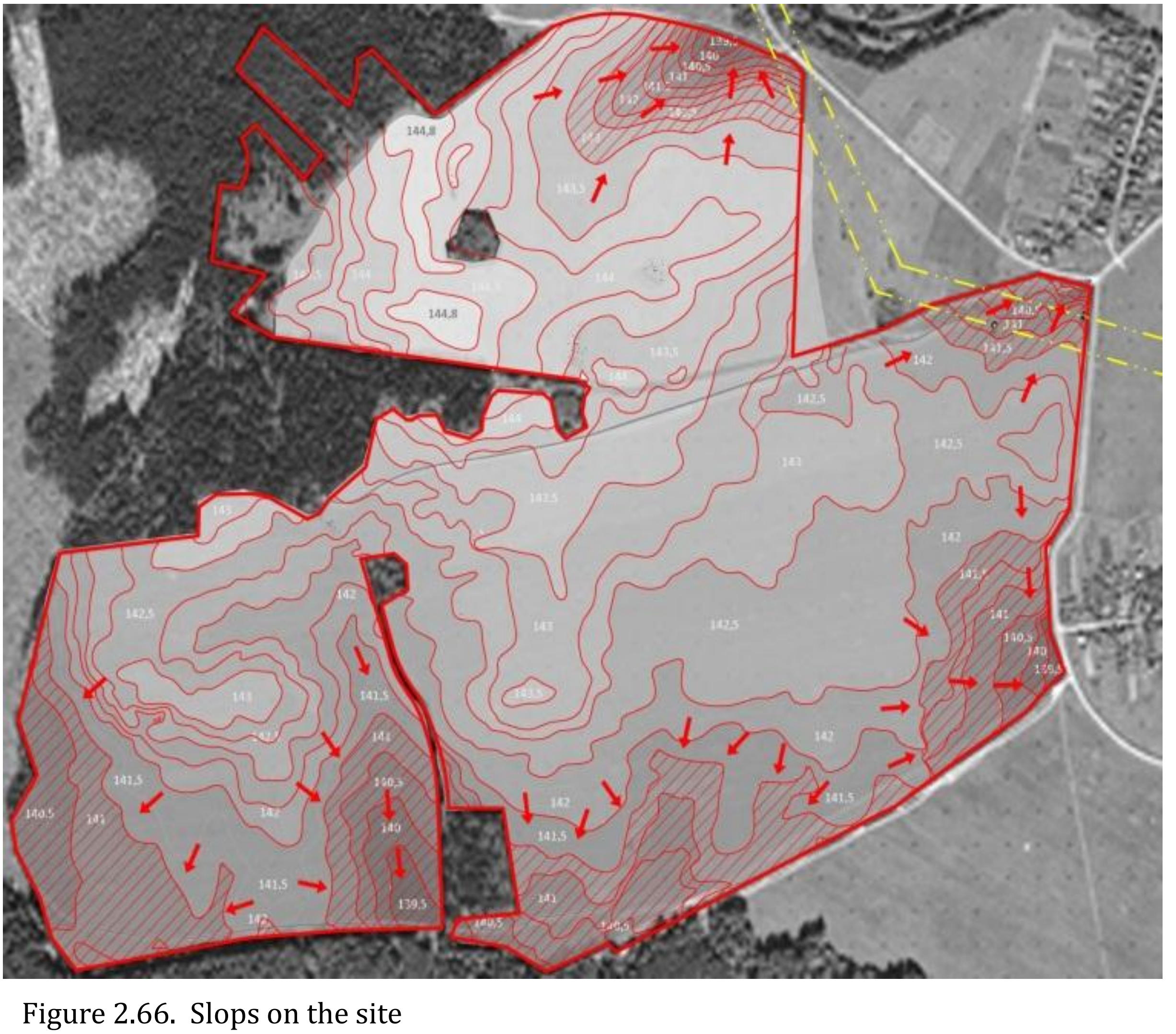


Figure 2.66. Slops on the site

2.2.3.4. Vegetation analysis

The site is field and, probably, in the past it was used for agricultural purposes. So, there is almost no forest on the site. In the southern part there are little pines and conifer. In the northern part the site includes the part of pine forest. This vegetation should be taken into consideration.

Figure 2.67. Conifer

Figure 2.68. Pine forest

Figure 2.69. Small pines

Figure 2.70. Vegetation on the site

2.3. SUMMARY

2.3.1. S.W.O.T. analysis

Strengths

- Thanks to the large number of forests, mainly the coniferous ones, Tverskaya region is considered as one of the most environmentally friendly regions of the European part of Russia
- The site is close to big city, the administrative center of the region
- Accessibility (link with Tver' due to train station and highway)
- The site is close to 2 rivers and forest
- Soils on the site are favorable for construction and don't need engineering preparation.

Weakness

- Bogginess of the lowest parts of the site is possible

Opportunities

- Tverskaya region is rich in peat deposits, mineral waters, therapeutic muds
- Railway station as opportunity for development of settlement
- 3 villages close to the site as opportunity for development of infrastructure
- Lines of electricity transmission close to the east boundary of the site as source of electricity that can be used for the settlement
- Forest on northern part of the site as opportunity to create park

Threats

- Low sunshine duration in autumn and winter period
- High level of pollution of environment in Tver', including emissions without treatment
- Noise and pollution from railway and road
- Lines of electricity transmission close to the east boundary of the site need sanitary zone

2.3.2. Opportunities and constraints map

The main aim of drawing of opportunities and constraints map is to summarize many items of information collected during analysis phase. Possibility to see all opportunities and constraints on one map helps in understanding of the main features of future project and leads to concept. In this case the most important opportunities were railway station as opportunity to create public space and links between railway station and villages and river, because project began from attempts to understand movement of people and means of transport on the site and position of center of future settlement. Also forest divided the site on 3 parts played significant role as opportunity to divide the site on 3 main functional zones.

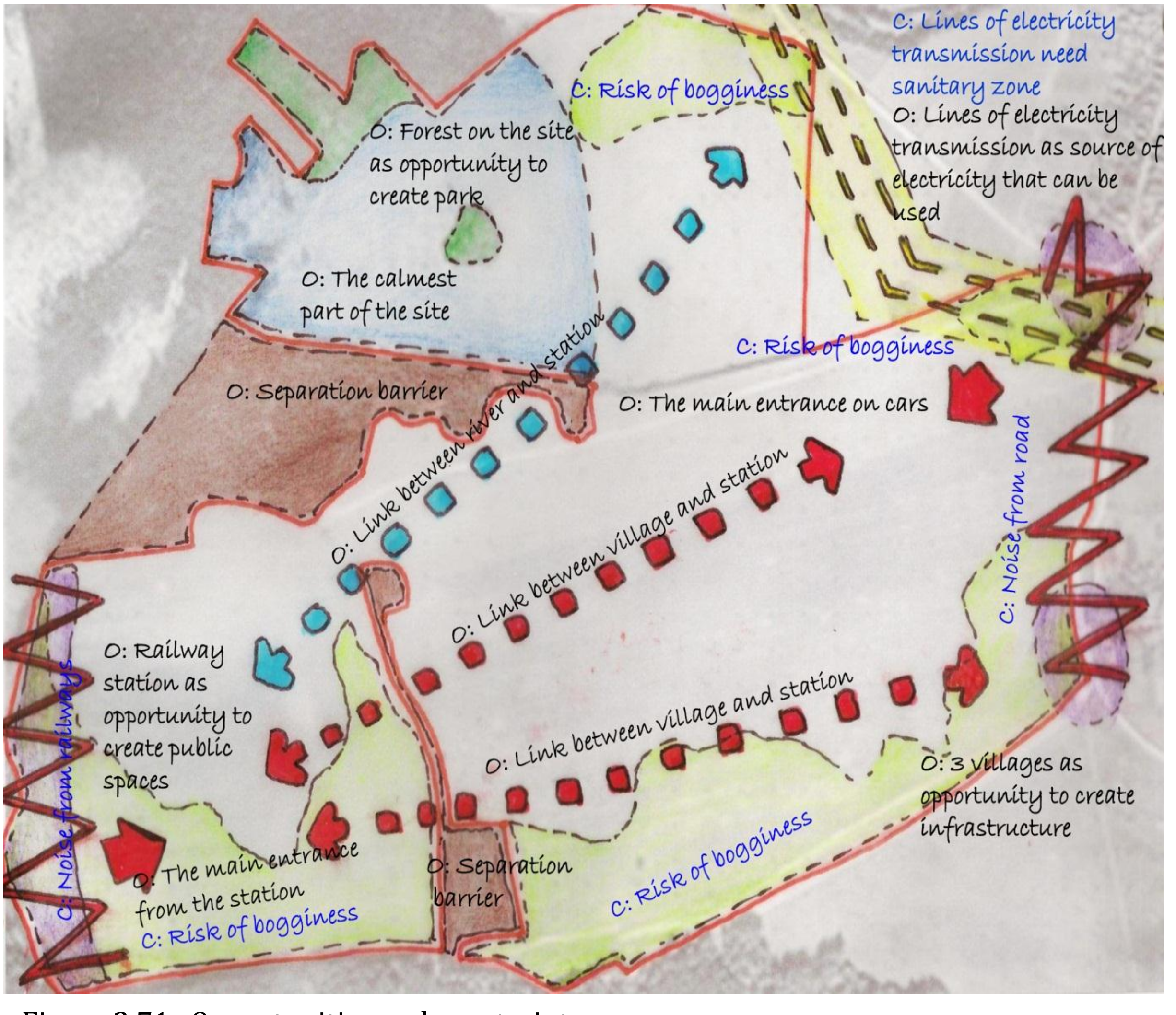


Figure 2.71. Opportunities and constraints map

2.3.3. Scale comparison

The main aim of scale comparison is to understand better the size of the site by comparing it with well known places.

In this case the places are centers of Lecco, Milan and Saint-Petersburg. It is possible to notice that the smallest part of the site, the western one, is almost equal to the center of Lecco and Sforza Castle with surrounding areas in Milan. Length of the longest side of the site is almost equal to the way from the center of Lecco to the outskirts, includes all the way from Sforza Castle to Duomo in Milan and more than half of Nevskij prospect in Saint-Petersburg.

Figure 2.72. Scale comparison

2.4. OPTIONS

2.4.1. Aims of the project

In the current situation, when there are lots of problems in different spheres of Russian life, it is necessary to deal with some of them in the project. Between modern social problems the most important ones are the ones relating to family as the base of society. That's why it was decided to set **the main aim of the project improvement of family's life and familiarization with Russian traditions and life values.**

After consideration of problems of modern families, the ones with which it is possible to deal in the project of settlement were selected.

- **Russian culture**

During the decades of Soviet Union everything was done to make Russian people forget about their own religion and culture with which Russia had lived during 1000 years. After the collapse of Soviet Union gradual revival of the lost begins. It is important to include in the project functions which will provoke familiarization of families with Russian traditions and life values, including learning of Orthodoxy, Russian language and literature, Russian traditional arts.

- **Accomodation**
    - Families with many children
    - Inginent families
    - Young families

In 2009 in Tver' there were 8912 families registered as in need for accommodation. According to new data, in 2011 there were 840 families with 3 and more children registered as in need for accommoation. Also it is necessary to consider that every year many new families are created. In 2009 number of marriage is 4298. The majority part of them also has problem with accommodation. As according to datas of 2009 average monthly salary in Tver' is 400 euro, it is difficult to solve this problem. In the project solutions of different types of economical accommodation should be elaborated, accent should be done on families with many children, as currently the majority of them are in difficult financial state.

- **Upbringing of children**
  - Russian traditions
  - Education and creativity
  - Sport

As the main aim of the project is improvement of family's life with special accent on families with many children, it is necessary to take into consideration the question of upbringing of children as one of the most important ones. As it was noticed above, at the moment it is necessary to support revival of Russian culture, it is important in upbringing of children. They should know and love their own country from their childhood. Also functions for education and sport should be provided.

- **Health**
  - Children with disabilities
  - Pregnant women and children
  - Old people

In the question of health it was noticed that in the task of competition there was medical center for motherhood and childhood, rehabilitation and medical care for the elderly. Taking into consideration special accent on families with many children and consequently on children themselves, it was decided to include in the project function for children with disabilities, as there is only 1 rehabilitation center for children with disabilities in Tver' while the number of such children only in Tver' is near 2000. In addition, meeting children with disabilities is useful not only for them but also for healthy children because it let bring them in compassion to children who differ from them. Also care of the elderly can play very important role in upbringing of children and young people, because it would be possible to organize their participation in care of old people what could help to implant in children and young people patience and love for people.

2.4.2. Means to reach

Aim		Means to reach
Russian culture		Russian cultural center, including Auditorium, museum, library, center of russian language and culture, russian art schools
Accomodation	Families with many children	Economical individual houses
	Ingignent families	Flats and townhouses
	Young families	Flats
Upbringing of children	Russian traditions	Russian cultural center, including Auditorium, museum, library, center of russian language and culture, russian art schools
	Education	Schools and kindergardens
	Sport	Sport complex, including open fields; swimming pool, equestrian sport club
Health	Children with disabilities	Sanatorium, linked with equestrian sport club and swimming pool; children's summer camp
	Pregnant women and children	Medical center
	Old people	House for old people with separated park

Table 2.13. Means to reach

2.4.2.1. Families with many children in Tver'

In Tverskaja region the system for supporting of families with many children was created. It includes:

- Payment for the birth of the third child;
- Monthly allowance for each child;
- Free supply of medecine for children of age up to 6 years in outpatient treatment;
- Primary enrolement in kindergardens;
- Allowments for house services for families with income below 1,5 subsistence minimums;
- Free hot meals for children in schools;
- Actions for providing all the necessary for school, etc.

By the order of the presedent if Russian Federation, the governor of Tverskaja region initieted the law «About free donationof land on the territory of Tverskaya region to families with 3 and more children». It came into force on 20 December 2011.

Now families with many children (3 and more) can receive in property gratuitous land **for housing (from 1000 to 1500 m2) or farming (from 1500 to 2500 m2)** in the territory of the city or area where they live.

For getting the site it is necessary to address yourself to administration of the city or district with application and all necessary documents. If proposed site is not suitable for family, it is possible t refuse and the turn of the family is not changed.

The land in the settlement can be proposed for donation with possibility of building of the houses with minimum price. Part of the price of the houses can be payed by the government of the district or by municipality of Tver'.[33]

[33] http://www.region69.gov.ru

2.4.2.2. Children with disabilities in Tver’

Urban Rehabilitation Center for children and teenages with disabilities

Figure 2.73. Urban Rehabilitation Center

Rehabilitation center operates in Tver‘ **during 11 years**.

Total area of the Center is 1250 square meters.

Treatments: massage, including a "dry" pool; physiotherapy with special trainers, physical therapy, treatment of opportunistic diseases.

Sanatorium included in the project of the settlement can be elaborated as suburban branch of Urban Rehabilitation Center. The branch with big territory, situated out of the city, can help to increase significantly the quality of rehabilitation in the Center as well as to give possibility of rehabilitation to larger number of children.[34]

Summer camps for children with disabilities

8 April 2010 the question of organization of children's summer holidays was discussed at the meeting of the Committee on Social Policy of Tver’ City Council. ”Tver’ camps are not suitable for recreation for children with disabilities”, said Alexei Borisov, Deputy Chief of Administration of the city.

In Tver’ there are 2,000 children living with disabilities, and for several years, only the Center is involved in the organization of summer holidays for the children. It is an excessive task for him. The committee decided to take under control problem with summer camps for children with disabilities.

Summer camp, which should be organized in the settlement according to the competition task, can be the part of the Center and can be oriented on organization of summer holidays for children with disabilities.

[34] http://www.dislife.ru – article «Оригинальные методики по реабилитации детей-инвалидов в Твери» («Original techniques for rehabilitation of children with disabilities in Tver’»)

2.4.3. Change of competition task

After formulation of aims and means to reach some necessary points were added in competition task (added points are red).

- Individual houses with a total area from 150 to 250 m2 (number of storeys 1-2) with plots from 1000 to 3000 m2;
- Townhouses;
- 3-storey houses with flats;
- Access roads and footpaths with asphalt;
- Open recreational areas;
- Parking;
- Buildings and structures for engineering infrastructures;
- Russian cultural center
- Sport complex, swimming pool, sport facilities (tennis courts, football and basketball fields, a platform for extreme sports, skiing, stands for the bullet shooting, etc.);
- Equestrian sport club
- Shops, offices, pharmacies, post offices, banks
- Kindergartens;
- Schools;
- Sanatorium for children with disabilities, linked with equestrian sport club and swimming pool;
- Medical center (motherhood and childhood, rehabilitation, medical care for the elderly);
- Summer camp for children with disabilities;
- Administration;
- Buildings of protection;
- Beach area around natural and artificial reservoirs;
- Territory of children's summer camps;

2.4.4. Goals

Goals for settlement

- **Walkability**
  - Most things within a 10-minute walk of home
  - Pedestrian friendly street design: buildings close to street; tree-lined streets
  - Pedestrian streets free of cars
- **Connectivity**
  - Interconnected street grid
  - A hierarchy of streets, boulevards, and alleys
- **Mix use**
  - Mix of shops, offices, appartments, townhouses and houses
- **Traditional neighborhood structure**
  - Discernable center and edge
  - Public space at center
  - Contains a range of uses and densities within 10-minute walk
- **Sustainability**
  - Minimal environmental impact of development and its operations
  - Eco-friendly technologies, respect for ecology and value of natural systems
  - Energy efficiency

Goals for houses

- **Comfort**

Comfortable conditions inside the house should be created. It is one of the most important goals, because it influences on the whole result of the work in such way, that without reaching of this goal all other goals lose its sense.

- **Quality**

Quality of the work and materials is important in every project, but in this case it is especially important, because houses are designed for groups of people with limited income. That's why it will be better if the house can stand without necessity of repair for a long time.

- **Longevity**

The houses should be designed with use of long-lived constructions and materials for giving the possibility to several generations to live in it.

- **Cost**

Because of material state of the families, for which the houses are designed, it is necessary to find the balance between quality and cost of materials.

- **Ecological compatibility**

Because of difficult ecological situation, respect to environment is the question of especial importance.

- **Energy efficiency**

Taking into account difficult ecological situation in the world as well as limited income of the families, for which the houses are designed, especially the ones with many children, energy-saving technologies should be used.

2.4.5. Concept plan

Variant I

Concept plan is based on Opportunities and constraints map. The first question was the link between railway station in western part of the site and 2 villages and river close to the eastern, south-eastern and northern parts. In variant I it was solved with direct roads, linking all the parts and intersecting in the northern link between 2 parts. The second question was the position of center of the settlement. In variant I it was determined in the intersection of roads close to the part linking the western and eastern parts. In addition, as in the southern part of the site there is zone with risk of bogginess and it would be better to avoid individual construction there, it was decided to place park with artificial reservoirs in this zone.

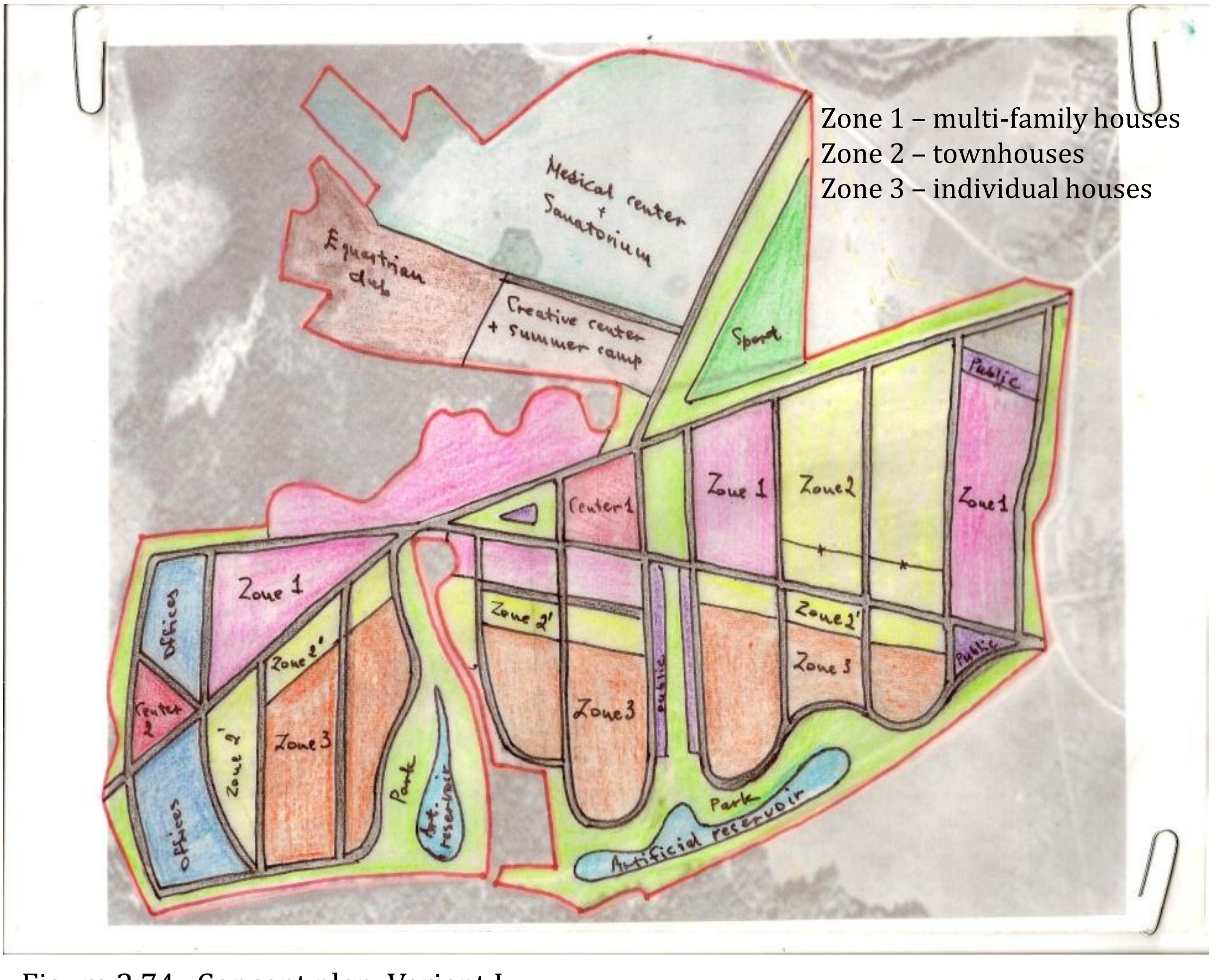


Figure 2.74. Concept plan. Variant I

Variant II

In variant II link between railway station and village «Olbovo» was made with direct diagonal road from north-eastern to southern part and then along the southern boundary of the site, because exactly in this place there is existing sandy road on the site. This diagonal determined direction of all the grid of roads on the plan. Position of center of the settlement was determined in the south-eastern part of the site close to the road, linking the site with railway station. While in the variant I, zone of individual houses was situated on the south, in variant II zone of individual houses is much, zones of townhouses and multi-family houses were concentrated close to public places like railway station, park and sport facilities. Northern part of the site was occupied by sanatorium, children's summer camp, equestrian club and sport facilities from beginning.

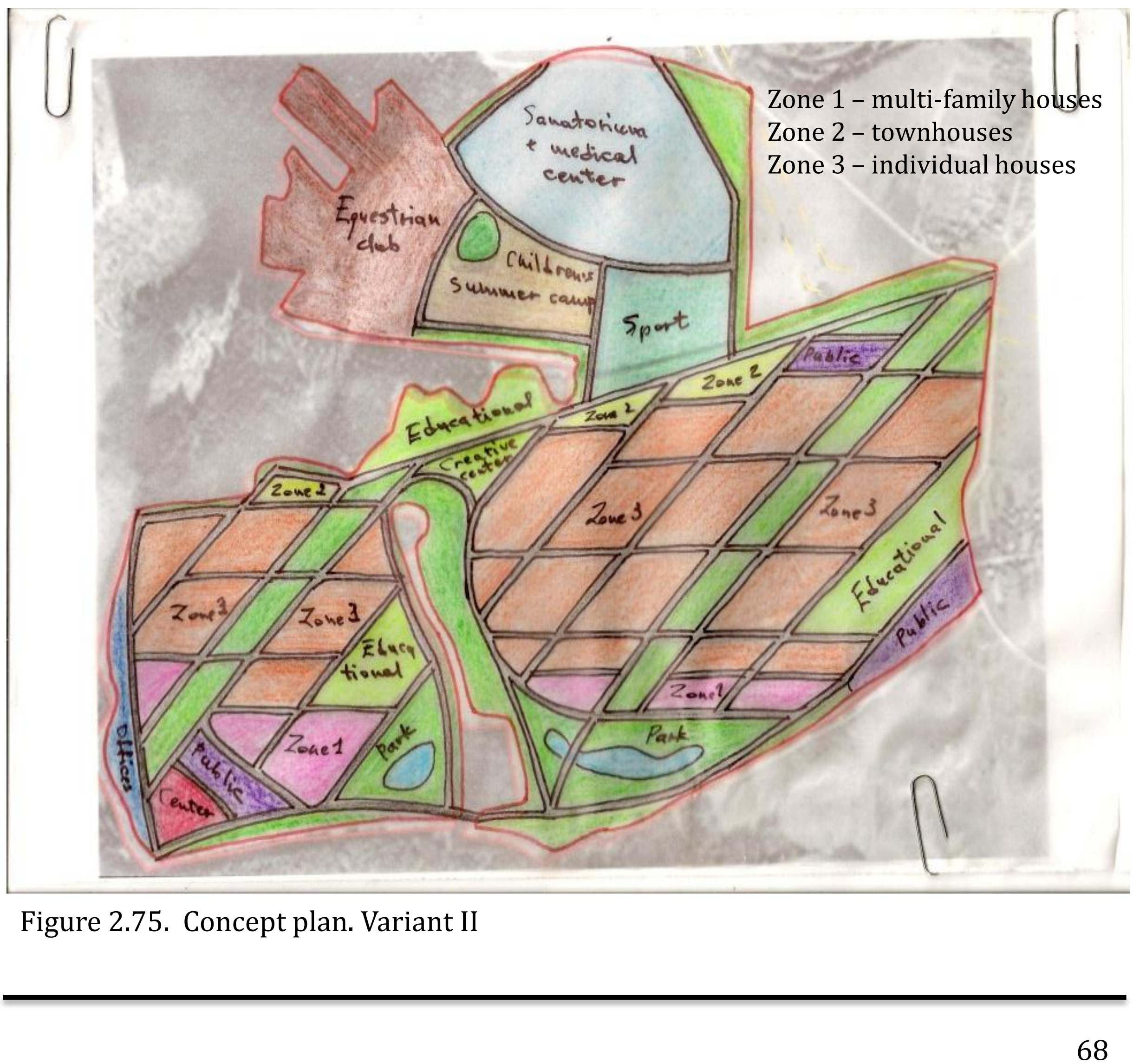


Figure 2.75. Concept plan. Variant II

Variant III

Variant III is resembled to the final one. The first decision was to place linking roads close to the boundaries of the site for avoiding division of parts of the site. The second decision was to determine different functions in 3 parts of the site. In the western part, which is situated close to the railway station, zone with high and medium density was placed. There are multi-family houses, townhouses and offices. In the eastern part, which is situated close to villages, zone with low and medium density was placed. The majority part of the territory is occupied by individual houses. Only close to sport facilities and linking road there are townhouses. The third decision was to choose reclangular grid of roads as the most convenient for cars and people.

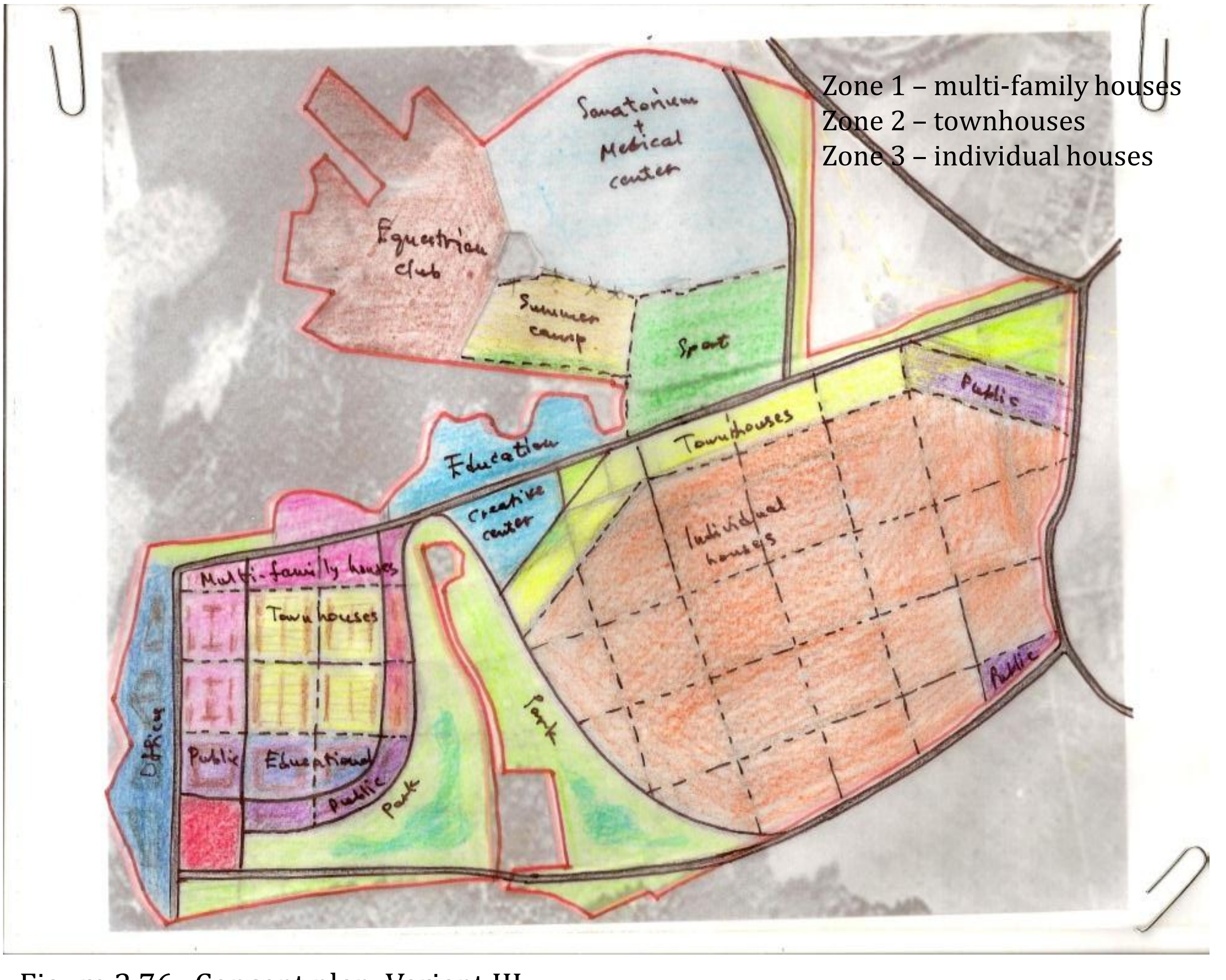


Figure 2.76. Concept plan. Variant III

Final variant

Very important point which was changed in final variant in comparizon with variant III was the position of center. The main center was determined in the zone linking western and eastern parts of the site. Direct road in this place was changed on the one repeating the form of the boundary for avoiding division of the main center with car road as it was planned as pedestrian zone. The second center close to the station is also important point but while the main center is more cultural with church and Russian cultural center inside, the second one is more administrative with administration, commercial center and offices around it. Also zones for schools and kindergardens were placed in centers of western and eastern parts of the site.

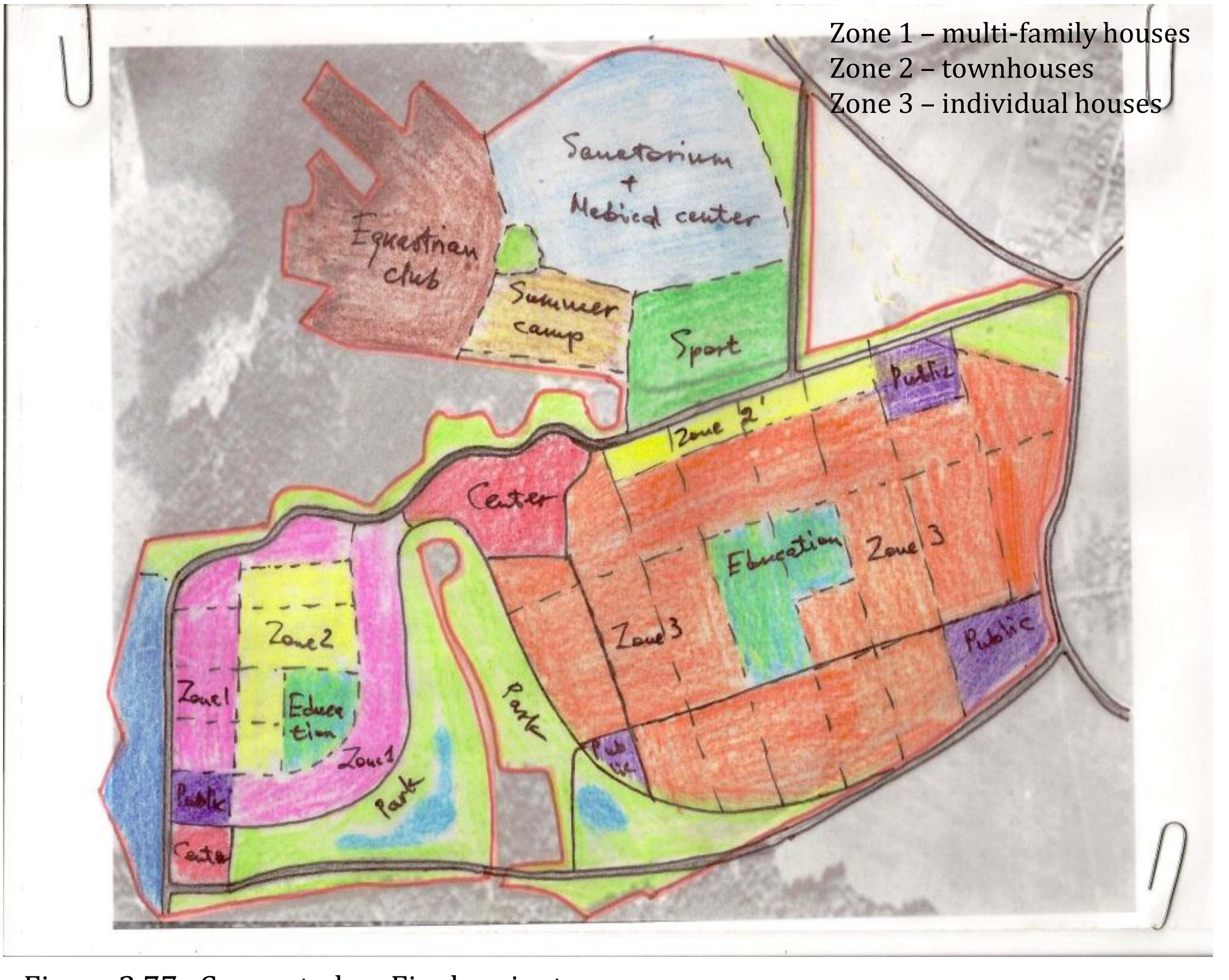


Figure 2.77. Concept plan. Final variant

2.4.6. Case studies

2.4.6.1. Residential settlement «Northern shining»

Figure 2.78. Location

Location

The site is located within the new borders of the city of Vsevolozhsk and borders from the south to the area, "Mill Stream", which is the most developed in terms of modern development and, therefore, the most expensive area of the city of Vsevolozhsk. To the east and the north area is bordered by forests, and on the west side it is adjacent to the site free of buildings area, which is planned for development for the construction of residential complexes.

The site is connected to the main roads of the region by three roads. It is possible to reach Saint-Petersburg by minibus. The distance to the St. Petersburg is 15 km. The distance to the nearest railway station is about 1000 m.

Planned facilities

- Apartments of approximately 100 m ^{2} (total of 70 apartments);
- Individual houses in an area of 2-3 floors of 130 to 300 m ^{2} on a land area of 10-20 acres (total of 352 houses);
- Townhouse area of 150-250 m ^{2} of 2-3 floors with built-in garages (total of 108 homes).

Engineering equipment of the village

Power supply at the rate of 10-15 kW per household, water supply center, sewerage, central heating steam (gas boiler) or individual gas boiler, paved roads. [35]

[35] http://www.megalit.ru/ – article «Жилой комплекс «Северное сияние» («Residential complex «Northern shining»)

Figure 2.79. Masterplan

1 – Public center; 2 – Commercial and entertainment center; 3 – Sport and health center with medical center; 4 – Engineering buildings; 5 – Concert hall; 6 – Kindergarden; 7 – Artificial reservoir; 8 – Tennis, volleyball and basketball fields; 9 – Playgrounds.

Infrastructure

The infrastructure of the village will include a supermarket, sports center, kindergarten, playground, sports courts (basketball, volleyball, tennis, bike path), commercial spaces for rent, office of family medicine, pharmacy, security guard.[36]

Figure 2.80. Public center

Figure 2.81. Artificial reservoir

[36] http://www.megalit.ru/ – article «Жилой комплекс «Северное сияние» («Residential complex «Northern shining»)

2.4.6.2. Children's clinical sanatorium «Evpatoriya»

Figure 2.82. Location

Location

Sanatorium is situated on the shores of the Gulf Kalamitsky in the heart of the resort Evpatoriya in Crimea, in the depths of a large park, which protects it from the noise of the city resort.

Description

Today sanatorium is a multi-treatment and rehabilitation center for 600 people of year-round filling with well-equipped physical facilities, infrastructure and private protected area[37] of 14 hectares.

Figure 2.83. Sanatorium

[37] http://www.evpatoriya-mdm.ru

Figure 2.84. View of the sanatorium

Figure 2.85. View of the sanatorium

Figure 2.86. View of the sanatorium

Directions of work:

- All the year – a very serious treatment of disorders of the musculoskeletal system and children's cerebral palsy;
- During summer period (from June to September) – summer housing for people, who wants to have a rest and to undergo health-improving treatment.

Sanatorium complex includes:

- Administrative building
- 4-storey buildings (offices) for year-round recreation and treatment
- 2-storey summer housing, located directly at the beach area
- Medical building
- Diagnostic building
- 3 therapeutic pools with thermal water

Infrastructure:

Infrastructure includes 3 treatment pools, playgrounds, volleyball and tennis courts, summer theater, 2 cafes, beauty salon, shop, bar, school, library, 2 saunas, beach, park.[38]

[38] http://www.evpatoriya-mdm.ru

Specialization of sanatorium:

- **Diseases of the nervous system**
    - Children's cerebral and birth palsy
    - Diseases of the peripheral nervous system
    - Consequences of neuroinfections and injuries
- **Diseases of musculoskeletal system**
    - Low back pain, scoliosis, kifo, arthritis, arthrosis and other diseases of spine and joints
    - Clubfoot clubhand, flatfoot, congenital hip dislocation and dysplasia
    - Chronic osteomyelitis, the effects of trauma and infection
- **Diseases of breathing organs and skin**
    - Asthma, allergic rhinitis
    - Bronchitis and chronic inflammatory diseases of the throat
    - Atopic dermatitis, eczema, psoriasis

The main methods of treatment:

- Sea-bathing
- Sun, air and sand baths
- therapeutic 4-5 meals a day with customized menu
- Therapeutic exercise, massage
- Mud treatments: baths, tampons, galvanic muds
- Hot woolen packs
- Hydrokinesitherapy in the pool with thermal mineral water
- Inhalation of mineral water and herbal remedies, aeroionotherapy, aromatherapy
- Reflexology: acupuncture, electro-and laser puncture, acupressure;[39]

[39] http://www.evpatoriya-mdm.ru

2.5. Materplan

2.5.1. Masterplan description

There are **2 main entrances in the settlement**:

- **For cars** in the eastern part of the settlement;
- **For people** from railway station in the western part of the settlement.

Driving into the settlement from the east close to village Kustovo, firstly it is possible to see green area near the entrance in the settlement and public area with meeting place. Then the main road goes along the line of townhouses, protecting individual houses zone located behind them from car and people noise. On the right side there sport facilities adjacent to the main road and the road linking residential part of the settlement with the river Cava. Follow this road one can reach sanatorium for children with disabilities, located in the northern part of the settlement close to the river. Behind the sanatorium in the north-western part of the settlement there summer camp for children with disabilities and equestrian club with fields and forest for horse ride and walking. Finally, right before the eyes there is cultural center of the settlement with church complex, Russian cultural center, Russian traditional art studios and wooden fortress. The main road rounds it from the right side and follows along the north-western boundary of the site to the railway station.

Entering in the settlement from the railway station in the south-western part of the site, one gets to the square with commercial and entertainment center and administration of the settlement. Public area starting from this place has 3 directions. The first road is the direct one, where there is public street formed by offices and public spaces on the ground floors of multi-family houses. Two next roads are along the boundaries of the park located in the southern part of the settlement near the forest. The second one lays along northen boundary of the park. On the left side public zone is with help of public spaces on the ground floors of multi-family houses. The third road runs along the boundaries of the site to the villages in the east.

Figure 2.87. Masterplan

1. Administration
2. Commercial and entertaining center
3. Open parking
4. Service center
5. Office
6. Multi-family houses. Type 1
7. Multi-family houses. Type 2
8. Multi-family houses. Type 3
9. Multi-family houses. Type 4
10. Townhouses. Type 1
11. Townhouses. Type 2
12. Individual houses. Type 1.
13. Individual houses. Type 2.
14. Individual houses. Type 3.
15. School
16. Football field
17. Basketball field
18. Volleyball field
19. Tennis court
20. Kindergarten
21. Park
22. Artificial reservoir
23. Restaurant
24. Wooden fortress
25. Filial of Tver' local history museum
26. Russian traditional handicraft studios
27. Russian folk music, dance and theatre studios
28. Center of Russian Culture and Traditional Art
29. Church complex
30. Sport complex
31. Swimming-pool
32. Summer camp housing
33. Hotel
34. Stables
35. Medical center
36. Diagnostic center
37. Treatment and recreation center
38. Therapeutic pools
39. Supermarket
40. Playground
41. Sanatorium housing

2.5.2. Land use

The main functional zones are:

- Residential zone, including multi-family houses, townhouses and individual houses;
- Public zone
- Office zone
- Educational zone, including schools and kindergartens
- Sport zone
- Medical zone, including sanatorium, children's summer camp and equestrian club

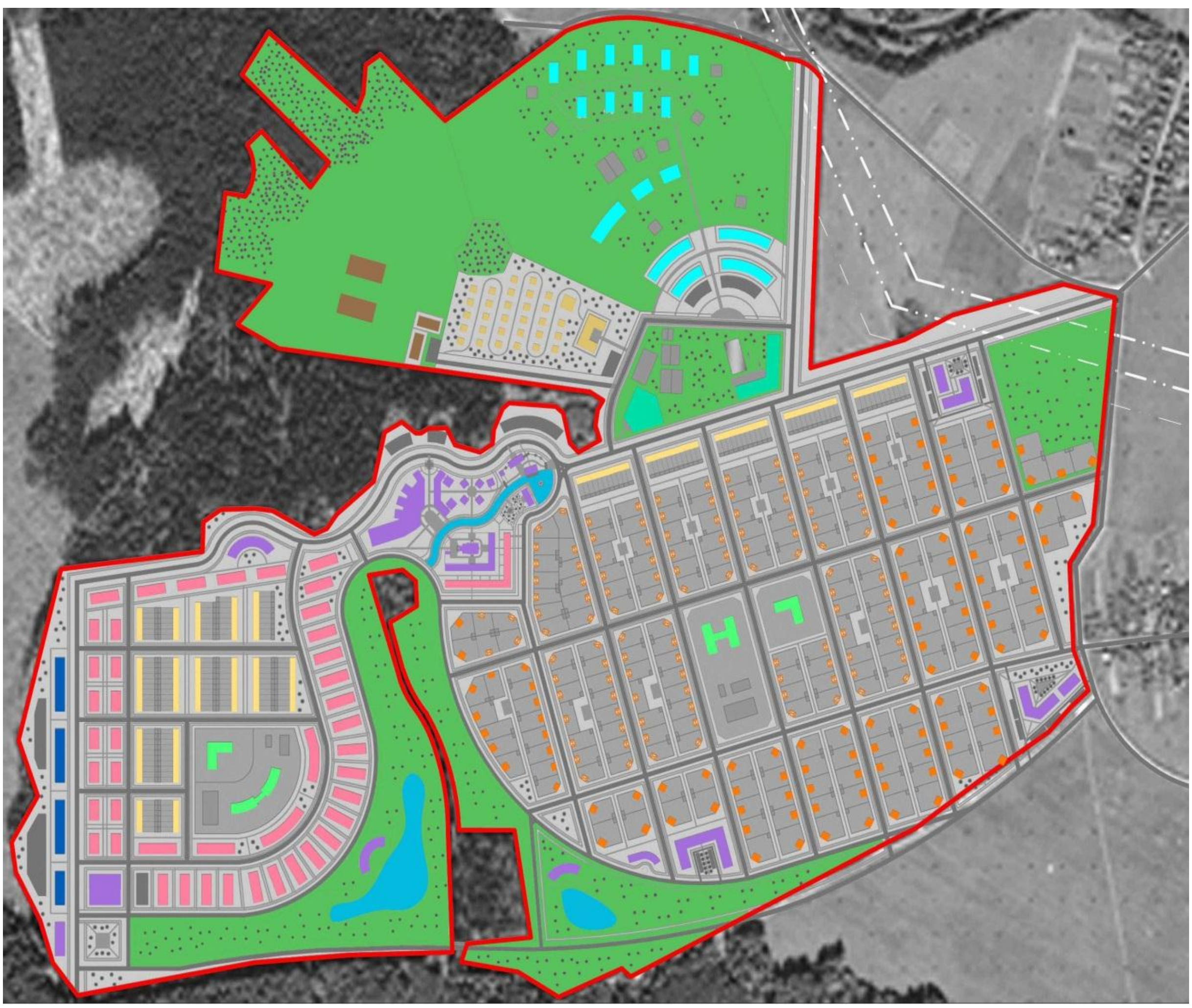


Figure 2.88. Land use

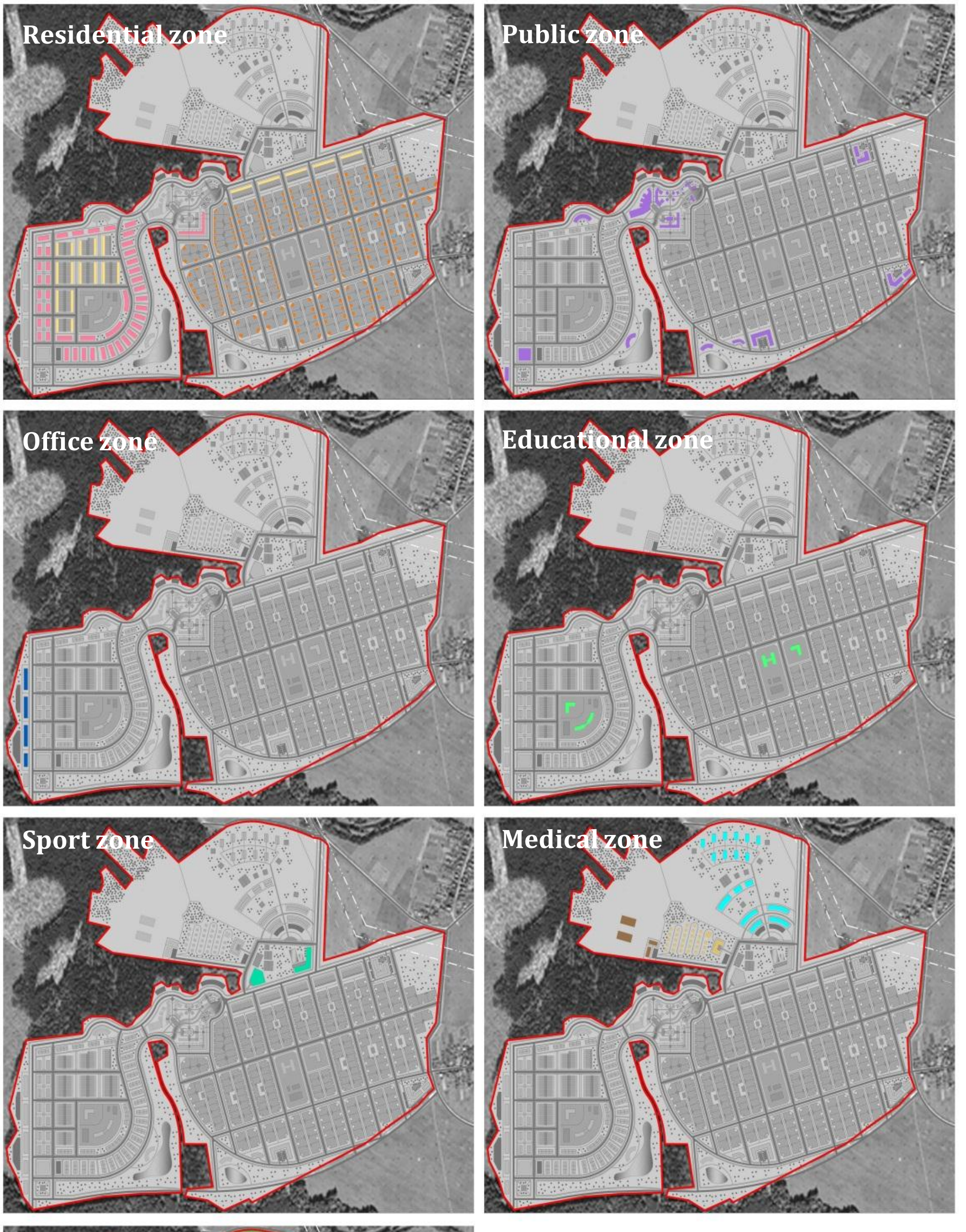


Figure 2.89. Land use

2.5.2.1. Residential zone

Residential zone is divided on 3 parts:

- Multi-family-houses
- Townhouses
- Individual houses

Multi-family houses and townhouses are situated in the zone with higher density, close to the railway station. Individual houses are situated in calmer zone close to the villages.

1. Multi-family houses. Type 1
2. Multi-family houses. Type 2
3. Multi-family houses. Type 3
4. Multi-family houses. Type 4
5. Townhouses. Type 1
6. Townhouses. Type 2
7. Multy-family house for Russian cultural center and church workers and hotel.
8. Individual houses. Type 1
9. Individual houses. Type 2
10. Individual houses. Type 3

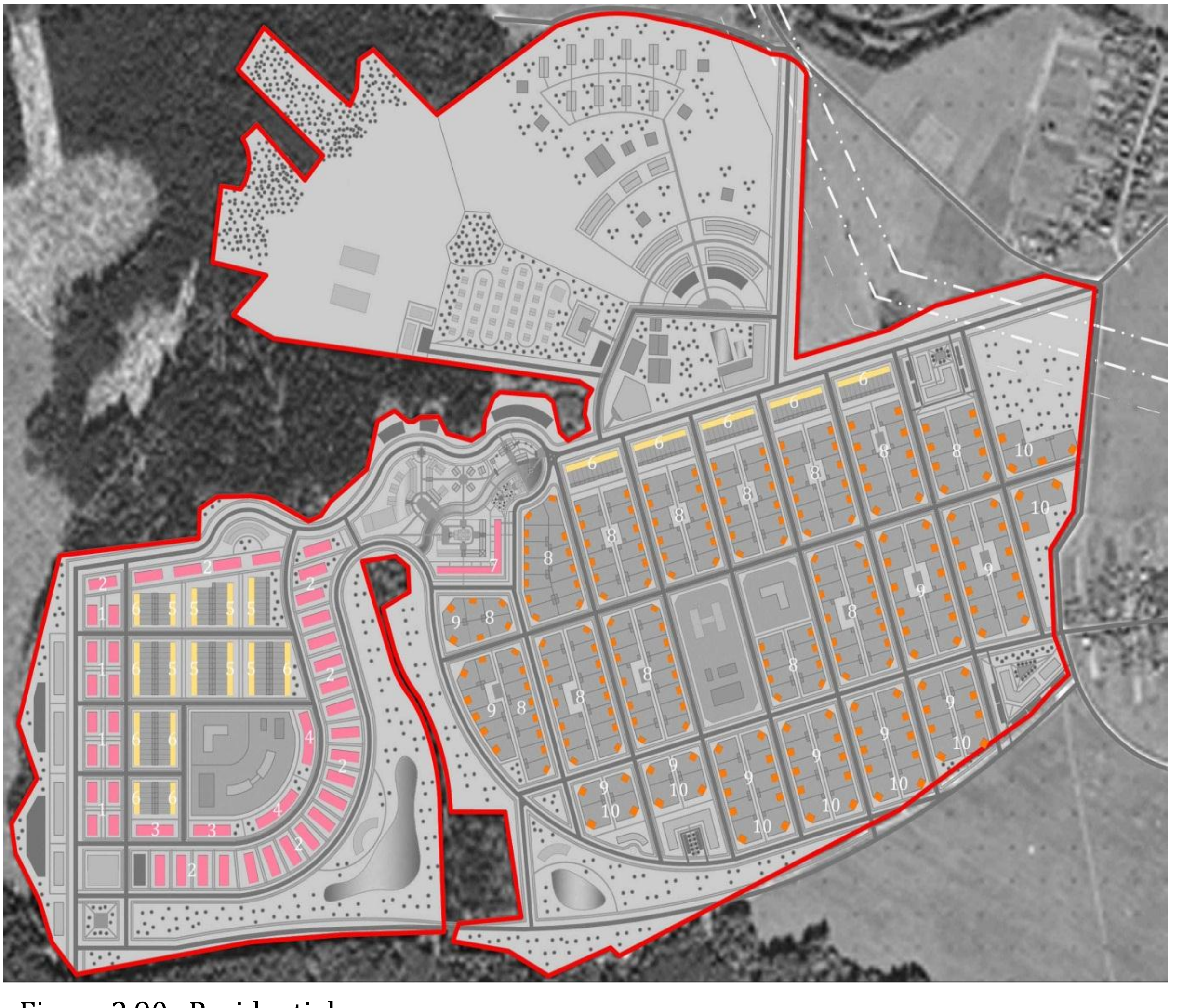


Figure 2.90. Residential zone

Multi-family houses include 4 types:

- **Type 1** includes 3-storeyed houses with corridor distribution of flats and one staircase and elevator block in the center. It gives possibility to spend less space on staircase and elevator blocks and to get more living space. Taking into account that there is no sunlight in the north, this type of houses can be used only in east-westen orientation, when sunlight goes to all the flats. In the basement floor there is parking, whicn is common for each 2 houses. On the ground floor there are areas for offices and public spaces.
- **Type 2, 3 and 4** include 3-storeyed section houses with 3, 4 and 5 sections. In each section there are two flats with two sided orientation as well as one flat with one side orientation, which should have possibility to get sunlight. In the basement floor there is parking, which is individual for each house. On the ground floor there are areas for offices and public spaces.

Townhouses are divided on the ones with common underground parking (Type 1), and the ones with individual parking in each house. Each townhouse includes site of 160 m^2 (without considering area with utility house) and separate utility house for storage of vegetables, garden instruments and keeping of animals.

Individual houses include 3 types with different areas of houses and sites:

- **Type 1** includes 2-storeyed house of 140 m^2, the site of 1000 m^2 and separate utility house.
- **Type 2** includes 2-storeyed house of 200 m^2, the site of 1200 m^2 and separate utility house.
- **Type 3** includes 2-storeyed house of 240 m^2, the site of 1500 m^2 and separate utility house.

Multi-family houses are oriented on young families. Townhouses with one part of multi-family houses are oriented on ingignent families with 1-2 children. Individual houses are oriented on families with 3-4 (Type 1), 5-6 (Type 2), 7 and more children (Type 3).

Table 2.14. Quantitative characteristics of residential zone

Type of the house	Quantity in the house			
	Area of the site m^2	Area of the house m^2	Quantity of floors	Quantity of inhabitants
Multi-family houses				
Type 1	-	1125	3	26
Type 2	-	2025	3	60
Type 3	-	2700	3	80
Type 4	-	3375	3	100
Townhouses				
Type 1	272	144	2	4
Type 2	272	144	2	4
Individual houses				
Type 1	1000	140	2	5
Type 2	1200	200	2	7
Type 3	1500	240	2	9

Table 2.15. Quantitative characteristics of residential zone

Type of the house	**Quantity in the settlememt**			
	Quantity of houses	General area of plot m^2 (ha)	General area of the houses m^2 (ha)	Quantity of inhabitants
Multi-family houses	**44**	**-**	**80550**	**2284**
Type 1	14	-	15750	364
Type 2	26	-	52650	1560
Type 3	2	-	5400	160
Type 4	2	-	6750	200
Townhouses	**183**	**49776 (4,9776)**	**26352**	**732**
Type 1	70	19040 (1,904)	10080	280
Type 2	113	30736 (3,0736)	16272	452
Individual houses	**229**	**255100 (25,51)**	**38940**	**1377**
Type 1	127	127000 (12,7)	17780	625
Type 2	83	99600 (9,96)	16600	581
Type 3	19	28500 (2,85)	4560	171
Total	**456**	**304876 (30,4876)**	**145842**	**4393**

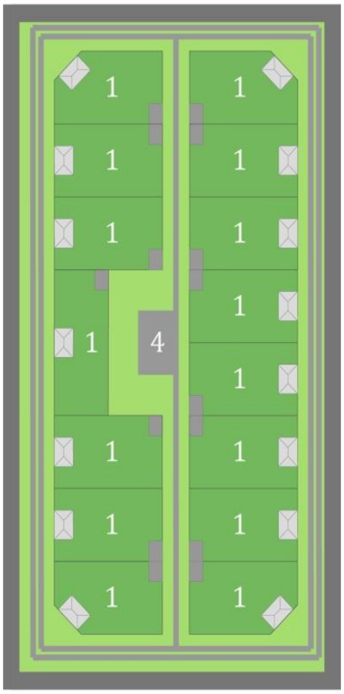


Figure 2.91. Zone A

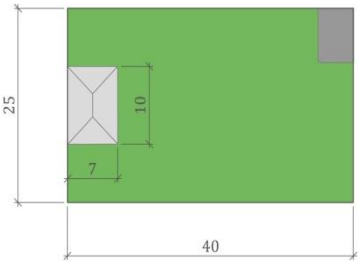


Figure 2.93. Individual houses. Type 1

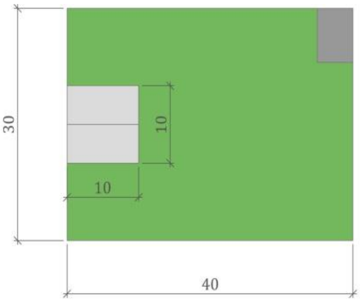


Figure 2.94. Individual houses. Type 2

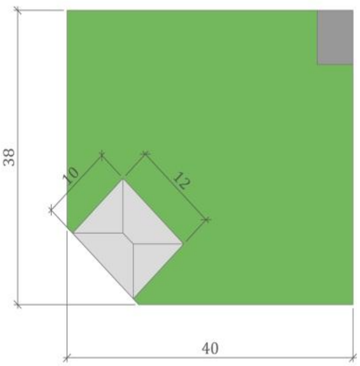


Figure 2.95. Individual houses. Type 3

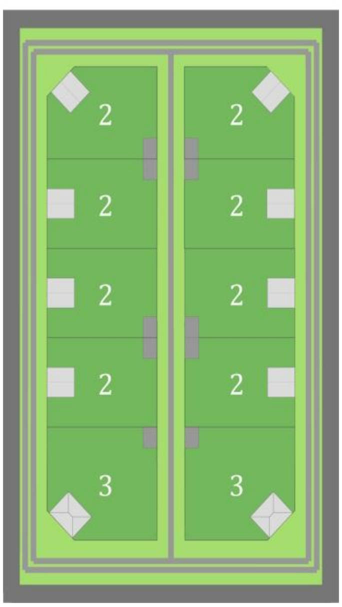


Figure 2.92. Zone B

1. Individual houses. Type 1
2. Individual houses. Type 2
3. Individual houses. Type 3
4. Meeting place with playground

Figure 2.96. Masterplan

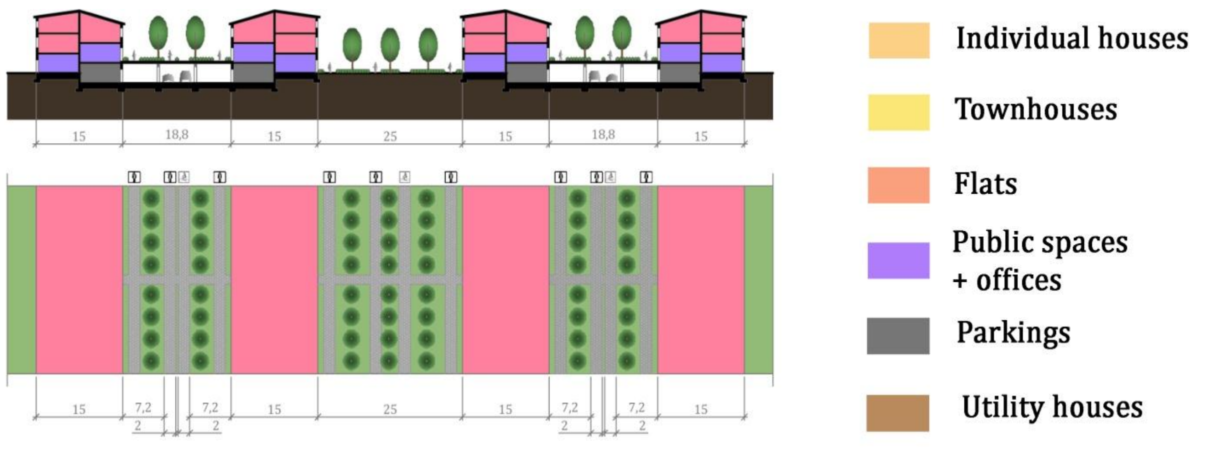


Figure 2.97. Multi-family houses. Type 1

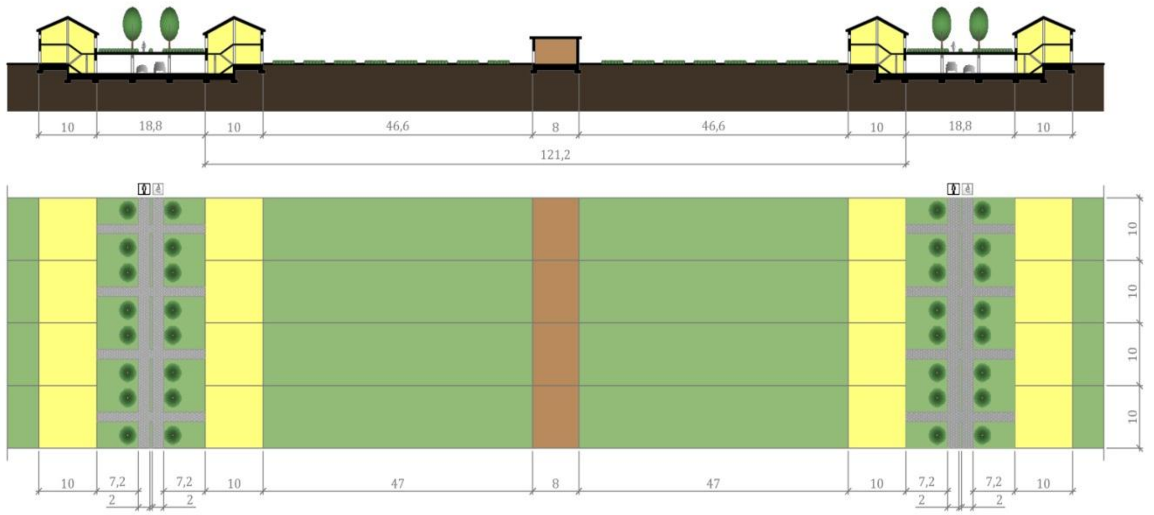


Figure 2.98. Townhouses. Type 1

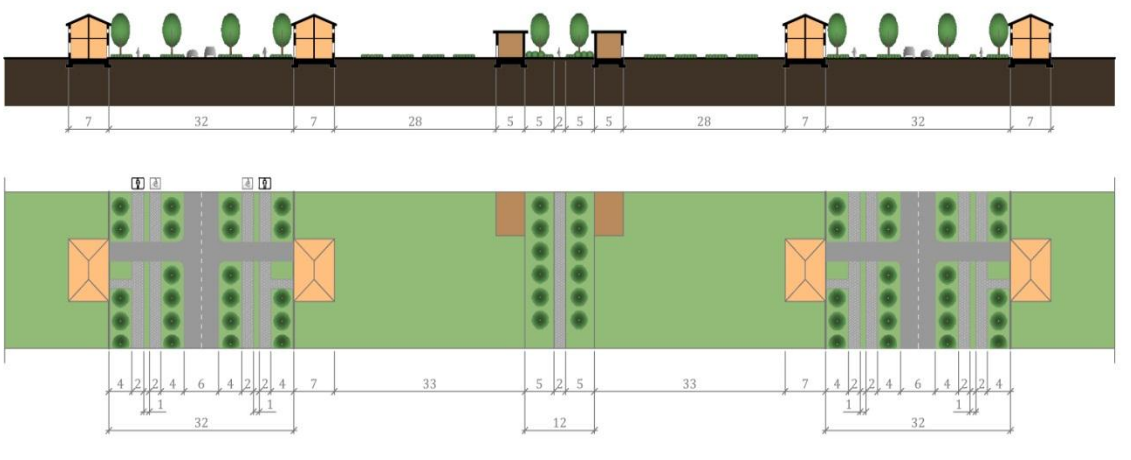


Figure 2.99. Individual houses. Type 1

2.5.2.2. Public zone

Public zone includes:

- Administration and commercial and entertainment center, close to railway station;
- Church complex with Russian cultural center in the center of the settlement;
- Restaurants on the banks of artificial reservoirs in the park;
- Service centers, including bank, pharmacy, repair services, post offices, etc. and supermarkets.

1. Administration
2. Commercial and entertaining center
3. Church complex
4. Russian cultural center
5. Russian folk music, dance and theatre studios
6. Russian traditional handicraft studios
7. Wooden fortress
8. Museum
9. Restaurant
10. Service center
11. Supermarket

Figure 2.100. Public zone

2.5.2.3. Office zone

Office zone is situated on the west side of the settlement. It is parallel to the railways and protect residential zone from noise. It passes along the main road and form public street with public areas on the first floors of multi-functional buildings.

Figure 2.101. Office zone

2.5.2.4. Educational zone

Educational zone is divided on 2 parts. The first part is situated in the center of dense multi-family and townhouses zone. The second one is situated in the center of individual houses zone. Each part includes kindergarten and school with separated buildings for junior school (1-3 class) and high school (4-10 class), connected with corridor. On the territory of the school there are football, basketball and volleyball fields.

1. Kindergarten
2. Junior school
3. High school

Figure 2.102. Educational zone

2.5.2.5. Sport zone

Sport zone is situated close to the center of the settlement as well as close to summer camp for children with disabilities and sanatorium.

It includes:

- Sport complex with football, volleyball, basketball fields and tennis courts;
- Swimming pool with close and open pools.

Sport facilities can be used by inhabitants of the settlement as well as by children from summer camp and sanatorium and their parents.

1. Sport complex
2. Swimming pool

Figure 2.103. Sport zone

2.5.2.6. Medical zone

Medical zone is situated in the calmest place of the site, close to the river and to the forest.

It includes:

- Sanatorium for children with disabilities;
- Summer camp for children with disabilities;
- Equestrian club.

1. Administration
2. Medical center
3. Diagnostic center
4. Treatment and recreation center
5. Treatment pools
6. Restaurant
7. Shop
8. Sanatorium housing
9. Summer camp housing
10. Hotel
11. Stables

Figure 2.104. Medical zone

Sanatorium is provided as a part of Urban rehabilitation center for teenagers and children with disabilities in Tver' with the aim of creation of suburban branch of the center for improvement for conditions of children's rehabilitation.

It is divided on 3 zones:

- Medical zone close to the entrance, including administration, medical, diagnostic and treatment and rehabilitation centers;
- Residential zone with 3-storeyed housing with elevators and ramps in the northern part on the site;
- Entertainment part between medical and rehabilitation zones, including supermarket, restaurant, therapeutic pools and park with playgrounds and sport fields.

Summer camp for children with disabilities is also provided as part of the center, which is the only organization trying to organize the rest of such children. As for the moment the center has no suitable conditions for such activities, it is necessary to provide the place, equipped specially for comfortable rest of such children.

Summer camp includes:

- Administration zone with restaurant
- Housing zone.

Children have possibility to use medical facilities, park and entertainments of sanatorium as well as treatments and entertainments in equestrian club and sport complex.

Equestrian club is provided for children of the settlement as well as for the children with disabilities from sanatorium and summer camp and their parents. It is important for sanatorium to have equestrian club close to it, because there is treatment for children with disabilities with help of riding.

As sanatorium is situated close to individual houses zone oriented on families with many children and there are common zones for all the children such as sport zone and equestrian club, there is possibility for healthy children to communicate with children with disabilities. It helps to cultivate the sense of compassion in children.

2.5.2.7. Green zones

Green zones of the settlement include:

- Park with artificial reservoirs in the middle of the settlement;
- Forest and fields of equestrian club;
- Sanatorium's park
- Green zone close to the entrance of the settlement.

Park in southern part of the settlement is the link as well as barrier between high and low density residential zones of the settlement. Due to its position between two residential zones, it can be used easily by inhabitants of both zones.

Figure 2.105. Green zone

2.5.3. Road types

The project provides the possibility to use different types of transport in the settlement.

On the plan three types of car roads are marked. It is linked not with different width of the roads themselves, but with different distances between roads and houses and presence or absence of trees between roads and houses.

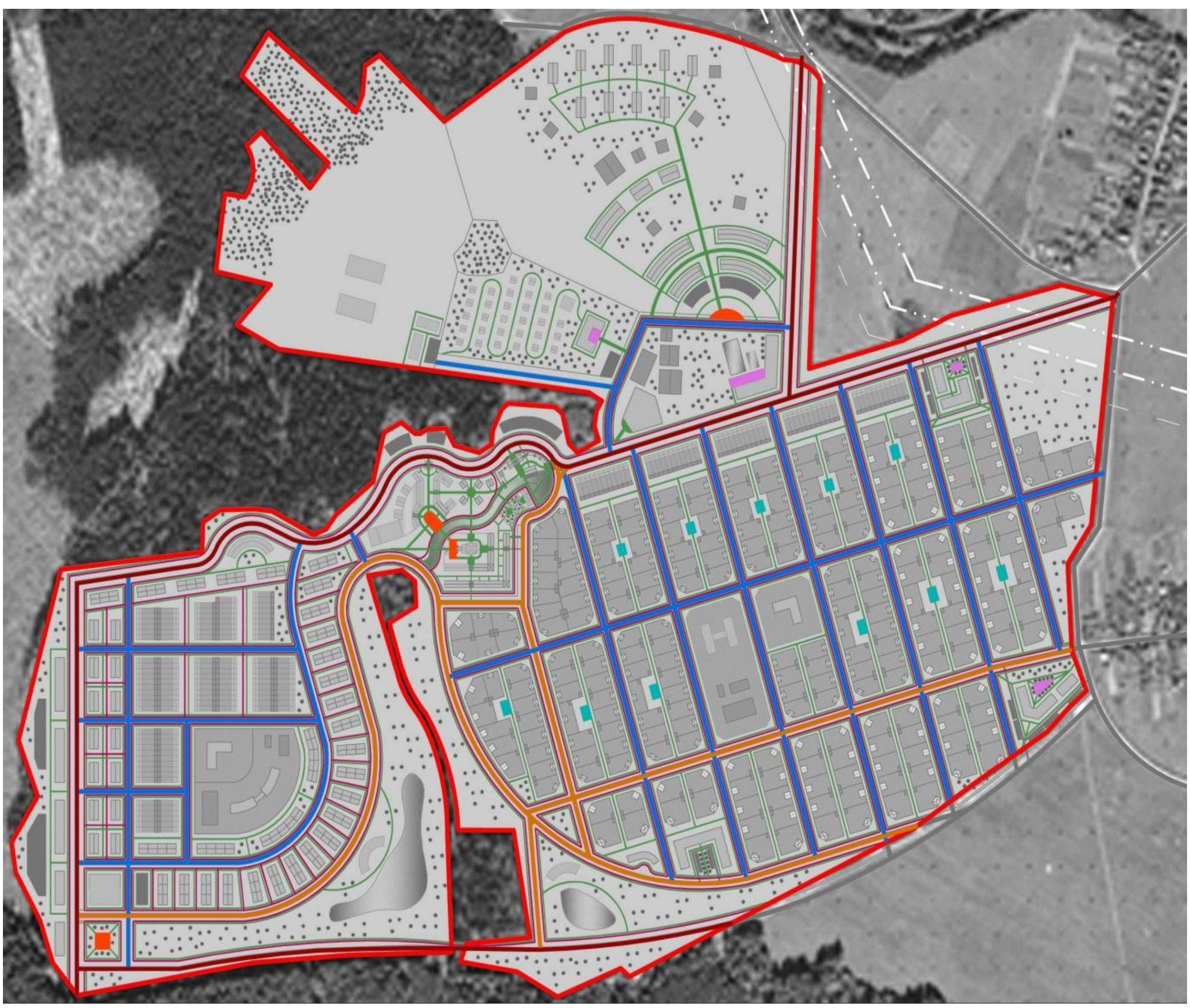


Figure 2.106. Road types

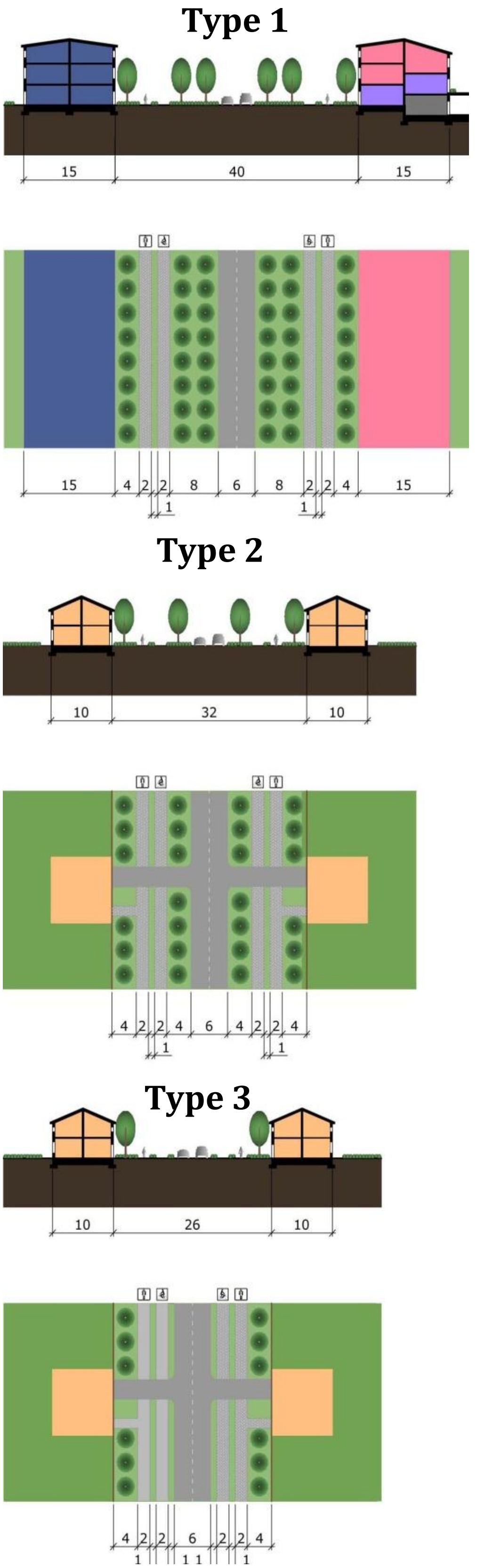


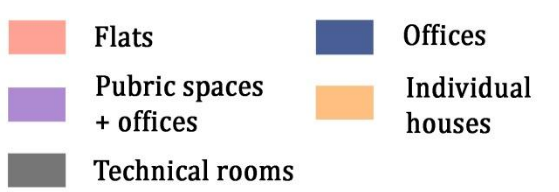
Figure 2.107. Road types

Type 1 is the main road, passing round the settlement. It is supposed that car flow and the speed is higher. Two lines of trees surround the road for protecting from noise and decreasing the impact on the enviroment.

Type 2 is the roads linking different parts of the settlement. It is surrounded by one line of trees.

Type 3 is the road inside the residential zone. It is supposed to be calm and does not need any special protection.

In order to decrease the number and movement of cars inside the settlement, it is necessary to include more healthy and environmentally friendly types of transport, as bycicles, rollers, etc., in the project and to make their use easy and convenient for people. This aim is reached with the help of providing special separate roads for bicycles and rollers in all the territory of the settlement. On the one hand, such roads, situated separately from the cars, ensure safe movement. On the other hand, the roads, situated separately from the pedestrian ones, give possibility to move fastly without disturbing pedestrians.



2.5.4. Transport

In order to decrease car flow inside the settlement public transport is included. Bus route runs around the settlement and connect the main places of the settlement – village Olbovo, Kustovo, center, railway station and park. Bus stops are distributed in such a way as to give the possibility to reach any place of the settlement easily.

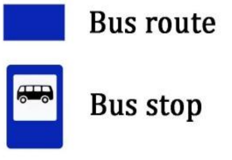


Figure 2.108. Transport

2.6. CASE STUDIES

There are several case studies which were used as examples during elaboration of the project of center of the settlement. These are some groups of buildings in Russia, knowledge of which helps in better understanding of the ideas of the project.

2.6.1. Valaamskij monastery

Valaamskij monastry is Orthodox monastery in Karelia, located in Valaam, the largest island in Lake Ladoga. It is supposed to be founded in X-XI century. Brick buildings of the monastery were built at the end of[40] XVIII century.

Figure 2.109. Valaamskij monastery

40 http://www.valaam.ru

2.6.2. Tver' Local History Museum

Tver' Local History Museum was opened on 9 August 1866. Its first name was provincial museum. The exposition presented samples of handicraft production and products of factories of the province. In 1872 - 1918 Archaeological Museum was located in the west wing of Putevoj palace. On the eve of the October Revolution, it was, it was one of the first places among the provincial "ancient depositories", in which the funds were more than *14000 antiques*.

In Soviet times, the museum often changed its name and location. By 1941, the museum's collection includes more than *100 thousand* units. During the Great Patriotic War and the occupation *95%* of the items were lost. In 2006, the Tver' Museum is the leading museum of Tver' State Museum Association, which consists of 32 branches. Its collection is about 400 thousand items of the main fund (originals).

Unique collections are exposed today in 15 rooms. In the departments of nature, archeology, history, visitors are introduced to the past and present of the region. There are expositions dedicated to Tverskaya region in XVII-XIX centuries, to the Great Patriotic War, to involvement in space exploration. [41]

Figure 2.110. Tver' Local History Museum

Figure 2.111. Tver' Local History Museum

[41] http://www.tvermuzeum.ru

2.6.3. Ethnographic park «Russian village «Shuvalovka»

Russian village «Shuvalovka» is situated in suburb of Saint-Petersburg.

In 1714 this land was «given to use» by degree of Peter I. It contained 5 yards of village with Finnish name «Korkuli». One of the owners of the village was count Ivan Shuvalov. Only the name and the land, on which the estate was, were conserved up to now. Some time ago new complex called Russian village «Shuvalovka» was built on this place.

On the territory of Ethnographic park there is complex of buildings, made in the best traditions of Russian wooden architecture of XVIII and XIX centuries. It contains Russian bathhouse, smithy and pottery workshops, ethnographic house, restaurant, hotel, bird and animal farms, mill and chapel. [42]

Figure 2.112. Russian village «Shuvalovka»

[42] http://www.shuvalovka.ru

Figure 2.113. Russian village «Shuvalovka»

Figure 2.114. Russian village «Shuvalovka»

Figure 2.115. Russian village «Shuvalovka»

Figure 2.116. Russian village «Shuvalovka»

Figure 2.117. Workshops

Figure 2.118. Workshops

The programmes of Ethnographic park include: craft and cooking workshops, workshops on Russian traditional craft, children's educational programmes, entertainment programmes for adults, team games and competitions, tasting programmes, excursions and folk programmes for turists.[43]

[43] http://www.shuvalovka.ru

2.7. CENTER OF THE SETTLEMENT

The main objective of the project of the center of the settlement is organization of public area for inhabitants of the settlement and visitors of sanatorium with accent on Russian culture. Accent on Russian culture is explained by necessity to restore, what was destroyed during the Soviet period, when organizers of revolution advanced slogans «Destroy up to the base!». During last 300 years, starting from the time of Peter I, interest of Russian people to their own culture and religion fell. This catastrophic falling was finished by the revolution, after which there was attempt to organize everything in absolutely new way. During this time many important things, including world-view, traditions and architecture, were lost. Nowadays, it is necessary to return interest to Russian culture and knowledge of Russian culture to people and to restore, what was lost.

As the majority inhabitants of the settlement are families with many children, **another objective** is organization of free time of children with involvement in Russian traditions and world-view and with possibility of interesting study of Russian culture. It cannot be only lectures in the class. There should be also practical trainings with involvement of children themselves. It is important to include the elements of game and tale in study process.

It is impossible to talk about Russian culture and world-view without involvement of Russian Orthodox Church, because Russian world-view and culture were based on it during 1000 years. For harmonious forming of world-view of children as well as for majority of adults, which were grown up in the time, when it was forbidden, knowledge of Russian Orthodox religion, on which many great persons were brought up, is especially important.

In concordance with these objectives **Center of Russian Culture and Traditional Art** was organized.

It contains 3 main parts:

- Church complex
- Center of Russian Traditional Art s
- Russian Cultural Center

Figure 2.119. Center of the settlement

1. Church complex
2. The main square
3. Center of Russian Traditional Arts

3.1. Russian traditional music, dnace and theatre studios

3.2. Russian traditional handicraft studios

3.3. Wooden fortress

3.4. Filial of Tver' Local History Museum (Archeology and Nature)

3.5. Observation tower

4. Russian Cultural Center
5. Multi-family house for Center's and Church's workers
6. Hotel
7. Individual houses. Type 1
8. Individual houses, Type 2
9. Multy-family houses. Type 2
10. Parking

2.7.1. Church complex

Figure 2.120. Russian Church

Church complex forms the single architectural ensemble with Russian Cultural Center. It emphasizes the unity of Russian culture and Russian Orthodox Church. The complex is situated in front of the main square and is linked with it by the bridge. In addition, the movements, started in railway station for pedestrians and in parking for people with car, finish in Church complex for marking out the complex as the object of special importance.

In front of the Church there is a square with Church shop. It is surrrounded by 2 lines of 2-storeyed houses including church art school, house of clergy, hotel, utility building and house for Center's and church's workers.

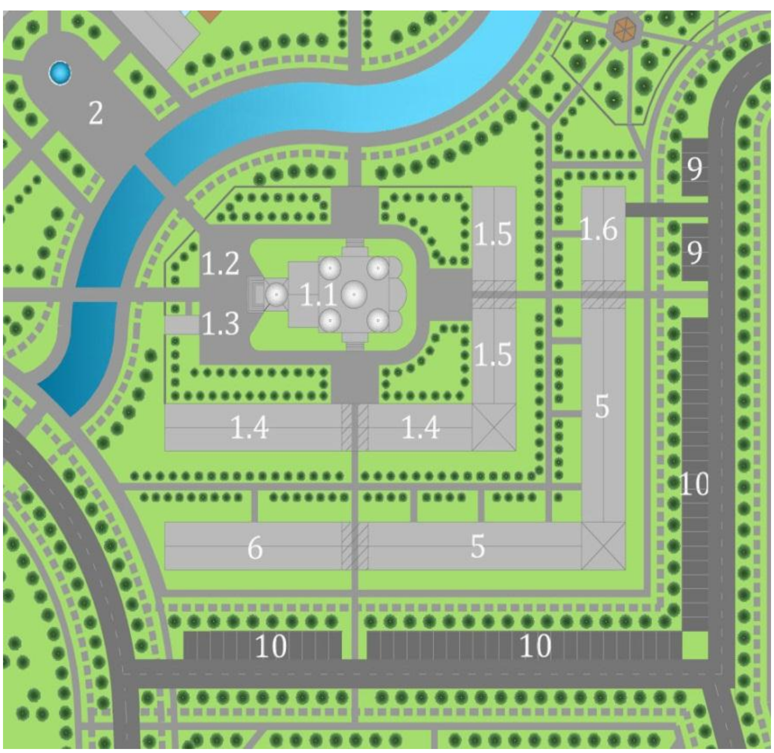


Figure 2.121. Church complex

1. Church complex
1.1. Church
1.2. Church square
1.3. Church shop
1.4. Church art school
1.5. House of Clergy
1.6. Utility building
2. The main square
5. Multi-family house for Center's and Church's workers
6. Hotel
10. Parking

2.7.2. Center of Russian Traditional Arts

The main objectives of Center of Russian Traditional Arts are:

- Study, conservation and development of Russian traditional art;
- Conservation of Russian identity;
- Involvement of modern Russian people in Russian traditional art and development of love to their native land;
- Upbringing of children in love to their native land and in labour;
- Organization of free time of children for defence from negative influence;
- Including of moral and spiritual base in upbringing of children during the lessons.

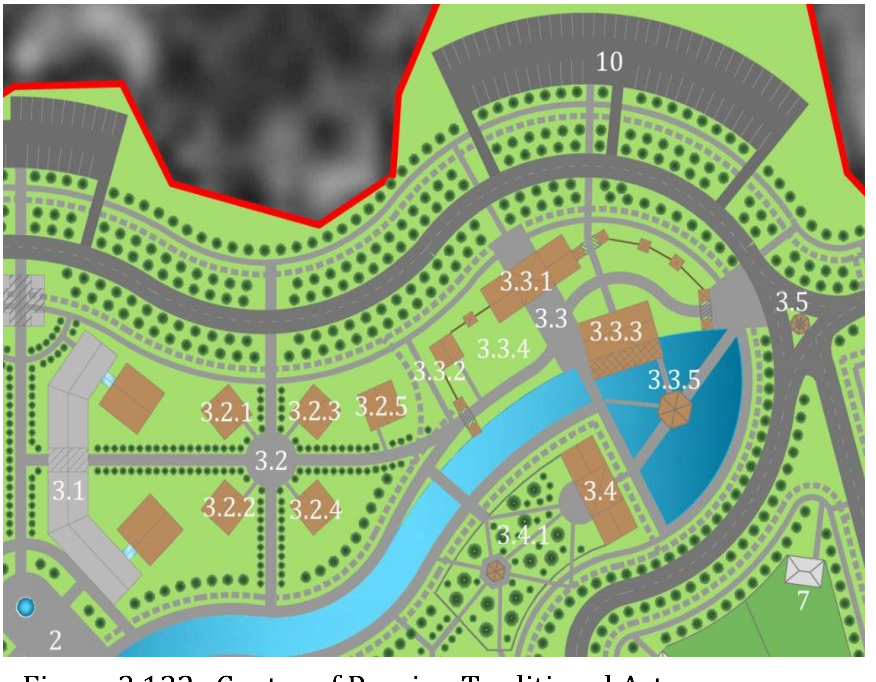


Figure 2.122. Center of Russian Traditional Arts

3. Center of Russian Traditional Art

3.1. Russian traditional music, dance and theatre studios

3.2. Russian traditional handicraft studios

3.2.1. Jewelry

3.2.2. Pottery and blacksmith's work

3.2.3. Ceramics and painting

3.2.4. Embroidery and weaving

3.2.5. Baking

3.3. Wooden fortress

3.3.1. Russian wooden art museum and carving handicraft studio

3.3.2. Traditional Russian peasant's log house

3.3.3. Russian restaurant

3.3.4. Wooden children's playground

3.3.5. Pavillion

3.4. Museum of Vegetation and Animal World

3.4.1. Garden

3.5. Observation tower

Figure 2.123. Russian music

Figure 2.124. Russian music

Figure 2.125. Russian dance

Figure 2.126. Russian theatre

The Center is divided on **4 parts**:

- **Russian traditional music, dance and theatre studios**

The main aim of these studios is involvement of children and adults in the world of Russian traditional music and dance.

Russian traditional music studio includes learning to play different musical instruments with accent on the Russian traditional ones such as balalaika, accordion, etc. There are different types of ensembles from duets up to big orchestras. Study process includes also choral classes with learning of Russian traditional songs, history of music and solfeggio.

Russian traditional dance school should prepare the flow of new forces to russian traditional dance ensemble. Study process involves children in understanding of art of Russian dance. It includes learning of choreography, staging and performance of consert numbers, asquisition of professional skills and ways to improve.

Russian traditional theatre studio includes performances based on Russian history and traditions. It is possible to create musical performances with participation of all three studios.

Figure 2.127. Blacksmith's work

Figure 2.128. Weaving

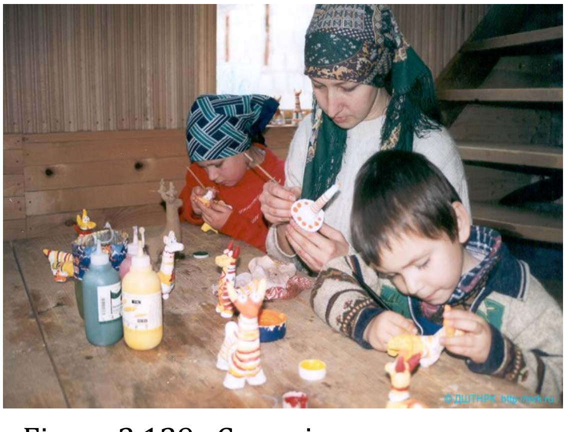


Figure 2.129. Ceramics

- **Russian traditional handicraft studio**

The studios are organized as Russian village. Studios are situated in separated house, made with use of Russian traditional and modern technologies.

They are divided on 3 groups: for boys, for girls and common.

Studios for boys should develop characterics necessary for future householders such as responsability, love to labour and ability to overcome difficulties. This group includes pottery, blacksmith's work and carving.

Studios for girls should train them to women's house work and involve them in Russian women's life in the past. This group includes embroidery, weaving and baking studios.

The last group is suitable **for boys and girls**. These studios should involve children in creative process. This group includes ceramics and painting studios.

Figure 2.130. Wooden house decorations

Figure 2.131. Carving

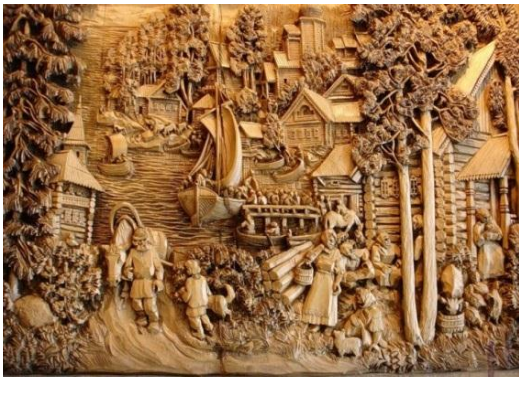


Figure 2.132. Carving

Figure 2.133. Wooden toys

- **Wooden fortress**

Wooden fortress is organized as traditional ancient Russian wooden fortress.

The main aims are:

- Involvment children in ancient Russian history and art;
- Development and study of carving;
- Popularization of carving as decoration for modern Russian houses;
- Development and popularization of Russian wooden toy.

On the territory of the fortess there are:

- Russian restaurant, where one can try traditional Russian kitchen;
- Russian traditional peasant's log house, where it is possible to see, how Russian peasants lived. This space also can be used for study performances for children with the aim of telling about life of Russian peasants in game.
- Museum of caving with studio of carving for children and adults.
- Workshop with studio of art of Russian wooden toy;
- Wooden playground with use of carving.

Figure 2.134. Museum of Vegetation and Animal World

Figure 2.135. Museum of Vegetation and Animal World

Figure 2.136. Museum of Vegetation and Animal World

- **Museum of Vegetation and Animal World**

Museum of Vegetation and Animal World is the branch of Tver' Local History Museum. It is situated in front of wooden fortress on another bank of artificial reservoir, which crosses the center of the settlement. On the south-west it borders with Church complex.

Museum contains ex positions, linked with animals, vegetation and archeology of Tverskaya region.

The main aims are:

- Study of vegetation and animals of the region;
- Arousing of interest to vegetation and animal world of the region;
- Cultivating of respect for nature of the region.

The aims are reached with research work, general and thematic excursions and lectures with use of elements of performances.

Themes of excursions: nature of Tverskaya region; animal kingdom of Tverskaya region; nature resources of the region and its use; birds of the region; insects of the region; geological history and development of the organic world; biogeocenosises.

Museum includes garden with different types of vegetation of the region.

CHAPTER 3. ARCHITECTURAL PART

3.1. RUSSIAN CULTURAL CENTER

Russian Cultural Center is situated on the main square between Church complex from one side and Center of Russian Traditional Art from another side. It is created as link between these two groups of buildings and inhabitants and visitors of the settlement.

Every group of people can participate in activities of the Center in its own way:

- Priests can organize meetings, discussions and conferences;
- Pupils of Church Art School as well as the ones of Center of Russian Traditional Art can participate in exhibitions with their works;
- Church choir as well as Choir of Russian Folk Song and Russian Folk Dance collectives can participate in the concerts and festivals;
- Pupils of Russian Theater Studio can include their performances in activities;
- Teacher of Center of Russian Traditional Art can organize seminars, lectures and conferences about Russian music, dance and theater as well as about Russian traditional arts;
- Workers of Russian Cultural Center can participate with lectures, discussions and conferences about Russian language, history of Tverskaya region, etc.
- Finally visitors and inhabitants, for whom it is done, can participate with their ideas, knowledge, skills and even with their mood.

So, the Center is elaborated for organization of public activities, including communication and sharing knowledge and skills.

3.1.1. Objectives

The main objectives of the Center are divided on 2 groups, but both groups of objectives have the single main aim – **conservation of Russian identity**.

The first group of objectives is linked with study of Russian language, literature, history, traditions and folk arts. It includes:

- Study with use of literature as well as research and analysis of originals (books, works of art, archeological exhibits, etc.)
- Organization of conferences, seminars, workshops, meeting, etc. between the specialists for increasing knowledge;
- Participation in conferences, seminars, workshops, etc.
- Travelling with the aim of collecting information;

The second group of objectives is linked with sharing the knowledge between the people for cultivating love to their own land and culture. It includes:

- Opening of permanent and temporary expositions for demonstration of works of arts as well as for involvement of visitors in Russian history;
- Organization of conferences, lectures, etc. for sharing theoretical information;
- Organization of workshops and seminars for sharing practical information;
- Organization of discussions and meetings for communication with the people;
- Holding of concerts and contests for involvement of visitors in the world of Russian music and dance;
- Holding of performances, based on historic themes, as well as on Russian tales;
- Organization of festivals, feasts and holydays, on with different types of activities can take place.

3.1.2. Activities

According to the objectives the activities of the center are divided on **3 main groups:**

- **Scientific activities**
    - Scientific research
    - Participation in forums, congresses, conferences and symposiums
    - Publishing activities
    - Scientific articles and publications in journals

  This group of activities deals with the first group of objectives and in with the second one by the means of publishing books and journals as well as by the means of publication of articles in other journals.
- **Educational activities**
    - Conferences and seminars
    - Lectures and discussions
    - Workshops and creative labs
    - Readings

  This group of activities deals with the part of second group of objectives, which is concerned with sharing of theoretical and practical knowledge and skills.
- **Public activities**
    - Festivals, concerts and contests
    - Folk holidays and feasts
    - Leisure evenings
    - Permanent expositions and temporary exhibitions

  This group of activities deals with the part of second group of objectives, which is concerned with organization of public events of different scales from small evenings up to big festivals.

3.1.3. Functional scheme

According to the function the space of the Center is divided on zones. For every group of activities its own space should be elaborated:

- **Scientific activities** are taken place in **Research zone**;
- **Educational activities** are taken place in **Study zone**;
- For **Public activities** several zones are provided: **Auditorium zone** with **Stage zone** for festivals and concerts, **Museum zone** for permanent expositions.

Library zone can be used for **scientific** as well as for **educational activities.** In addition, there are **general group of zones**, which are linked with all the groups of activities. It includes **Entrance zone**, **Church over gates zone** and **Administrative zone.**

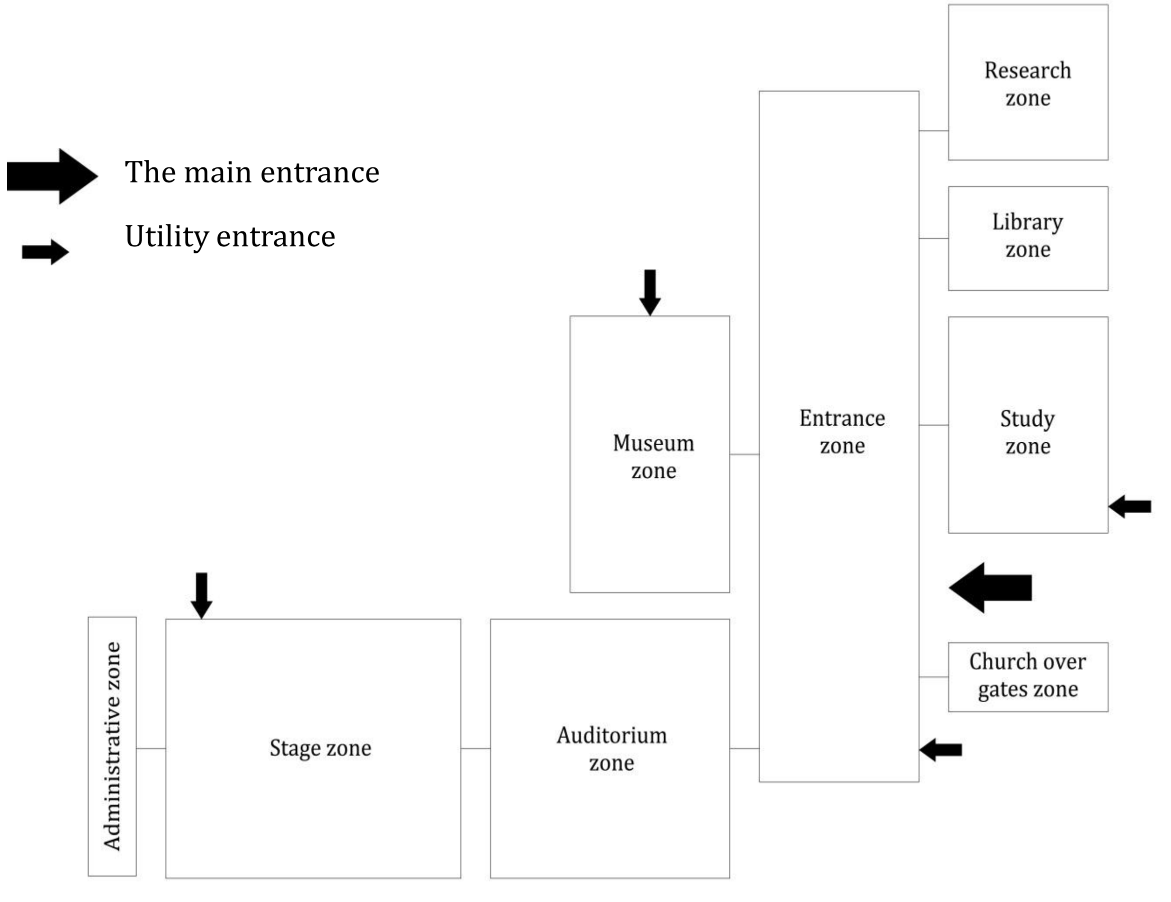


Figure 3.1. Functional scheme

3.2. CASE STUDIES

3.2.1. Kurcan Regional Philharmonic Society

Kurgan is the city with population 334 thousand people, administrative center of Kurganskaya region, important economic, scietific and cultural center, big transportation hub.[44] Concert Hall is situated on the bank of river Tobol in the park.

The Hall was built in 1984. The scheme of the building is traditional spectacular axis. It is designed for all types of concerts, meetings and performances of theaters.

Total capasity – 1200 seats, including 240 seats on balcony.[45]

Figure 3.2. Location

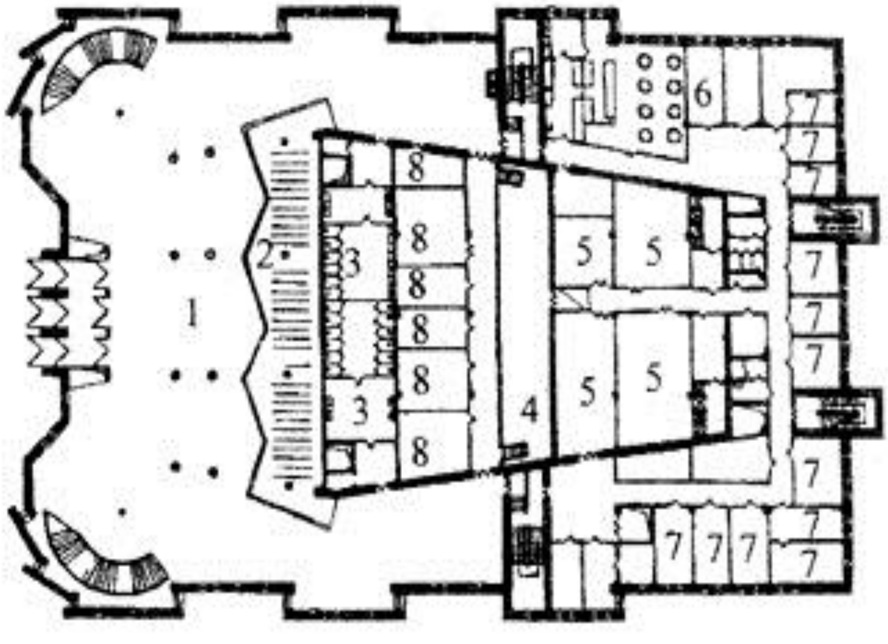
Figure 3.3. Kurgan Regional Philarmonic Society

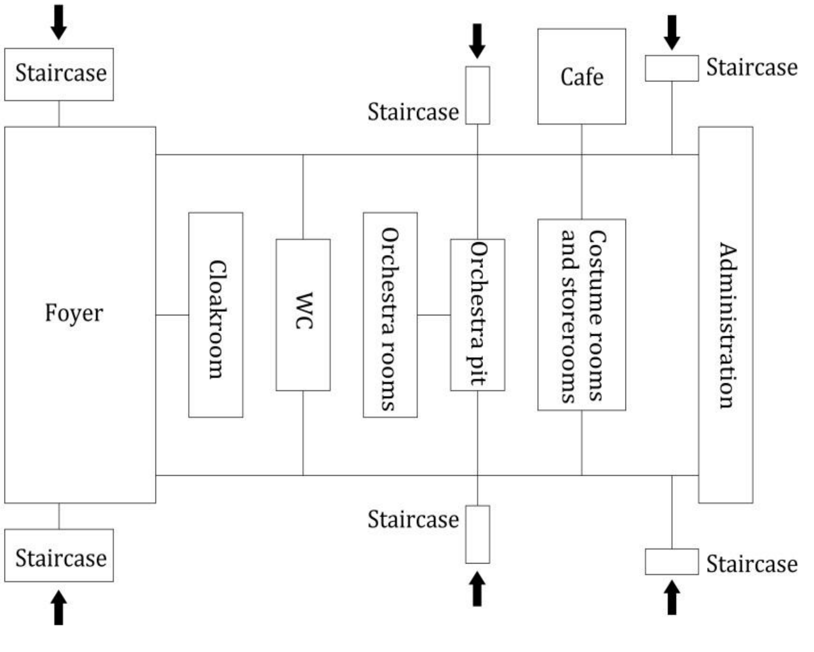
Figure 3.5. Kurgan Regional Philarmonic Society

Figure 3.4. Kurgan Regional Philarmonic Society

44 http://ru.wikipedia.org – article «Курган» («Kurgan»)
45 Recomendations for design of concert halls

Figure 3.6. Ground floor plan

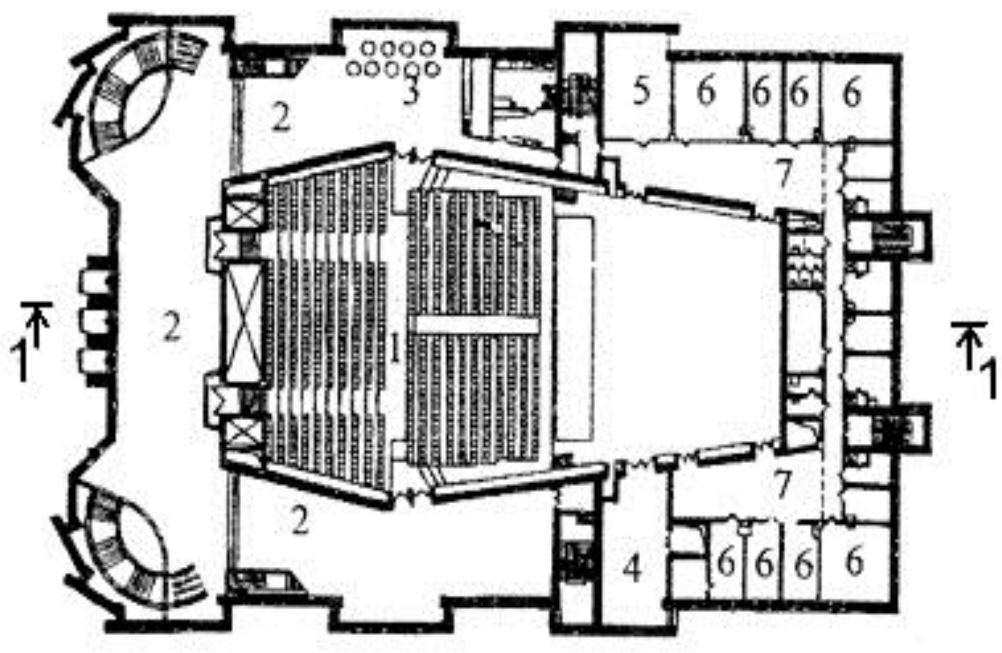


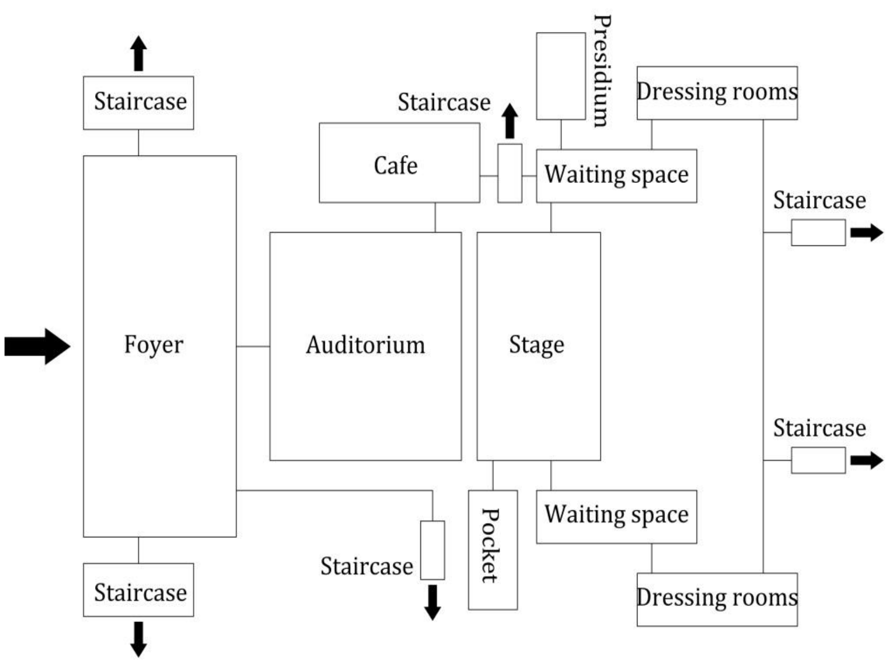


1. Foyer
2. Cloakroom
3. WC
4. Orchestra pit
5. Costume rooms and storerooms
6. Cafe
7. Administration
8. Orchestra rooms

Figure 3.7. Functional scheme of the ground floor

Figure 3.8. First floor plan

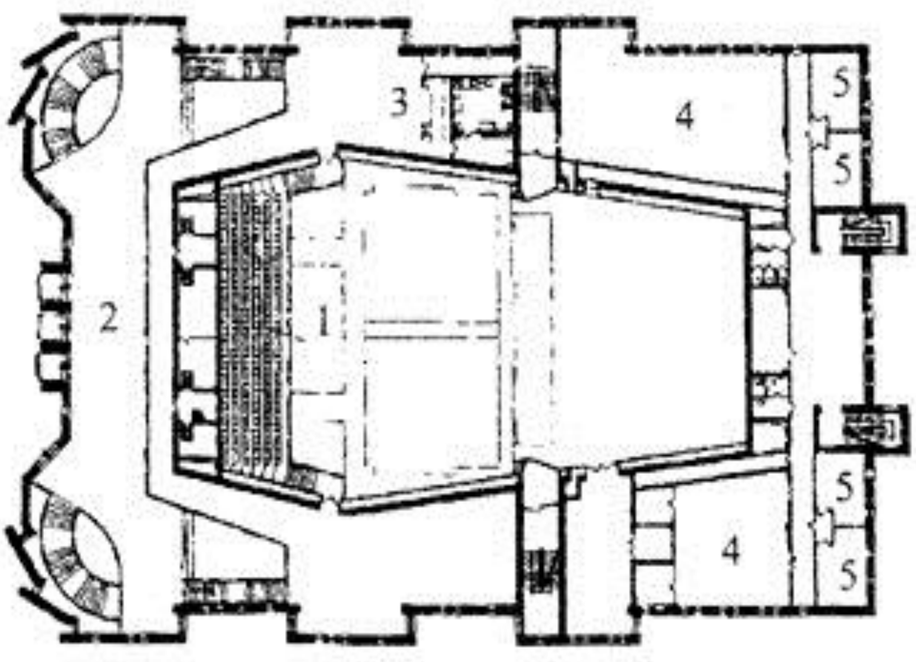




1. Auditorium
2. Foyer
3. Cafe
4. Pocket
5. Presidium
6. Dressing rooms
7. Waiting space before going on stage

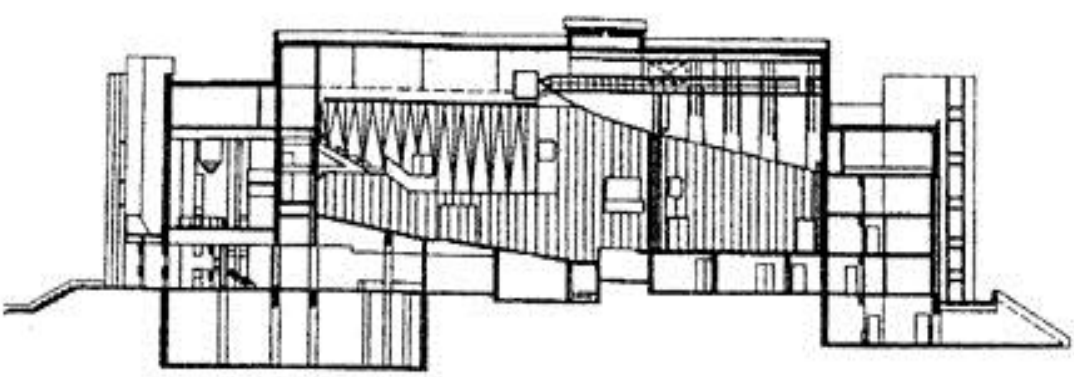
Figure 3.9. Functional scheme of the first floor

Figure 3.10. Second floor plan



1. Auditorium
2. Foyer
3. Cafe
4. Pocket
5. Presidium
6. Dressing rooms
7. Waiting space before going on stage

Figure 3.11. Section



3.2.2. House of Culture in Ludenscheid

Ludenscheid is a town with population of 80 thousand people in western Germany.[46]

House of Culture was built in 1978-1981.

Rooms of different application were grouped around the theater with transformable stage. Rooms also can be transformed with movable partitions. Some rooms are close to the restaurant with kitchen and utility block while the others are oriented on separate exits and internal communications. Thus, rooms for 10, 30, 50, 100, 200, 250, 650-950 visitors and staff were organized.[47]

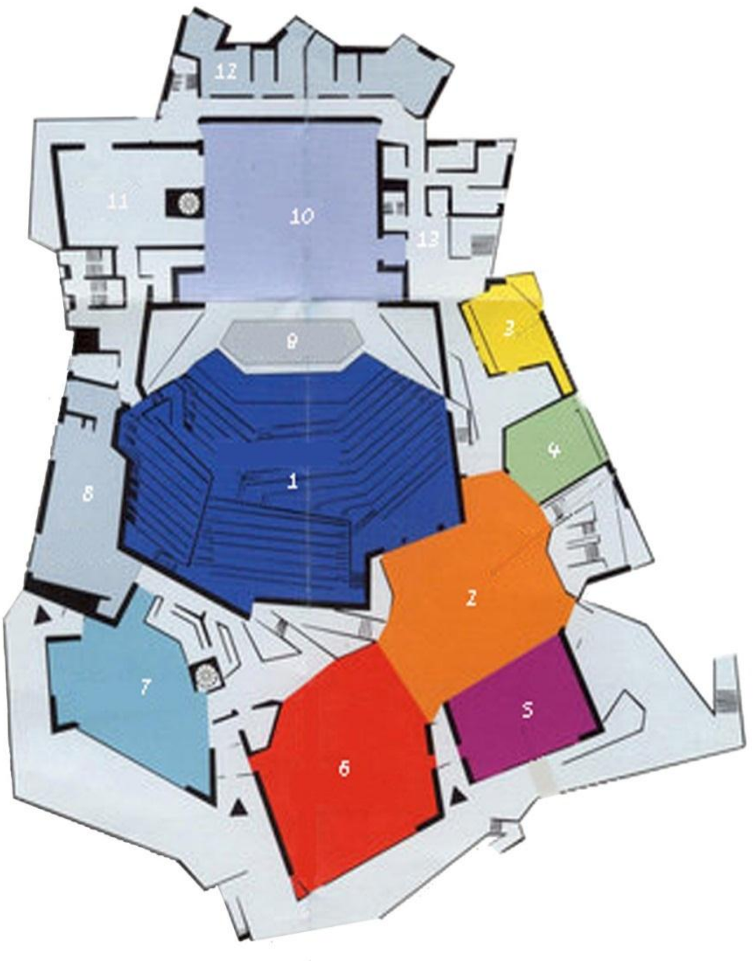
Figure 3.12. Location

Figure 3.14. House of Culture in Ludensceid

Figure 3.13. House of Culture in Ludensceid

[46] http://en.wikipedia.org – article «Ludenscheid»
[47] Recomendations for design of concert halls

Figure 3.15. First floor plan



1. Auditorium
2. Foyer
3. Yellow hall
4. Green hall
5. Violet hall
6. Red hall
7. Restaurant
8. Kitchen
9. Orchestra pit
10. Stage
11. Storeroom
12. Dressing rooms
13. Elevators

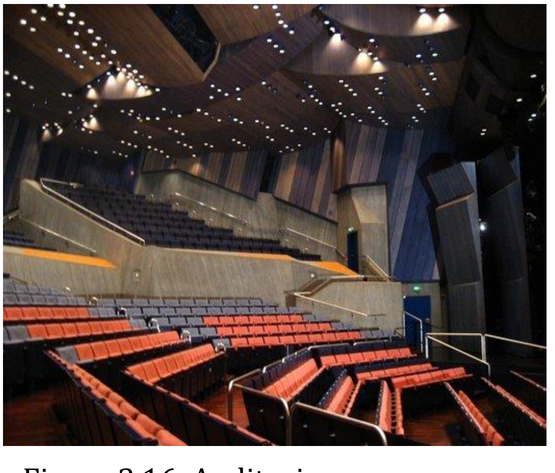


Figure 3.16. Auditorium

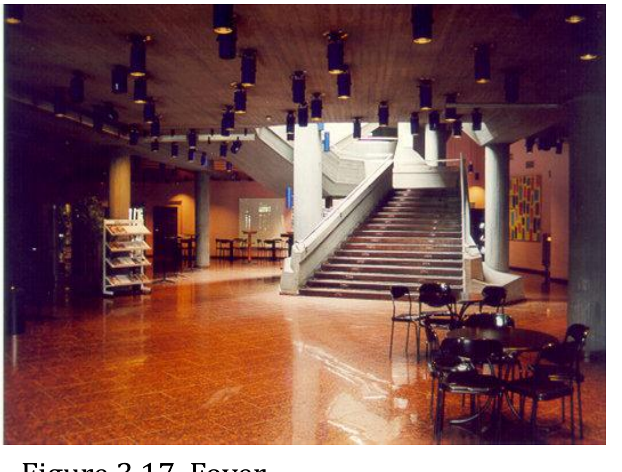
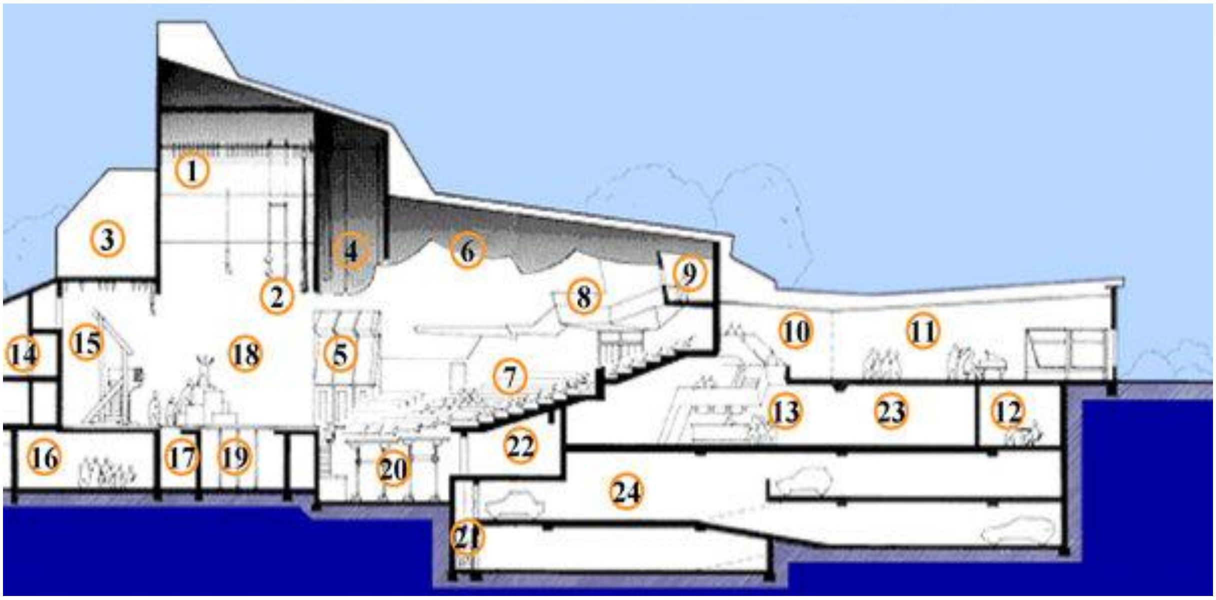


Figure 3.17. Foyer

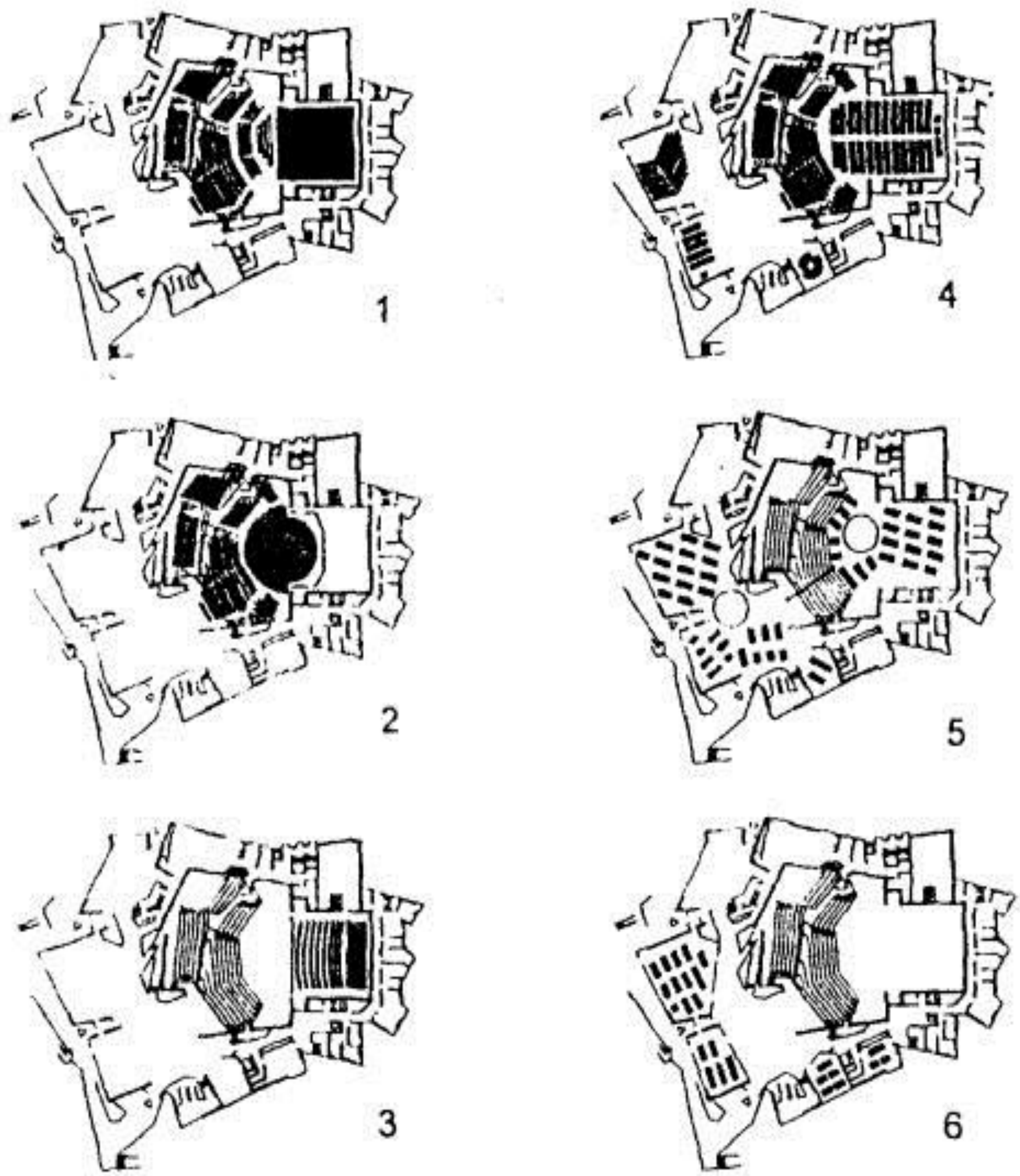
Figure 3.18. Section



1. Stage tower
2. Proscenium arch
3. Cooling plant
4. Proscenium gridiron
5. Variable rotating towers
6. Suspended ceiling
7. Auditorium
8. Sound booth
9. Central direnction
10. Foyer
11. Red hall
12. Office
13. Cafe
14. Dressing rooms
15. Rear stage
16. Theater tavern
17. Backdrop storeroom
18. Stage
19. Space under stage
20. Orchestra pit
21. Elevator
22. Seats storeroom
23. Cloakroom
24. Underground parking

Figure 3.19. Transformation scheme

1. Theater 2. Concert 3. Studio 4. Congress 5. Festival 6. Holiday



3.3. ARCHITECTURAL PLANS

Figure 3.20. Ground floor plan

Figure 3.21. First floor plan

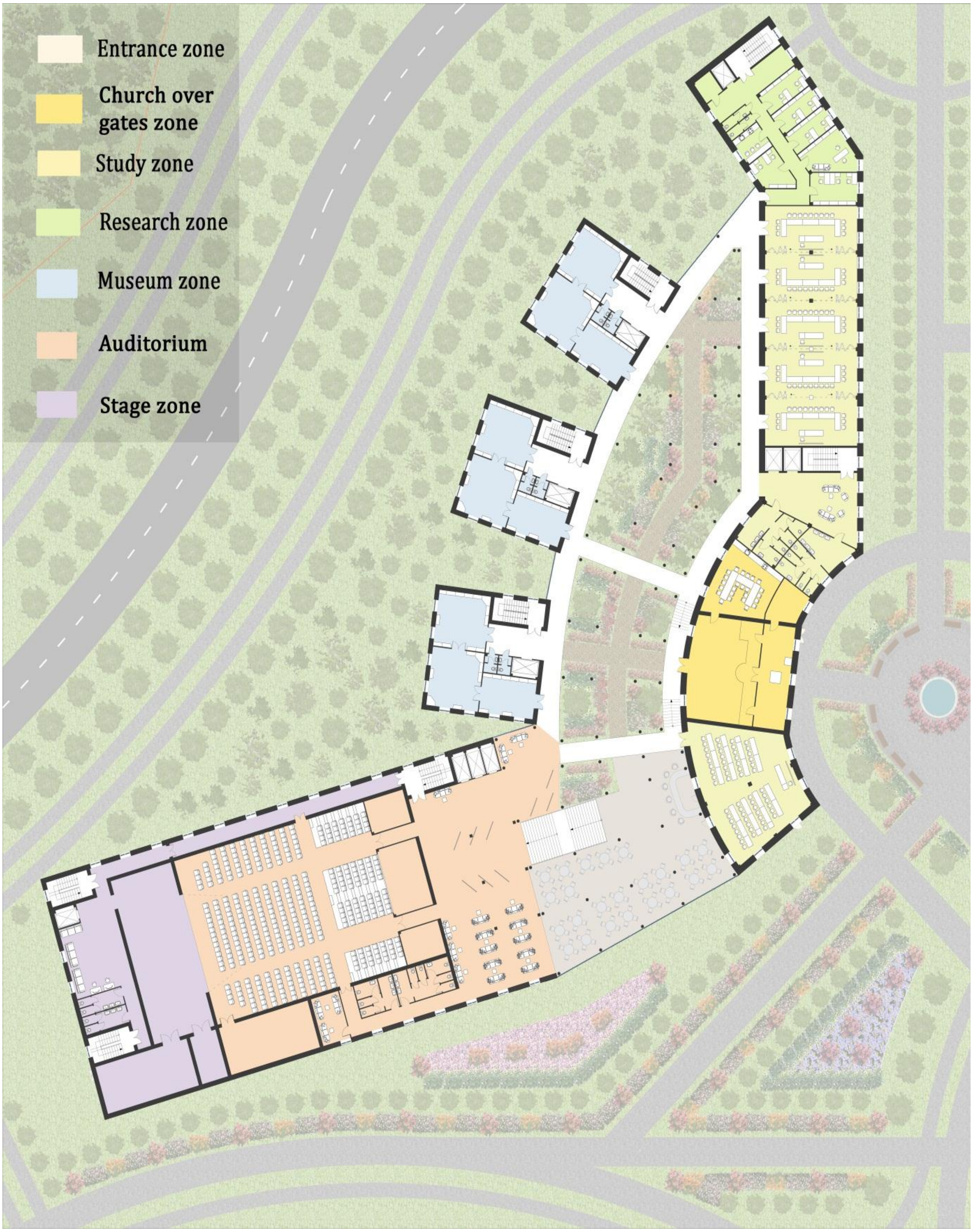


Figure 3.22. Second floor plan

Figure 3.23. Third floor plan

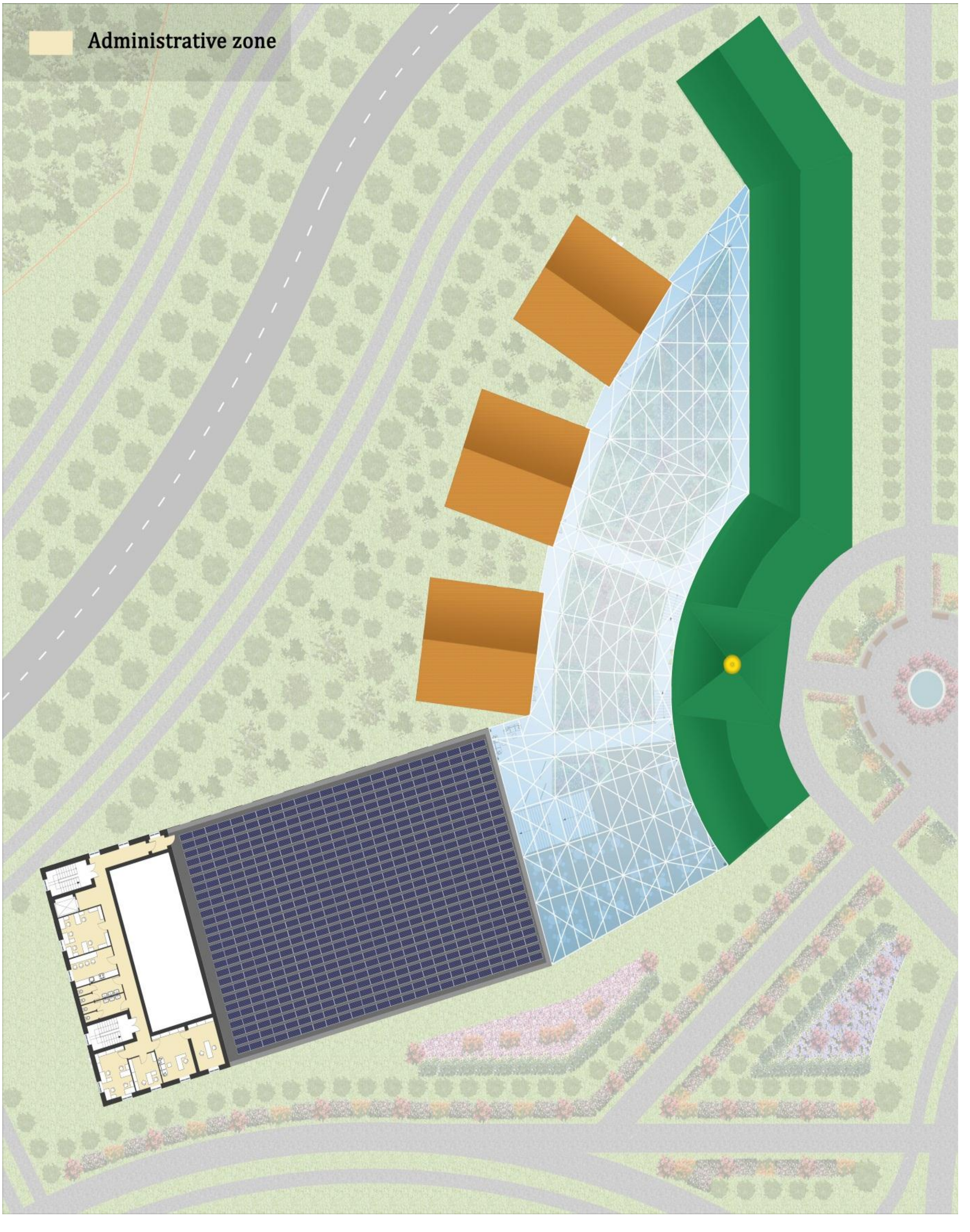
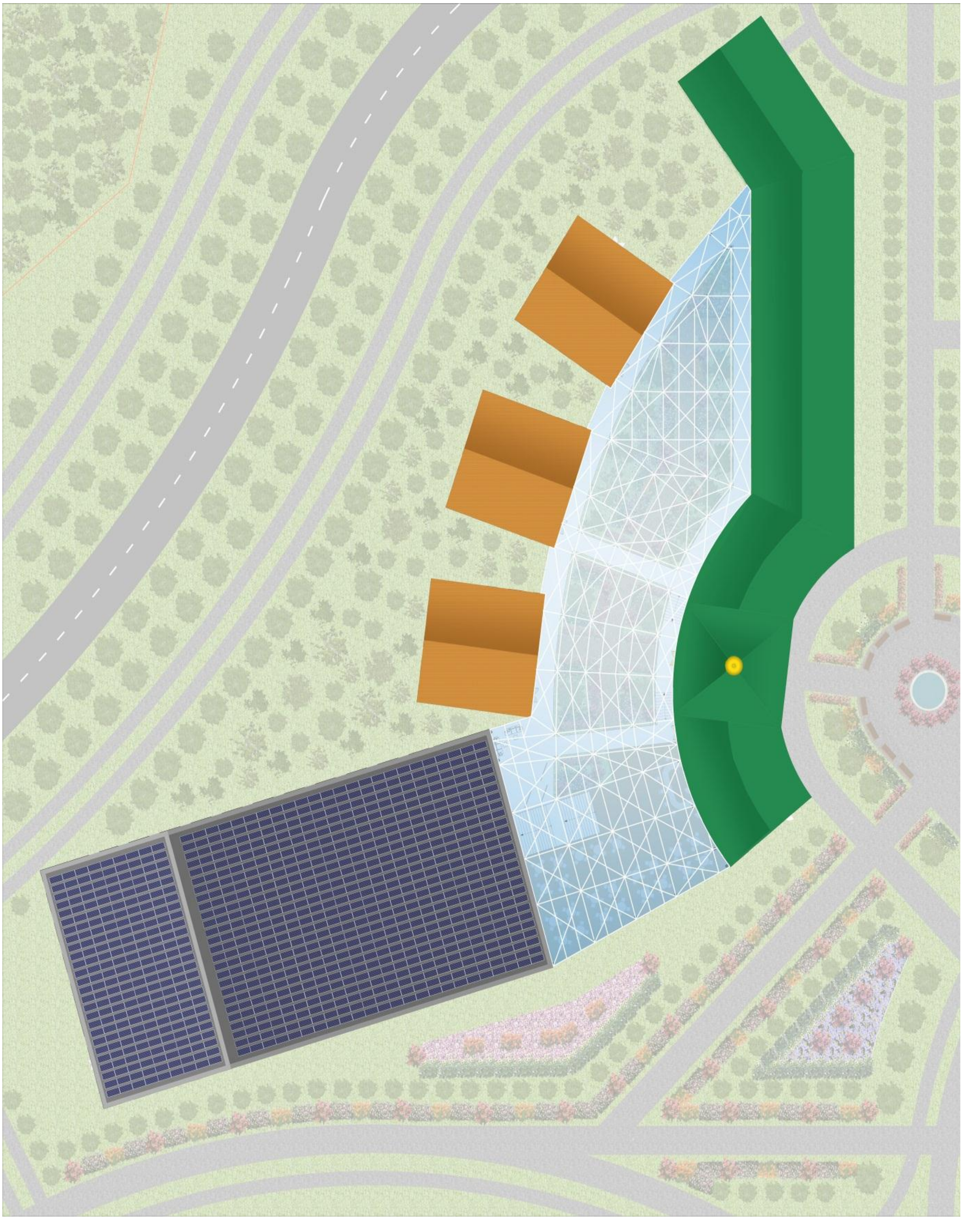


Figure 3.24. Roof plan



3.3.1. Educational building

Educational building includes **4 zones**:

- Church over gates zone
- Entrance zone
- Library zone
- Study zone
- Research zone

Figure 3.25. Russian church

Figure 3.26. Russian kitchen

Church over gates zone

Church over gates zone attract the attention, because it is the highest point in the building. It is situated on the second floor of the building above the arch with the main entrance. This zone emphasizes the unity of Russian Cultural Center and Church complex. It contains little church with utility spaces. The space of the church is divided on 3 main areas:

- The middle part of the church for people;
- Solea area with space for choir;
- Sanctuary area;

Utility spaces include sacristy linked with sanctuary and refectory linked with the middle part of the church.

Entrance zone

Entrance zone of education building is situated on the ground floor and contains only kitchen of Russian restaurant, which is situated in winter garden.

Library zone

Library zone is situated on the ground floor. It is divided on 2 main areas:

- Open fund with bookstands and seats for reading;
- Closed fund with place for receiving books and separated reading hall.

Figure 3.27. Library zone

Study zone

The main spaces of study zone such as conference hall and lecture rooms are situated on the first floor. The area of lecture rooms is big space with movable partitions. It gives possibility to change the size of the rooms according to the activity. On both floors there are foyers, where visitors of both study and library zone can have a rest. On the ground floor there is book shop containing the books about Russian culture as well as the ones about other subjects.

Figure 3.28. Study zone

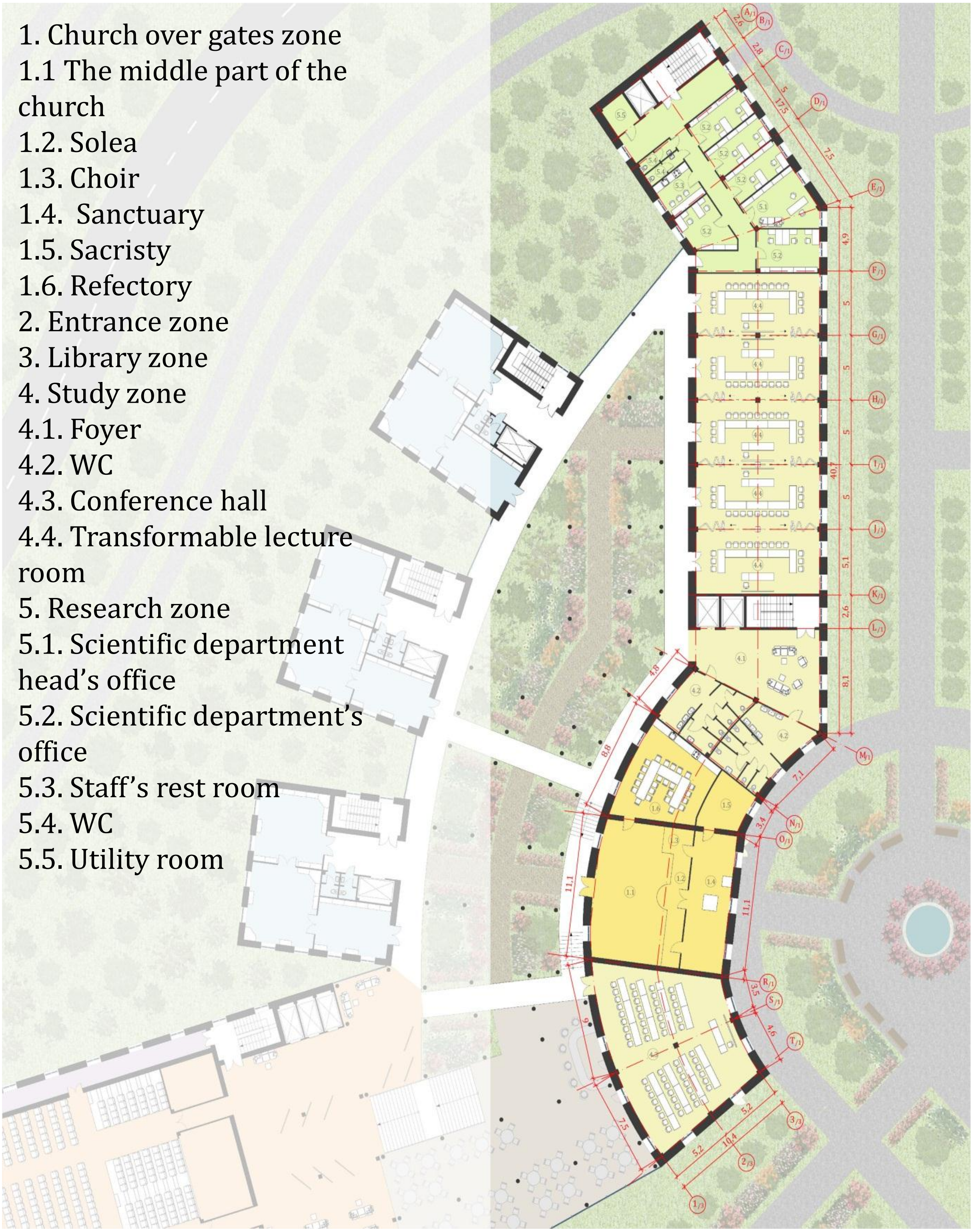
Research zone

Research zone is situated on both floors and contains 2 departments, each of which is situated on the one floor. On the ground floor there is publishing department dealing with publication of books and journals about Russian language, art, culture and church. On the first floor there is scientific department, the main task of which is study of Russian language and culture. It also deals with organization of conferences, lectures, workshops, discussions, readings, etc. about it.

Figure 3.29. Research zone

Figure 3.30. Educational building. Ground floor plan

Figure 3.31. Educational building. First floor plan



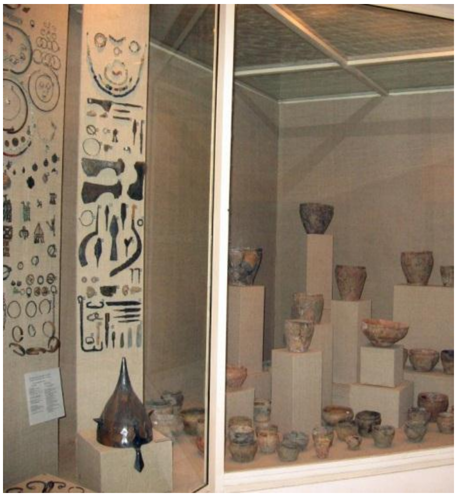


Figure 3.32. Tverskaya region in ancient times

Figure 3.33. Tverskaya region in XVI-XVII centuries

Figure 3.34. Tverskaya region in XX century

3.3.2. Museum buildings

Three museum buildings contain only museum zone. On the ground floor of the first two buildings there are storerooms for exhibits and restoration rooms. The ground floor of the last building contains head's office and offices for scientific work. On the second and third floors there are exposition rooms.

Museum is the branch of Tver' Local History Museum and includes collections about history of Tverskaja region from ancient times up to 1945. In each museum building there is one historical period. In the first one, the closest to foyer of auditorium, there are expositions about Tverskaya region in ancient times. The second one conteins expositions about Tverskaya region in XVI-XVII ceturies. In the last one there are expositions about Kalininskij district during the Great Patriotic War.

Themes of excursions: how ancient people lived; the arrival of the Slavs; the first cities of Upper Volga; old Tver'; the region in the XVIII century; Tver' in the XIX century; the war of 1812; the Decembrists; the development of national trade and industry in the Tverskaya region in the second half of the XIX century; Kalininskij district during the Great Patriotic War.

Figure 3.35. Museum buildings. Ground floor plan

Figure 3.36. Museum buildings. First floor plan

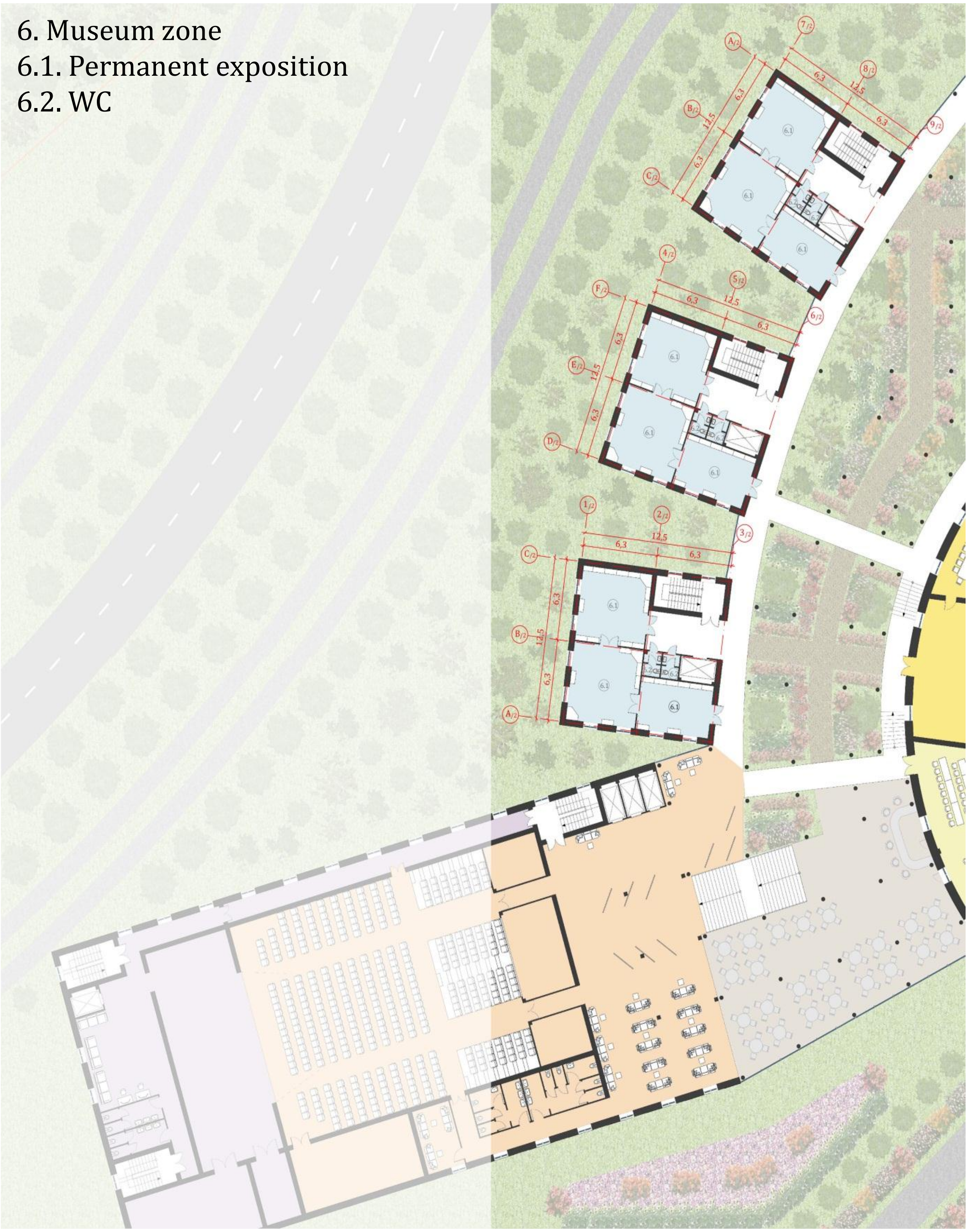
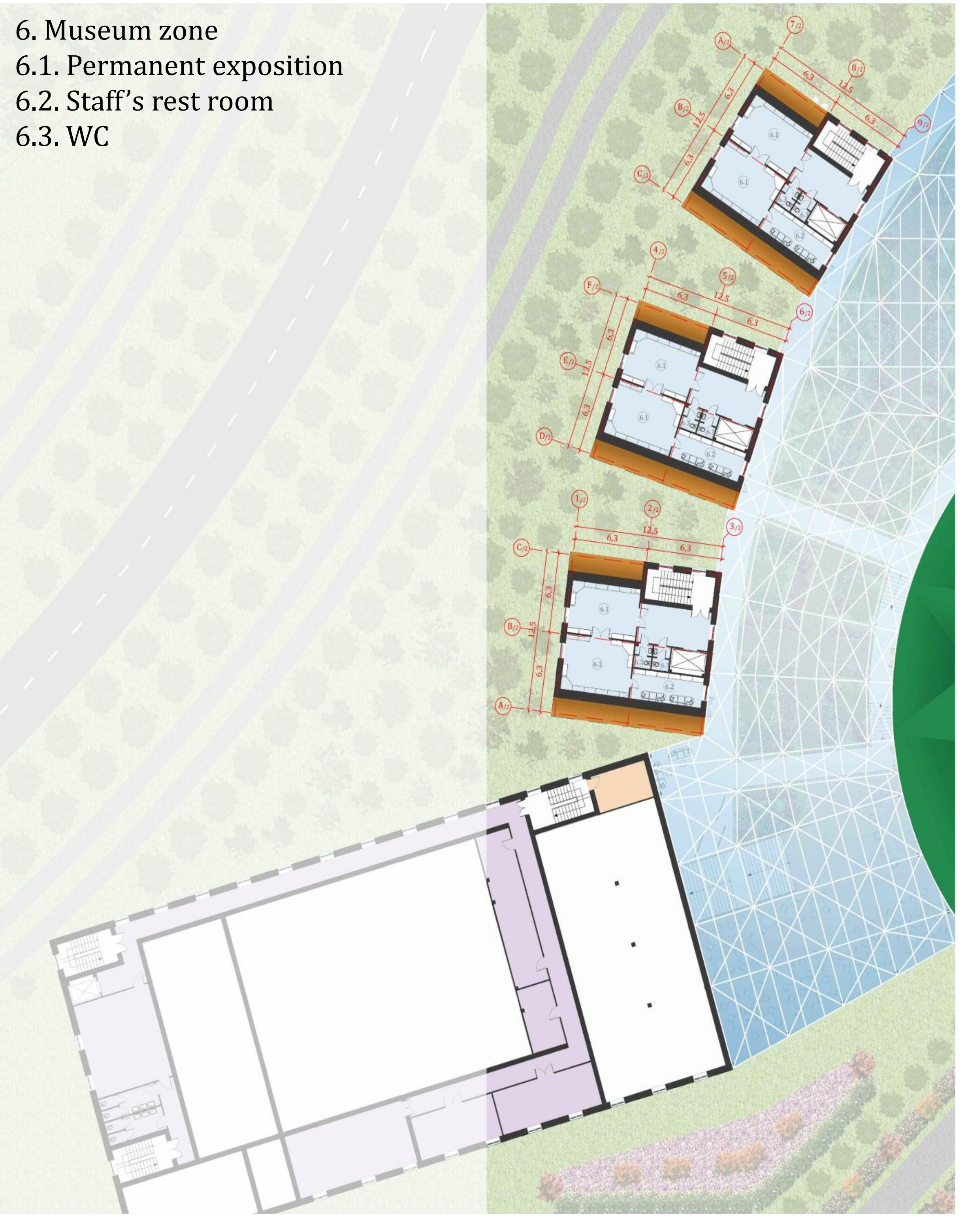


Figure 3.37. Museum buildings. Second floor plan



3.3.3. Auditorium building

Auditorium building includes **4 zones**:

- Entrance zone
- Auditorium zone
- Stage zone
- Administrative zone

Figure 3.38. Entrance zone

Entrance zone

Entrance zone of auditorium building is situated on the ground floor and includes preparatory spaces for people, which are usually used in the first place after entering into the building, such as distribution hall with cloackroom. Sanitary spaces and smoking rooms are situted on both ground and first floors and are linked with distribution hall and foyer.

Figure 3.39. Auditorium zone

Auditorium zone

Auditorium zone is situated on the first floor and includes foyer, which can be used for auditorium as well as for museum and conference hall; auditorium and storage areas for movable seats and transformable tribunes of auditorium. Auditorium seats 400 spectators. It is suitable for concerts as well as for theatre performances and festivals.

Figure 3.40. Stage zone

Figure 3.41. Stage zone

Figure 3.42. Administrative zone

Stage zone

Stage zone is situated on the ground, first and second floors. On the ground floor there are 4 groups of spaces:

- Spaces for artists such as individual and collective dressing rooms, make up rooms, costume rooms and rehearsal hall;
- Offices of art director and art managers;
- Orchestra pit with room for musicians and storeroom for instruments;
- Stage mechanics under the stage and mechanics under transformable orchestra pit.

On the first floor there is stage itself with the spaces, which should be on the one floor with the stage, such as decoration and equipment storerooms and waiting space for artists before going on the stage.

On the second floor there are technical spaces such as light equipment and thyristor, light projection and sound equipment rooms, and workshops, which can deal with creation and repair of decorations.

Administrative

Administrative zone is situated on the last floor and includes offices for administration of the Center, such as director’s office, personnel, accounting, technical and utility departments’ offices.

Figure 3.43. Auditorium building. Ground floor plan

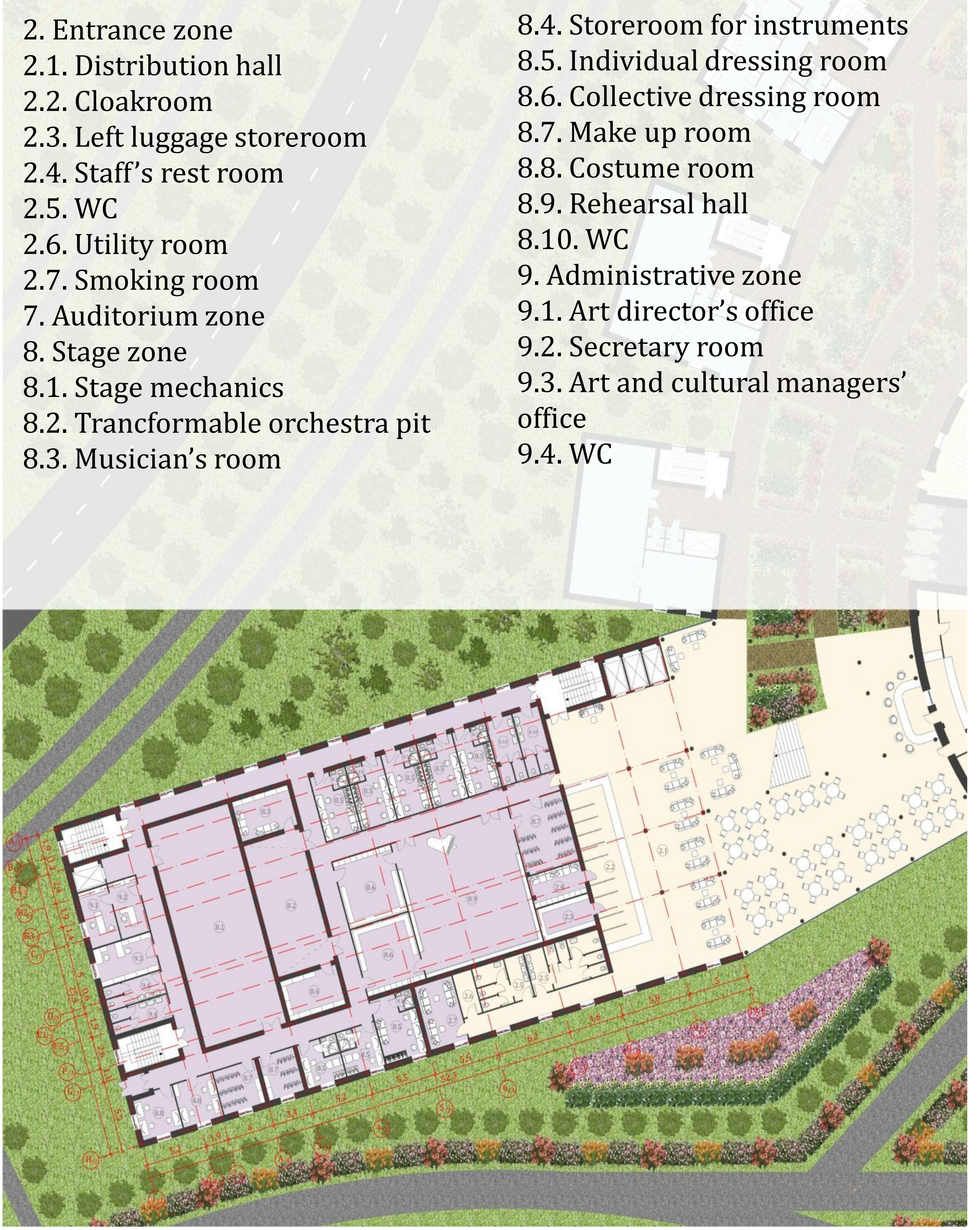


Figure 3.44. Auditorium building. First floor plan

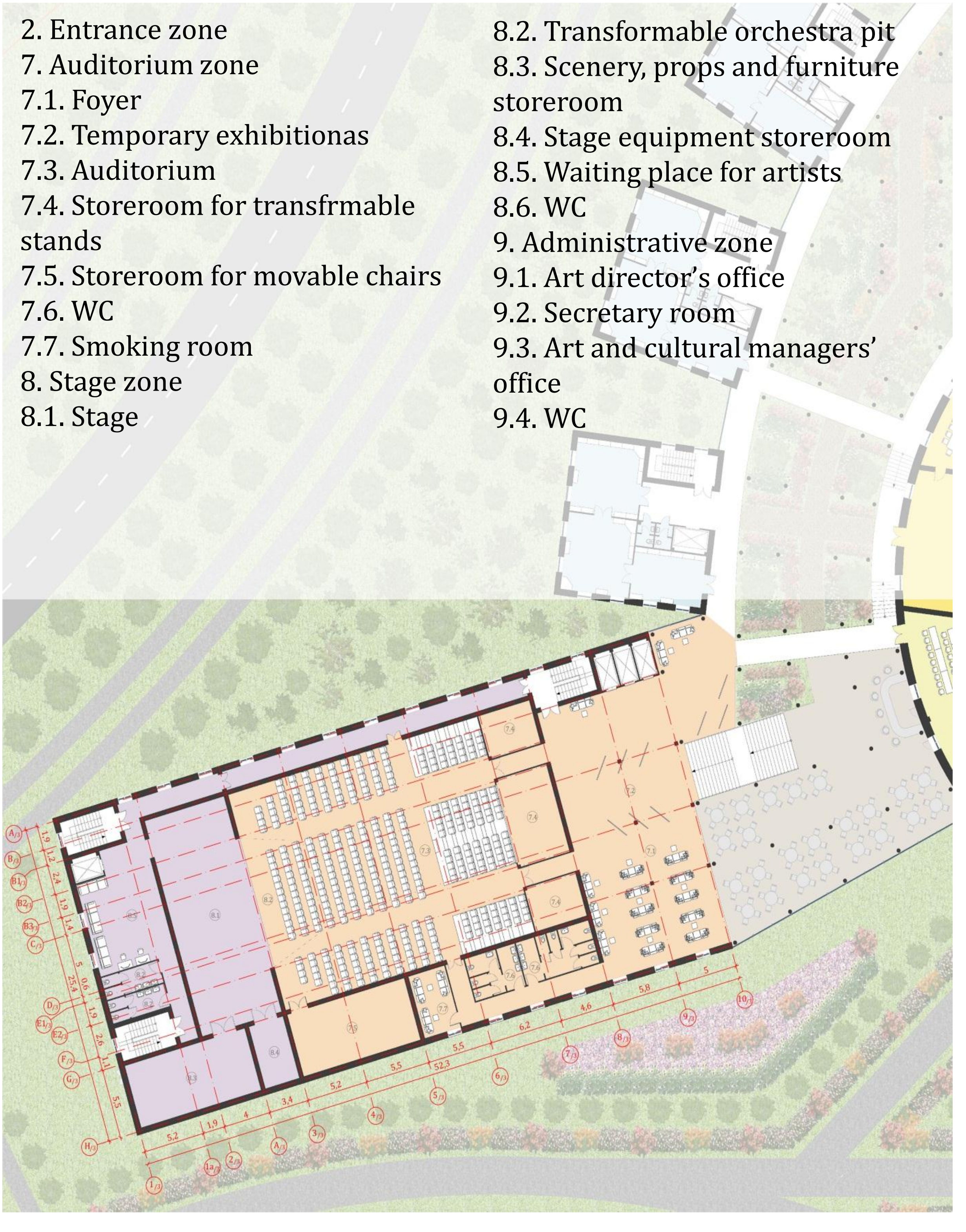


Figure 3.45. Auditorium building. Second floor plan

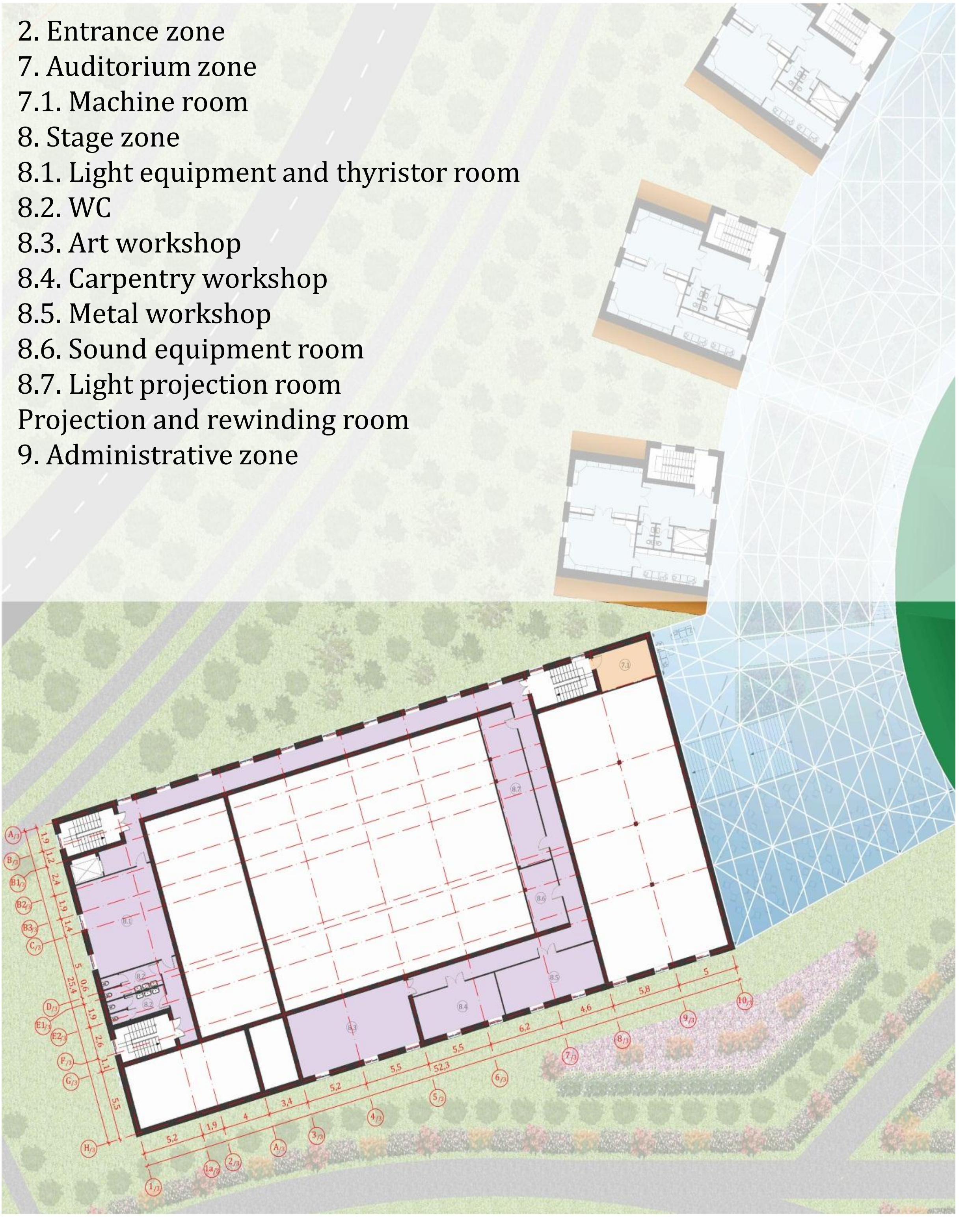
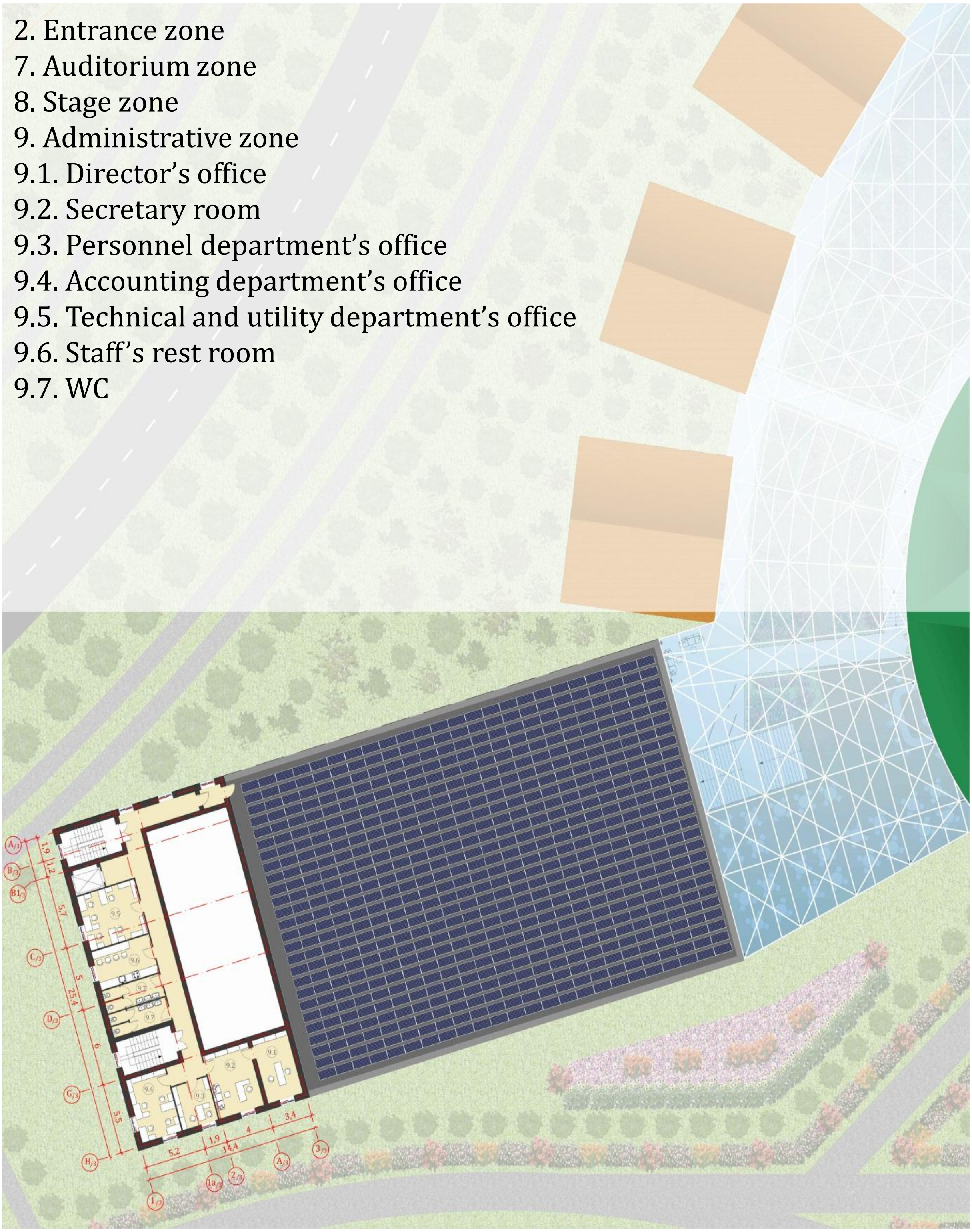


Figure 3.46. Auditorium building. Third floor plan



3.3.4. Winter garden

In the regions with cold winters, where half of the year one cannot see greenery outside, green zone can be created inside for giving to people the possibility to stay in the warm green space irrespective of the season.

In the project winter garden plays the role of the space, which works as link between all the zones. The zone can be used for the rest as well as for giving information about some specific plants. In different parts of the garden different types of plants can be grown. Besides green zone, winter garden includes russian restaurant.

Figure 3.47. Winter garden

Figure 3.48. Winter garden

3.4. ARCHITECTURAL SECTIONS

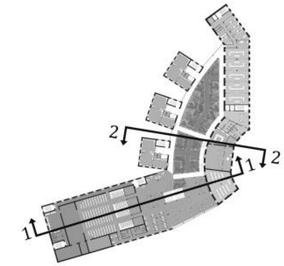


Figure 3.49. Section 1 – 1

Figure 3.50. Section 2 – 2

Figure 3.51. Section 3 – 3

Figure 3.52. Section 4 – 4

3.5. ELEVATIONS

Figure 3.53. South-western elevation

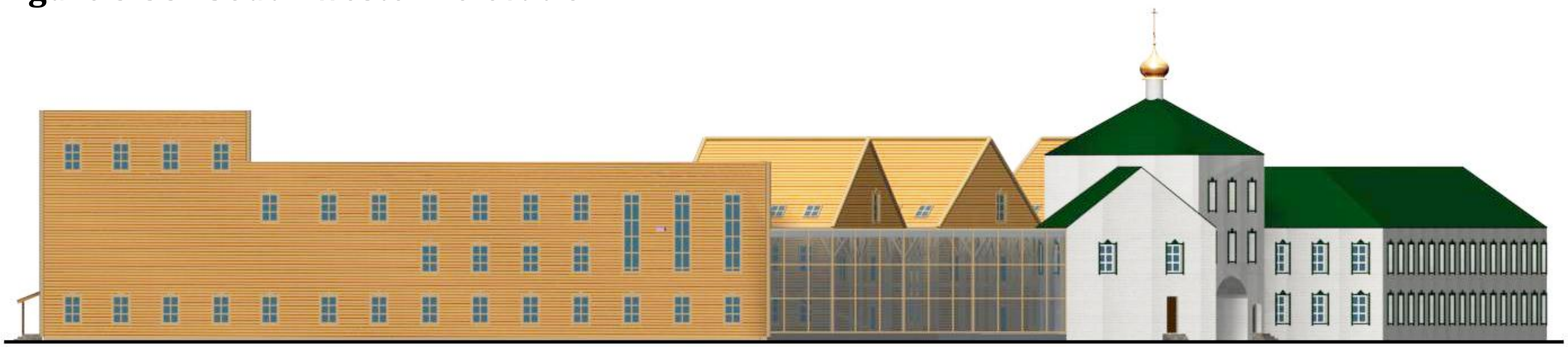


Figure 3.54. Northern elevation

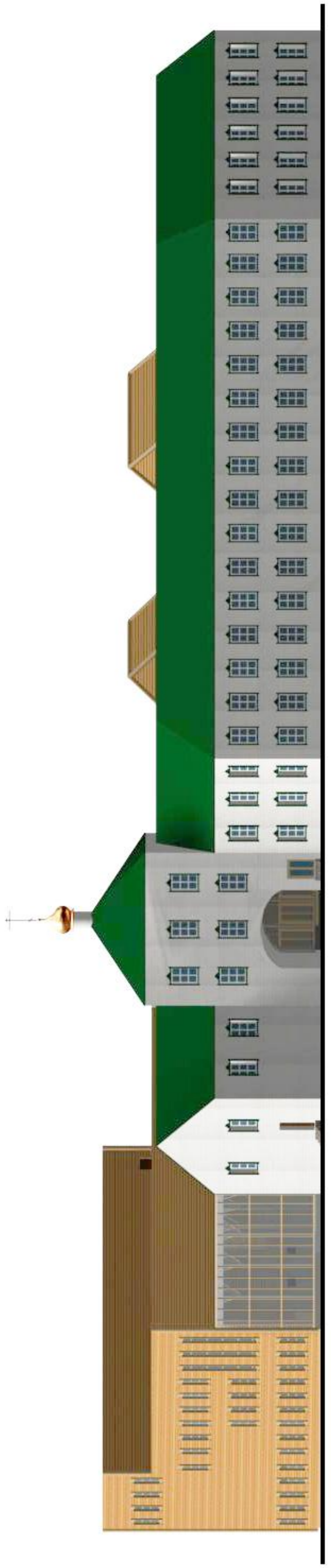


Figure 3.55. Eastern elevation

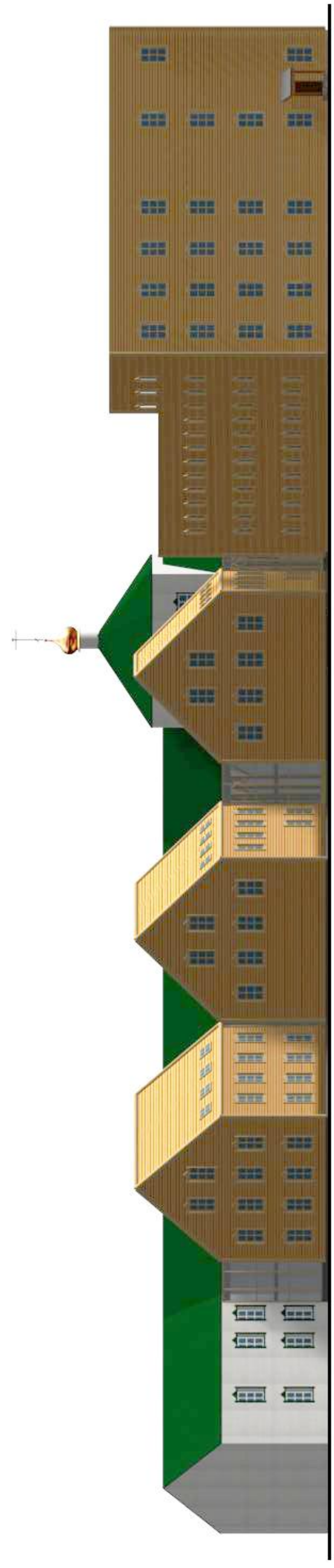


Figure 3.56. Western elevation

3.6. RENDERS

Figure 3.57. South-eastern view

Figure 3.58. South-western view

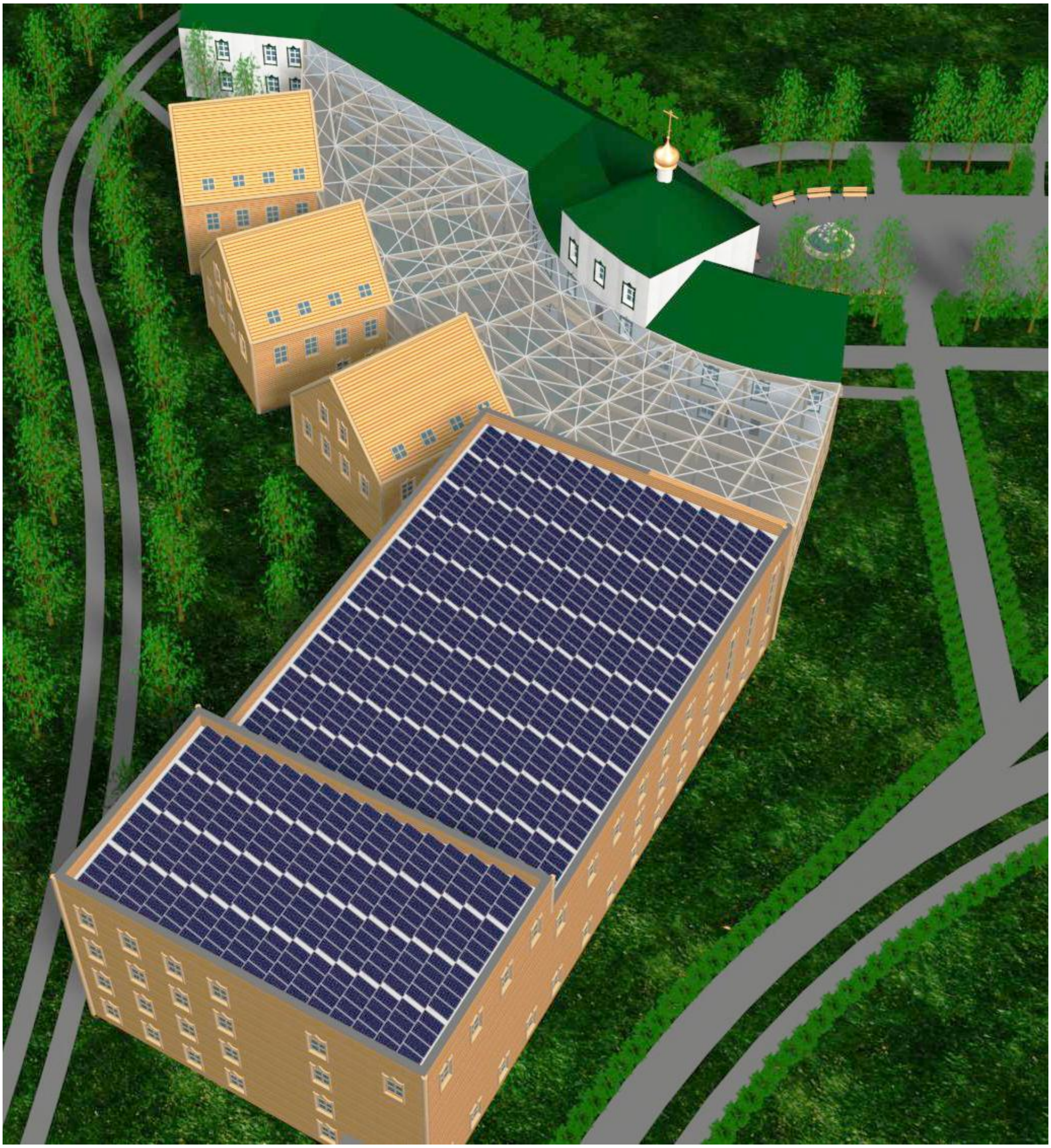


Figure 3.59. View on the main square

Figure 3.60. View on museum buildings

CHAPTER 4. TECHNOLOGICAL DESIGN

4.1. CONCEPT

The main idea of technological design part is to give the new life to the materials, used in Russia during 1000 years. Choice of materials caused by combination of 2 Russian traditional materials in one building – timber and brick. Using traditional materials in a new way is the measure for creating the link between the history and modern life.

The building is divided on 3 zones:

- **Zone 1:** cross-laminated timber panels with soft thermal insulation and wooden facing. This zone includes administrative, auditorium and museum zones.
- **Zone 2:** reinforced concrete bearing frame and non-bearing brick walls with soft thermal insulation and painted brick facing. This zone includes study, research, library and church over gates zones.
- **Zone 3:** bearing timber frame and facade glazing with timber studs.

Figure 4.1. Russian house

Figure 4.2. Russian church

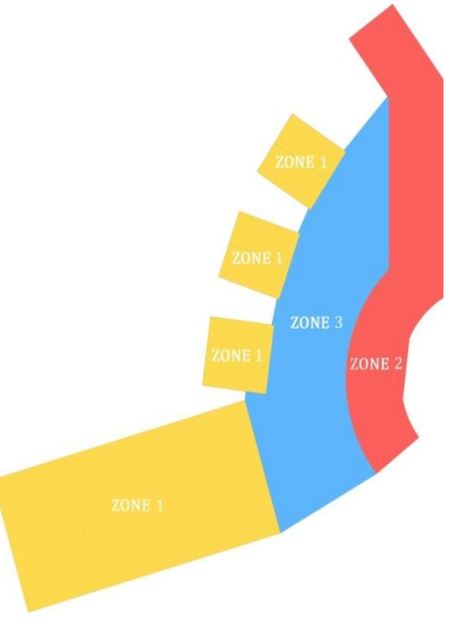


Figure 4.3. Building zones

Because of big dimentions of the building it is necessary to focus attention on the detailed elaboration of the part of the building.

One of the buildings of museum was chosen for detail elaboration. It is explained by 2 reasons:

- Museum is one of the main function of Russian Cultural Center, as its main aim is linked with study of russian language, literature, history, traditions and folk arts and sharing the knowledge
- The buildings of museum underline Russian traditional form and material and it is one of the main accent in the project.

Figure 4.4. Choice of building part for elaboration

Figure 4.5. Museum building

Technological design of the building is based on the goals for houses, which have been formulated in Urban design part:

- Comfort
- Quality
- Longevity
- Cost
- Ecological compatibility
- Energy-efficiency

These goals can be reached with energy-efficient planning of the building envelope.

The energy-efficient planning of the building envelope means guaranteeing that the interior climate conditions necessary can be maintained over the whole year with low energy requirements and, wherever possible, essentially without any costly energy supply technologies.

The main objectives of energy-efficient planning are:

- Creation of built environment that is livable, comfortable, safe and productive
- Avoiding of resource depletion of energy, water and raw materials
- Prevention of environmental degradation, caused by facilities and infrastructure throughout their life cycle[48]

Optimization of building envelope is divided on 4 parts according to different systems of the building:

- Building envelope
- Building service systems
- Lighting
- Electricity

Every part has its own goals. For reaching the goals in the project some concepts were chosen.

[48] http://www.wbdg.org – article «Sustainable»

Table 4.1. Technological design concept[49]

	Goals	Concepts
Building envelope	Minimizing of life cycle environmental impact	Use of greener materials
	Maintaining the heat	Surface optimisation and envelope geometry
		Thermal insulation of opaque components
		Thermal insulation of transparent components
	Avoiding overheating	Reducing incoming solar radiation
Building service systems	Indoor environmental quality	Geothermal heating and cooling system
		Hydronic radiant floor heating
		Heat recovery ventilation system
	Protection and conservation of water	Rainharvesting system
Lighting	Using the light	Geometric optimisation
Electricity	Generating electricity	Photovoltaic system

[49] M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p.85

4.2. CLIMATE

For energy-efficient planning of building envelope it is important to know climet conditions of the territory. It includes information about climate of Kalininskij district and the one from Ecotect about Moscow.

4.2.1. Climate of Kalininskij district

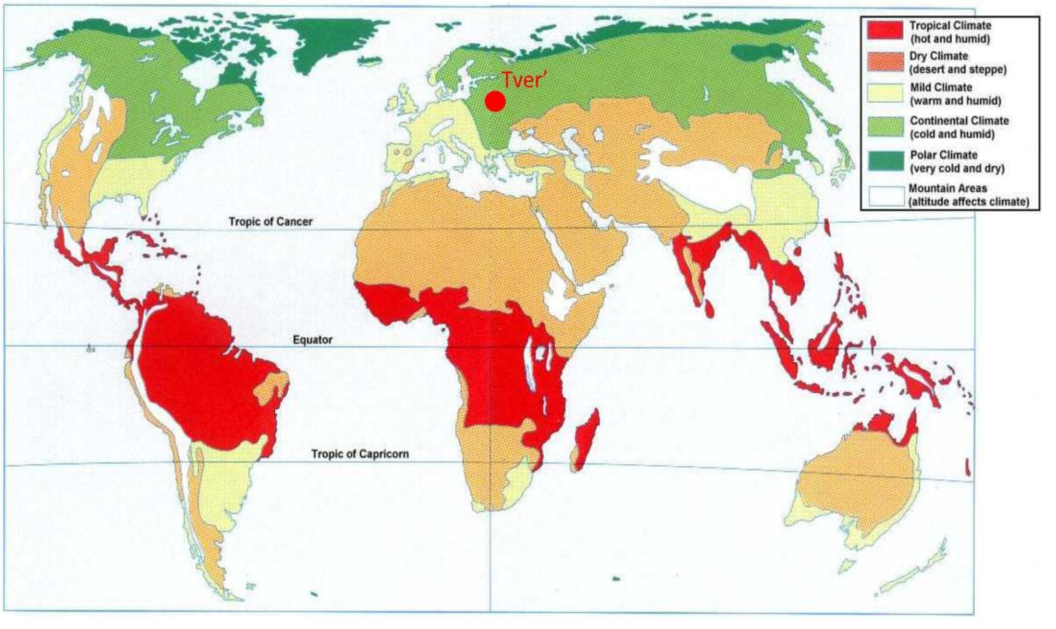


Figure 4.6. Climate zones

The territory is characterized by **humid continental climate.**

The main features of this species of temperate climate is **hot summers and cold winters** (minimum temperatures – in January and February, maximum temperatures – in July and August).

The amount of rainfall varies with proximity to the Atlantic. The climate is influenced by the transport of Atlantic air masses.

Humidification changes from north and north-west to south and south-east. This is the reason for the change of natural areas (from the taiga to the steppe). Atlantic air masses, moving inland, assume more continental characteristics.

Table 4.2. Climate characteristics

Absolute minimum	*-50 ° C*
Absolute maximum	*+36 ° C*
Average minimum temperature	*-14.4 ° C*
Average maximum temperature	*+23 ° C*
Average long-term date of first frost	*11 August*
Average length of the summer period	*11 June*
Period with temperatures above 0 ° C	*213 days*
Average duration of period with steady frost Beginning End	*121 days* *December 1* *March 31*
Average duration of period with thaw: November December January February March	 *17,7* *8,1* *5,8* *5* *15,2*
Average duration of the period with an average daily temperature above 15 ° C	*58 days*
Average length of vegetative period	*170 days*
Quality of days without sun per year (mainly in autumn-winter period). November and December are especially gloomy. Sunshine duration. Quantity of days without sun per mounth	*113 days* *about 10%* *22-23 days*

Table 4.3. Climate characteristics

During the year, most precipitation falls in summer. Maximum annual precipitation	*885 mm*
Minimum annual precipitation	*348 mm*
Average frequency of drizzling rain per year	*15 days*
Average period with snow cover (from the last week of November up to March).	*125 days*
Average height of snow cover	*40-60 cm*
The winds are west and south-west. A small wind speed observed in autumn and winter.	
Wind speed	*8 m/sec*
Wind pressure	*0.23 kPa*
Calculated temperature for the design of heating systems	*-29 ° C*
Calculated temperature for the design of ventilation systems	*-15 ° C*
Duration of the heating season	*219 days*
Depth of freezing of soils	*135 cm*

4.2.2. Ecotect weather data

In Ecotect there are only 2 Russian cities – Moscow and Saint-Petersburg. Taking into account that Tver' is situated in 134 km from Moscow and in 484 km from Saint-Petersburg, it is possible to use weather data of Moscow for the site.

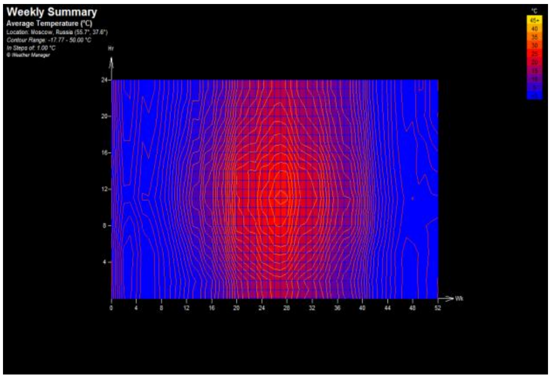


Figure 4.7. Average temperature

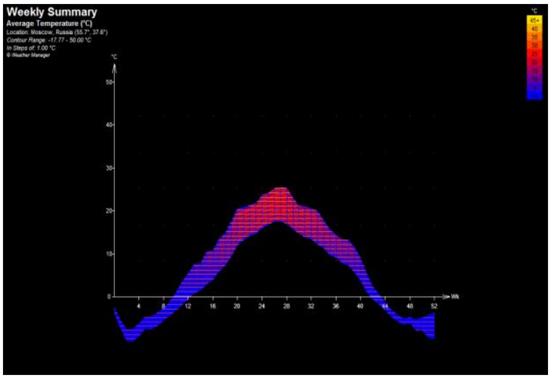


Figure 4.8. Average temperature

Average temperature graph shows changing of average temperature during the year on weekly basis.

The highest temperature is 25°C from 26 to 28 week from 10 to 12 o'clock. 26-28 weeks are the last weeks of July. Maximum temperature graph shows that temperature in this period can reach 30°C. It means that in July cooling loads increase.

From 0 to 12 and from 42 to 52 weeks there are temperatures below 0°C. These weeks are from the second half of October to the first half of March. The coldest time is the second half of January from 2 to 4 week. As temperatures are below 0°C, building needs heating during this period.

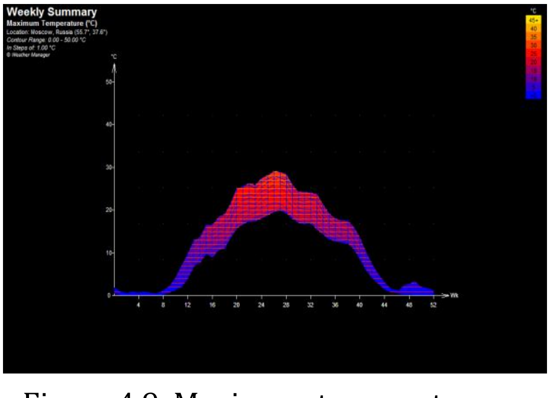


Figure 4.9. Maximum temperature

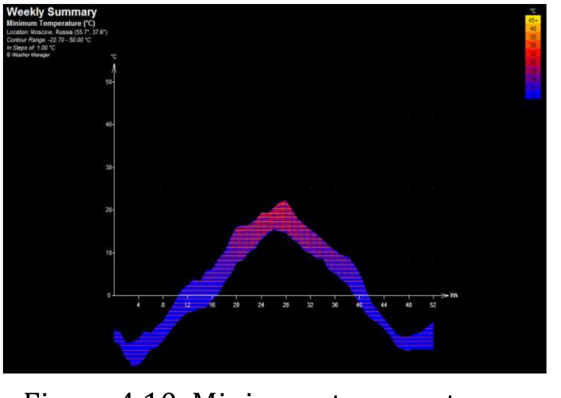


Figure 4.10. Minimum temperature

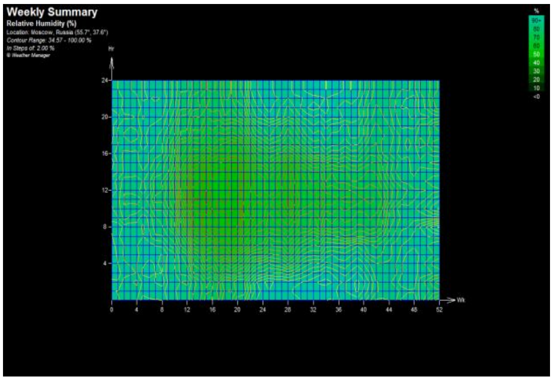


Figure 4.11. Relative humidity

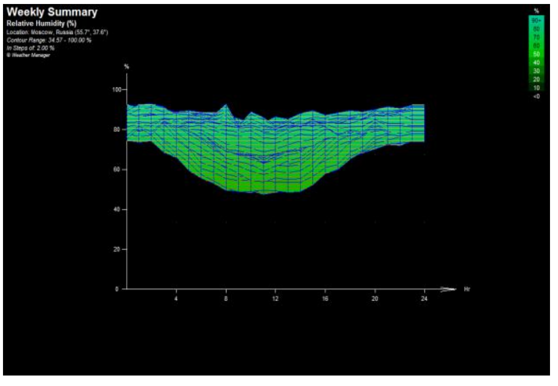


Figure 4.12. Relative humidity

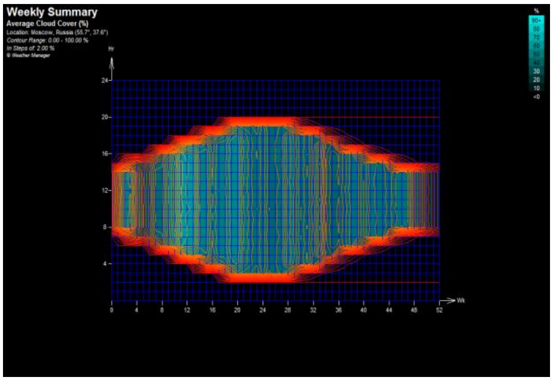


Figure 4.13. Cloud cover

Relative humidity graph shows that the highest relative humidity is more than 90% from 0 to 8 week in January and February from 16 o'clock up to 8 o'clock, from 24 to 41 week from July to October From 21 up to 2 o'clock and from 44 to 52 week in Novermber and December from 0 up to 10 o'clock.

The lowest relative humidity is about 50% from 13 to 20 week in April and May from 8 up to 14 o'clock.

Cload cover graph shows that the highest cload cover is about 70% in 11 week, the third week of March.

The lowest cload cover is about 10% in 52 week, the last week of December.

On the graph of wind speed one can see that the highest wind speed is about 10 km/h from 16 to 18 week in the first weeks of May from 7 up to 12 o'clock and in 52 week, the last week of December, from 11 up to 17 o'clock.

The lowest wind speed is about 1 km/h from 23 to 27 week in June and July from 20 up to 24 o'clock.

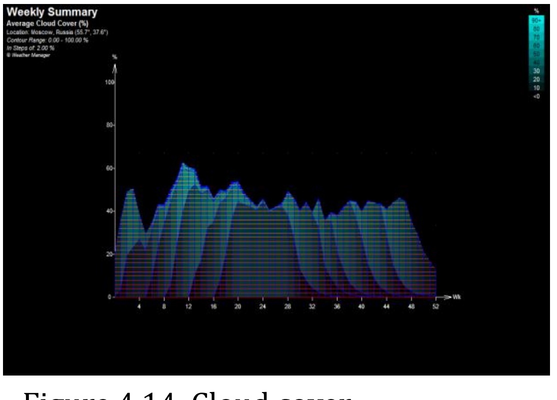


Figure 4.14. Cloud cover

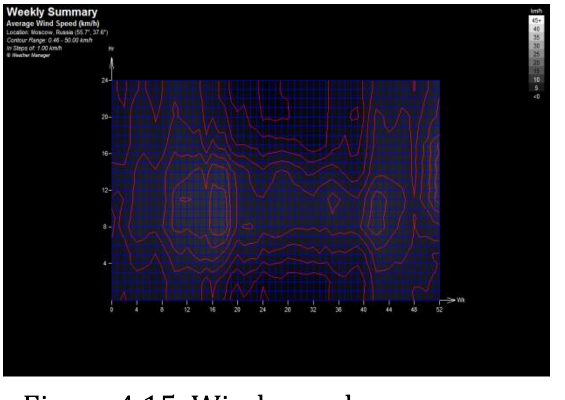


Figure 4.15. Wind speed

Monthly diurnal graph shows maximum, minimum and average temperatures as well as diract and diffuse solar radiation during all the year. Yellow zone shows comfort conditions. On the graph one can see that from November up to March temperature is much lower than the comfort one. It means that it is necessary to provide heating for reaching comfort conditions. On the contrary from May up to August temperature is higher than the confort one. In this case it is possible to reach comfort conditions providing cooling.

This information should be taken into account in the process of heating and cooling loads calculation and in design of necessary service systems.

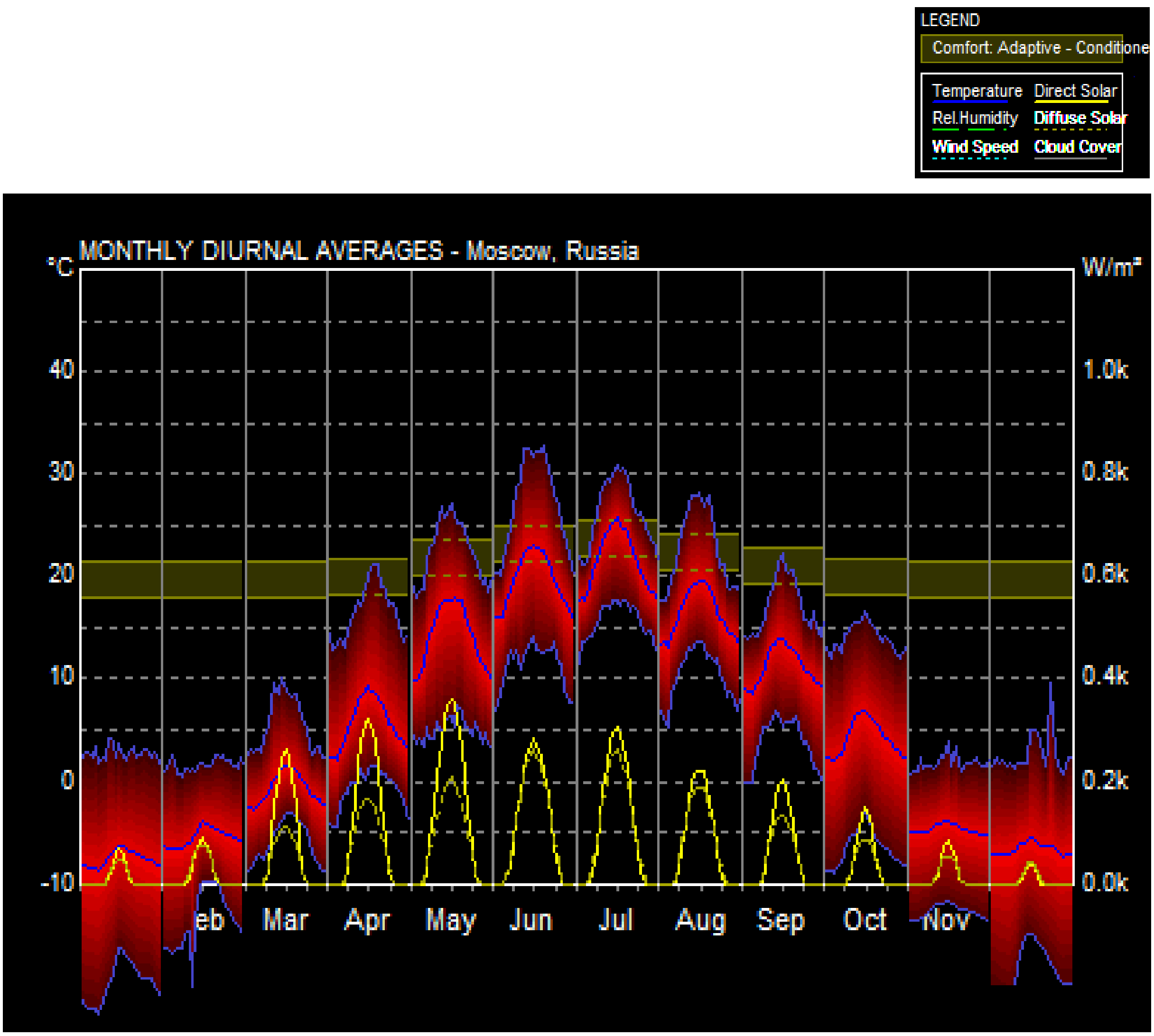


Figure 4.16. Monthly diurnal averages

4.3. BUILDING ENVELOPE

In the temperate and cold zones of the Earth it is particularly important to guarantee agreeable interior conditions by the way of appropiate measures when outside temperatures are low. The primary aim is to keep as much heat within the building by constructing an optimized building envelope.

A thermal balance can be drawn up for the building in order to analyze the heat flows, specifying the relationship between heat losses and heat gains throughout the year.

Table 4.4. Thermal balance[50]

Losses	Gains
Transmission heat losses	Heating requirement
	Active use of solar radiation
Ventilation heat losses	Passive solar gains
	Internal gains

The properties of the building envelope should contribute to evening out this balance as far as possible. The difference between the two sides of the equation determines the heating requirement that must be provided via mechanical means. As the internal heat sources are determined by the type of use, the optimization potential of the building envelope lies in minimizing heat losses and maximising the solar gains.

As the use of the building as museum introduces its own specific requirements concerning ventilation and and solar radiation, entering through the windows, which do not allow to use passive solar gains, minimizing of transmission heat losses by means of envelope geometry and composition plays a very important role for thermal balance of the building.

[50] M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p. 86

4.3.1. Choice of materials

Choice of materials has a great influence on the behavior of the building. Energy-efficient building should be constructed of materials that minimize life-cycle environmental impacts, provide safe structure of the building and thermal quality of the space.[51]

4.3.1.1. Cross-laminated timber panel

The main structural material of museum is cross-laminated timber.

Cross-laminated timber system was developed in Germany around 12 years ago and it's rapidly spreading in most European countries such as Austria, Switzerland, Italy and Nordic Countries.

M1 BSP crossplan is large-format, solid cross-laminated timber panel with multilayer, crosswise cross-section lay-up.

Production

Finger-jointed and planed lamellas are loosely laid next to each other and the flat surfaces of the layers glued at right angles to one another. To avoid uncontrolled stress cracks, the narrow sides are not glued. The layers are pushed laterally to dimension before applying the pressure (*1,2 N/mm²*) in order to obtain a gap-free surface.

Areas of use

It can be used as wall, ceiling and floor element.[52]

Figure 4.17. M1 BSP crossplan

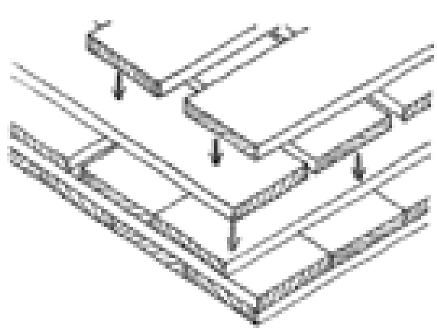


Figure 4.18. Production

[51] http://www.wbdg.org – article «Sustainable»
[52] http://www.mm-kaufmann.com

Table 4.5. Technical data[53]

Dimentions	Length – up to *16,5 m* Standard widths – *2,4 m / 2,65 m / 2,75 m / 2,9 m / 3 m* Thickness – from *78* to *278 mm*
Types of wood	Spruce (Picea abies) from domestic forests; other wood species on request
Lamellas	*19* to *40 mm*, kiln-dried, quality graded and finger-jointed
Gluing	Melamine resin-based adhesive, Adhesive Type I acc. to EN 301 approved for the gluing of load-bearing timber components, for both interiors and exteriors, weather-resistant with transparent glued joint
Density	$480\ kg / m^3$
Moisture content	*12 % (+ / - 2 %)* on delivery
Thermal conductivity	$\lambda = 0{,}13\ W / mK$
Heat capacity	$c = 1{,}60\ kJ / kgK$
Water vapour resistance factor	$\mu = 60$ (at *12 %* moisture content)
Airtightness	Airtight from a panel thickness of 95 mm
Reaction to fire	According EN 13501: D, s2, d0 (standard inflammability, average smoke emission, no combustible drips)

[53] http://www.mm-kaufmann.com

Advantages

- **Flexible design**

This high degree of flexibility in planning allows for customized solutions to a variety of building tasks.

Figure 4.19. Flexible design

- **Space gain due to reduced component thickness**
- **Shape and dimensional accuracy**

M1 BSP crossplan is cut to size at the factory by computer-controlled CNC machining systems on request. It minimizes the risk of assembly errors due to accurately fitting components.

- **Prefabricated, ready to assemble elements**

The extremely high degree of prefabrication results in short assembly times and, hence, in lower building costs.

Figure 4.20. Prefabrication

- **Short building time due to dry construction**
- **Recommended for environmentally compatible architecture**

The perceived surface temperature of M1 BSP crossplan lies significantly above any other type of building material. Even at lower room temperatures this leads to a pleasant perception of temperature.

- **Reduced carbon footprint**

Timber is the only building material that is distinguished by its positive contribution to the carbon footprint.[54]

Figure 4.21. Reduced carbon footprint

[54] http://www.mm-kaufmann.com

4.3.1.2. Thermal insulation

Mineral wool

For thermal and sound insolation of the building mineral wool IZOVOL Cт was chosen. Mineral wool IZOVOL Cт is thermal, sound and fire insolation, produced with applying of unique melting unit excluding coke and providing the highest quality of the melt due to its stable viscosity and fluidity and maintaining of constant temperature of the melt. It allows to obtain the products with high stable physical and mechanical properties and at the same time optimal thermal conductivity.

Table 4.6. Technical data

Dimentions	*600 x 1000 x 100 mm*
Density	*90 kg/m^3*
Compressive strength	*18 kPa*
Strength in tearing of layers	*7 kPa*
Thermal conductivity	*0,035 W/m°C*
Water absorption	*1%*
Water vapour permeability	*0,3 mg/m h Pa*
Flammability	*non-flammable*

Areas of use:

- Multilayer walls
- Rainscreen systems
- Pitched roofs
- Internal partitions
- Floors
- Ventilation and heating systems
- Industrial equipment[55]

Figure 4.22. IZOVOL Cт

[55] http://www.izovol.ru

Advantages

- **Low thermal conductivity**

The low thermal conductivity of the rock wool IZOVOL is caused by its fibrous structure with a huge amount of microspores, which prevent convection of air, unlike glass wool, which has a one-way structure.

- **Water repellency**

Water absorption of IZOVOL is not more than 1% of its volume. It is much less than in most of the materials used in thermal insulation purposes.

- **Longevity**

Stability of the basic characteristics of mineral wool and slabs on its basis during the experiments (2360 cycles) as well as the preservation of the structure of the fibers and the adhesion of the binder to them allow to determine the long-term (more than 50 years) life of mineral wool in temperate cold climate zone.

- **High fire resistance**

Natural stone materials, which are the basis for the IZOVOL production, belong to the category of non-flammable. During the fire thermal insulation IZOVOL fully retains its mechanical properties and fire resistant ability.

- **High sound insulation**

Mineral products IZOVOL has advanced sound insulation characteristics. It completely prevents distribution of sound waves.

- **High vapour permeability**

Excess moisture premises can easily penetrate through the fiber structure of IZOVOL panels. Condensate does not accumulate in the thickness of insulation and evaporates from the surface of the panels.

- **Chemical resistance**

Mineral wool IZOVOL is chemically resistant to organic substances (solvents, acids, bases, etc.). It protects the insulated surface from corrosion, fully meet health and safety standards. It is stable in volume and shape, resistant to house fungi, microorganisms and rodents.[56]

[56] http://www.izovol.ru

4.3.2. Envelope geometry

Selecting a form for a building has a substantial influence on its energy requirements. Surface areas of different sizes have different energy losses: the smaller the envelope area required for a given volume, the lower is the building's heating requirement.[57]

Taking into account this concept, it was decided to avoid any unjustified complexity in the forms of the building. Despite the fact, the form of whole the building is complex, the forms of the parts of the building is quite simple.

For the buildings of museum the form of square was chosen. Simple envelope of the building underlines the traditional form of roof. All the building of museum has the same heating requirements, so method of thermal zoning in the case cannot be applied.

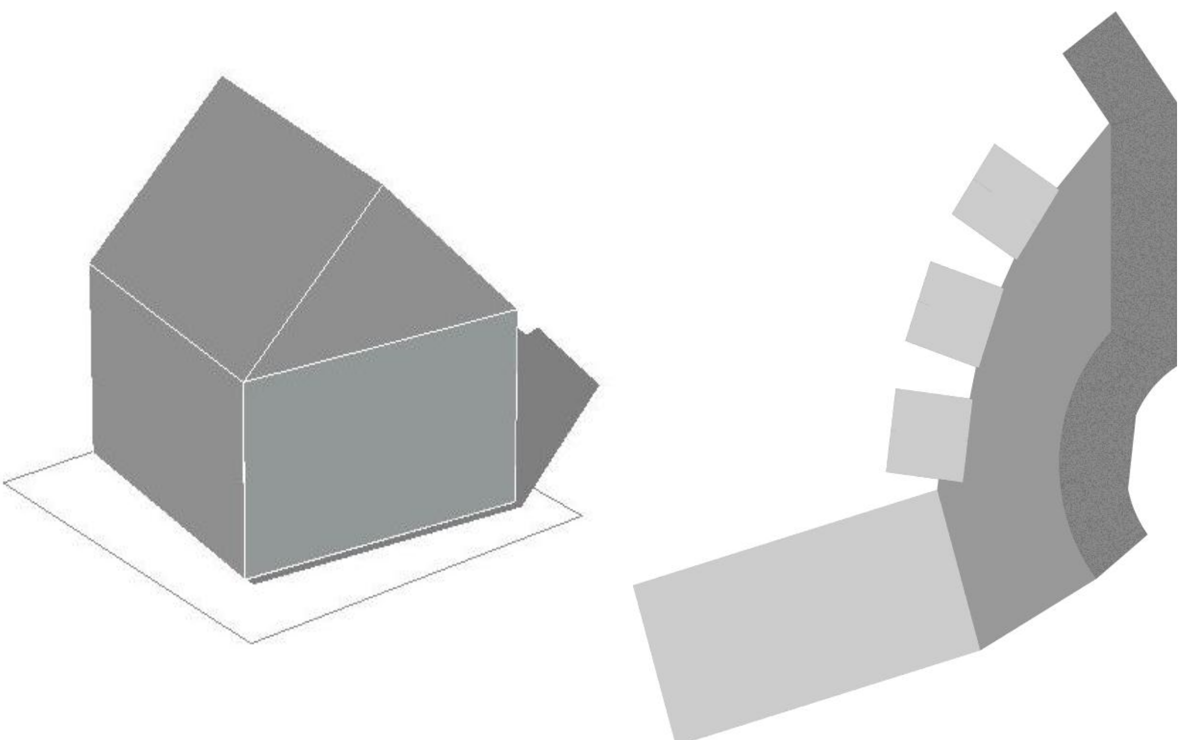


Figure 4.23. Envelope simplicity

[57] M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p.86

4.3.3. Envelope composition

Envelope composition has a considerable influence on thermal balance of the building. Building envelope consists of opaque and transparent components, which should be analyzed for minimizing of transmission heat losses.

4.3.3.1. Opaque components

The magnitude of transmission heat losses through opaque building envelopes is essentially determined by the thermal conductivity of the components enclosing the heat volume. It depends on specific properties of the materials and construction of the components involved.

The parameter for the thermal quality of a building component is the thermal transmittance (*U-value*) measured in m^2*K/W. It describes the heat flow under static conditions and is calculated as the heat output per square meter for a difference of $1\ K$ between two surfaces of the component. The lower this value, the better is the thermal performance of a component.

Heat flow for a homogeneous wall: [58]

$\phi = (t_i - t_e) / (1/h_i + s/\lambda + 1/h_e) * S = ((t_i - t_e) / R) * S = U * S * (t_i - t_e)$

$R = 1/h_i + s/\lambda + 1/h_e$

$U = 1/R$

For multilayer walls with air cavities:

$U = 1 / (1/h_i + \sum s/\lambda + 1/C + 1/h_e)$

where:

h_i (h_e) is internal (external) convective coefficient

S is surface

R is thermal resistance of the wall

λ is thermal conductivity

C is thermal conductance of the cavity

[58] M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p.87

Table 4.7. External wall composition

	Material	(S) Thickness m	(λ) Thermal conductivity W/m*K	(R) RESISTANCE m^2*K / W
	R external			*0,04*
1	Timber facing	*0,04*	*0,12*	*0,333*
2	Ventilation gap Timber spruce battens	*0,05*	*0,278*	*0,18*
3	Vapour-permeable membrane	-	-	-
4	ISOVOL Ст-90 Timber spruce battens	*0,05*	*0,035*	*1,428*
5	ISOVOL Ст-90 Timber spruce battens	*0,1*	*0,035*	*2,857*
6	M1 BSP crossplan	*0,095*	*0,13*	*0,73*
7	ISOVOL Ст-90 Timber spruce battens	*0,05*	*0,035*	*1,428*
8	Timber facing	*0,02*	*0,12*	*0,167*
	R internal			*0,13*
				7,293
	0,405 m			*U value – 0,137*

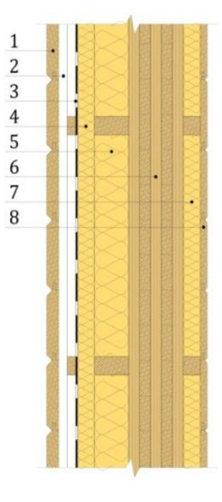


Figure 4.24. External wall composition

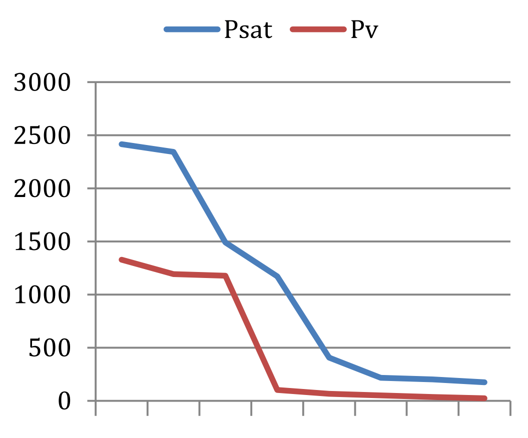


Figure 4.25. Glaser diagram

Table 4.8. Roof composition

	Material	(S) Thickness m	(λ) Thermal conductivity W/m*K	(R) RESISTANCE m²*K / W
	R external			*0,04*
1	Timber facing	*0,04*	*0,12*	*0,333*
2	Ventilation gap Timber spruce battens	*0,05*	*0,278*	*0,18*
3	Steel roofing	*0,001*	*52*	*0*
4	Vapour-permeable roofing membrane	-	-	-
5	Full formwork	*0,012*	*5,2*	*0,002*
6	ISOVOL Ст-90 Timber spruce rafters	*0,2*	*0,035*	*5,714*
7	ISOVOL Ст-90 Timber spruce battens	*0,05*	*0,035*	*1,428*
8	Vapour barrier	-	-	-
9	Timber facing	*0,02*	*0,12*	*0,167*
	R internal			*0,17*
				8,034
	0,373 m			*U value – 0,124*

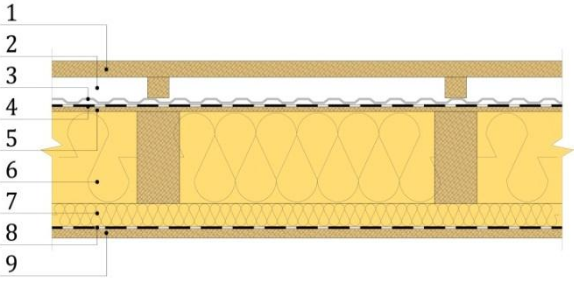


Figure 4.26. Roof composition

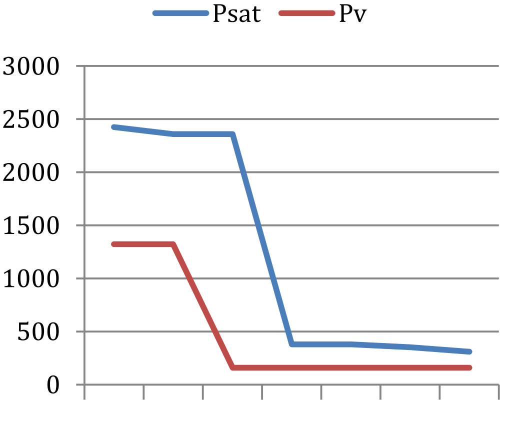


Figure 4.27. Glaser diagram

4.3.3.2. Transparent components

Transparent components play a very important role in energy-efficient planning. Usually it exhibits poorer thermal performance than opaque because of materials used. The size and arrangement of areas of glazing, therefore, have a great influence on the transmission heat loss. [59]

For the windows in the project timber windows with triple glazing were chosen. Timber windows are made of three-laminated window beam with cross section *78 x 78 mm* from pine. In the process of manufacture such defects of wood as knots and voids are deleted. The beam glued together from several layers of wood in different directions, has a high resistance to stress. 2 contours of seal close window securely, protecting from dust, drafts and street noise. Impregnations and varnishes which were used in manufacture are water-based and timber treated with them is airtight and creates comfortable environment in the room.

Triple glazing with thickness of *38 mm* installed in wooden windows, eliminates blowing.

The most exposed part of the window is bottom of sash. It is closed with aluminium profile.[60]

Figure 4.28. Timber window

[59] M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p.90
[60] http://www.oknaexclusive.ru

4.3.4. Thermal analysis

Thermal analysis was used for evaluating heating and cooling loads of the building.

For having the possibility to evaluate energy-efficiency of the building envelope, different envelope compositions were analyzed.

Envelope composition 1 is the one, applied in the building, timber wall with *U = 0,13 m²*K/W* and timber windows with *U = 0.8 m²*K/W*. Because of museum requirements, full air-conditioning was applied for all the cases.

Table 4.9. Envelope composition 1 Timber wall *U = 0,13 m²*K/W* and windows *U = 0,8 m²*K/W*

Month	Heating Wh	Cooling Wh	Total
January	1546666	0	1546666
February	1313549	0	1313549
March	900666	0	900666
April	270749	82062	352811
May	1008	663446	664454
June	0	1053493	1053493
July	0	1223729	1223729
August	0	835468	835468
September	0	368313	368313
October	393445	91658	485103
November	1294903	0	1294903
December	1555747	0	1555747
Total	7276733	4318169	11594902

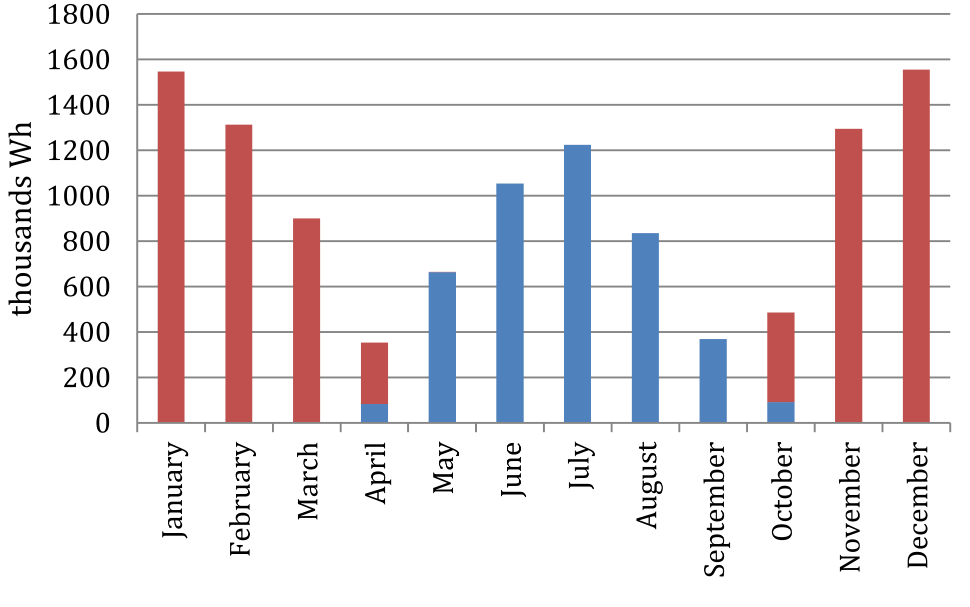


Figure 4.29. Thermal analysis. Envelope composition 1

In **Envelope composition 2** usual timber walls with *U = 0,35 m²*K/W* was applied in order to understand, how increase of energy-efficiency of walls influences on energy consumption.

The result shows that total energy consumption increased by *2370306 Wh*, what is *20%*, in comparison with Envelope composition 1, applied in the project.

Table 4.10. Envelope composition 2 Timber wall *U = 0,35 m²*K/W* and windows *U = 0,8 m²*K/W*

Month	Heating Wh	Cooling Wh	Total
January	2092726	0	2092726
February	1784261	0	1784261
March	1264585	0	1264585
April	406876	91024	497900
May	14301	660863	675164
June	0	1105521	1105521
July	0	1305021	1305021
August	0	832330	832330
September	7277	314385	321662
October	559468	66110	625578
November	1767068	0	1767068
December	2100268	0	2100268
Total	9589954	4375254	1396520 8

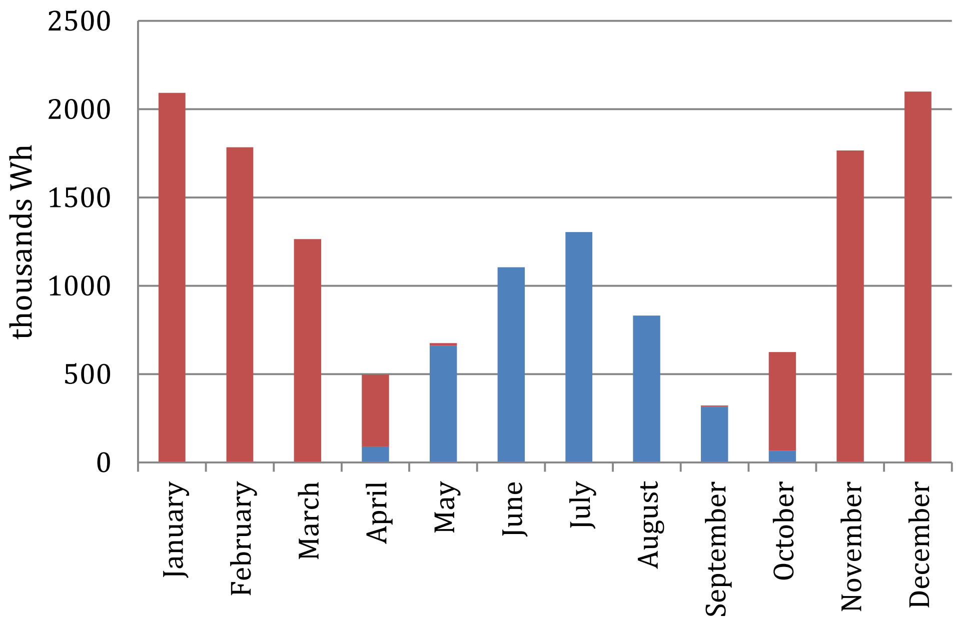


Figure 4.30. Thermal analysis. Envelope composition 2

In **Envelope composition 3** usual timber windows with *U = 1,5 m²*K/W* was applied in order to understand, how increase of energy-efficiency of windows influences on energy consumption.

The result shows that total energy consumption increased by *1430587 Wh*, what is *12%*, in comparison with Envelope composition 1, applied in the project.

Finally, it is possible to conclude that decrease of thermal transmittance of building components reduces significantly energy consumption of the building.

Table 4.11. Envelope composition 3 Timber wall *U = 0,13 m²*K/W* and windows *U = 1,5 m²*K/W*

Month	Heating Wh	Cooling Wh	Total
January	1837757	0	1837757
February	1565016	0	1565016
March	1105490	0	1105490
April	368714	78383	447097
May	15302	638414	653716
June	0	1058096	1058096
July	0	1242384	1242384
August	0	817230	817230
September	9187	328813	338000
October	494025	76197	570222
November	1546464	0	1546464
December	1844017	0	1844017
Total	8785972	4239517	1302548 9

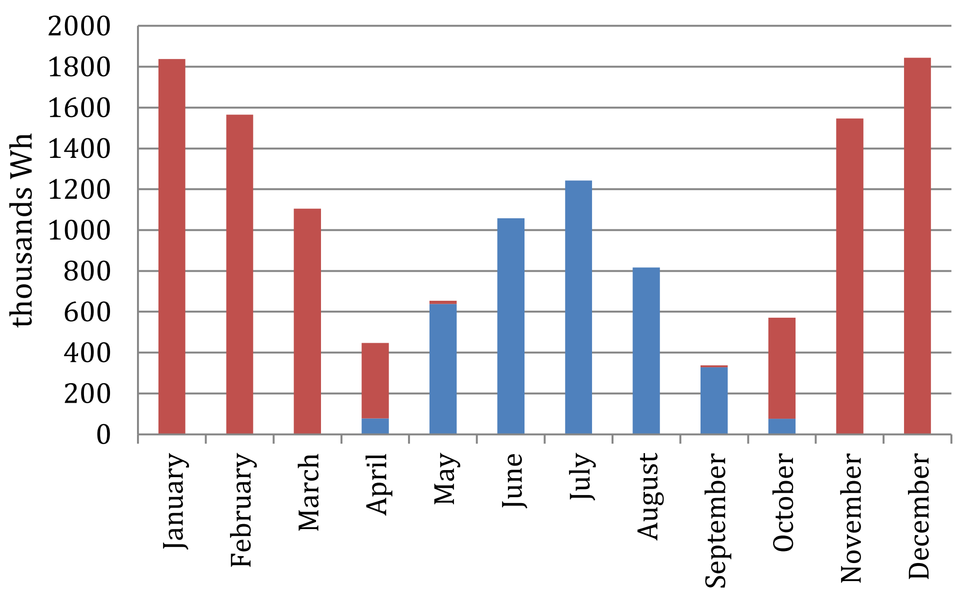


Figure 4.31. Thermal analysis. Envelope composition 3

4.4. LIGHTING

Lighting is a key for pleasant interior conditions. Natural light stimulates the human organism and controls a number of bodily functions. It is critical for our visual perception and has a considerable influence on our work.[61]

In lighting of museums several important tasks should be solved. Firstly, it is necessary to present each work of art qualitatively. On the one hand, details proving its artificial values such as shape, texture, color and material should be shown entirely and without defects. On the other hand, taking into account the specifics of human vision, possible negative factors such as glare, blinding light, contrasts should be eliminated. Secondly, it is important to keep all exhibits unharmed, as lighting influences them negatively: paper fades, biological substances can be broken and change the chemical properties of paints.[62]

From psychophysiological considerations, **natural light** is preferable, when it is allowed by the requirements of conservation. In the majority of cases it is necessary to avoid falling of direct sunlight on the exposits.

The advantages of **artificial lighting** are:

- Independence from the weather;
- Possibility of use of rooms in the evening;
- Creation of qualitative and quantitative characteristics of light, depending on the requirements of the exposition;
- Ability to adjust the intensity and spectral composition of light;
- Providing planning flexibility.

Artificial lighting device should provide:

- Possibility of qualitative look of the exhibits;
- Individual highlighting of the main exhibits (or interior parts of artistic value);
- fire safety;
- normal operating conditions in the work area.[63]

Level of illumination in exposition halls should be provided with taking into account light sensitivity of the exhibits.

61 M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p. 102

62 http://www.svetpro.ru – article «Специфика экспозиционного освещения в музее» («Specifics of exposure light in the museum»)

63 Recomendations for design of museums, CNIIEP of B.S.Mezencev – Moscow: Stroyizdat, 1988

Table 4.12. Allowed illumination intensity [64]

Type of exhibit	Recommended source of light	Allowed illumination intensity
Exhibits with low sensitivity to light: items made of stone, ceramics, minerals (except the ones with high sensitivity to light), jewelry, glass, enamels	Natural light. Luminescent lamps with color temperature of *4000 - 6500 K*. Incandescent lamps. Lamps with iodine cycle. Small projectors.	Usually < *300 lux*
Paintings, varnishes, wood, ivory, distemper	Natural light. Luminescent lamps. Incandescent lamps.	< *150 lux* Maximum annual illumination of paintings is *650 thousands lux/hr*
Exhibits with high sensitivity to light: watercolors, drawings, textiles, clothing, manuscripts, zoological and botanical collections	Incandescent lamps.	< *50 lux* with maximum decrease of exposition time

Considering the fact that there is no exact information about the items in the museum in the project, several concepts of lighting can be used:

- Combination of natural and artificial lighting
- Possibility of changing of the level of natural lighting
- Possibility of avoiding of natural light access in the case of exhibits with high sensitivity to light

For evaluating of quantity of light in the building shadow, insolation and daylight analysis were used.

[64] Recomendations for design of museums, CNIIEP of B.S.Mezencev – Moscow: Stroyizdat, 1988

4.4.1. Shadow analysis

Shadow analysis helps to understand the movement of the sun during the day and during the year, what is necessary to take into account energy-efficient planning of the building. It is especially useful during the process of determining of size and quantity of windows, types of shadow systems and solar panels areas location.

In daily shadows analysis it is possible to see that minimum shadows period is from 10 to 14 o'clock, when almost all south-eastern area is free of shadows. Maximum shadows period starts from 16 o'clock.

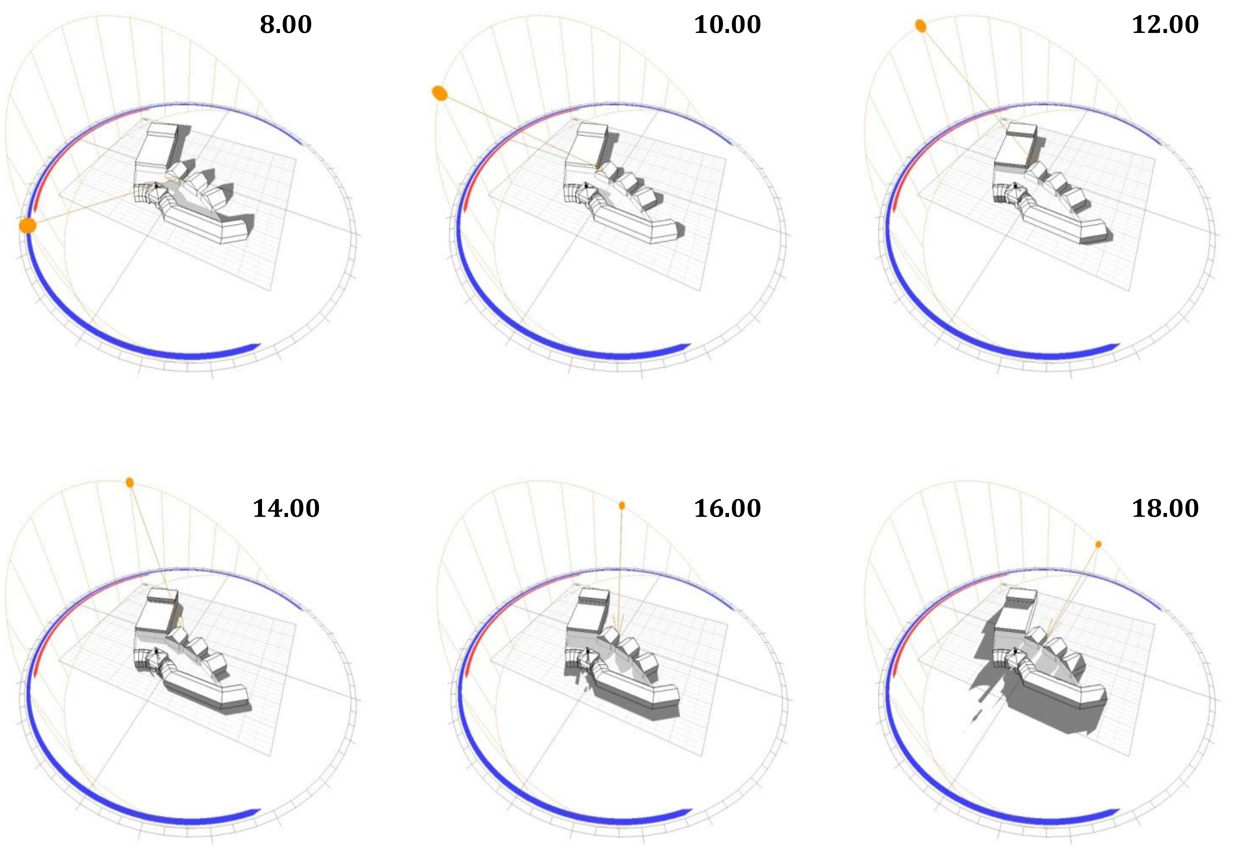


Figure 4.32. Daily shadows

Annual shadows analysis shows shadows at 12 o'clock during all the year. It can be mentioned that the difference in size of shadows in difference seasons is significant. Minimum size of shadows is in July and the maximum one is in January. Size of shadows at 12 o'clock in January is more than at 18 o'clock in July. The difference is caused by changing of position of the sun above the horizon. In January, the height of the sun above the horizon is very low, it starts to increase and in July it reaches its maximum, after which it starts to decrease.

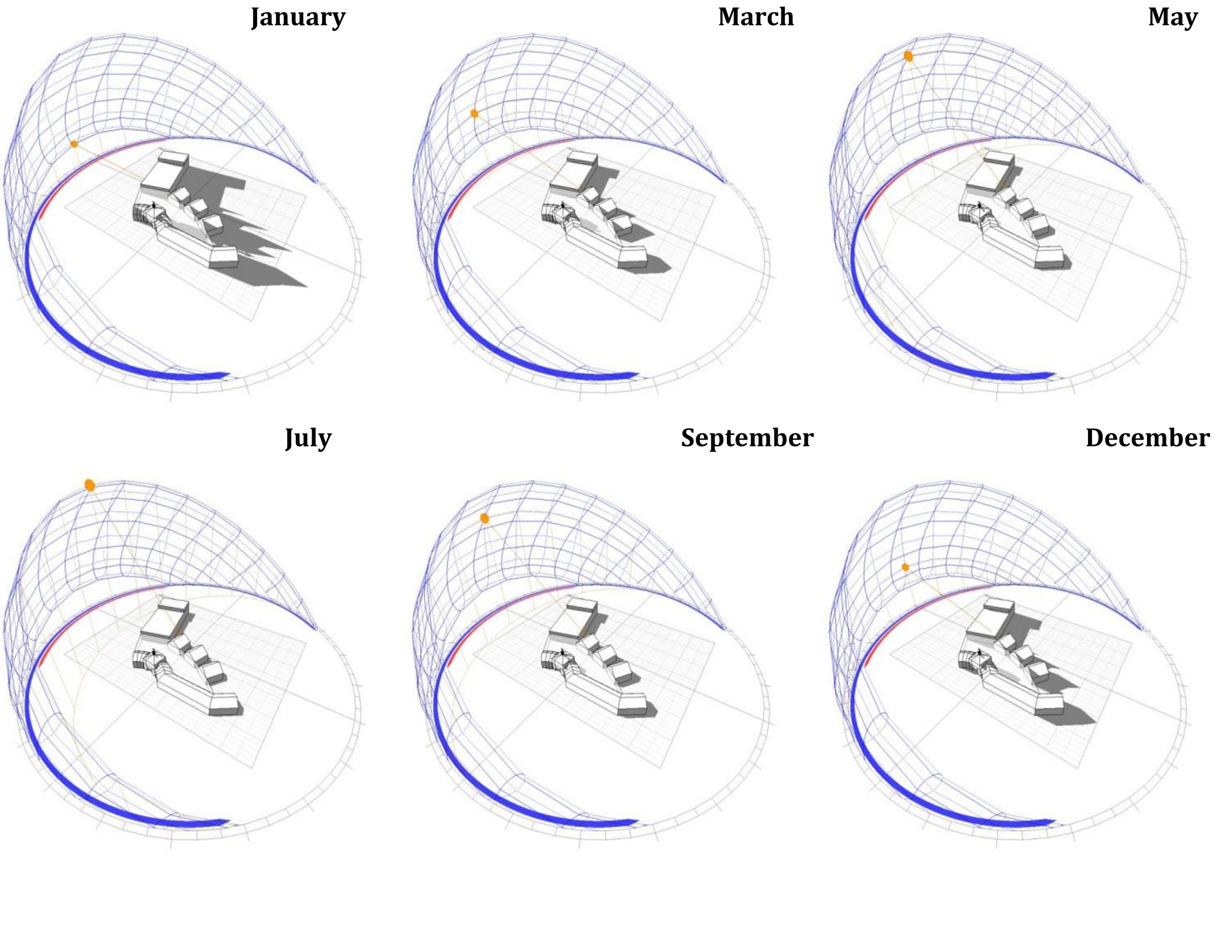


Figure 4.33. Annual shadows

4.4.2. Daylight analysis

For analyzing daylight quality in the room daylight factor (*DF*) approach was used. Daylight factor describes the ratio of outside illuminance over inside illuminance, expressed in per cent. The higher the DF, the more natural light is available in the room. [65]

$DF = 100 * E_{in} / E_{Ex}$

where:

E_{in} is inside illuminance at fixed point

E_{ex} is outside horizontal illuminance under an overcast (CIE sky) or uniform sky

The E_{in} illuminance can be considered as the sum of three different illuminances:

- the direct illuminance if the sky is visible from considered point (E_D)
- the illuminance due to the reflections on the outside environment (E_{ER})
- the illuminance due to the reflections on the inside surfaces (E_{IR})

Hence, the daylight factor can be expressed as the sum of three components:

$DF = DC + ERC + IRC$

where:

DC is direct component

ERC is externally reflected component[66]

IRC is internally reflected component

Table 4.13. Daylight factor

DF	Apperance	Energy implications
< 2 %	Room looks gloomy	Electric lighting needs most of the day.
2 to 5 %	Predominantly daylight appearance, but supplementary artificial lighting is needed.	Good balance between lighting and thermal aspects
> 5 %	Room appears strongly daylight.	Daytime electric lighting rarely needed, but potential thermal problems

65 M.Hegger, M.Fuchs, T.Stark, M.Zeumer, Energy manual, Birkhäuser – Munich: Detail, 2008. p.102
66 http://www.new-learn.info – article «Daylight»

For determining suitable size of windows in museum exposition rooms it is necessary to determine daylight factor for this rooms with different size of windows and to compare the results.

As the quantity of daylight in exposition rooms should be limited for better conservation of the exhibits, big size of windows should be avoided. For analysis medium and little size of windows were chosen.

The first variant is with medium windows *1,2 x 1,8 m*. Daylight level of the majority part of the Room 1 is *near 90 lux* (DF *near 1%*). It is acceptable for all the exhibits, except the ones with high sensitivity to light (< *50 lux*), but the room looks gloomy. Additional electric lighting can be necessary. Daylight level of the Room 2 is *near 290 lux* (DF *near 3%*) in the zone close to the walls, what is acceptable only for the exhibits with low sensitivity to light, and *near 490 lux* (DF *near 5%*) in the zone close to the windows, what is not acceptable for the exhibits and can cause overheating. Daylight level of the Room 3 is *near 90 lux* (DF *near 1%*) in the zone close to the walls, what is acceptable for almost all the exhibits, and *near 290 lux* (DF *near 3%*) in the zone close to the windows, what is acceptable only for the exhibits with low sensitivity to light.

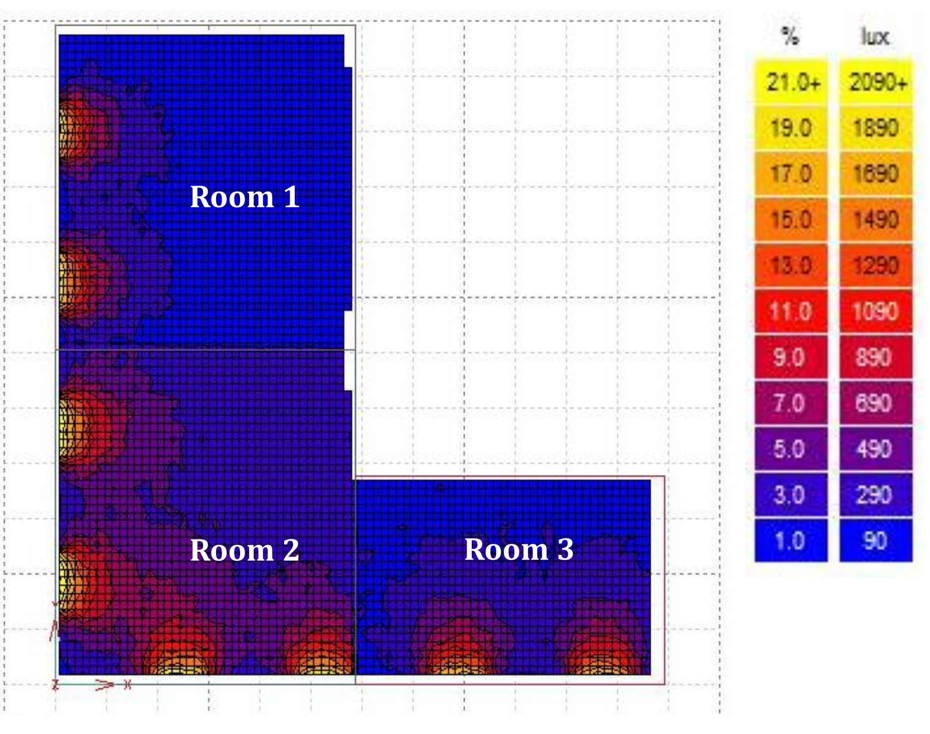


Figure 4.34. Daylight analysis. Variant I

The second variant is with small windows *1,2 x 1,2 m*. Daylight level of the majority part of the Room 1 is *near 54 lux* (DF *near 0,6%*). It is acceptable for all the exhibits, even for the ones with high sensitivity to light, but the room looks too gloomy. Additional electric lighting is necessary all the day. Daylight level of the Room 2 is *near* 124 *lux* (DF *near 1,6%*) in the zone close to the walls, what is acceptable for all the exhibits except the ones with low sensitivity to light, and *near 194 lux* (DF *near 2,6%*) in the zone close to the windows, what is acceptable only for the exhibits with low sensitivity to light. Daylight level of majority part of the Room 3 is *near 124 lux* (DF *near 1,6%*), what is acceptable for almost all the exhibits except the ones with high sensitivity to light, but the room looks gloomy. Additional electric lighting can be necessary.

As two rooms in the second variant look gloomy and require additional electric lighting, the first variant with medium windows was chosen. For solving the problem with excessive lighting in the Room 2 as well as for giving possibility to change daylight level and to place exhibits with any sensibility to light in any room shading system should be applied.

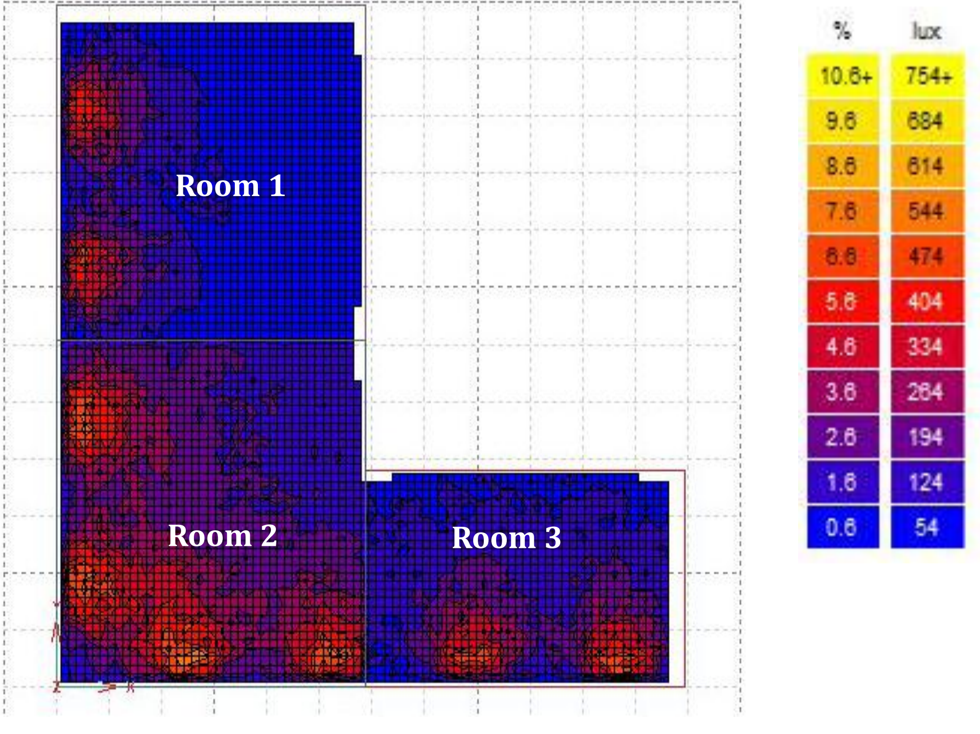


Figure 4.35. Daylight analysis. Variant II

Daylight analysis was used for determining the suitable size of windows in the museum exposition rooms of the attic floor. Three variants were analyzed: without roof windows, with small and medium roof windows.

The first variant is without roof windows. Daylight level of the majority part of the rooms is *near 34 lux* (DF *near 0,4%*). It is acceptable for all the exhibits, but the rooms are too gloomy. Electric light will be needed most of the time during the day.

The second variant is with small windows *1,2 x 1,2 m*. Daylight level of the rooms is *near 99 lux* (DF *near 1,2%*) in the zone close to the walls, what is acceptable for almost all the exhibits except the ones with high sensibility to light, and *near 329 lux* (DF *near 3,2%*) in the zone close to the windows, what is not acceptable for the exhibits.

The third variant is with medium windows *1,8 x 1,2 m*. Daylight level of the rooms is *near 140 lux* (DF *near 1,5%*) in the zone close to the walls, what is acceptable for almost all the exhibits except the ones with high sensibility to light, and *near 450 lux* (DF *near 5,5%*) in the zone close to the windows, what is not acceptable for the exhibits and can cause overheating.

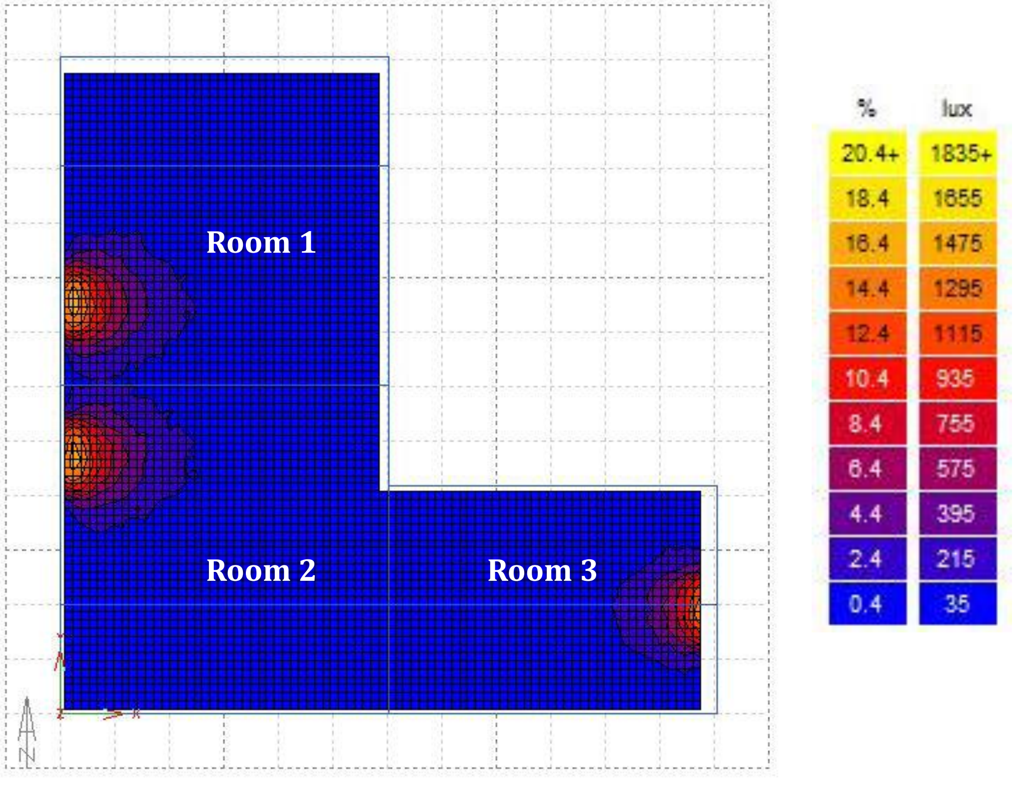


Figure 4.36. Daylight analysis. Attic floor. Variant I

As rooms in the first variant look too gloomy and require additional electric lighting while excessive light in the third variant can cause overheating, the second variant with small roof windows was chosen. For solving the problem with excessive lighting and for changing of daylight level shading system should be applied.

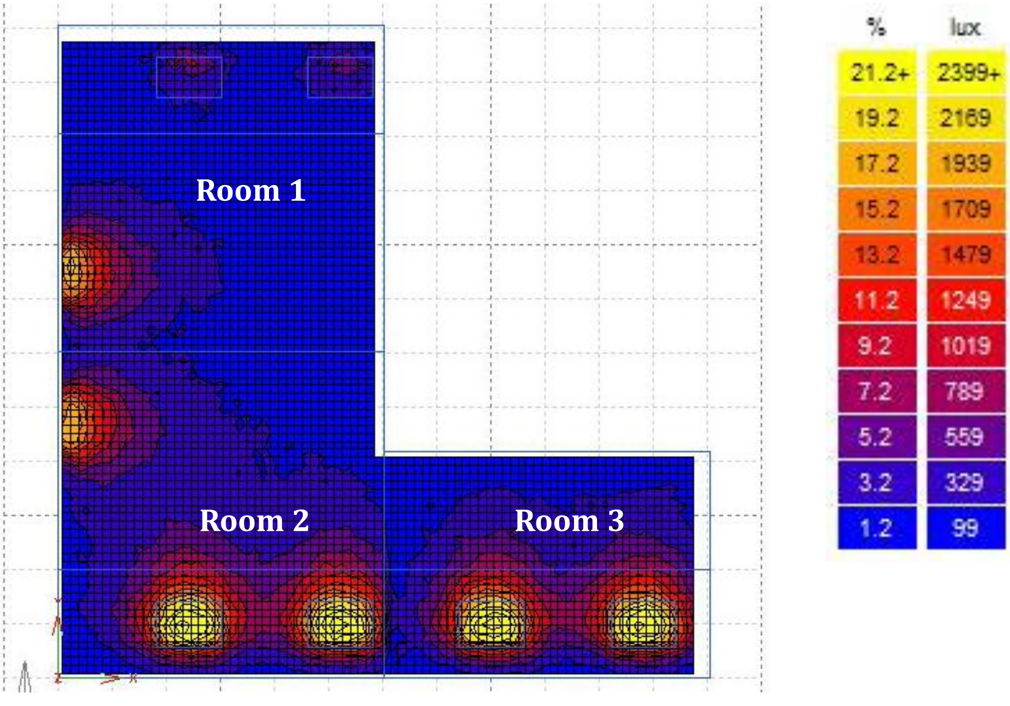


Figure 4.37. Daylight analysis. Attic floor. Variant II

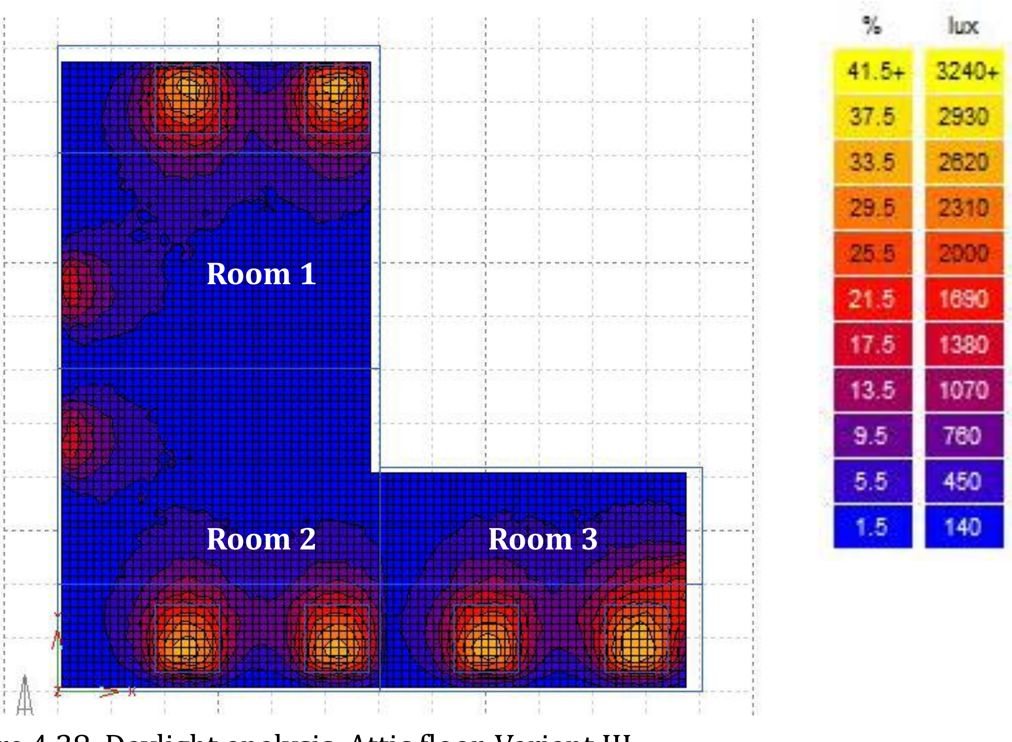


Figure 4.38. Daylight analysis. Attic floor. Variant III

4.4.3. Shading systems

Shading system is effective measure for control of access of natural light in the room. Among different types of shadow systems timber shutters were chosen.

Advantages of this shadow system:

- Natural material
- Possibility to close only part of the window
- Possibility of regulation of natural light access by rotating the plates
- Possibility of avoiding of natural light access

Timber shutters is made of timber plates with width 5 cm. Different types of timber can be used. Special three-layer protective coating prolongs the life of the shutters.

Timber shutters give the possibility to place any exhibit in the room. As the shutters are movable, the size of windows can be decrease according to the requirements for exhibits, placing in the room. Changing of the angle of inclination of the plates allows to avoid falling of direct sun light on the exhibits and to provide diffuse lighting in the room.

Analysis of Room 2 with closing of western / southern window or changing the height of the windows shows significant decrease of daylight level in the room.

Timber shutters can be also used for roof windows with incline up to 45°.[67]

Figure 4.39. Timber shutters

Figure 4.40. Timber shutters

[67] http://www.zazuzy.ru

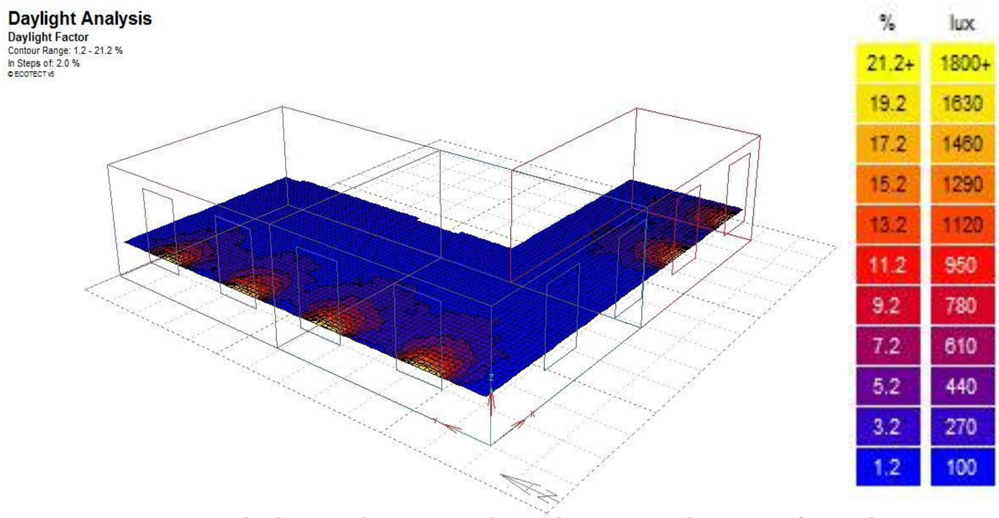


Figure 4.41. Daylight analysis. Timber shutters. Closing of southern windows

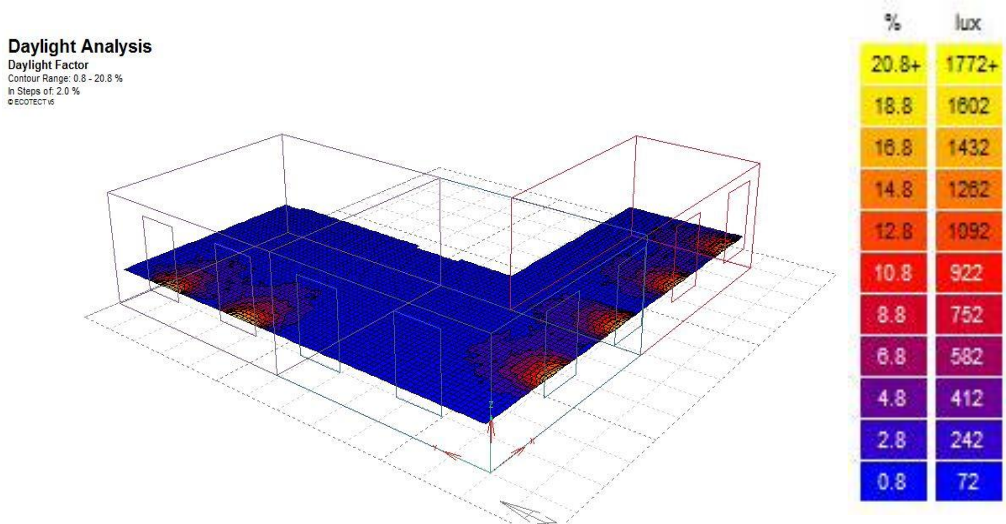


Figure 4.42. Daylight analysis. Timber shutters. Closing of western windows

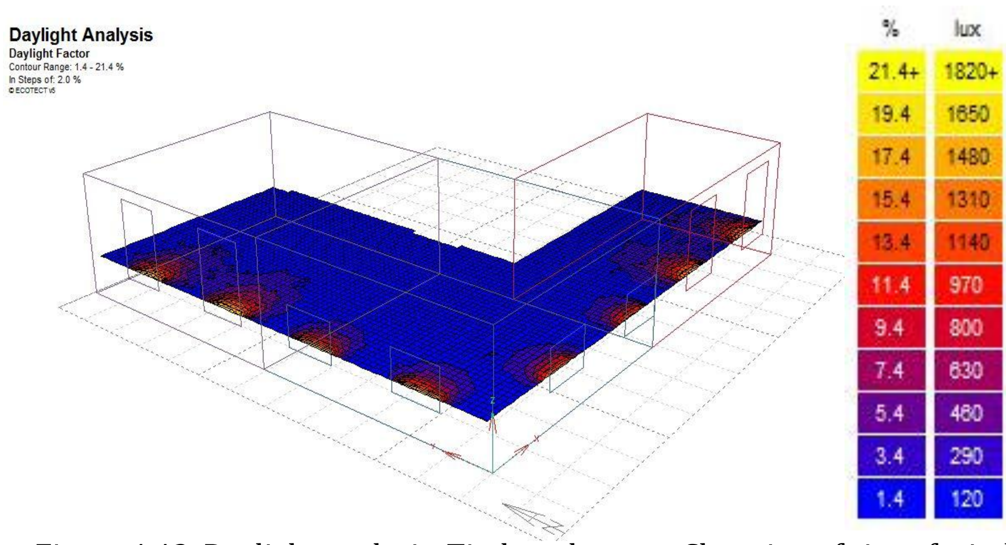


Figure 4.43. Daylight analysis. Timber shutters. Changing of size of windows

4.5. BUILDING SERVICE SYSTEMS

4.5.1. Geothermal heating and cooling system

The earth is a huge solar energy device that absorbs 48% of the sun's energy. Underground temperatures remain virtually the same year round. Geothermal system takes advantage of the heat stored in the earth in the winter and the relative cool in the summer.

In the winter, the fluid circulating through the loop system absorbs the earth's heat and carries it to the home. In the summer, the system reverses and exchanges the heat from the home to the relative cool of the earth.

Geothermal systems, also known as Geoexchange and Ground source heat pumps (GSHP), circulate water through pipes buried in the ground to extract the diffuse low temperature resource which is available everywhere. The temperature of the water in the pipes is lower than the surrounding ground and so it warms up slightly. The returning water is chilled back down by a heat pump, where it is used to heat up a refrigerant. By compressing this 'warmed' refrigerant the temperature is further increased before being transferred to the building heating system. The heating water output from the heat pump is typically 45ºC - 55ºC. This process can be reversed, using the ground as a heat sink, to provide cooling water for the building.[68]

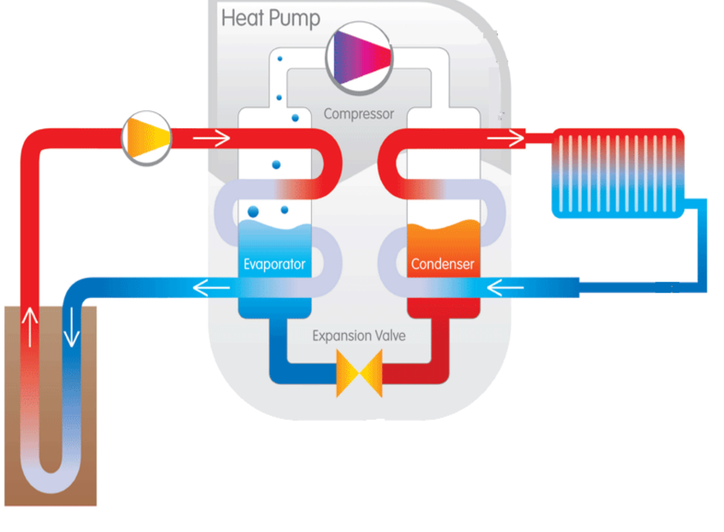


Figure 4.44. Geothermal system

[68] http://www.mvgeothermal.com

Between different types of system the one with closed vertical loops was chosen for the building, because the climate of Kalininskij region is quite cold and it is necessary to put the pipes deeply to the ground to get required temperature of the fluid. Geothermal systems are suitable for almost any new building and are compatible with underfloor heating, radiators, fan coils, ducted air, chilled beams and distributed water to air heat pumps.

Benefits of Geothermal systems:

- lowest life-cycle cost
- nearly silent while operating
- no delivery of fuel/gas
- no outside equipment (A/C)
- virtually maintenance free [69]

Figure 4.45. Heat pump

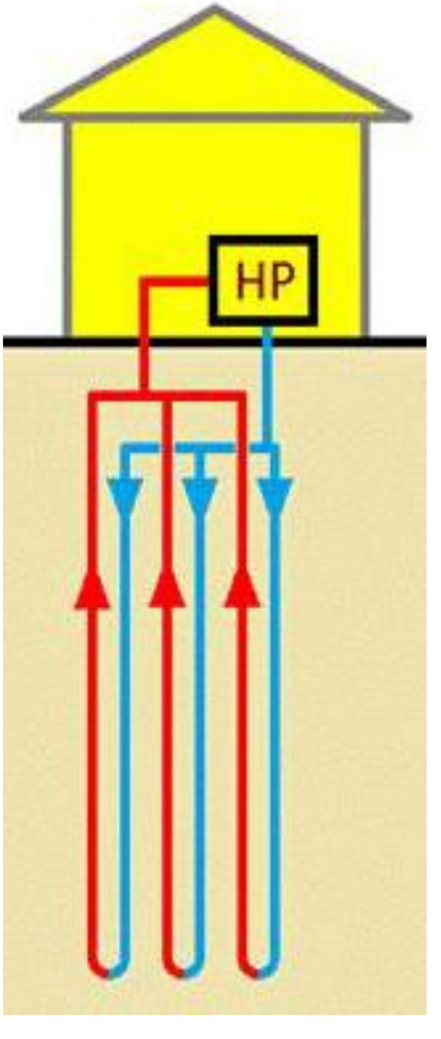


Figure 4.46. Geothermal system with vertical loops

[69] http://www.mvgeothermal.com

4.5.2. Hydronic radiant floor heating and cooling

Indoor environmental quality is a very important goal in the project of museum not only because unfavorable conditions influence on visitors and museum workers, but also because conservation of exhibits requires maintaining of temperature and humidity on determined level.

Hydronic radiant floor heating gives possibility to maintain necessary temperature during winter. Radiant floor is a complete heating system, an alternative to the classical system of heating. Hydronic radiant floor is pipes, by which heat transfer agent – water – passes. Between the floor and floor covering network of winding mini-pipelines is installed. In these pipes water with the temperature necessary to create comfort conditions is supplied. Water heated by ground source heat pump is uniformly distributed in the pipes, providing a stable and steady heat to all surface of the floor.[70]

Advantages:

- **Energy-efficiency**
  - High productivity with low temperature of heat transfer agent
  - There is no convective flow of warm air up, that's why roof, windows and external walls do not overheat. It gives possibility to place exhibits on or close to external wall.
- **Comfort**
  - Regulation of temperature in each room gives possibility to maintain required temperature for different groups of exhibits.
  - Uniform distribution of heat
- **Safety**
  - Absence of open surfaces with high temperature
  - All items of the system are hidden from direct access, which significantly reduces the risk of accidental damage of the system.
  - The number of connections is 2-3 times lower than the one of the radiator heating system. It reduces the risk of leakage.[71]

Between different constructive systems, **light polystyrene system** was chosen for the building.

[70] http://www.eco-h.ru
[71] http://www.greenwoodhouse.ru – article «Radiant floor»

Advantages of light systems:

- Smaller weight compared to concrete system allows to apply water floor heating in the buildings where the loads on the floors and walls are limited, for example, on the second floor of the wooden house.
- Absence of "wet process" allows to start and to operate the system after installation.
- Smaller thickness (minimum thickness of light system is 18 mm, the one of concrete system is 80 mm)
- Because of lower inertness the system responds on the change of settings more quickly.[72]

1. Floor covering
2. Waterproofing gypsum sheet
3. Pipe (diameter 17 mm)
4. Aluminium plate with slot
5. Polystyrene
6. Polyethylene film
7. Separating tape

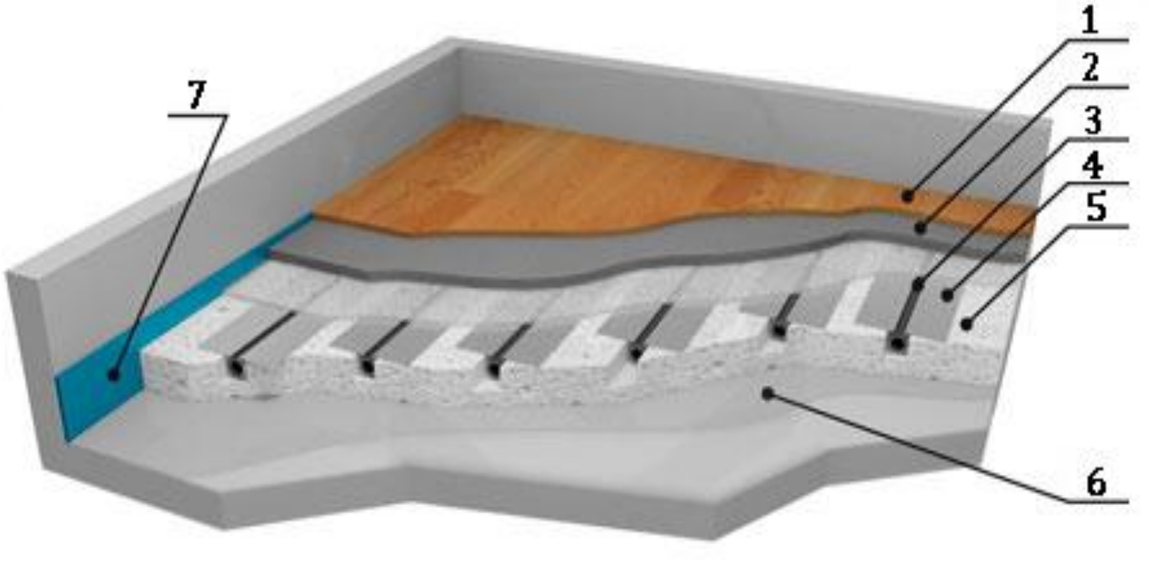


Figure 4.47. Hydronic radiant floor heating and cooling

[72] http://www.eco-h.ru

4.5.3. Ventilation system

Ventilation system plays a very important role in providing of indoor environmental quality. Conservation of exhibits requires to take more attention on the quality of air in exhibition halls and storerooms. During all the year temperature 18 - 22°C and humidity 55% +/- 5[73] should be maintained. Constant air change is necessary. The air should be cleaned from dust, soot and other contaminations. Because of this strict requirements natural ventilation cannot be used for ventilation of exhibition halls and storerooms. In this case mechanical ventilation system is necessary solution.

For choosing the type of mechanical ventilation system, which is suitable for the building, it is necessary to calculate air flow rate. Ventilation rate for exhibition rooms should be *6 air changes/h*. Ventilation rate for exhibits storerooms and sanitary rooms should be *2 air changes/h*.

$Q = N * V$

where:

Q is air flow rate

N is ventilation rate

V is volume of the room

Ground floor:

$Q_{gr} = 2 * 286{,}96 = 573{,}92\ m^3/h$

First floor:

$Q_1 = 6 * 270{,}53 + 2 * 16{,}42 =$

$= 1656{,}02\ m^3/h$

Second floor:

$Q_2 = 6 * 234{,}35 + 2 * 16{,}42 =$

$= 1438{,}94\ m^3/h$

$Q = 573{,}92 + 1656{,}02 + 1438{,}94 =$

$= 3668{,}88\ m^3/h$

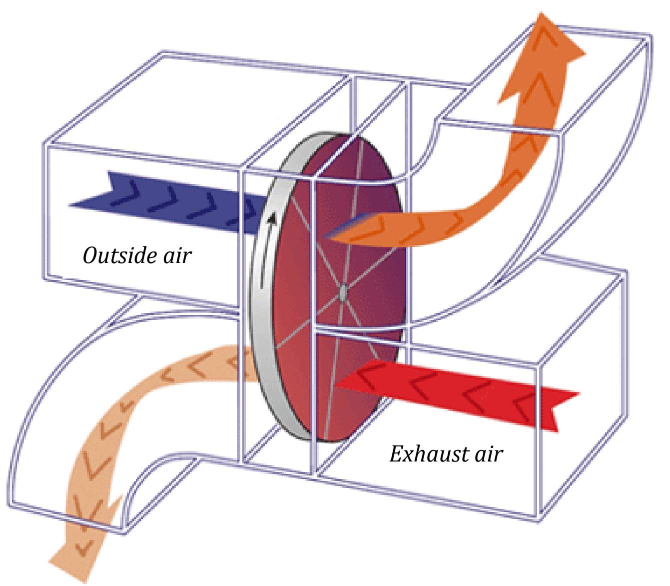


Figure 4.48. Rotary heat exchanger

Because of high air flow rate, centralized mechanical ventilation system was chosen. Ventilation heat losses represent a significant item in the energy balance of a building. Energy-efficient ventilation demands a controlled supply and extracts system with integral heat exchanger. With degrees of efficiency exceeding 90%, the ventilation heat losses can be almost avoided.

73 Recomendatins for design of museums, CNIIEP of B.S.Mezencev – Moscow: Stroyizdat, 1988

Jet Air Storm

Jet Air Storm is plant for ventilation and air-conditioning of company «General climate» with multimodule construction, intended for work inside the rooms. It has 12 dimension types. Its air flow rate is from *1000* m^3/h to *100000* m^3/h.

Its main functions:

- Supplying and removing of the air
- Cleaning of the air
- Heating and cooling of the air
- Hudification and dehumidification

Figure 4.49. Jet Air Storm

The main functional elements:

- **Air valve**

Air valve is used for controlling of the flow of supply air and regulating of mixing of two flows in recirculation.

- **Cartridge filter**
- **Water heater**

Water heater is used for heating of supply air, preheating of the air before and after humidification, before and after recirculation and for heating of the air after drying.

- **Water cooler**

Water cooler is used for cooling of supply air and dehumidification in summer period.

- **Water humidifier**

Water humidifier is used for regulating of relative humidity of supply air.

- **Rotary heat exchanger**

Rotary heat exchanger is used as a tool, giving the possibility to use the air which is removing from the room as secondary energy resource with the aim of economy of heat and cold. As heat exchanger rotating round heat exchangers are used. Working temperature is from -40°C to +40°C. Heat exchanger efficiency depends on temperature difference between the flows and reaches 85%.

- **Fan**
- **Noise silencer**

Noise silencer is used for reducing of noise from the fan.[74]

[74] http://www.generalclimate.ru

4.5.4. Rainharvesting systems

Reducing water consumption and protecting water quality is one of the goals of sustainable design. To ensure availability for future generations, the withdrawal of fresh water from an ecosystem should not exceed its natural replacement rate. Besides, water pumping, delivery, and wastewater treatment facilities consume a significant amount of energy. Rainwater harvesting is one of solution for reduction of withdrawal of fresh water from an ecosystem.

Rainwater harvesting is the practice of collecting rain water run-off from the roof of one or more buildings and then storing is for re-use as and when is required. By filtering during the collecting process, any debris is removed prior to storage, resulting in clean, clear water suitable for a variety of non-potable uses. Harvested rainwater can be used in place of mains water for such purposes as toilet flushing, irrigation, laundry use, process water, etc. This reduces water supply costs.

By reducing stormwater run-off, rainwater harvesting can be a component of sustainable drainage scheme, giving further environmental benefit by reducing the risk of flooding.

The systems are designed to provide clean rainwater with the minimum of maintenance. They involve a multi-stage cleaning process.

The quality of rainwater collected using this process is greatly removed and can be stored for long periods without becoming stale. Systems are fully automatic and only activate when water is needed. The system reverts to mains water when there is insufficient rainwater in the collection tank.

Rainwater harvesting was chosen for the project, because the quantity of precipitation in Kalininskij region is quite big. Maximum annual precipitation is *885 mm*. The system gives the possibility to use this water.

Among different types of rainharvesting systems **commercial systems** was chosen for the building because of large size of the building, large area of roofs and large demand of water required.

Commercial systems are usually larger, more sophisticated versions of those used for domestic situations. Components will be larger, sized on supply and demand of water required and a facility to monitor mains and rain water can be included.[75]

[75] http://www.rainharvesting.co.uk

There are different types of commercial systems. In the case the best choice is **direct system**, because in the building there is no possibility to incorporate a header tank internally. The system can be used for all the parts of the building, except auditorium with green roof, because green roofs tend to give low yield due to high absorbency and resulting water is often discoloured.[76]

1. Wisy WFF vortex filter
2. Calmed inlet
3. Dual submersible pipes
4. Floating suction filters
5. Control unit
6a. Solenoid valve
6b. Main demand float switch
6c. Type AA air gap
7. Dry-run float switch
8. Expansion vessel
9. Pressure hoses
10. Drainage pipe
11. Overflow trap
12. Optional level gauge

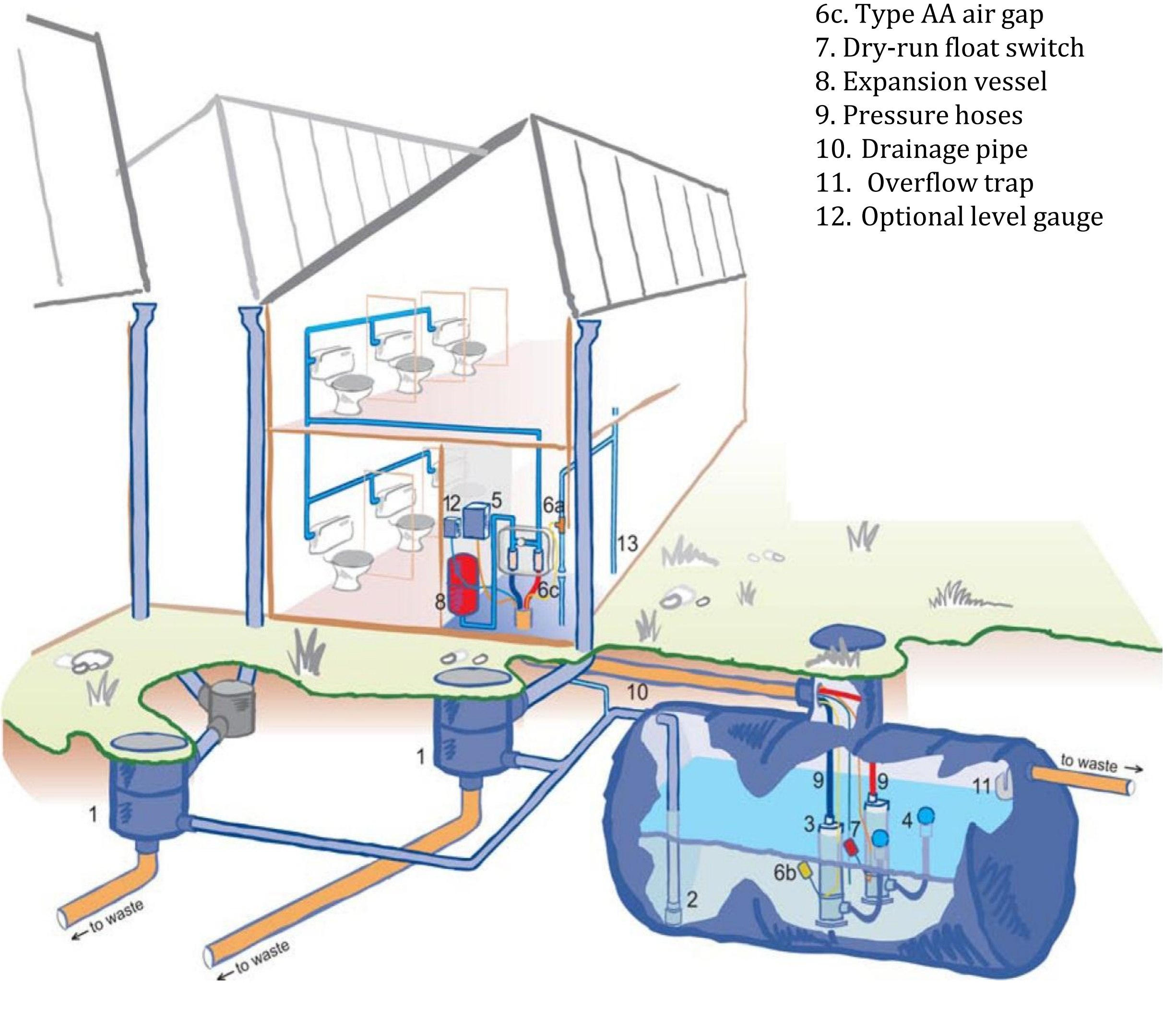


Figure 4.50. Rainharvesting system

[76] http://www.rainharvesting.co.uk

How Direct system works:

- Rainwater is collected from the roof drainage system by underground Wisy WFF voltex filter (1). This filter out the debris from the water and deverts about 90% of it into the storage tank. The remaining water goes to soakaway or storm drain in the user manner, as the excess water from the tank. As water enters the tank it passes through a calmed inlet (2), which smooths the flow of water and prevents disturbance of the float switch and any sediments.
- Water is then supplied on demand by the submersible pumps (3) through floating suction filters (4) to specific outlets, usually WCs, washing plants, etc. The pumps are controlled by a control unit (5), which turns the pumps on and off when required. The control unit comprises a switchboard and control panel, the panel can provide duty/assist and/or duty/standby and provides duty tank cycling and pump empty alarm. A float switch (7) provides dry-running protection, and an expansion vessel (8) prevents pump «hunting».
- Mains water top-up is provided by a solenoid valve (6a) controlled by a second float switch in the storage tank (6b). Water is discharged to the tank via a type AA air gap turnish (6c) compiant with current water regulations. This gravity feeds to the tank through 50 mm pipe that then connects with outlet pipe from the filter.
- Pressure hoses (9) and cables are ducted to the building through a 160 mm drainage pipe (10).
- An overflow tap (11) provides water seal against any foul odours from drains.
- An optional level gauge (12) gives visual indication of tank water level.[77]

[77] http://www.rainharvesting.co.uk

4.6. ELECTRICITY

Photovoltaic system

A photovoltaic (PV), or solar electric system, is made up of several photovoltaic solar cells. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. To boost the power output of PV cells, they are connected together to form larger units called modules. Modules, in turn, can be connected to form even larger units called arrays, which can be interconnected to produce more power, and so on. In this way, PV systems can be built to meet almost any electric power need, small or large. By themselves, modules or arrays do not represent an entire PV system. Systems also include structures that point them toward the sun and components that take the direct-current electricity produced by modules and "condition" that electricity, usually by converting it to alternate-current electricity. PV systems may also include batteries.

When light shines on a PV cell, it may be reflected, absorbed, or pass right through. But only the absorbed light generates electricity. The energy of the absorbed light is transferred to electrons in the atoms of the PV cell semiconductor material. With their newfound energy, these electrons escape from their normal positions in the atoms and become part of the electrical flow, or current, in an electrical circuit. A special electrical property of the PV cell—what is called a "built-in electric field"—provides the force, or voltage, needed to drive the current through an external load, such as a light bulb.[78]

Figure 4.51. Photovoltaic modules

Figure 4.52. Photovoltaic modules

[78] http://www.eere.energy.gov – article «Photovoltaic systems»

Components of PV system:

- Photovoltaic cell -- Thin squares, discs, or films of semiconductor material that generate voltage and current when exposed to sunlight.
- Module -- Photovoltaic cells wired together and laminated between a clear superstrate (glazing) and encapsulating substrate
- Array -- One or more modules with mounting hardware and wired together at specific voltage.
- Charge Controller -- Power-conditioning equipment to regulate battery voltage.
- Battery storage -- A medium that stores direct current (DC) electrical energy.
- Inverter -- An electrical device that changes direct current to alternating current (AC) to operate loads that require alternating current.
- DC Loads -- Appliances, motors and equipment powered by direct current.
- AC Loads --Appliances, motors and equipment powered by alternating current.

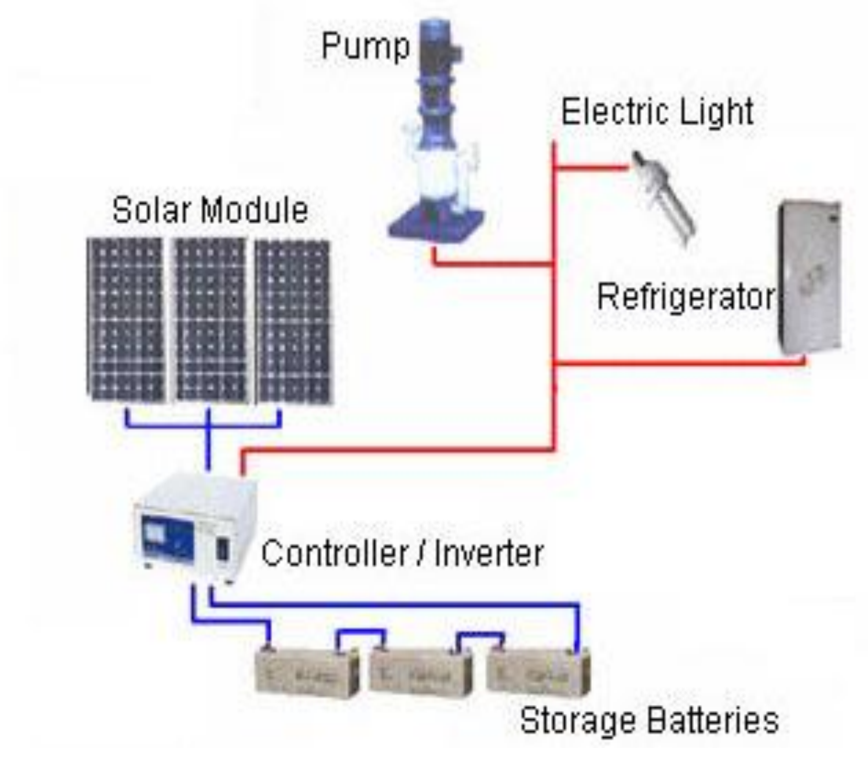
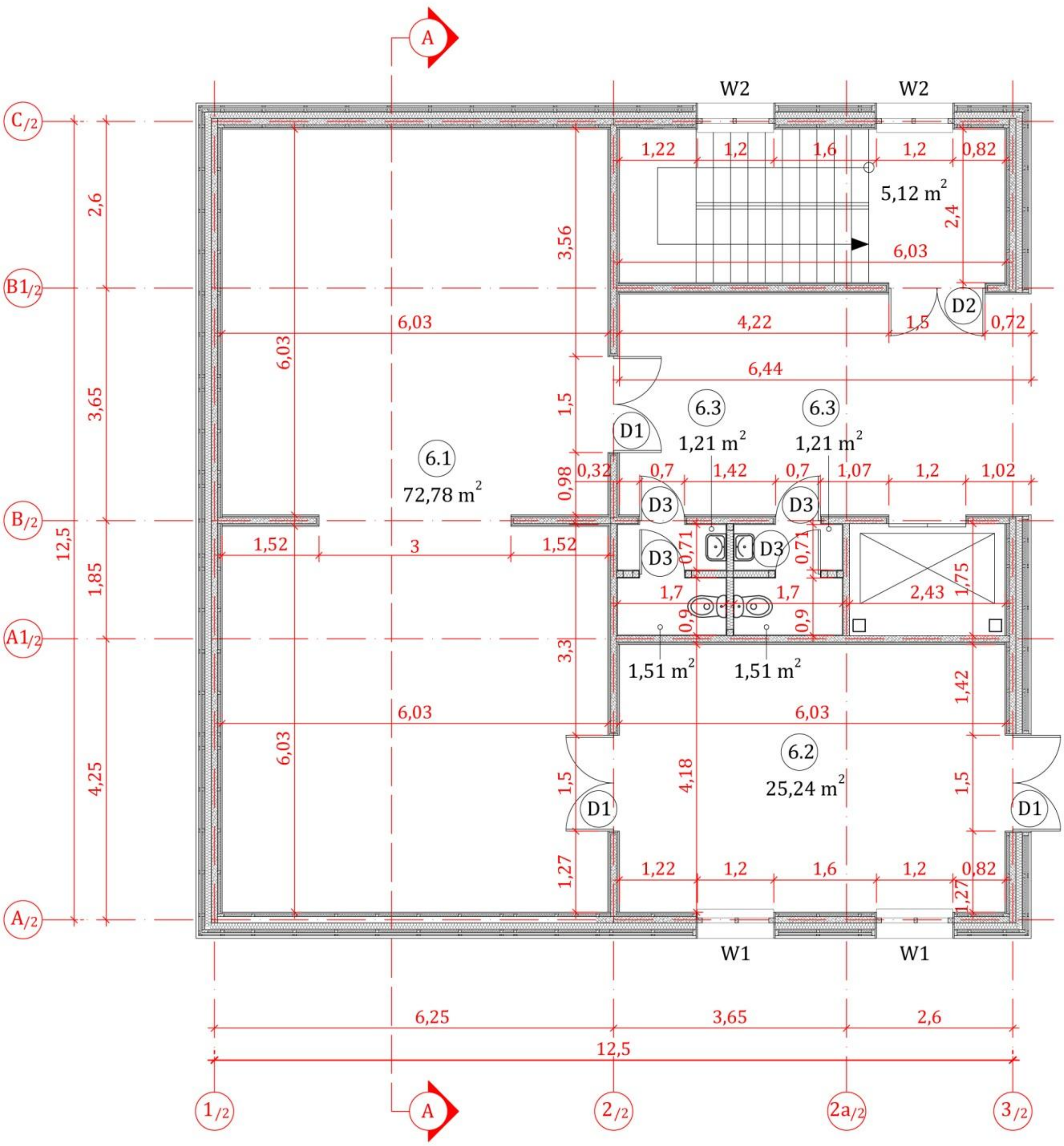


Figure 4.53. Photovoltaic electric system

4.7. TECHNOLOGICAL PLANS

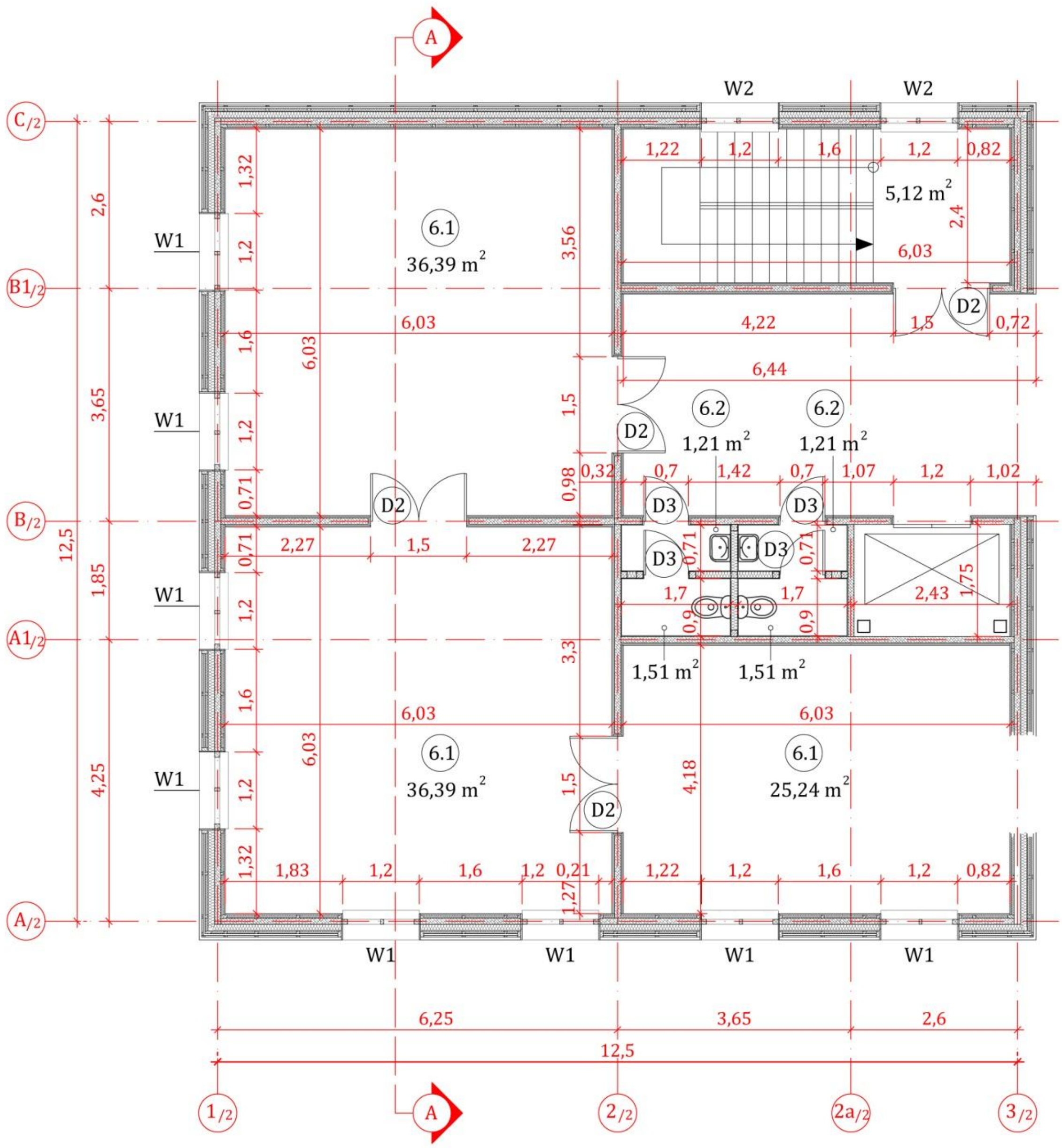
Figure 4.54. Ground floor plan. Scale 1:100



Explication of rooms

N	Description
6.1	Storeroom for exhibits
6.2	Restoration workshop
6.3	WC

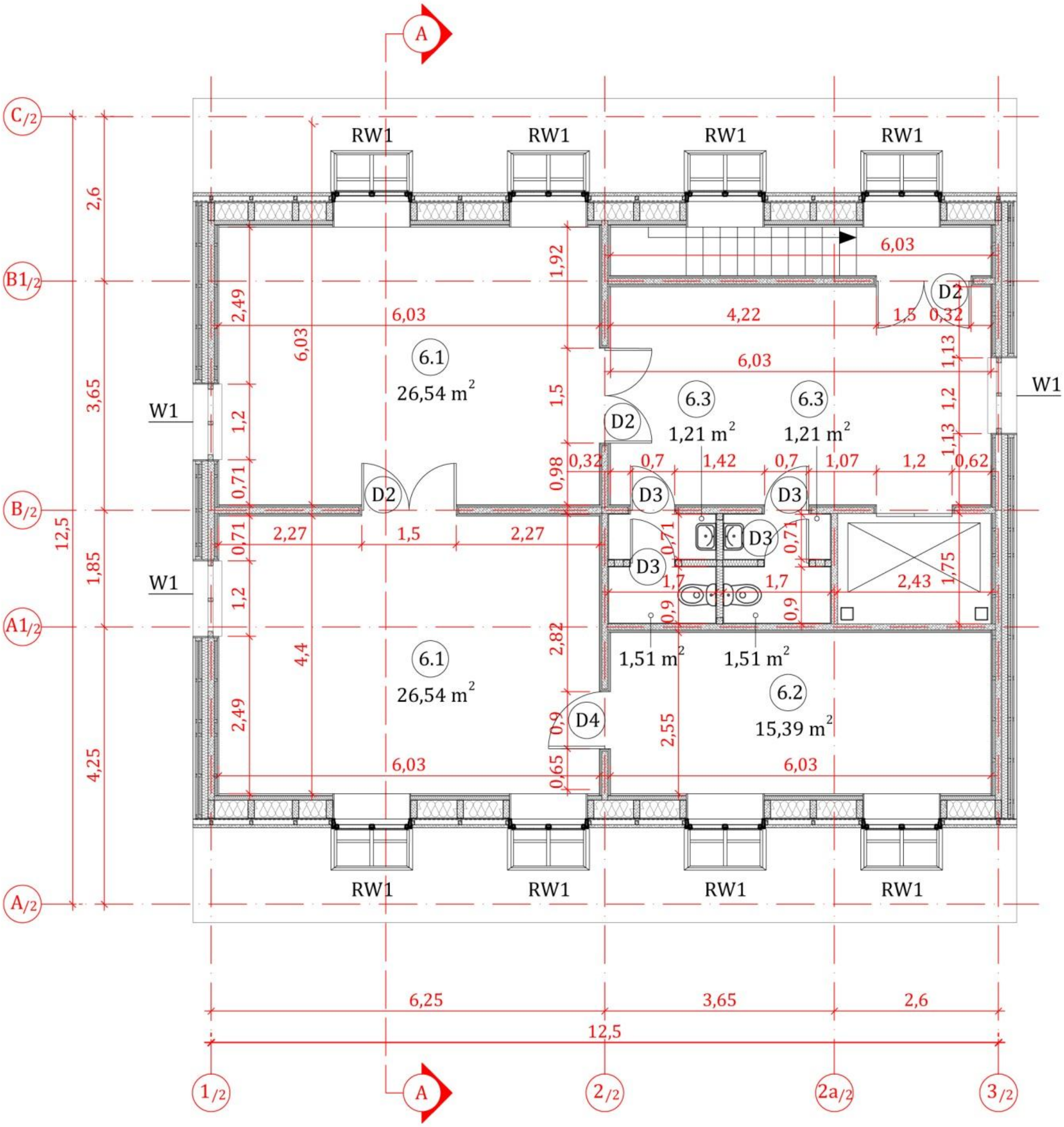
Figure 4.55. First floor plan. Scale 1:100



Explication of rooms

N	Description
6.1	Permanent exposition
6.2	WC

Figure 4.56. Second floor plan. Scale 1:100



Explication of rooms

N	Description
6.1	Permanent exposition
6.2	Staff’s rest room
6.3	WC

Table 4.14. Window specification

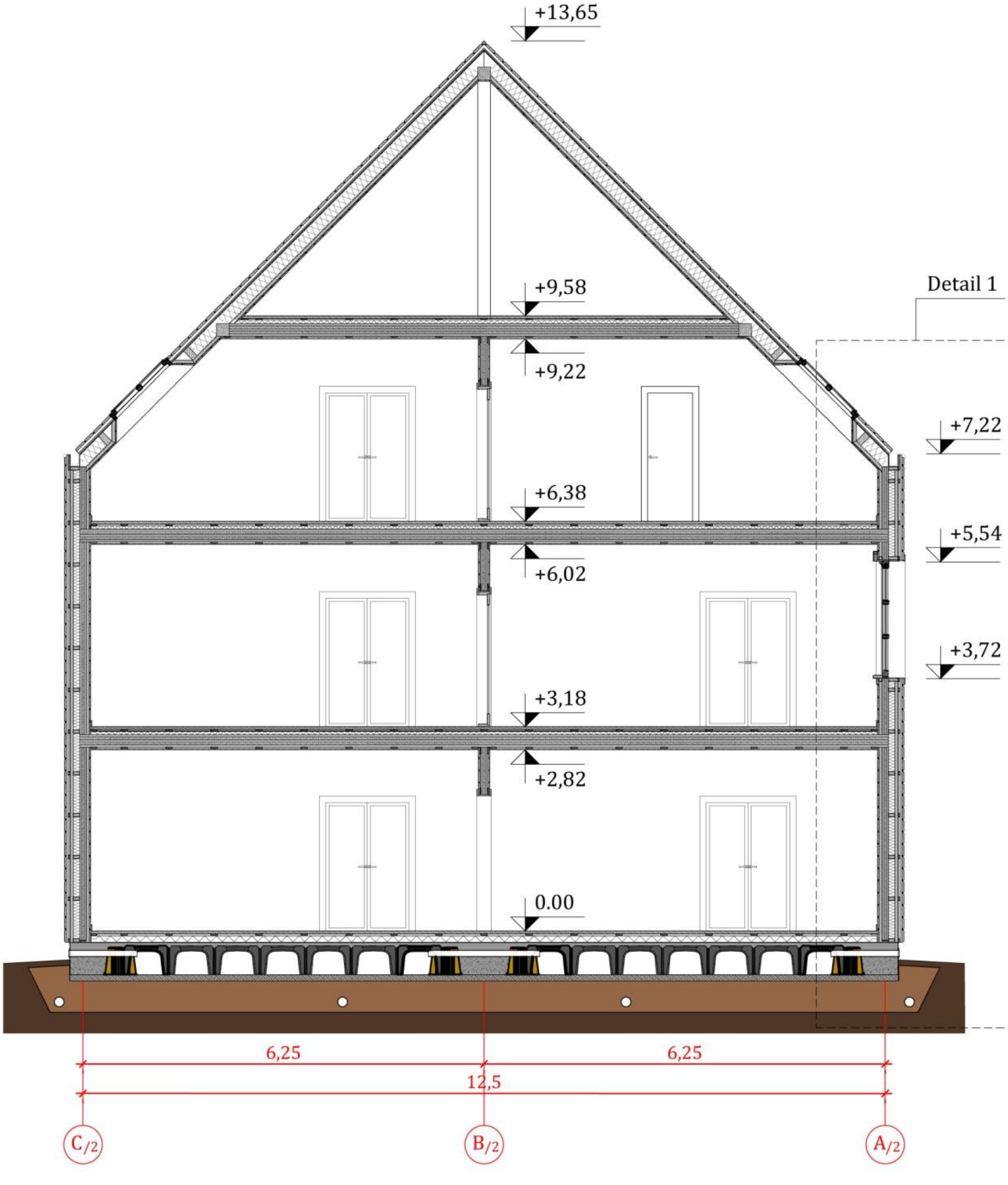
	Size m	Material	Ground floor	1 floor	2 floor	Total
W1	1,2 x 1,8	Timber + Alumimium	2	8	3	13
W2	1,2 x 1,2	Timber + Alumimium	2	1	-	3
RW1	1,2 x 1,2	Timber + Alumimium	-	-	8	8

Table 4.15. Door specification

	Size m	Material	Ground floor	1 floor	2 floor	Total
D1	1,5 x 2,1	Timber	3	-	-	3
D2	1,5 x 2,1	Timber + Glass	1	5	3	9
D3	0,8 x 2,1	Timber	2	2	2	3
D4	0,9 x 2,1	Timber	-	-	1	1

4.8. TECHNOLOGICAL SECTION

Figure 4.57. Section A – A. Scale 1:100



4.9. TECHNOLOGICAL DETAILS

Figure 4.58. Detail 1

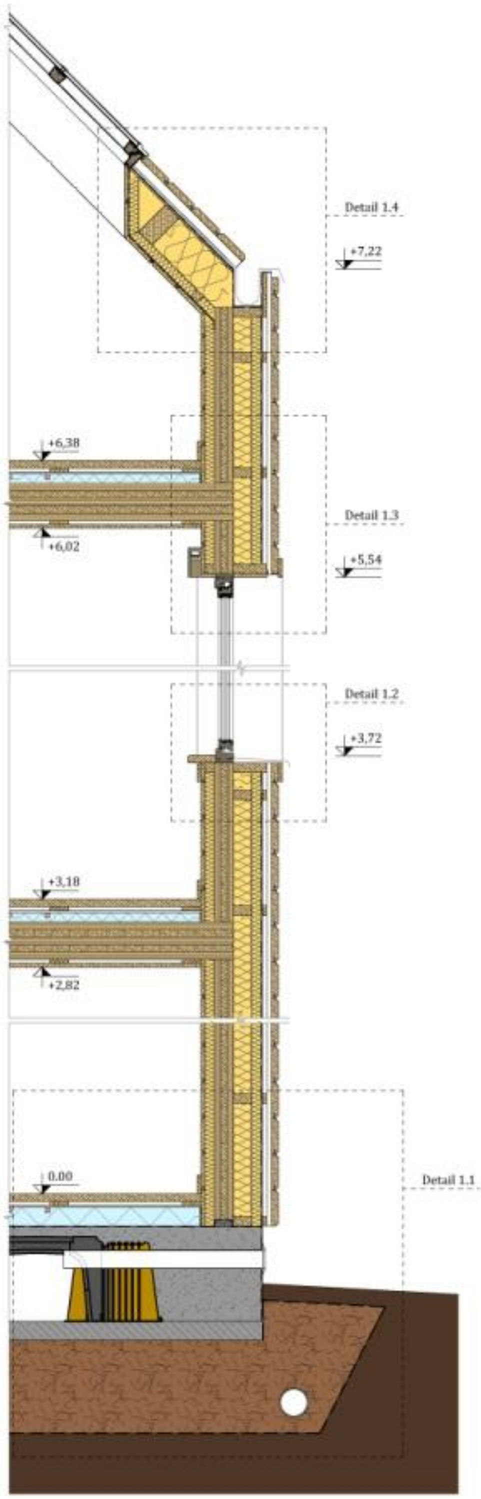
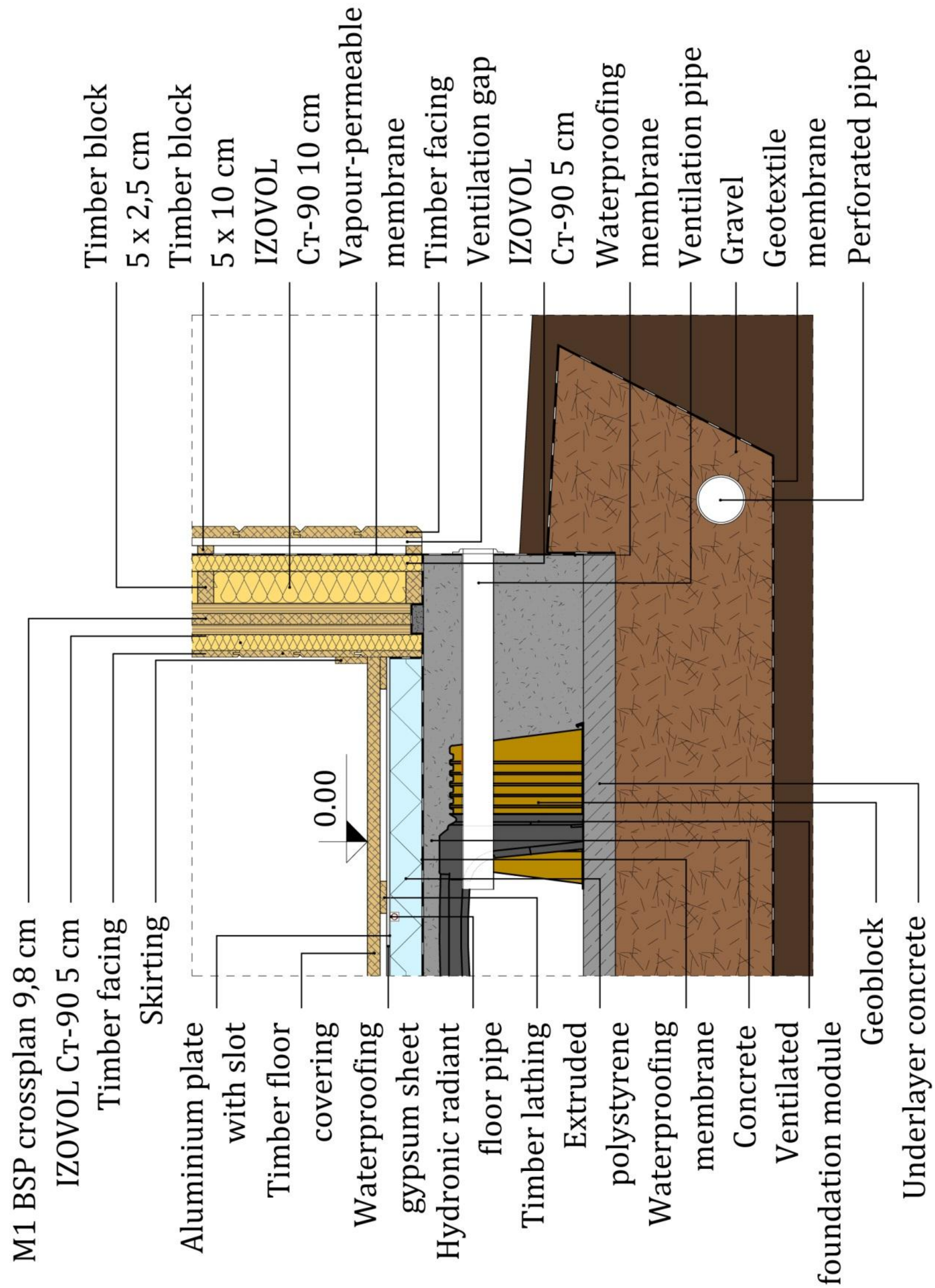


Figure 4.59. Detail 1.1. 1:20



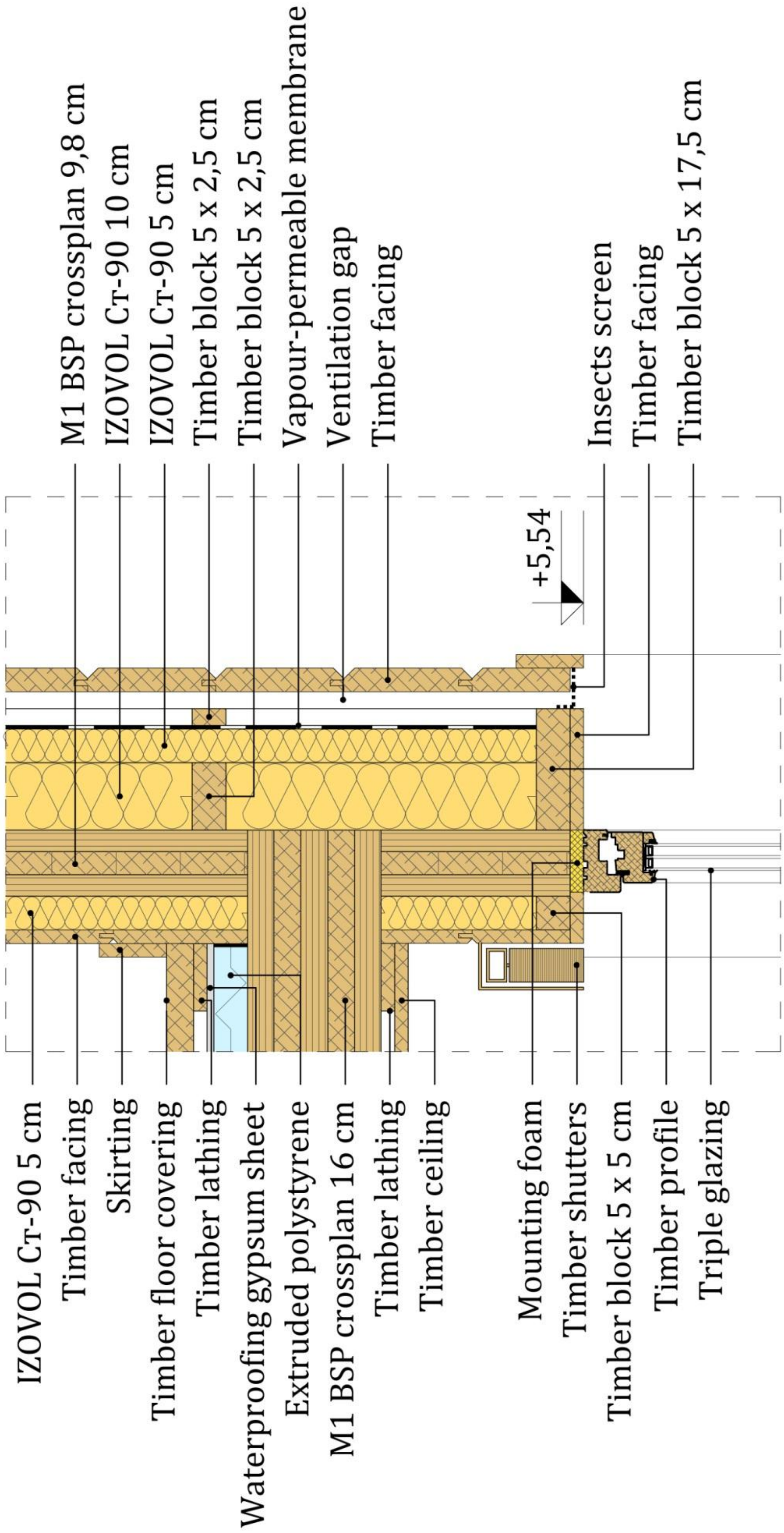


Figure 4.60. Detail 1.2. 1:10

Figure 4.61. Detail 1.3. 1:10

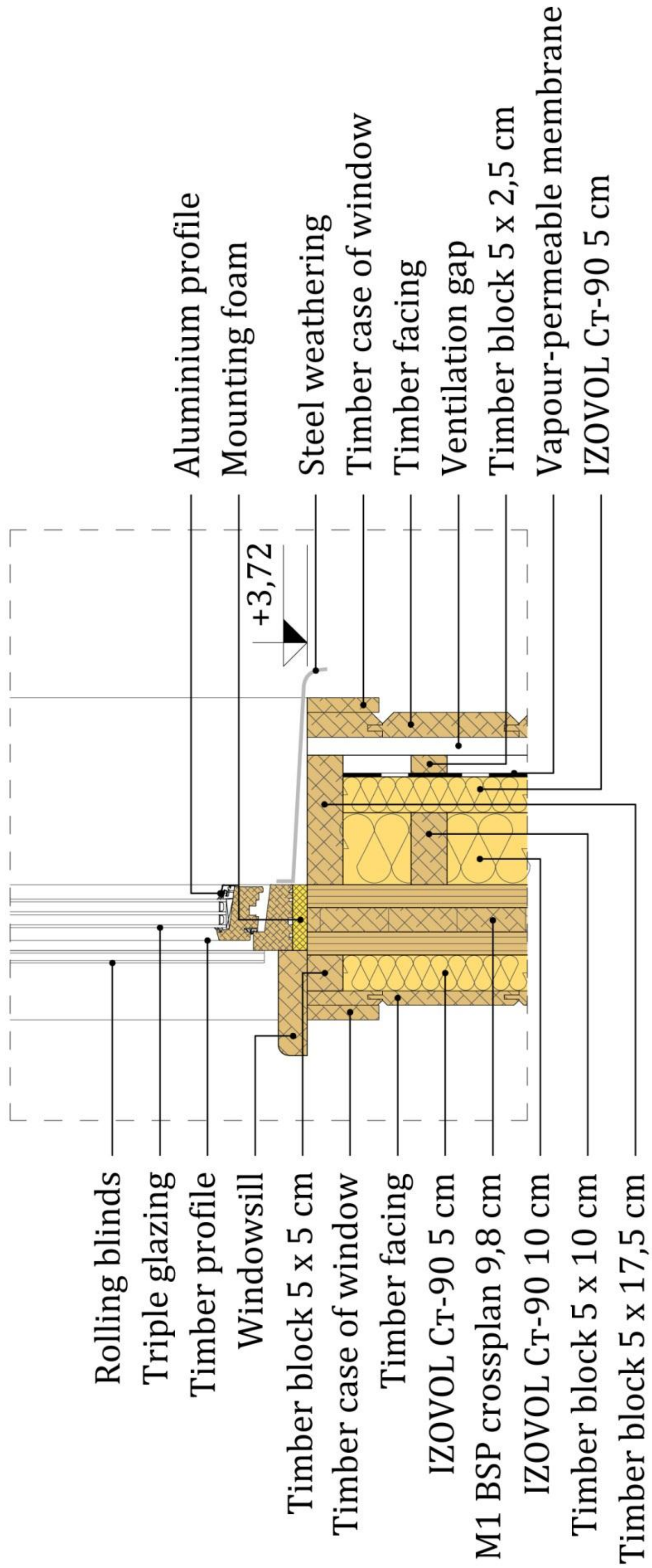
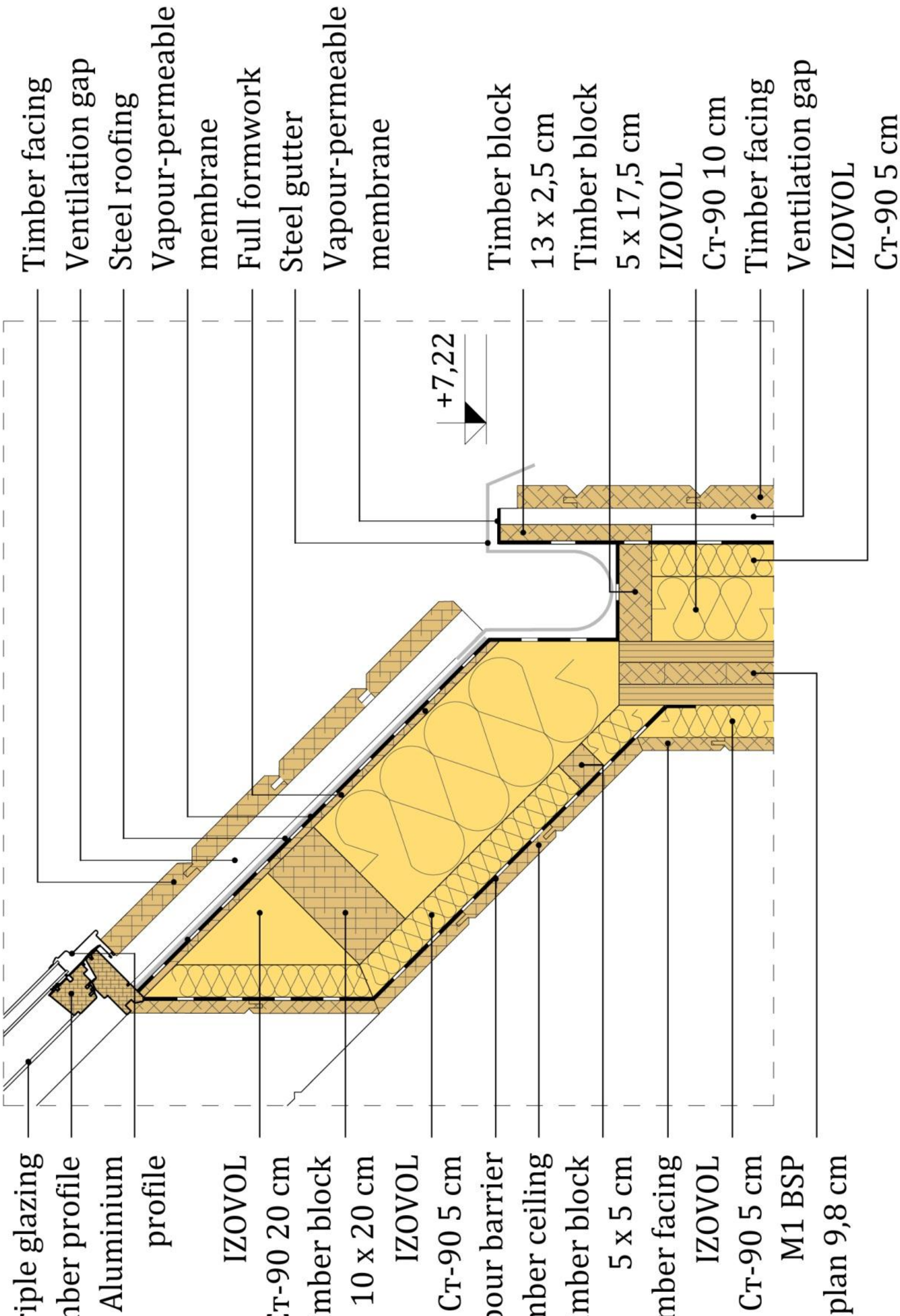


Figure 4.62. Detail 1.4. 1:10



CHAPTER 5. STRUCTURAL DEISGN

5.1. MATERIAL PROPERTIES

For the structure of museum cross-laminated timber system was chosen.

Cross-laminated timber is an industrially prefabricated timber panel of superior strength. Each panel is made up of layers of timber; 3-5 board layers are used for walls while 5-board layers are used for floors. Its structural performance is comparable with pre-cast concrete.

Advantages:

- Excellent strength and stiffness to weight ratio
- It can be produced in any length and size
- Very good load distribution properties in both directions
- As it is a dry building system, it does not use concrete or masonry, it also minimizes shrinkage and swelling.
- More even distribution of defects throughout the section reduces variability and generally increases the strength of the timber
- Pre-cambers can easily be incorporated during manufacturing process
- It is suitable for earthquake zones due to ductile behavior of timber buildings[79]

Cross-laminated timber panels were used for the walls, cross-laminated timber slabs were used for the floors and glulam rafters were used for roof structure.

Cross-laminated timber structures were designed in accordance with the requirements of Eurocode 5 Part 1.1.

Figure 5.1. Cross laminated timber

[79] http://www.woodsolutions.com.au

Table 5.1. Cross-laminated timber[80]

Strength class of lamellas	*C24*
Modulus of elasticity: • Parallel to fibre direcion of lamellas, E_0 • Perpendicular to fibre direction of lamellas E_{90}	11600 N/mm^2 370 N/mm^2
Fifth-percentile modulus of elasticity: • Parallel to fibre direcion of lamellas, $E_{0,05}$	9400 N/mm^2
Mean modulus of elasticity: • Parallel to fibre direcion of lamellas, $E_{0,05}$	9400 N/mm^2
Modulus of shear: • Parallel to fibre direcion of lamellas, G_0 • Perpendicular to fibre direction of lamellas, G_{90}	650 N/mm^2 50 N/mm^2
Bending strength: • Parallel to fibre direcion of lamellas, $f_{m.k.}$	24 N/mm^2
Tensile strength: • Perpendicular to fibre direction of lamellas, $f_{t.90.k.}$	0,12 N/mm^2
Compressive strength: • Parallel to fibre direction of lamellas, $f_{c.0.k.}$ • Perpendicular to fibre direction of lamellas, $f_{c.90.k.}$	21 N/mm^2 2,5 N/mm^2
Shear strength: • Parallel to fibre direction of lamellas, $f_{v.0.k.}$ • Perpendicular to fibre direction of lamellas, $f_{v.90.k.}$	2,5 N/mm^2 1,1 N/mm^2

80 http://www.mm-kaufmann.com

5.2. LOADS

5.2.1. Self-weight of structural and non-structural elements

Table 5.2. External wall

	Layer	Thickness *m*	Specific weight *kN/m³*	Weight *kN/m²*
1	Timber facing	*0,04*	*5,1*	*0,2*
2	Timber spruce battens	*0,025 x 0,05*	*5,1*	*0,01*
3	Timber spruce battens	*0,025 x 0,05*	*5,1*	*0,01*
4	Timber spruce battens	*0,05 x 0,05*	*5,1*	*0,02*
5	ISOVOL Ст-90	*0,05*	*0,34*	*0,02*
6	Timber spruce battens	*0,05 x 0,1*	*5,1*	*0,04*
7	ISOVOL Ст-90	*0,1*	*0,34*	*0,03*
8	M1 BSP crossplan	*0,098*	*4,7*	*0,46*
9	ISOVOL Ст-90	*0,05*	*0,34*	*0,02*
10	Timber spruce battens	*0,05 x 0,1*	*5,1*	*0,04*
11	Timber facing	*0,02*	*5,1*	*0,1*
			Total	***0,95***

Height of the floor is *3 m*.

3 x 0,95 = 2,85 kN/m;

Assuming 11% of openings,

2,85 x 0,11 = 0,31 kN/m;

2,85 – 0,31 kN/m = ***2,54 kN/m****;*

Table 5.3. Internal wall

	Layer	Thickness *m*	Specific weight *kN/m³*	Weight *kN/m²*
1	Timber facing	*0,04*	*5,1*	*0,2*
2	Timber spruce battens	*0,02 x 0,05*	*5,1*	*0,01*
3	M1 BSP crossplan	*0,098*	*4,7*	*0,46*
4	Timber spruce battens	*0,02 x 0,05*	*5,1*	*0,01*
5	Timber facing	*0,02*	*5,1*	*0,1*
			Total	***0,78***

Height of the floor is *3 m*.
3 x 0,78 = ***2,34 kN/m****;*

Table 5.4. Internal partitions

	Layer	Thickness *m*	Specific weight *kN/m³*	Weight *kN/m²*
1	Ceramic tiles	*0,01*	*22,55*	*0,23*
2	Plasterboard (2 layers)	*0,025*	*8,82*	*0,22*
4	Timber spruce battens	*0,1 x 0,1*	*5,1*	*0,1*
5	ISOVOL Ст-90	*0,1*	*0,34*	*0,03*
7	Plasterboard (2 layers)	*0,025*	*8,82*	*0,22*
8	Ceramic tiles	*0,01*	*22,55*	*0,23*
			Total	***1,03***

Height of the floor is *3 m*.
1,03 x 3 = ***3,09 kN/m****;*

Table 5.5. Inside floor

	Layer	Thickness *m*	Specific weight *kN/m³*	Weight *kN/m²*
1	Timber floor covering	*0,04*	*5,1*	*0,2*
2	Timber lathing	*0,02 x 0,1*	*5,1*	*0,02*
4	Waterproofing gypsum sheet	*0,012*	*12,25*	*0,001*
5	Extruded polystyrene	*0,05*	*0,28*	*0,01*
6	M1 BSP crossplan	*0,198*	*4,7*	*0,93*
7	Timber lathing	*0,02 x 0,1*	*5,1*	*0,02*
8	Timber ceiling	*0,04*	*5,1*	*0,2*
			Total	***1,38***

Table 5.6. Roof

	Layer	Thickness *m*	Specific weight *kN/m³*	Weight *kN/m²*
1	Timber facing	0,04	5,1	0,2
2	Timber spruce battens	0,05 x 0,05	5,1	0,02
4	Steel roof decking	0,01	26,48	0,26
5	Plywood sheathing	0,012	0,07	-
6	ISOVOL Ст-90	0,2	0,34	0,1
7	Timber rafters	0,1 x 0,2	5,1	0,2
8	ISOVOL Ст-90	0,05	0,34	0,02
9	Timber spruce battens	0,05 x 0,05	5,1	0,02
10	Timber ceiling	0,012	5,1	0,06
			Total	**0,88**

5.2.2. Imposed load

Imposed load for category C3 (areas without obstacles for moving people, e.g. museum, etc.; EN-1991-1-1, Tables 6.1 and 6.2) is *5 kN/m²*.

5.2.3. Snow load

$s = \mu_i \times C_e \times C_t \times s_k$

where:

μ_i is the snow load shape coefficient

$\mu_i = 0.8\,(60 - \alpha)/30$ for pitch roofs with angle 30° < α <60°.

$\mu_i = 0.8\,(60 - 45)/30 = 0{,}4$

C_e is the exposure coefficient function of the topography of the site

$C_e = 1$ – for normal topography

C_t is the thermal coefficient

$C_t = 1$

s_k is the characteristic value of snow load on the ground

$s_k = 0.79Z + 0.375 + A/336$

$Z = 2.35\ kN/m^2$

$A = 135\ m$

$s_k = 0.79 * 2.35 + 0.375 + 135/336 = 1.857 + 0.375 + 0.402 = 2.634\ kN/m^2$

$\mathbf{s = 0.4 * 1 * 1 * 2.634 = 1.0536\ kN/m^2}$

5.2.4. Wind load

$F_{w,e} = c_s c_d * \sum w_e * A_{ref}$

where:

$F_{w,e}$ is external wind force

$c_s c_d$ is structural factor. For buildings with a height less than *15 m* the value of $c_s c_d$ may be taken as *1,0*.

A_{ref} is reference area

w_e is external wind pressure

$w_e = c_{pe} * q_p(z)$

where:

c_{pe} is pressure coefficient for the external pressure

External pressure coefficients c_{pe} depend on the size the loaded area A. As $A > 10\ m^2$, external pressure coefficient should be c_{pe10}.

z is reference height for the external pressure

The reference height z for buildings with duopitch roofs should be taken as

$z = h = 14,05.$

$q_p(z)$ is peak velocity pressure

$q_p(z) = c_e(z) * q_b$

where:

$c_e(z)$ is exposure coefficient

$c_e(z) = (1 + 7I_v(z)) * c_r(z)^2 * c_0(z)^2$

where:

$I_v(z)$ is turbulence intensity

$I_v(z) = k_I / (c_{0(z)} * ln(z/z_0))$ for $z_{min} <= z <= z_{max}$

where:

k_I is turbulence factor

The recommended value is $k_I = 1,0$

$c_0(z)$ is orography coefficient. Orography (e.g. hills, cliffs, etc.) increases wind velocity for more than *5%.* The effect of orography may be neglected, when the average slope of the upwind terrain is less than $3°$. The recommended value is $c_0(z) = 1,0$.

z_0 is roughness length

z_{min} is minimum height

For terrain category III (area with regular cover of vegetation or buildings or with isolated obstacles with separation of maximum 20 obstacles heights such as villages, suburban terrain, permanent forest) $z_0 = 0,3\ m$ and $z_{min} = 5\ m$.

z_{max} is to be taken as $200\ m$

$c_r(z)$ is roughness coefficient, which accounts for the variability of the mean wind velocity at the site of the structure due to the height above ground level and the ground roughness of the terrain upwind of the structure in the wind direction considered.

$c_r = k_r * ln(z/z_0)$ for $z_{min} <= z <= z_{max}$

where:

k_r is terrain factor depending on roughness length z_0

$k_r = 0,19 * (z_0/z_{0,II})^{0,07} = 0,19 * (0,3/0,05)^{0,07} = 0,21$

$z_{0,II} = 0,05\ m$

$c_e(z) = k_r(z)^2 * ln(z/z_0) * (7 + ln(z/z_0))$

$c_e(z) = 0,21^2 * ln(14,05/0,3) * (7 + ln(14,05/0,3)) = 1,84$

q_b is basic velocity pressure

$q_b = ½ * ρ * v_b^2$

where:

$ρ$ is air density

$ρ = 1,25\ kg/m^3$

v_b is basic wind velocity

$v_b = c_{dir} * c_{season} * v_{b,0}$

where:

$v_{b,0}$ is fundamental value of basic wind velocity

For 4 region of Russia $v_{b,0} = 28\ m/s$

Figure 5.2. Zoning of the territory by average wind velocity

c_{dir} is directional factor. The recommended value is *1,0*.

c_{season} is season factor. The recommended value is *1,0*.

$v_b = 1,0 * 1,0 * 28 = 28\ m/s$

$q_b = ½ * 28^2 * 1,25 = 490\ N/m^2$

$q_p(z) = c_e(z) * q_b = 1,84 * 490 = 901,6\ N/m^2$

Zone F

$w_e = -1,4 * 901,6 = -1,26\ kN$

$F_{w,e} = 1,0 * (-1,26) * 59,68 = -75,2\ kN$

Zone G

$w_e = -1,2 * 901,6 = -1,08\ kN$

$F_{w,e} = 1,0 * (-1,08) * 81,19 = -87,68\ kN$

Zone H

$w_e = -1,0 * 901,6 = -0,9 kN$

$F_{w,e} = 1,0 * (-0,9) * 73,48 = -66,13\ kN$

Zone I

$w_e = -0,9 * 901,6 = -0,81\ kN$

$F_{w,e} = 1,0 * (-0,81) * 91,68 = -74,26\ kN$

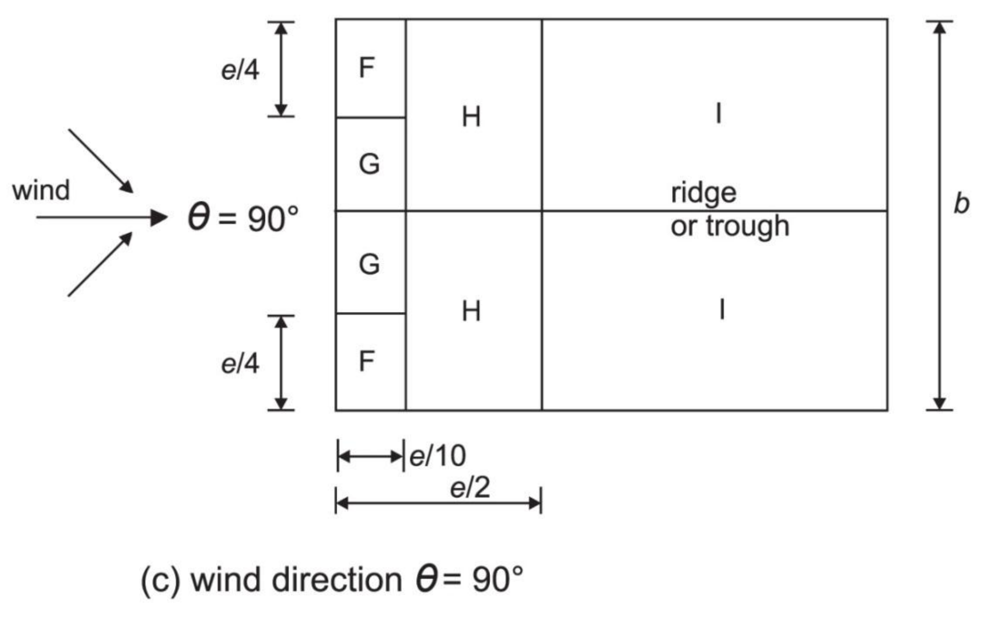


Figure 5.3. Duopitch roofs

5.3. DESIGN OF WALL PANELS

Walls structure consists of cross-laminated timber panels. In this part the wall panels of the ground floor, which bears the greatest loads, were designed. Only wall panels, which bear the main loads from the slabs and roof, were included in the design.

Design procedure includes:

- Determination of the main geometric parameters, including calculation of effective moment of inertia and slenderness ratio
- Determination of actions and partial safety factors
- Determination of design compressive stress and strength
- Checking of compressive stresses

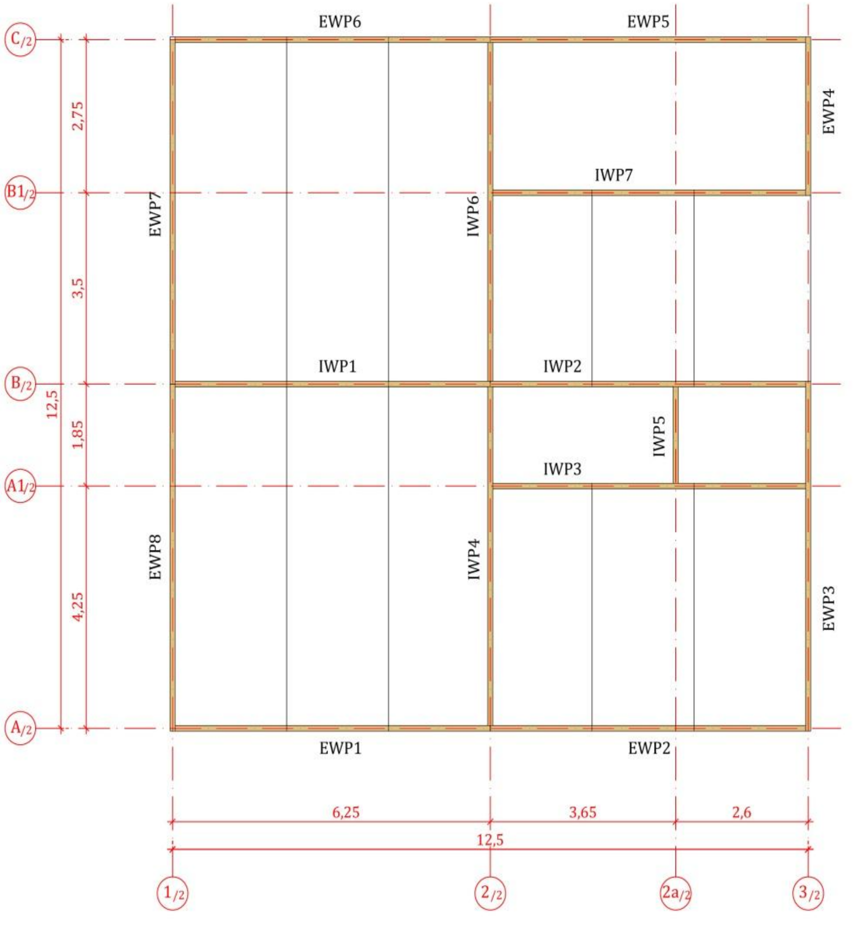


Figure 5.4. Ground floor plan with wall panels

EWP1

Geometric properties

Height

$h = 3\ m$

Length

$l = 6,2\ m$

Width

$b = 9,8\ cm$

Depth of transversal layer

$t_2 = 3,4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3,2\ cm$

Cross-section area

$A = l * b = 620 * 9,8 = 6076\ cm^2$

Effective cross-area (excluding 2 windows with width *1,2 m*)

$A_{eff} = 6076 - 2 * 120 * 9,8 = 3724\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

where:

I_i – individual moment of inertia of transversal layers

a_i – center of gravity

A_i – area of transversal layers

γ_i – flexibility factor

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (620 * 3,4^3) / 12 = 2030,71\ cm^4$

Center of gravity

$a_2 = 4,9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3,4 * 620 = 2108\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3,14 * 116 * 2108 * 3,4) / (300^2 * 0,5 * 620))^{-1} = 0,914$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2030,71 + 0,914 * 2108 * 4,9^2 = 4,8 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4,8 * 10^4 / 3724)^{1/2} = 3,59\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 3,59 = 83,56$

Partial safety factors

Permanent actions

$\gamma_G = 1,35$

Variable actions

$\gamma_Q = 1,5$

Material factor for cross-laminated timber

$\gamma_M = 1,25$

Actions

Influence area

$A = 19,47\ m^2$

Permanent actions

Ground floor external wall: $2,54 * 6,2 = 15,75\ kN$

First floor external wall: $15,75\ kN$

Second floor external wall: $0,95 * 0,8 * 6,2 = 4,71\ kN$

First floor : $1,38 * 19,47 = 26,87\ kN$

Second floor: $26,87\ kN$

Roof: $0,88 * 19,47 = 17,13\ kN$

Total permanent action: $G_k = 107,08\ kN$

Variable actions

Imposed load: $5 * 19,47 = 97,35\ kN$

Snow load: $1,05 * 19,47 = 20,44\ kN$

Total variable action: $Q_k = 117,79\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 107{,}08 * 1{,}35 + 117{,}79 * 1{,}5 = 321{,}24\ kN$

Wind load for Zone F: $75{,}2 / 3 = 25{,}07\ kN/m$

$q_{wd} = q_w * \gamma_Q = 25{,}07 * 1{,}5 = 37{,}6\ kN/m$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 321240 / 372400 = 0{,}86\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0{,}8 / 1{,}25 = 13{,}44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0{,}05})^{1/2} = (83{,}56 / 3{,}14) * (21 / 9400)^{1/2} = 1{,}26$

Factor β_c for cross-laminated timber

$\beta_c = 0{,}1$

Factor k

$k = 0{,}5 * (1 + \beta_c * (\lambda_{rel} - 0{,}3) + \lambda_{rel}^2) = 0{,}5 * (1 + 0{,}1 * (1{,}26 - 0{,}3) + 1{,}26^2) = 1{,}34$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1{,}34 + (1{,}34^2 - 1{,}26^2)^{1/2})^{-1} = 0{,}55$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0{,}86 / (13{,}44 * 0{,}55) = 0{,}12 < 1$

Shear strength

Design value of the shear force

$V_d = q_w * h / 2 = 37{,}6 * 3 / 2 = 56{,}4\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * l * b) = 3 * 56400 / (2 * 6200 * 98) = 0{,}14\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}14 / 1{,}8 = 0{,}08 < 1$

EWP2

Geometric properties

Height

$h = 3\ m$

Length

$l = 6{,}2\ m$

Width

$b = 9{,}8\ cm$

Depth of transversal layer

$t_2 = 3{,}4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3{,}2\ cm$

Cross-section area

$A = l * b = 620 * 9{,}8 = 6076\ cm^2$

Effective cross-area (excluding 2 windows with width *1,2 m*)

$A_{eff} = 6076 – 2 * 120 * 9{,}8 = 3724\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

$I_2 = (b * t_2^3) / 12 = (620 * 3{,}4^3) / 12 = 2030{,}71\ cm^4$

Center of gravity

$a_2 = 4{,}9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3{,}4 * 620 = 2108\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3{,}14 * 116 * 2108 * 3{,}4) / (300^2 * 0{,}5 * 620))^{-1} = 0{,}91$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2030{,}71 + 0{,}91 * 2108 * 4{,}9^2 = 4{,}8 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4{,}8 * 10^4 / 3724)^{1/2} = 3{,}59\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 3{,}59 = 83{,}56$

Actions

Influence area

$A = 13,89\ m^2$

Permanent actions

Ground floor external wall: $2,54 * 6,2 = 15,75\ kN$

First floor external wall: $15,75\ kN$

Second floor external wall: $0,95 * 0,8 * 6,2 = 4,71\ kN$

First floor : $1,38 * 13,89 = 19,17\ kN$

Second floor: $19,17\ kN$

Roof: $0,88 * 13,89 = 12,22\ kN$

Total permanent action: $G_k = 86,77\ kN$

Variable actions

Imposed load: $5 * 13,89 = 69,45\ kN$

Snow load: $1,05 * 13,89 = 14,58\ kN$

Total variable action: $Q_k = 84,03\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 86,77 * 1,35 + 84,03 * 1,5 = 243,18\ kN$

Wind load for Zone I: $74,26 / 3 = 24,75\ kN/m$

$q_{wd} = q_w * \gamma_Q = 24,75 * 1,5 = 37,13\ kN/m$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 243180 / 372400 = 0,65\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0,8 / 1,25 = 13,44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (83,56 / 3,14) * (21 / 9400)^{1/2} = 1,26$

Factor β_c for cross-laminated timber

$\beta_c = 0,1$

Factor k

$k = 0,5 * (1 + \beta_c * (\lambda_{rel} - 0,3) + \lambda_{rel}^2) = 0,5 * (1 + 0,1 * (1,26 - 0,3) + 1,26^2) = 1,34$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1,34 + (1,34^2 - 1,26^2)^{1/2})^{-1} = 0,55$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0,65 / (13,44 * 0,55) = 0,09 < 1$

Shear strength

Design value of the shear force

$V_d = q_w * h / 2 = 37,13 * 3 / 2 = 55,7\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * l * b) = 3 * 55700 / (2 * 6200 * 98) = 0,14\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2,5 * 0,9 / 1,25 = 1,8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0,14 / 1,8 = 0,08 < 1$

EWP6

Geometric properties

Height

$h = 3\ m$

Length

$l = 6,2\ m$

Width

$b = 9,8\ cm$

Depth of transversal layer

$t_2 = 3,4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3,2\ cm$

Cross-section area

$A = l * b = 620 * 9,8 = 6076\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (620 * 3,4^3) / 12 = 2030,71\ cm^4$

Center of gravity

$a_2 = 4,9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3,4 * 620 = 2108\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3,14 * 116 * 2108 * 3,4) / (300^2 * 0,5 * 620))^{-1} = 0,91$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2030,71 + 0,91 * 2108 * 4,9^2 = 4,8 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A)^{1/2} = (4,8 * 10^4 / 6076)^{1/2} = 2,81\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 2,81 = 106,76$

Actions

Influence area

$A = 19,47\ m^2$

Permanent actions

Ground floor external wall: *2,54 * 6,2 = 15,75 kN*

First floor external wall: *15,75 kN*

Second floor external wall: *0,95 * 0,8 * 6,2 = 4,71 kN*

First floor : *1,38 * 19,47 = 26,87 kN*

Second floor: *26,87 kN*

Roof: *0,88 * 19,47 = 17,13 kN*

Total permanent action: $G_k = 107,08\ kN$

Variable actions

Imposed load: *5 * 19,47 = 97,35 kN*

Snow load: *1,05 * 19,47 = 20,44 kN*

Total variable action: $Q_k = 117,79\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 107,08 * 1,35 + 117,79 * 1,5 = 321,24\ kN$

Wind load for Zone F: $75{,}2 / 3 = 25{,}07\ kN/m$

$q_{wd} = q_w * \gamma_Q = 25{,}07 * 1{,}5 = 37{,}6\ kN/m$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A = 321240 / 607600 = 0{,}53\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0{,}8 / 1{,}25 = 13{,}44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (106{,}76 / 3{,}14) * (21 / 9400)^{1/2} = 1{,}6$

Factor β_c for cross-laminated timber

$\beta_c = 0{,}1$

Factor k

$k = 0{,}5 * (1 + \beta_c * (\lambda_{rel} - 0{,}3) + \lambda_{rel}^2) = 0{,}5 * (1 + 0{,}1 * (1{,}6 - 0{,}3) + 1{,}6^2) =$
$= 1{,}84$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1{,}84 + (1{,}84^2 - 1{,}6^2)^{1/2})^{-1} = 0{,}36$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0{,}53 / (13{,}44 * 0{,}36) = 0{,}11 < 1$

Shear strength

Design value of the shear force

$V_d = q_w * h / 2 = 37{,}6 * 3 / 2 = 56{,}4\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * l * b) = 3 * 56400 / (2 * 6200 * 98) = 0{,}14\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}14 / 1{,}8 = 0{,}08 < 1$

EWP7

Geometric properties

Height

$h = 3\ m$

Length

$l = 6{,}3\ m$

Width

$b = 9{,}8\ cm$

Depth of transversal layer

$t_2 = 3{,}4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3{,}2\ cm$

Cross-section area

$A = l * b = 630 * 9{,}8 = 6174\ cm^2$

Effective cross-area (excluding 2 windows with width *1,2 m*)

$A_{eff} = 6174 - 2 * 120 * 9{,}8 = 3822\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (630 * 3{,}4^3) / 12 = 2063{,}46\ cm^4$

Center of gravity

$a_2 = 4{,}9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3{,}4 * 630 = 2142\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * h))^{-1} =$

$= (1 + (3{,}14 * 116 * 2142 * 3{,}4) / (300^2 * 0{,}5 * 630))^{-1} = 0{,}914$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2063{,}46 + 0{,}914 * 2142 * 4{,}9^2 = 4{,}9 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4{,}9 * 10^4 / 3822)^{1/2} = 3{,}58\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 3{,}58 = 83{,}8$

Resisting moment

$W_{eff} = 2 * I_{eff} / b = 2 * 4{,}9 * 10^4 / 9{,}8 = 10000\ cm^3$

Actions

Permanent actions

Ground floor external wall: *2,54 * 6,3 = 16 kN*

First floor external wall: *16 kN*

Second floor external wall: *0,95 * 17,72= 16,83 kN*

Third floor external wall: *0,95 * 18,99 = 18,04kN*

Third floor : *1,38 * 24,26 = 33,48 kN*

Total permanent action: $G_k = 100{,}35\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G = 100{,}35 * 1{,}35 = 135{,}47\ kN$

Wind load for Zone G: *87,68 / 3 = 29,23 kN/m*

$q_{wd} = q_w * \gamma_Q = 29{,}23 * 1{,}5 = 43{,}84$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 135470 / 382200 = 0{,}35\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0{,}8 / 1{,}25 = 13{,}44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (83{,}8 / 3{,}14) * (21 / 9400)^{1/2} = 1{,}26$

Factor β_c for cross-laminated timber

$\beta_c = 0{,}1$

Factor *k*

$k = 0{,}5 * (1 + \beta_c * (\lambda_{rel} - 0{,}3) + \lambda_{rel}^2) = 0{,}5 * (1 + 0{,}1 * (1{,}26 - 0{,}3) + 1{,}26^2) = 1{,}34$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1{,}34 + (1{,}34^2 - 1{,}26^2)^{1/2})^{-1} = 0{,}55$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0{,}35 / (13{,}44 * 0{,}55) = 0{,}12 < 1$

Bending strength

Design bending moment

$M_d = q_{wd} * h^2 / 8 = 43{,}74 * 3^2 / 8 = 49{,}2\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 49200000 / 10000000 = 4{,}92\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0{,}9 * 1{,}1 / 1{,}25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 4{,}92 / (1 * 19) = 0{,}26 < 1$

Checking with eccentric compression formula

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) + \sigma_{m.d} / (k_{crit} * f_{m.d}) = 0{,}35 / (13{,}44 * 0{,}55) + 4{,}92 / (1 * 19) =$
$= 0{,}38 < 1$

IWP1

Geometric properties

Height

$h = 3\ m$

Length

$l = 6{,}2\ m$

Width

$b = 9{,}8\ cm$

Depth of transversal layer

$t_2 = 3{,}4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3{,}2\ cm$

Cross-section area

$A = l * b = 620 * 9{,}8 = 6076\ cm^2$

Effective cross-area (excluding door with width *1,5 m*)

$A_{eff} = 6076 - 150 * 9{,}8 = 4606\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (620 * 3{,}4^3) / 12 = 2030{,}71\ cm^4$

Center of gravity

$a_2 = 4{,}9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3{,}4 * 620 = 2108\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2\ ) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3{,}14 * 116 * 2108 * 3{,}4) / (300^2 * 0{,}5 * 620))^{-1} = 0{,}91$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2030{,}71 + 0{,}91 * 2108 * 4{,}9^2 = 4{,}8 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4{,}8 * 10^4 / 4606)^{1/2} = 3{,}23\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 3{,}23 = 92{,}87$

Actions

Influence area

$A = 39\ m^2$

Permanent actions

Ground floor internal wall: *2,34 * 6,2 = 14,5 kN*

First floor internal wall: *14,5 kN*

Second floor internal wall: *14,5 kN*

First floor : *1,38 * 39 = 53,82 kN*

Second floor: *53,82 kN*

Roof: *0,88 * 39 = 34,32 kN*

Total permanent action: $G_k = 185{,}46\ kN$

Variable actions

Imposed load: *5 * 39 = 195 kN*

Snow load: *1,05 * 39 = 40,95 kN*

Total variable action: $Q_k = 235{,}95\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 185{,}46 * 1{,}35 + 235{,}95 * 1{,}5 = 604{,}3\ kN$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 604300 / 460600 = 1,31\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0,8 / 1,25 = 13,44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (92,87 / 3,14) * (21 / 9400)^{1/2} = 1,4$

Factor β_c for cross-laminated timber

$\beta_c = 0,1$

Factor k

$k = 0,5 * (1 + \beta_c * (\lambda_{rel} - 0,3) + \lambda_{rel}^2) = 0,5 * (1 + 0,1 * (1,4 - 0,3) + 1,4^2) = 1,53$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1,53 + (1,53^2 - 1,4^2)^{1/2})^{-1} = 0,46$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 1,31 / (13,44 * 0,46) = 0,21 < 1$

IWP2

Geometric properties

Height

$h = 3\ m$

Length

$l = 6,2\ m$

Width

$b = 9,8\ cm$

Depth of transversal layer

$t_2 = 3,4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3,2\ cm$

Cross-section area

$A = l * b = 620 * 9,8 = 6076\ cm^2$

Effective cross-area (excluding 2 doors with width *0,7 m* and door with width *1,2 m*)

$A_{eff} = 6076 - 260 * 9,8 = 3528\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (620 * 3,4^3) / 12 = 2030,71\ cm^4$

Center of gravity

$a_2 = 4,9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3,4 * 620 = 2108\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3,14 * 116 * 2108 * 3,4) / (300^2 * 0,5 * 620))^{-1} = 0,914$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2030,71 + 0,914 * 2108 * 4,9^2 = 4,8 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4,8 * 10^4 / 3528)^{1/2} = 3,69\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 3,69 = 81,3$

Actions

Influence area

$A = 11,04\ m^2$

Permanent actions

Ground floor internal wall: *2,34 * 6,2= 14,5 kN*

First floor internal wall: *14,5 kN*

Second floor internal wall: *14,5 kN*

First floor : *1,38 * 11,04 = 15,23 kN*

Second floor: *15,23 kN*

Roof: *0,88 * 11,04 = 9,71 kN*

Total permanent action: $G_k = 83,67\ kN$

Variable actions

Imposed load: *5 * 11,04 = 55,2 kN*

Snow load: $1{,}05 * 11{,}04 = 11{,}59\ kN$

Total variable action: $Q_k = 66{,}79\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 83{,}67 * 1{,}35 + 66{,}79 * 1{,}5 = 213{,}13\ kN$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 213130 / 352800 = 0{,}6\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0{,}8 / 1{,}25 = 13{,}44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.0.k} / E_{0,05})^{1/2} = (81{,}3 / 3{,}14) * (21 / 9400)^{1/2} = 1{,}22$

Factor β_c for cross-laminated timber

$\beta_c = 0{,}1$

Factor k

$k = 0{,}5 * (1 + \beta_c * (\lambda_{rel} - 0{,}3) + \lambda_{rel}^2) = 0{,}5 * (1 + 0{,}1 * (1{,}22 - 0{,}3) + 1{,}22^2) = 1{,}29$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1{,}29 + (1{,}29^2 - 1{,}22^2)^{1/2})^{-1} = 0{,}68$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0{,}6 / (13{,}44 * 0{,}68) = 0{,}07 < 1$

IWP3

Geometric properties

Height

$h = 3\ m$

Length

$l = 6{,}15\ m$

Width

$b = 9{,}8\ cm$

Depth of transversal layer

$t_2 = 3,4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3,2\ cm$

Cross-section area

$A = l * b = 615 * 9,8 = 6027\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (615 * 3,4^3) / 12 = 2014,33\ cm^4$

Center of gravity

$a_2 = 4,9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3,4 * 615 = 2091\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3,14 * 116 * 2091 * 3,4) / (300^2 * 0,5 * 615))^{-1} = 0,914$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2014,33 + 0,914 * 2091 * 4,9^2 = 4,79 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4,79 * 10^4 / 6027)^{1/2} = 2,82\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 2,82 = 106,38$

Actions

Influence area

$A = 13,78\ m^2$

Permanent actions

Ground floor external wall: *2,34 * 6,15 = 14,39*

First floor external wall: *14,39 kN*

Second floor external wall: *14,39 kN*

First floor : *1,38 * 13,78 = 19,02 kN*

Second floor: *19,02 kN*

Roof: *0,88 * 13,78 = 12,13 kN*

Total permanent action: $G_k = 93{,}34\ kN$
Variable actions
Imposed load: $5 * 13{,}78 = 68{,}9\ kN$
Snow load: $1{,}05 * 13{,}78 = 14{,}47\ kN$
Total variable action: $Q_k = 83{,}37\ kN$
Design compressive action for critical load combination
$N_d = G_k * \gamma_G + Q_k * \gamma_Q$
$N_d = 93{,}34 * 1{,}35 + 83{,}37 * 1{,}5 = 251{,}05\ kN$

Compressive strength
Design compressive stress
$\sigma_{c.0.d} = N_d / A_{eff} = 251050 / 602700 = 0{,}42\ N/mm^2$
Design compressive strength
$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0{,}8 / 1{,}25 = 13{,}44\ N/mm^2$
Buckling resistance condition
Relative slenderness
$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (106{,}38 / 3{,}14) * (21 / 9400)^{1/2} = 1{,}6$
Factor β_c for cross-laminated timber
$\beta_c = 0{,}1$
Factor k
$k = 0{,}5 * (1 + \beta_c * (\lambda_{rel} - 0{,}3) + \lambda_{rel}^2) = 0{,}5 * (1 + 0{,}1 * (1{,}6 - 0{,}3) + 1{,}6^2) = 1{,}84$
Instability factor
$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (1{,}84 + (1{,}84^2 - 1{,}6^2)^{1/2})^{-1} = 0{,}36$
Checking of compressive stresses
$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0{,}42 / (13{,}44 * 0{,}36) = 0{,}09 < 1$

IWP5

Geometric properties
Height
$h = 3\ m$
Length
$l = 1{,}75\ m$

Width

$b = 9{,}8\ cm$

Depth of transversal layer

$t_2 = 3{,}4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3{,}2\ cm$

Cross-section area

$A = l * b = 175 * 9{,}8 = 1715\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (175 * 3{,}4^3) / 12 = 573\ cm^4$

Center of gravity

$a_2 = 4{,}9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3{,}4 * 175 = 595\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3{,}14 * 116 * 595 * 3{,}4) / (300^2 * 0{,}5 * 175))^{-1} = 0{,}094$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 573 + 0{,}094 * 595 * 4{,}9^2 = 1{,}9 * 10^3\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (1{,}9 * 10^3 / 1715)^{1/2} = 1{,}05\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 1{,}05 = 285{,}71$

Actions

Influence area

$A = 3{,}27\ m^2$

Permanent actions

Ground floor external wall: *2,34 * 3,27 = 7,65 kN*

First floor external wall: *7,65 kN*

Second floor external wall: *7,65 kN*

First floor : *1,38 * 3,27 = 4,51 kN*

Second floor: *4,51 kN*

Roof: $0,88 * 3,27 = 2,87\ kN$

Total permanent action: $G_k = 32,84\ kN$

Variable actions

Imposed load: $5 * 3,27 = 16,35\ kN$

Snow load: $1,05 * 3,27 = 3,43\ kN$

Total variable action: $Q_k = 19,78\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 32,84 * 1,35 + 19,78 * 1,5 = 74\ kN$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 74000 / 171500 = 0,43\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0,8 / 1,25 = 13,44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (285,71 / 3,14) * (21 / 9400)^{1/2} = 4,3$

Factor β_c for cross-laminated timber

$\beta_c = 0,1$

Factor k

$k = 0,5 * (1 + \beta_c * (\lambda_{rel} - 0,3) + \lambda_{rel}^2) = 0,5 * (1 + 0,1 * (4,3 - 0,3) + 4^2) = 8,7$

Instability factor

$k_c = (k + (k^2 - \lambda_{rel}^2)^{1/2})^{-1} = (8,7 + (8,7^2 - 4^2)^{1/2})^{-1} = 0,06$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0,43 / (13,44 * 0,06) = 0,53 < 1$

Length

$l = 6{,}15\ m$

Width

$b = 9{,}8\ cm$

Depth of transversal layer

$t_2 = 3{,}4\ cm$

Depth of longitudinal layers

$T_{1,3} = 3{,}2\ cm$

Cross-section area

$A = l * b = 615 * 9{,}8 = 6027\ cm^2$

Effective cross-area (excluding door with width *1,5 m*)

$A_{eff} = 6027 – 150 * 9{,}8 = 4557\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layer

$I_2 = (l * t_2^3) / 12 = (615 * 3{,}4^3) / 12 = 2014{,}33\ cm^4$

Center of gravity

$a_2 = 4{,}9\ cm$

Areas of transversal layer

$A_2 = t_2 * l = 3{,}4 * 615 = 2091\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_2 * t_2) / (h^2 * G_{90} * l))^{-1} =$

$= (1 + (3{,}14 * 116 * 2091 * 3{,}4) / (300^2 * 0{,}5 * 615))^{-1} = 0{,}914$

$I_{eff} = I_2 + \gamma_2 * A_2 * a_2^2 = 2014{,}33 + 0{,}914 * 2091 * 4{,}9^2 = 4{,}79 * 10^4\ cm^4$

Radius of gyration

$i = (I_{eff} / A_{eff})^{1/2} = (4{,}79 * 10^4 / 4557)^{1/2} = 3{,}24\ cm$

Slenderness ratio

$\lambda = h / i = 300 / 3{,}24 = 92{,}59$

Actions

Influence area

$A = 10{,}95\ m^2$

Permanent actions

Ground floor internal wall: $2{,}34 * 6{,}15 = 14{,}4\ kN$

First floor internal wall: $14{,}4\ kN$

Second floor internal wall: $14{,}4\ kN$

First floor : $1{,}38 * 10{,}95 = 15{,}11\ kN$

Second floor: $15{,}11\ kN$

Roof: $0{,}88 * 10{,}95 = 9{,}64\ kN$

Total permanent action: $G_k = 83{,}06\ kN$

Variable actions

Imposed load: $5 * 10{,}95 = 54{,}75\ kN$

Snow load: $1{,}05 * 10{,}95 = 11{,}5\ kN$

Total variable action: $Q_k = 66{,}25\ kN$

Design compressive action for critical load combination

$N_d = G_k * \gamma_G + Q_k * \gamma_Q$

$N_d = 83{,}06 * 1{,}35 + 66{,}25 * 1{,}5 = 211{,}5\ kN$

Compressive strength

Design compressive stress

$\sigma_{c.0.d} = N_d / A_{eff} = 211500 / 455700 = 0{,}46\ N/mm^2$

Design compressive strength

$f_{c.0.d} = f_{c.0.k} * k_{mod.med} / \gamma_M = 21 * 0{,}8 / 1{,}25 = 13{,}44\ N/mm^2$

Buckling resistance condition

Relative slenderness

$\lambda_{rel} = (\lambda / \pi) * (f_{c.o.k} / E_{0,05})^{1/2} = (92{,}59 / 3{,}14) * (21 / 9400)^{1/2} = 1{,}4$

Factor β_c for cross-laminated timber

$\beta_c = 0{,}1$

Factor k

$k = 0{,}5 * (1 + \beta_c * (\lambda_{rel} – 0{,}3) + \lambda_{rel}^2) = 0{,}5 * (1 + 0{,}1 * (1{,}4 – 0{,}3) + 1{,}4^2) = 1{,}53$

Instability factor

$k_c = (k + (k^2 – \lambda_{rel}^2)^{1/2})^{-1} = (1{,}53 + (1{,}53^2 – 1{,}4^2)^{1/2})^{-1} = 0{,}46$

Checking of compressive stresses

$\sigma_{c.0.d} / (f_{c.0.d} * k_c) = 0{,}46 / (13{,}44 * 0{,}46) = 0{,}07 < 1$

5.4. DESIGN OF SLABS

Structure of floors consists of cross-laminated timber slabs.

Design procedure includes:

- Determination of the main geometric parameters, including calculation of effective moment of inertia and resisting moment
- Determination of actions, partial safety factors and modification coefficients
- Determination of bending moment, shear force and reactions
- Checking of bending stresses, shear stresses and bearing stresses
- Determination of deflection

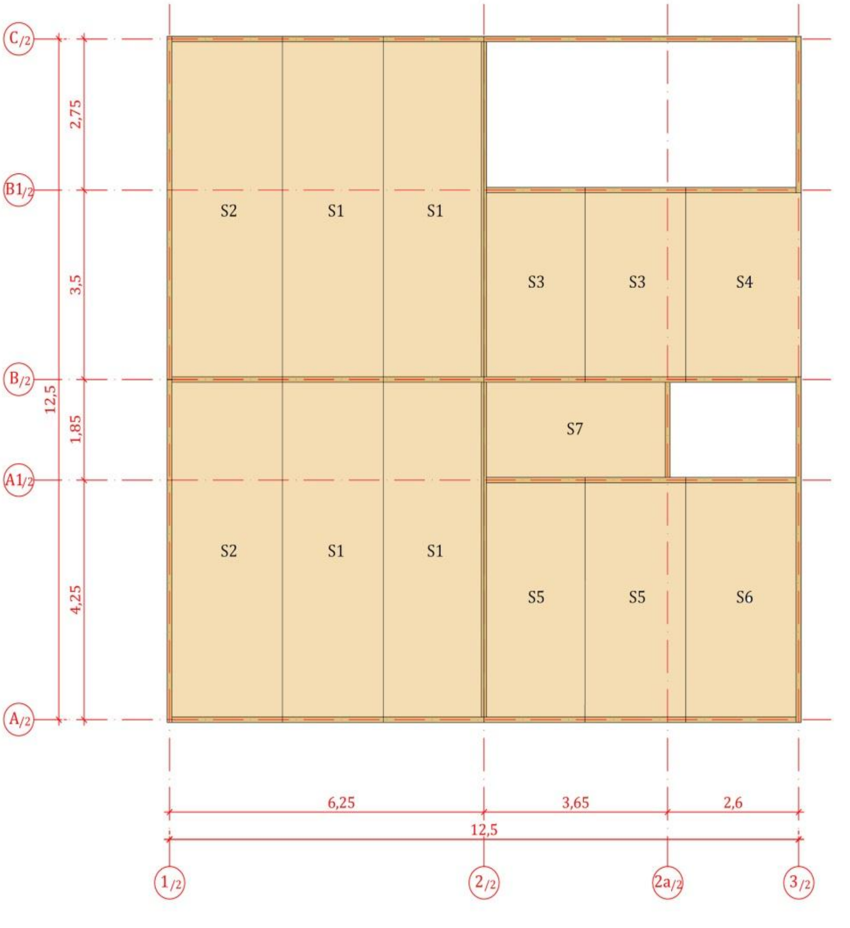


Figure 5.5. Ground floor plan with slabs

S1

Geometric properties

Effective span of the slab

$l = 6,3\ m$

Bearing lengths at the ends of the slab

$l_1 = 9,8\ cm$

$l_2 = 4,9\ cm$

Width

$b = 2\ m$

Depth

$h = 19,8\ cm$

Depth of transversal layers

$t_{1,5} = 3,9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 200 * 19,8 = 3960\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t_{1,5}^3) / 12 = (200 * 3,9^3) / 12 = 988,65\ cm^4$

$I_3 = (b * t_{,3}^3) / 12 = (200 * 4^3) / 12 = 1066,67\ cm^4$

Centers of gravity

$a_{1,5} = t_1/2 + t_2 + t_3/2 = 1,95 + 4 + 2 = 7,95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3,9 * 200 = 780\ cm^2$

$A_3 = t_3 * b = 4 * 200 = 800\ cm^2$

Flexibility factors

$\gamma_{1,7} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 780 * 3,9) / (630^2 * 0,5 * 200))^{-1} = 0,973$

$\gamma_{3,5} = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 800 * 4) / (630^2 * 0,5 * 200))^{-1} = 0,972$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 988,65 + 1066,67 + 2 * 0,973 * 780 * 7,95^2 + 0,972 * 800 * 7,95^2 =$

$= 1,48 * 10^5\ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1,48 * 10^5 / 19,8 = 14949,49\ cm^3$

Actions

Permanent actions

Second floor: *1,38 * 2 = 2,76 kN/m*

Variable actions

Imposed load: *5 * 2 = 10 kN/m*

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 2,76 * 1,35 + 10 * 1,5 = 18,73\ kN/m$

Combination 1

On both spans: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 18{,}73\ kN/m$

Figure 5.6. Bending moment diagram

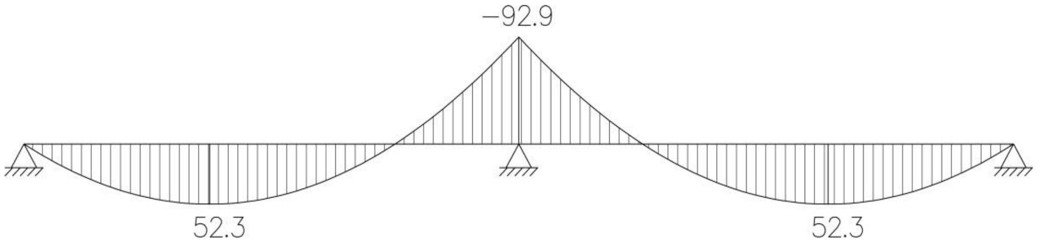


Figure 5.7. Shear force diagram

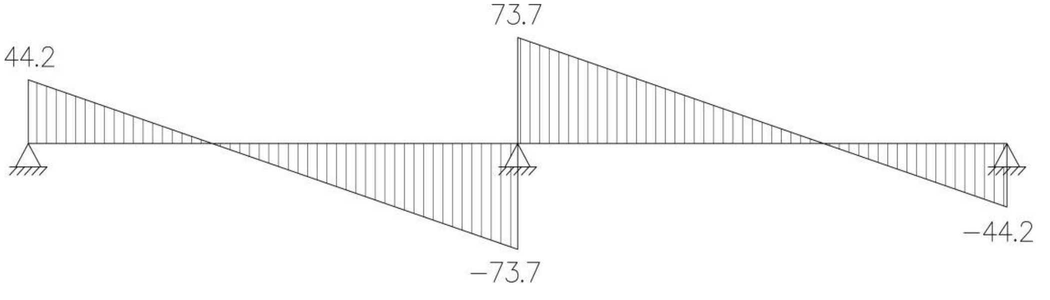
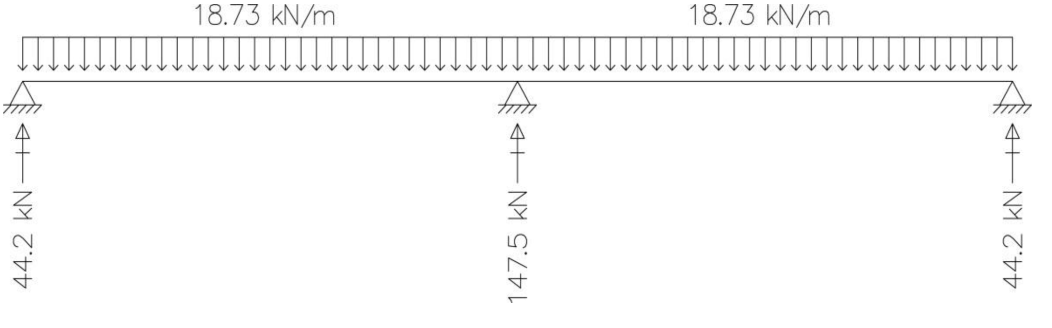


Figure 5.8. Reactions



Combination 2

On the right span: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 18{,}73\ kN/m$

On the left span: $q_d = G_k * \gamma_G = 3{,}73\ kN/m$

Figure 5.9. Bending moment diagram

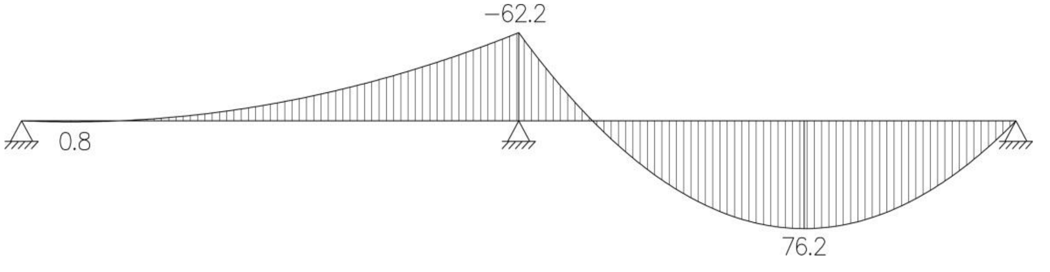


Figure 5.10. Shear force diagram

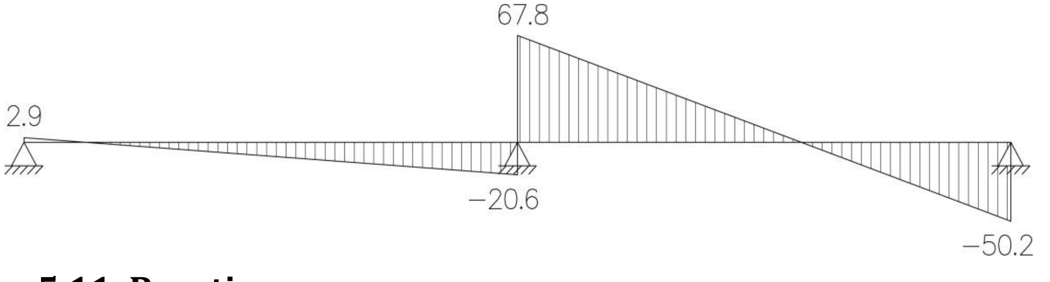
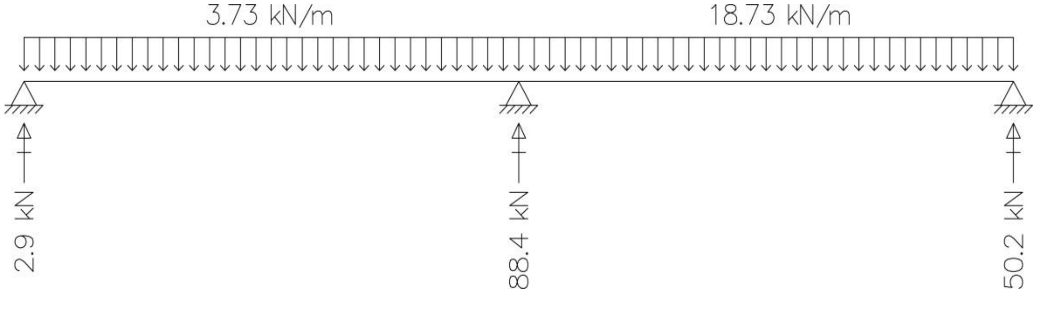


Figure 5.11. Reactions



Combination 3

On the right span: $q_d = G_k * \gamma_G = 3{,}73\ kN/m$

On the left span: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 18{,}73\ kN/m$

Figure 5.12. Bending moment diagram

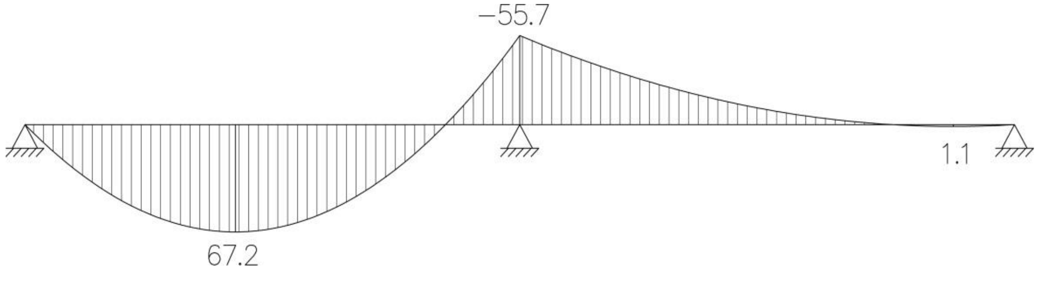


Figure 5.13. Shear force diagram

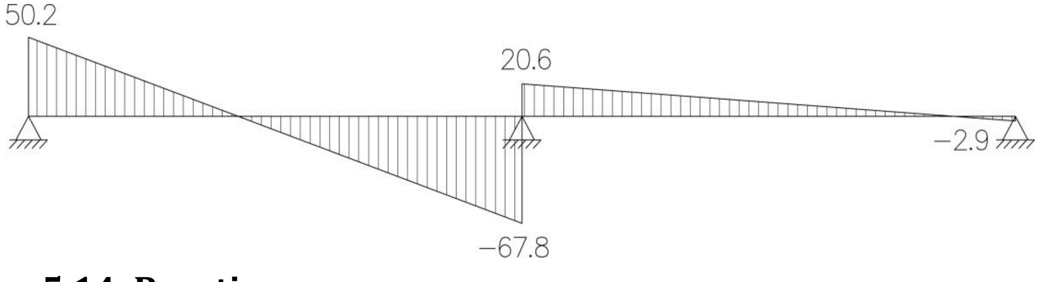
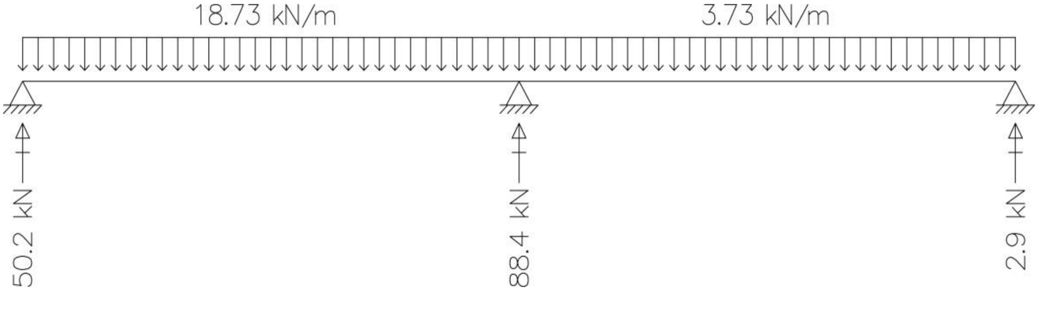


Figure 5.14. Reactions



Modification factors

Factor for short-duration loading

$k_{mod,\ short} = 0{,}9$

Size factor for depth less than *600 mm*

$k_h = 1{,}1$

Lateral stability factor

$k_{crit} = 1$

Deformation factor

$k_{def} = 0{,}6$

Bending strength

Design bending moment

$M_d = 92{,}9\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 92900000 / 14949490 = 6{,}21\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0{,}9 * 1{,}1 / 1{,}25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 6{,}21 / (1 * 19) = 0{,}33 < 1$

Shear strength

Design value of the end shear force

$V_d = 73{,}7\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 73700 / (2 * 2000 * 198) = 0{,}28\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}28 / 1{,}8 = 0{,}15 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 147{,}5\ kN$

Design bearing stress

$\sigma_{c.90.d.1} = R_d / (b * l_1) = 147500 / (2000 * 98) = 0{,}75\ N/mm^2$

$\sigma_{c.90.d.2} = R_d / (b * l_2) = 147500 / (2000 * 49) = 1{,}5\ N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of bearing stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0{,}75 / 1{,}8 = 0{,}42 < 1$

$\sigma_{c.90.d.2} / f_{c.90.d} = 1{,}5 / 1{,}8 = 0{,}83 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 27{,}6 * 630^4) / (384 * 116 * 10^4 * 1{,}48 * 10^5) = 0{,}3\ cm = 3{,}3\ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 100 * 630^4) / (384 * 116 * 10^4 * 1{,}48 * 10^5) = 1{,}19\ cm = 11{,}9\ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 3{,}3 + 11{,}9 = 15{,}2\ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 6300 / 300 = 21\ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 3{,}3 * (1 + 0{,}6) = 5{,}28\ mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 11{,}9 * (1 + 0{,}6) = 19{,}04\ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 5{,}28 + 19{,}04 = 24{,}32\ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 6300/250 = 25{,}2\ mm$ – the slab does not exceed the limit

S2

Geometric properties

Effective span of the slab

$l = 6{,}3\ m$

Bearing lengths at the ends of the slab

$l_1 = 9{,}8\ cm$

$l_2 = 4{,}9\ cm$

Width

$b = 2{,}3\ m$

Depth

$h = 19{,}8\ cm$

Depth of transversal layers

$t_{1,5} = 3{,}9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 230 * 19{,}8 = 4554\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t_{,1,5}^3) / 12 = (230 * 4^3) / 12 = 1226{,}67 cm^4$

$I_3 = (b * t_3^3) / 12 = (230 * 3{,}9^3) / 12 = 1136{,}95\ cm^4$

Centers of gravity

$a_{1,5} = t_1/2 + t_2 + t_3/2 = 1{,}95 + 4 + 2 = 7{,}95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3{,}9 * 230 = 897\ cm^2$

$A_3 = t_3 * b = 4 * 230 = 920\ cm^2$

Flexibility factors

$\gamma_{1,7} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 897 * 3,9) / (630^2 * 0,5 * 230))^{-1} = 0,973$

$\gamma_{3,5} = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 920 * 4) / (630^2 * 0,5 * 230))^{-1} = 0,971$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 1226,67 + 1136,95 + 2 * 0,973 * 897 * 7,95^2 + 0,971 * 920 * 7,95^2 =$

$= 1,7 * 10^5 \ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1,7 * 10^5 / 19,8 = 17171,72 \ cm^3$

Actions

Permanent actions

Second floor: *1,38 * 2,3 = 3,17 kN/m*

Variable actions

Imposed load: *5 * 2,3 = 11,5 kN/m*

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 3,17 * 1,35 + 11,5 * 1,5 = 21,53 \ kN/m$

Combination 1

On both spans: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 21{,}53\ kN/m$

Figure 5.15. Bending moment diagram

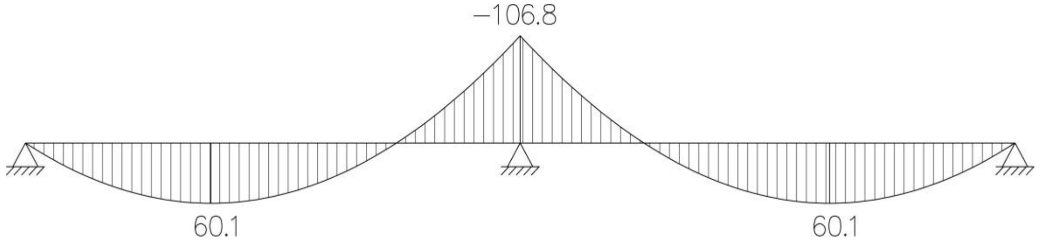


Figure 5.16. Shear force diagram

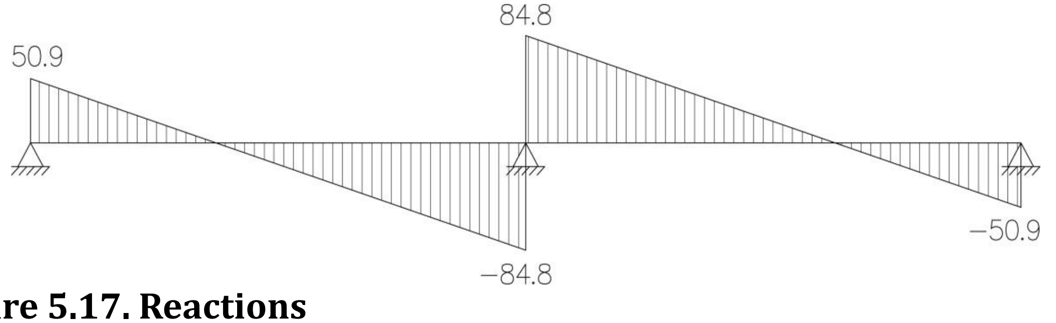
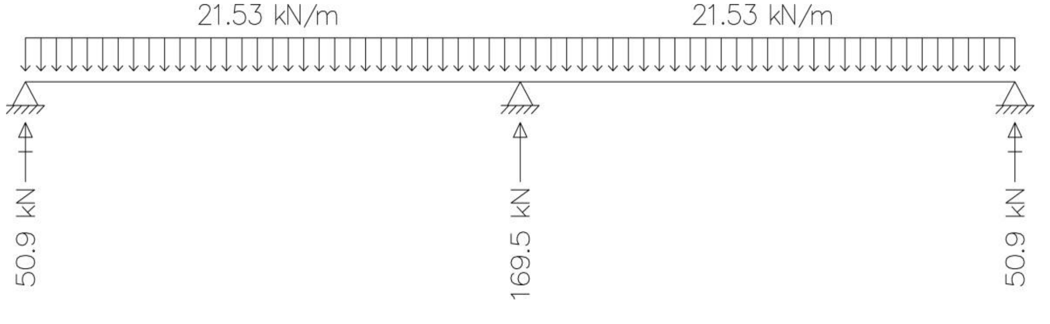


Figure 5.17. Reactions



Combination 2

On the right span: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 21{,}53\ kN/m$

On the left span: $q_d = G_k * \gamma_G = 4{,}28\ kN/m$

Figure 5.18. Bending moment diagram

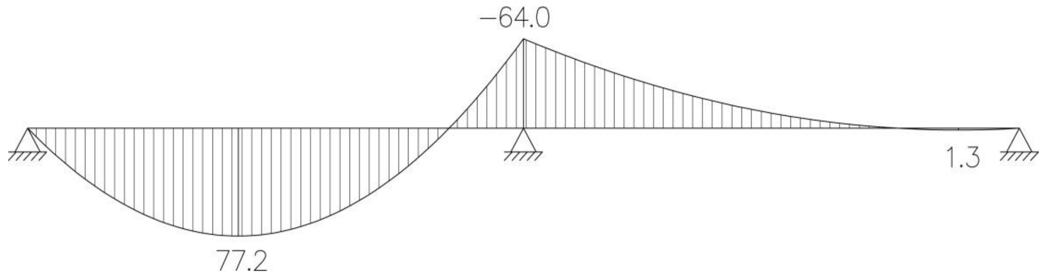


Figure 5.19. Shear force diagram

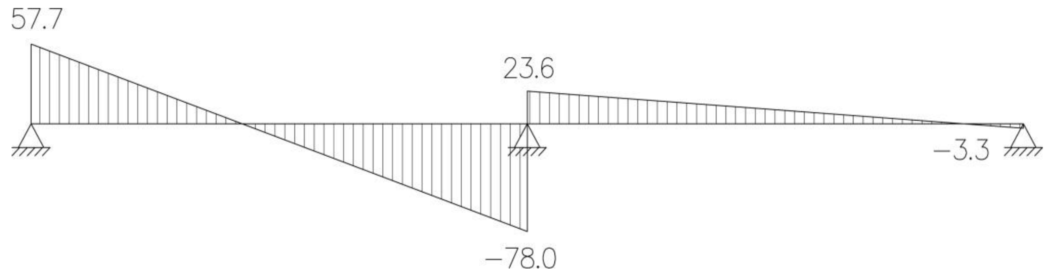
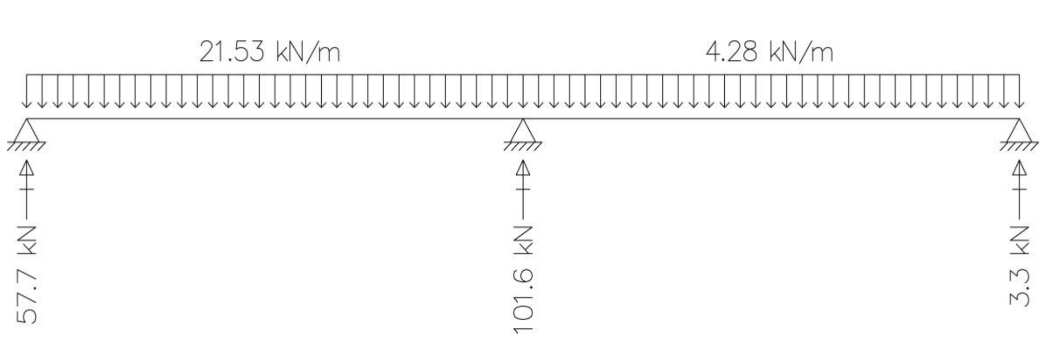


Figure 5.20. Reactions



Combination 3

On the right span: $q_d = G_k * \gamma_G = 4{,}28\ kN/m$

On the left span: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 21{,}53\ kN/m$

Figure 5.21. Bending moment diagram

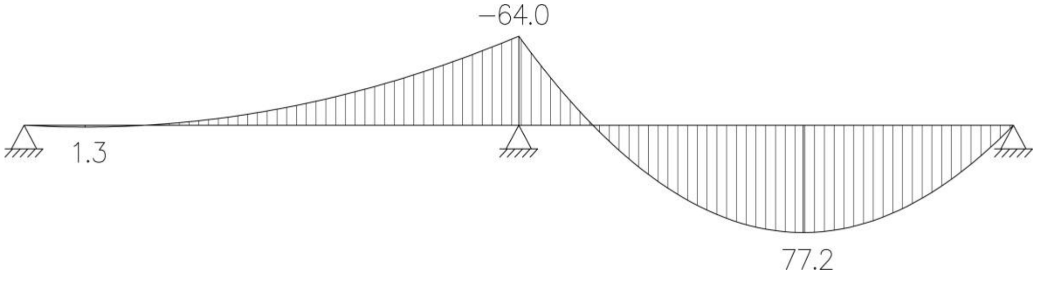


Figure 5.22. Shear force diagram

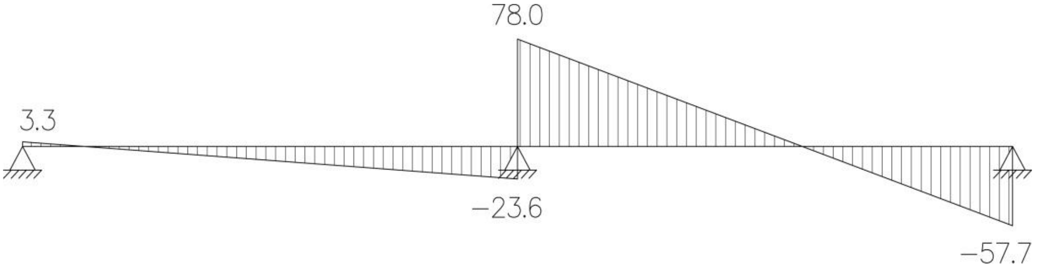
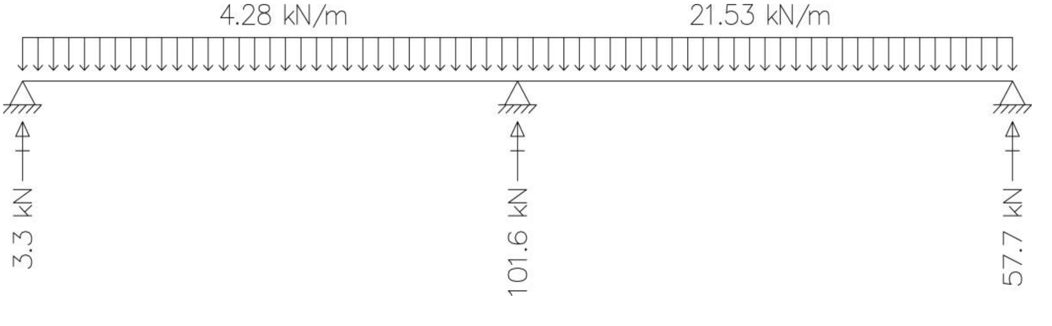


Figure 5.23. Reactions



Bending strength

Design bending moment

$M_d = 106{,}8\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 106800000 / 17171720 = 6{,}22\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0{,}9 * 1{,}1 / 1{,}25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 6{,}22 / (1 * 19) = 0{,}33 < 1$

Shear strength

Design value of the end shear force

$V_d = 84{,}8\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 84800 / (2 * 2300 * 198) = 0{,}28\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}28 / 1{,}8 = 0{,}15 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 169{,}5\ kN$

Design bearing stress

$\sigma_{c.90.d.1} = R_d / (b * l_1) = 169500 / (2300 * 98) = 0{,}75\ N/mm^2$

$\sigma_{c.90.d.2} = R_d / (b * l_2) = 169500 / (2300 * 49) = 1{,}5\ N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of bearing stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0{,}75 / 1{,}8 = 0{,}42 < 1$

$\sigma_{c.90.d.2} / f_{c.90.d} = 1{,}5 / 1{,}8 = 0{,}83 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 31{,}7 * 630^4) / (384 * 116 * 10^4 * 1{,}7 * 10^5) = 0{,}3 \ cm = 3{,}3 \ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 115 * 630^4) / (384 * 116 * 10^4 * 1{,}7 * 10^5) = 1{,}2 \ cm = 12 \ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 3{,}3 + 12 = 15{,}3 \ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 6300 / 300 = 21 \ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 3{,}3 * (1 + 0{,}6) = 5{,}28 mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 12 * (1 + 0{,}6) = 19{,}2 \ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 5{,}28 + 19{,}2 = 24{,}48 \ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 6300/250 = 25{,}2 \ mm$ – the slab does not exceed the limit

S3

Geometric properties

Effective span of the slab

$l = 3{,}5 \ m$

Bearing lengths at the ends of the slab

$l_1 = 9{,}8 \ cm$

Width

$b = 2 \ m$

Depth

$h = 19{,}8 \ cm$

Depth of transversal layers

$t_{1,5} = 3,9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 200 * 19,8 = 3960\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t_{1,5}^3) / 12 = (200 * 3,9^3) / 12 = 988,65\ cm^4$

$I_3 = (b * t_{,3}^3) / 12 = (200 * 4^3) / 12 = 1066,67\ cm^4$

Centers of gravity

$a_{1,3,5} = t_1/2 + t_2 + t_3/2 = 1,95 + 4 + 2 = 7,95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3,9 * 200 = 780\ cm^2$

$A_3 = t_3 * b = 4 * 200 = 800\ cm^2$

Flexibility factors

$\gamma_{1,7} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 780 * 3,9) / (350^2 * 0,5 * 200))^{-1} = 0,917$

$\gamma_{3,5} = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 800 * 4) / (350^2 * 0,5 * 200))^{-1} = 0,913$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 988,65 + 1066,67 + 2 * 0,917 * 780 * 7,95^2 + 0,913 * 800 * 7,95^2 =$

$= 1,4 * 10^5\ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1,4 * 10^5 / 19,8 = 14141,41\ cm^3$

Actions

Permanent actions

Second floor: $1,38 * 2 = 2,76\ kN/m$

Variable actions

Imposed load: $5 * 2 = 10\ kN/m$

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 2{,}76 * 1{,}35 + 10 * 1{,}5 = 18{,}73\ kN/m$

Bending strength

Design bending moment

$M_d = q_d * l^2 / 8 = 18{,}73 * 3{,}5^2 / 8 = 28{,}68\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 28680000 / 14141410 = 2{,}03\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0{,}9 * 1{,}1 / 1{,}25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 2{,}03 / (1 * 19) = 0{,}11 < 1$

Shear strength

Design value of the end shear force

$V_d = q_d * l / 2 = 18{,}73 * 3{,}5 / 2 = 32{,}78\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 32780 / (2 * 2000 * 198) = 0{,}12\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}12 / 1{,}8 = 0{,}067 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 32{,}78\ kN$

Design bearing stress

$\sigma_{c.90.d} = R_d / (b * l_1) = 32780 / (2000 * 98) = 0{,}17\ N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of bearing stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0,17 / 1,8 = 0,09 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 27,6 * 350^4) / (384 * 116 * 10^4 * 1,4 * 10^5) = 0,03 \ cm = 0,3 \ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 100 * 350^4) / (384 * 116 * 10^4 * 1,4 * 10^5) = 0,12 \ cm = 1,2 \ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 0,3 + 1,2 = 1,5 \ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 3500 / 300 = 11,67 \ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 0,3 * (1 + 0,6) = 0,48 \ mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 1,2 * (1 + 0,6) = 1,92 \ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 0,48 + 1,92 = 2,4 \ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 3500/250 = 14 \ mm$ – the slab does not exceed the limit

S4

Geometric properties

Effective span of the slab

$l = 3,5 \ m$

Bearing lengths at the ends of the slab

$l_1 = 9,8 \ cm$

Width

$b = 2,3 \ m$

Depth

$h = 19{,}8\ cm$

Depth of transversal layers

$t_{1,5} = 3{,}9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 230 * 19{,}8 = 4554\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of

transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t_{,1,5}^3) / 12 = (230 * 4^3) / 12 = 1226{,}67 cm^4$

$I_3 = (b * t_3^3) / 12 = (230 * 3{,}9^3) / 12 = 1136{,}95\ cm^4$

Centers of gravity

$a_{1,3,5} = t_1/2 + t_2 + t_3/2 = 1{,}95 + 4 + 2 = 7{,}95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3{,}9 * 230 = 897\ cm^2$

$A_3 = t_3 * b = 4 * 230 = 920\ cm^2$

Flexibility factors

$\gamma_{1,7} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3{,}14 * 116 * 897 * 3{,}9) / (350^2 * 0{,}5 * 230))^{-1} = 0{,}917$

$\gamma_{3,5} = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3{,}14 * 116 * 920 * 4) / (350^2 * 0{,}5 * 230))^{-1} = 0{,}913$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 1226{,}67 + 1136{,}95 + 2 * 0{,}917 * 897 * 7{,}95^2 + 0{,}913 * 920 * 7{,}95^2 =$

$= 1{,}6 * 10^5\ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1{,}6 * 10^5 / 19{,}8 = 16161{,}62\ cm^3$

Actions

Permanent actions

Second floor: *1,38 * 2,3 = 3,17 kN/m*

Variable actions

Imposed load: *5 * 2,3 = 11,5 kN/m*

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 3{,}17 * 1{,}35 + 11{,}5 * 1{,}5 = 21{,}53\ kN/m$

Bending strength

Design bending moment

$M_d = q_d * l^2 / 8 = 21{,}53 * 3{,}5^2 / 8 = 32{,}96\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 32960000 / 16161620 = 2{,}04\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0{,}9 * 1{,}1 / 1{,}25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 2{,}04 / (1 * 19) = 0{,}11 < 1$

Shear strength

Design value of the end shear force

$V_d = q_d * l / 2 = 21{,}53 * 3{,}5 / 2 = 37{,}68\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 37680 / (2 * 2300 * 198) = 0{,}12\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}12 / 1{,}8 = 0{,}07 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 37{,}68\ kN$

Design bearing stress

$\sigma_{c.90.d} = R_d / (b * l_1) = 37680 / (2300 * 98) = 0,17\ N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2,5 * 0,9 / 1,25 = 1,8\ N/mm^2$

Checking of shear stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0,17 / 1,8 = 0,09 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 31,7 * 350^4) / (384 * 116 * 10^4 * 1,6 * 10^5) = 0,03\ cm = 0,3\ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 115 * 350^4) / (384 * 116 * 10^4 * 1,6 * 10^5) = 0,12\ cm = 1,2\ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 0,3 + 1,2 = 1,5\ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 3500 / 300 = 11,67\ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 0,3 * (1 + 0,6) = 0,48\ mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 1,2 * (1 + 0,6) = 1,92\ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 0,48 + 1,92 = 2,4\ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 3500/250 = 14\ mm$ – the slab does not exceed the limit

S5

Geometric properties

Effective span of the slab

$l = 4,5\ m$

Bearing lengths at the ends of the slab

$l_1 = 9,8\ cm$

Width

$b = 2\ m$

Depth

$h = 17,3\ cm$

Depth of transversal layers

$t_{1,5} = 3,9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 200 * 19,8 = 3960\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t_{1,5}^3) / 12 = (200 * 3,9^3) / 12 = 988,65\ cm^4$

$I_3 = (b * t_3^3) / 12 = (200 * 4^3) / 12 = 1066,67\ cm^4$

Centers of gravity

$a_{1,3,5} = t_1/2 + t_2 + t_3/2 = 1,95 + 4 + 2 = 7,95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3,9 * 200 = 780\ cm^2$

$A_3 = t_3 * b = 4 * 200 = 800\ cm^2$

Flexibility factors

$\gamma_{1,7} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 780 * 3,9) / (450^2 * 0,5 * 200))^{-1} = 0,948$

$\gamma_{3,5} = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 800 * 4) / (450^2 * 0,5 * 200))^{-1} = 0,945$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 988,65 + 1066,67 + 2 * 0,948 * 780 * 7,95^2 + 0,945 * 800 * 7,95^2 =$

$= 1,44 * 10^5\ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1,44 * 10^5 / 19,8 = 14545,45\ cm^3$

Actions

Permanent actions

Second floor: $1,38 * 2 = 2,76\ kN/m$

Variable actions

Imposed load: $5 * 2 = 10\ kN/m$

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 2,76 * 1,35 + 10 * 1,5 = 18,73\ kN/m$

Bending strength

Design bending moment

$M_d = q_d * l^2 / 8 = 18,73 * 4,5^2 / 8 = 47,41\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 47410000 / 11907510 = 3,98\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0,9 * 1,1 / 1,25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 3,98 / (1 * 19) = 0,21 < 1$

Shear strength

Design value of the end shear force

$V_d = q_d * l / 2 = 18,73 * 4,5 / 2 = 42,14\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 42140 / (2 * 2000 * 198) = 0,16\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2,5 * 0,9 / 1,25 = 1,8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0,16 / 1,8 = 0,09 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 42{,}14\ kN$

Design bearing stress

$\sigma_{c.90.d} = R_d / (b * l_1) = 42140 / (2000 * 98) = 0{,}21 N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of bearing stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0{,}21 / 1{,}8 = 0{,}12 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 27{,}6 * 450^4) / (384 * 116 * 10^4 * 1{,}44 * 10^5) = 0{,}088\ cm = 0{,}88\ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 100 * 450^4) / (384 * 116 * 10^4 * 1{,}44 * 10^5) = 0{,}32\ cm = 3{,}2\ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 0{,}88 + 3{,}2 = 4{,}08\ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 4500 / 300 = 15\ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 0{,}88 * (1 + 0{,}6) = 1{,}41\ mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 3{,}2 * (1 + 0{,}6) = 5{,}12\ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 1{,}41 + 5{,}12 = 6{,}53\ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 4500/250 = 18\ mm$ – the slab does not exceed the limit

S6

Geometric properties

Effective span of the slab

$l = 4,5\ m$

Bearing lengths at the ends of the slab

$l_1 = 9,8\ cm$

Width

$b = 2,3\ m$

Depth

$h = 19,8\ cm$

Depth of transversal layers

$t_{1,5} = 3,9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 230 * 19,8 = 4554\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t,_{1,5}^3) / 12 = (230 * 4^3) / 12 = 1226,67 cm^4$

$I_3 = (b * t_3^3) / 12 = (230 * 3,9^3) / 12 = 1136,95\ cm^4$

Centers of gravity

$a_{1,3,5} = t_1/2 + t_2 + t_3/2 = 1,95 + 4 + 2 = 7,95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3,9 * 230 = 897\ cm^2$

$A_3 = t_3 * b = 4 * 230 = 920\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 897 * 3,9) / (450^2 * 0,5 * 230))^{-1} = 0,948$

$\gamma_3 = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 920 * 4) / (450^2 * 0,5 * 230))^{-1} = 0,945$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 1226,67 + 1136,95 + 2 * 0,948 * 897 * 7,95^2 + 0,945 * 920 * 7,95^2 =$

$= 1,66 * 10^5\ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1,66 * 10^5 / 19,8 = 16767,68\ cm^3$

Actions

Permanent actions

Second floor: $1,38 * 2,3 = 3,17\ kN/m$

Variable actions

Imposed load: $5 * 2,3 = 11,5\ kN/m$

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 3,17 * 1,35 + 11,5 * 1,5 = 21,53\ kN/m$

Bending strength

Design bending moment

$M_d = q_d * l^2 / 8 = 21,53 * 4,5^2 / 8 = 54,5\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 54500000 / 16767680 = 3,25\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0,9 * 1,1 / 1,25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 3,25 / (1 * 19) = 0,17 < 1$

Shear strength

Design value of the end shear force

$V_d = q_d * l / 2 = 21,53 * 4,5 / 2 = 48,44\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 48440 / (2 * 2300 * 198) = 0{,}16\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}16 / 1{,}8 = 0{,}09 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 48{,}44\ kN$

Design bearing stress

$\sigma_{c.90.d} = R_d / (b * l_1) = 48440 / (2300 * 98) = 0{,}21\ N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of bearing stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0{,}21 / 1{,}8 = 0{,}12 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 31{,}7 * 450^4) / (384 * 116 * 10^4 * 1{,}66 * 10^5) = 0{,}088\ cm = 0{,}88\ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 115 * 450^4) / (384 * 116 * 10^4 * 1{,}66 * 10^5) = 0{,}32\ cm = 3{,}2\ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 0{,}88 + 3{,}2 = 4{,}08\ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 4500 / 300 = 15\ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 0{,}88 * (1 + 0{,}6) = 1{,}41\ mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 3{,}2 * (1 + 0{,}6) = 5{,}12\ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 1{,}41 + 5{,}12 = 6{,}53\ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 4500/250 = 18\ mm$ – the slab does not exceed the limit

S7

Geometric properties

Effective span of the slab

$l = 3,75\ m$

Bearing lengths at the ends of the slab

$l_1 = 9,8\ cm$

Width

$b = 1,75\ m$

Depth

$h = 19,8\ cm$

Depth of transversal layers

$t_{1,5} = 3,9\ cm$

$t_3 = 4\ cm$

Depth of longitudinal layers

$t_{2,4} = 4\ cm$

Cross-section area

$A = b * h = 175 * 19,8 = 3465\ cm^2$

Effective moment of inertia

$I_{eff} = \sum (n_i * I_i + \gamma_i * n_i * A_i * a_i)$

Individual moment of inertia of transversal layers

$I_i = (b_i * t_i^3) / 12$

$I_{1,5} = (b * t_{,1,5}^3) / 12 = (175 * 4^3) / 12 = 933,33\ cm^4$

$I_3 = (b * t_3^3) / 12 = (175 * 3,9^3) / 12 = 865,07\ cm^4$

Centers of gravity

$a_{1,3,5} = t_1/2 + t_2 + t_3/2 = 1,95 + 4 + 2 = 7,95\ cm$

Areas of transversal layers

$A_{1,5} = t_{1,5} * b = 3,9 * 175 = 682,5\ cm^2$

$A_3 = t_3 * b = 4 * 175 = 700\ cm^2$

Flexibility factors

$\gamma_{1,5} = (1 + (\pi * E * A_{1,5} * t_{1,5}) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 682,5 * 3,9) / (375^2 * 0,5 * 175))^{-1} = 0,927$

$\gamma_3 = (1 + (\pi * E * A_3 * t_3) / (l^2 * G_{90} * b))^{-1} =$

$= (1 + (3,14 * 116 * 700 * 4) / (375^2 * 0,5 * 175))^{-1} = 0,923$

$I_{eff} = 2 * I_{1,5} + I_3 + 2 * \gamma_{1,5} * A_{1,5} * a_{1,5}^2 + \gamma_3 * A_3 * a_3^2 =$

$= 2 * 933,33 + 865,07 + 2 * 0,927 * 682,5 * 7,95^2 + 0,923 * 700 * 7,95^2 =$

$= 1,23 * 10^5\ cm^4$

Resisting moment

$W_{eff} = 2 * I_{eff} / h = 2 * 1,23 * 10^5 / 19,8 = 12424,24\ cm^3$

Actions

Permanent actions

Internal partitions: *3,09 * 5,3 = 16,38 kN/m*

Second floor: *1,38 * 1,75 = 2,41 kN/m*

Total permanent action: $G_k = 18,79\ kN$

Variable actions

Imposed load: *5 * 1,75 = 8,75 kN/m*

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 18,79 * 1,35 + 8,75 * 1,5 = 38,49\ kN/m$

Bending strength

Design bending moment

$M_d = q_d * l^2 / 8 = 38,49 * 3,75^2 / 8 = 67,66\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W_{eff} = 67660000 / 12424240 = 5,44\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0,9 * 1,1 / 1,25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 5,44 / (1 * 19) = 0,29 < 1$

Shear strength

Design value of the end shear force

$V_d = q_d * l / 2 = 38,49 * 3,75 / 2 = 72,17\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / (2 * b * h) = 3 * 72170 / (2 * 1750 * 198) = 0{,}31\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0{,}31 / 1{,}8 = 0{,}17 < 1$

Bearing strength

Design value of the end reaction

$R_d = V_d = 72{,}17\ kN$

Design bearing stress

$\sigma_{c.90.d} = R_d / (b * l_1) = 72170 / (1750 * 98) = 0{,}42\ N/mm^2$

Design bearing strength

$f_{c.90.d} = f_{c.90.k} * k_{mod.short} / \gamma_M = 2{,}5 * 0{,}9 / 1{,}25 = 1{,}8\ N/mm^2$

Checking of bearing stresses

$\sigma_{c.90.d.1} / f_{c.90.d} = 0{,}42 / 1{,}8 = 0{,}23 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst} = (5 * G_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 187{,}9 * 375^4) / (384 * 116 * 10^4 * 1{,}23 * 10^5) = 0{,}34\ cm = 3{,}4\ mm$

$u_{Qinst} = (5 * Q_k * l^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 87{,}5 * 375^4) / (384 * 116 * 10^4 * 1{,}23 * 10^5) = 0{,}16\ cm = 1{,}6\ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst} + u_{Qinst} = 3{,}4 + 1{,}6 = 5\ mm$

Limitation of deflection at the instantaneous state

$w_{inst} = l / 300 = 3750 / 300 = 12{,}5\ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG} = u_{Ginst} * (1 + k_{def}) = 3{,}4 * (1 + 0{,}6) = 5{,}44\ mm$

Final deflection due to variable actions

$u_{finQ} = u_{Qinst} * (1 + k_{def}) = 1{,}6 * (1 + 0{,}6) = 2{,}56\ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 5{,}44 + 2{,}56 = 8\ mm$

Adopting EC5 limitation on deflection

$w_{net.fin} = l / 250 = 3750/250 = 15\ mm$ – the slab does not exceed the limit

5.5. DESIGN OF RAFTERS

R1

Geometric properties

Effective span of the beam

$l = l_1 + l_2 = 3 + 6 = 9\ m$

Width

$b = 10\ cm$

Depth

$h = 20\ cm$

Cross-section area

$A = b * h = 10 * 20 = 200\ cm^2$

Moment of inertia

$I = (b * h^3) / 12 = (10 * 20^3) / 12 = 6666{,}67\ cm^4$

Resisting moment

$W = 2 * I / h = 2 * 6666{,}67 / 20 = 666{,}67\ cm^3$

Actions

Permanent actions

Roof weight: $0{,}88 * 0{,}1 = 0{,}088\ kN/m$

Variable actions

Snow load: $1{,}054 * 0{,}1 = 0{,}105\ kN/m$

Design compressive action for critical load combination

$q_d = G_k * \gamma_G + Q_k * \gamma_Q$

$q_d = 0{,}088 * 1{,}35 + 0{,}105 * 1{,}5 = 0{,}28\ kN/m$

Combination 1

On both spans: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 0{,}28\ kN/m$

Figure 5.24. Bending moment diagram

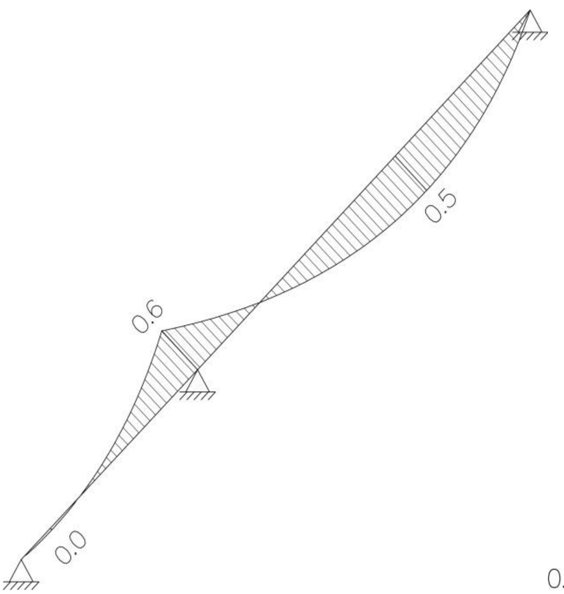


Figure 5.26. Reactions

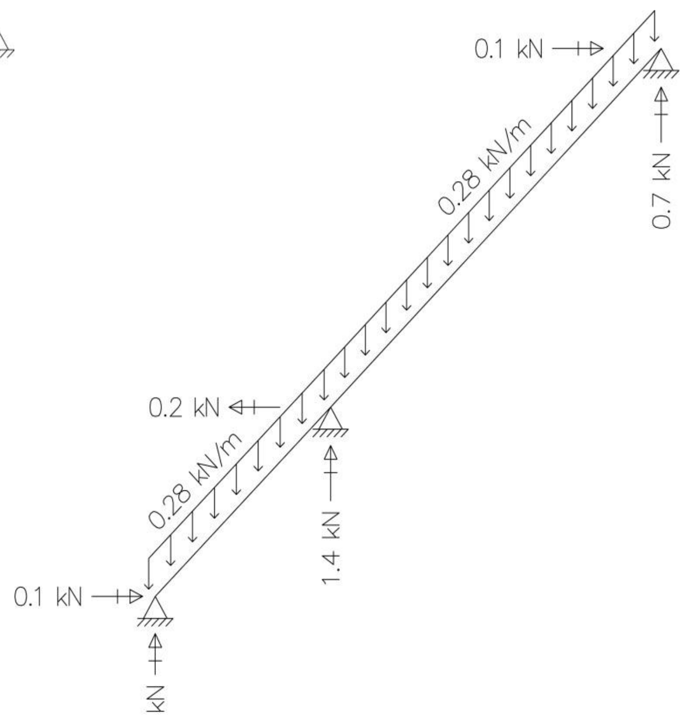
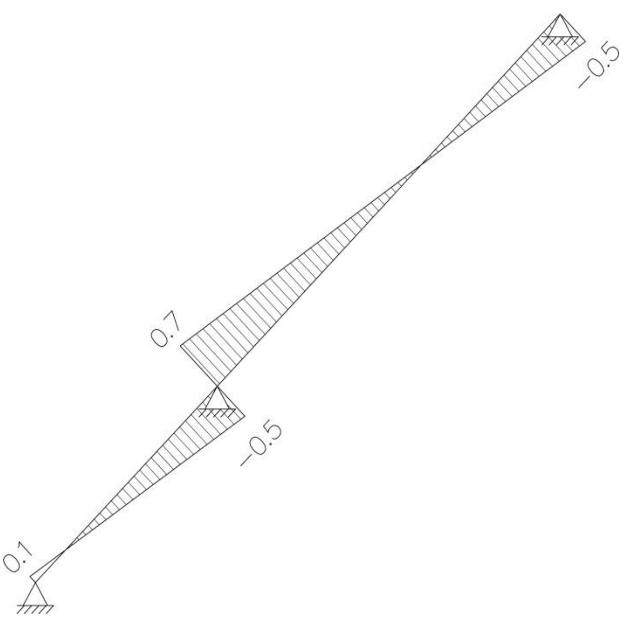
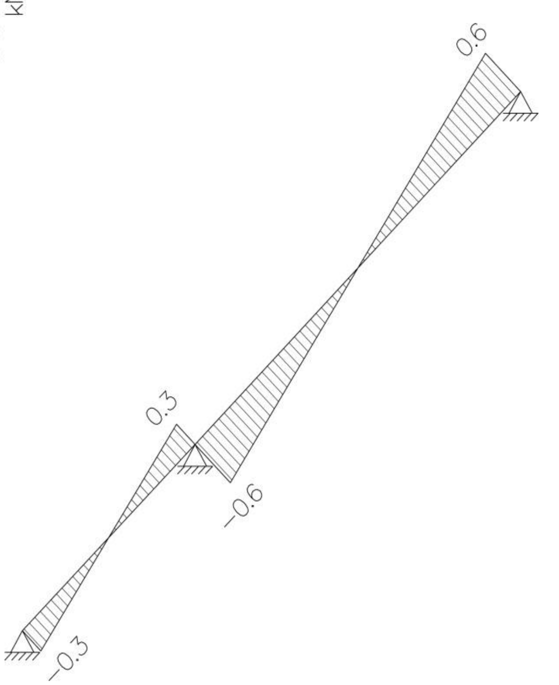


Figure 5.25. Shear force diagran





Combination 2

On the right span: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 0{,}28\ kN/m$

On the left span: $q_d = G_k * \gamma_G = 0{,}12\ kN/m$

Figure 5.27. Bending moment diagram

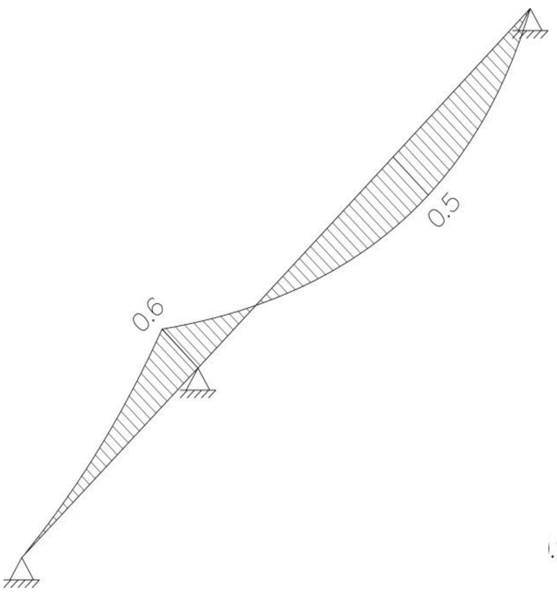


Figure 5.29. Reactions

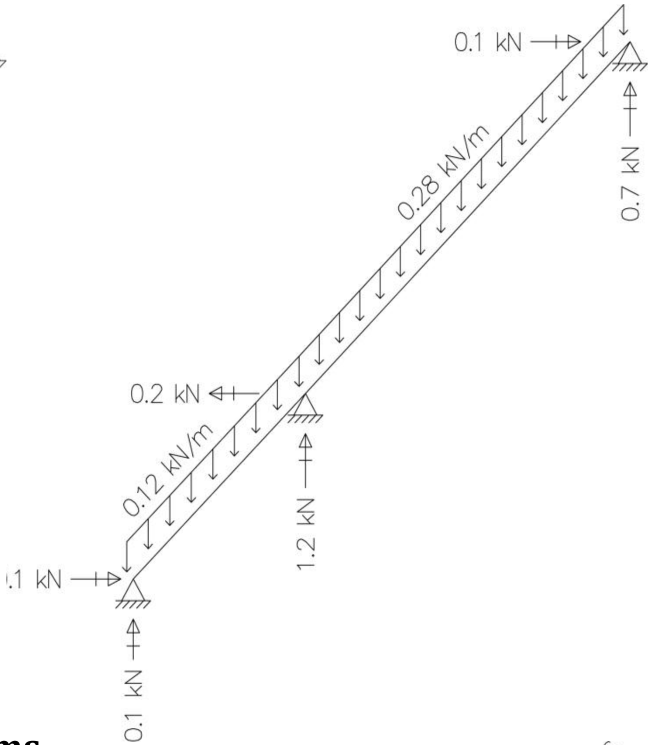
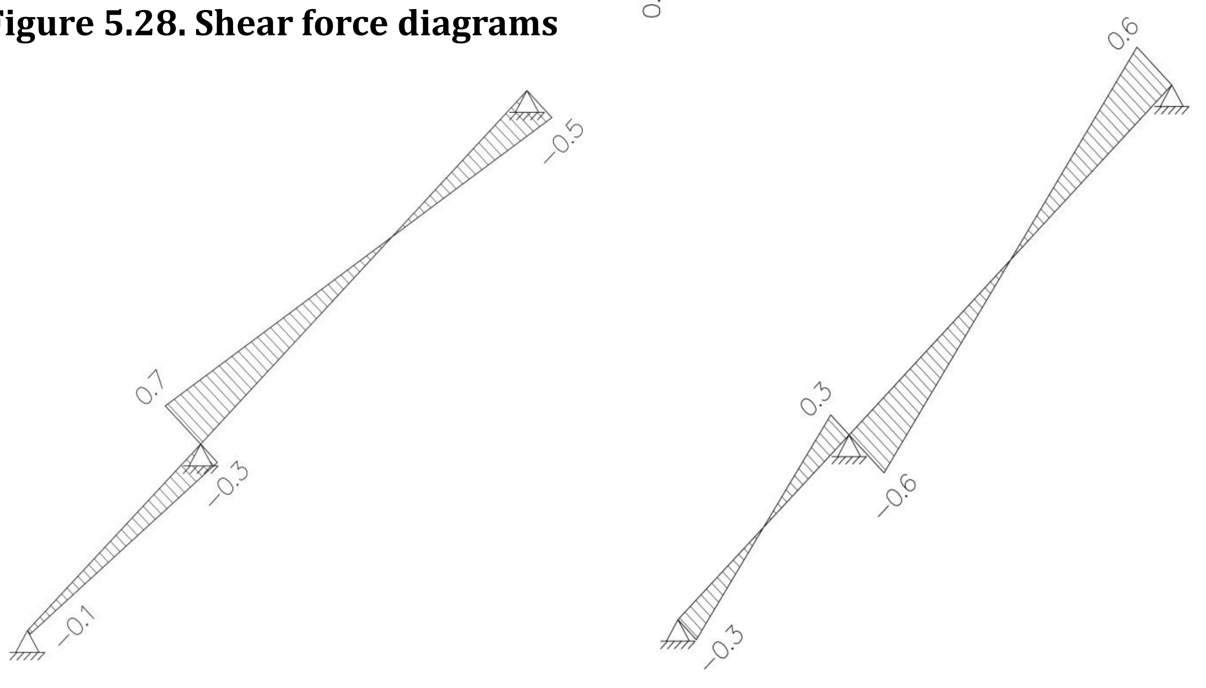


Figure 5.28. Shear force diagrams



Combination 3

On the right span: $q_d = G_k * \gamma_G = 0,12\ kN/m$

On the left span: $q_d = G_k * \gamma_G + Q_k * \gamma_Q = 0,28\ kN/m$

Figure 5.30. Bending moment diagram

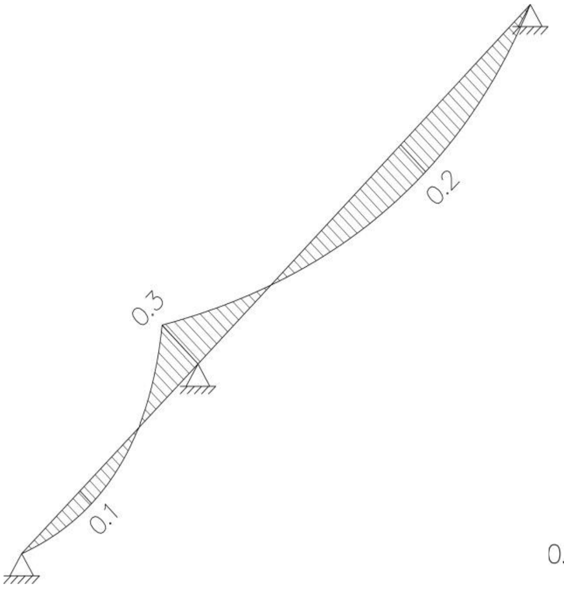


Figure 5.32. Reactions

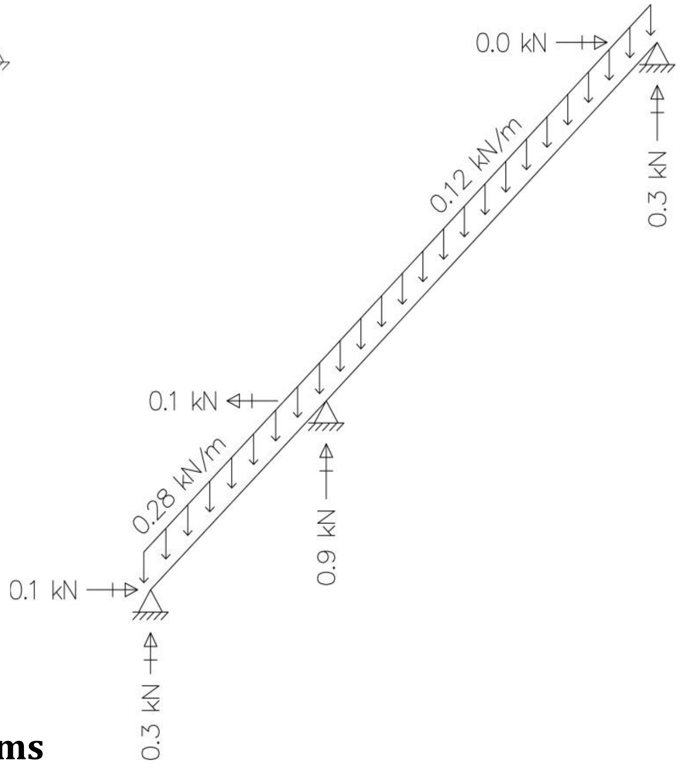
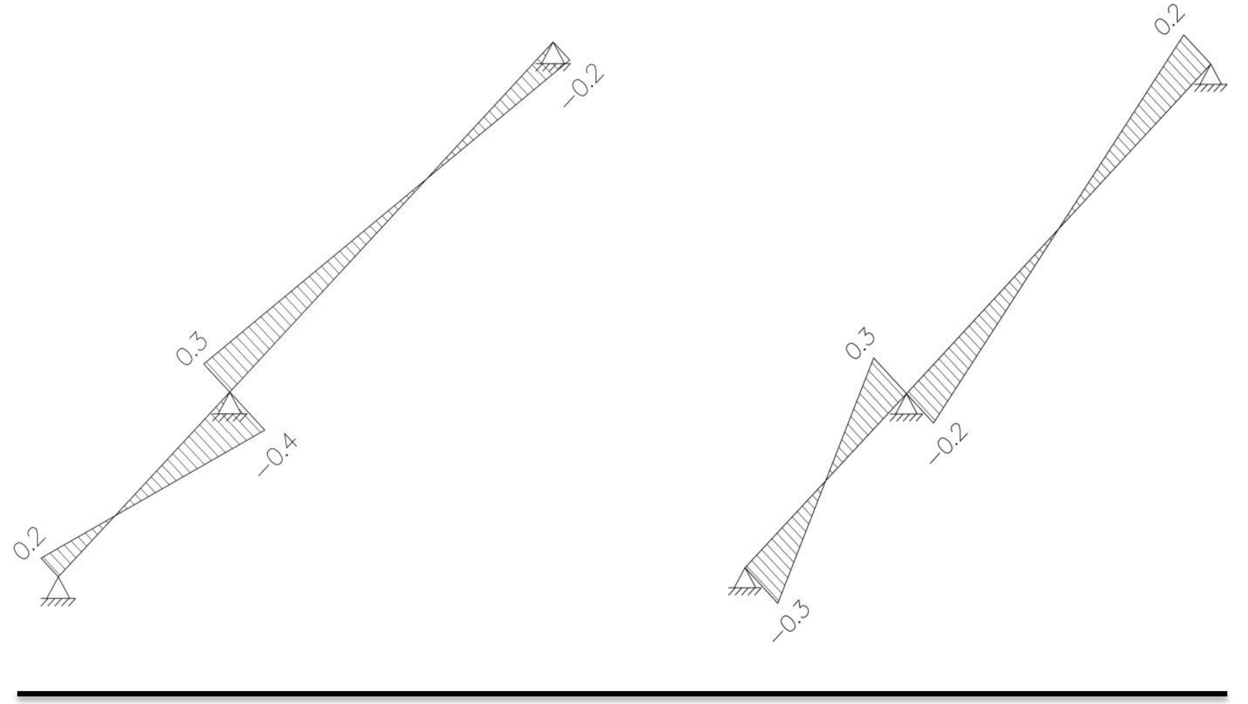


Figure 5.31. Shear force diagrams



Bending strength

Design bending moment

$M_d = 0,6\ kN\ m$

Design bending stress

$\sigma_{m.d} = M_d / W = 600000 / 666670 = 0,9\ N/mm^2$

Design bending strength

$f_{m.d} = f_{m.k} * k_{mod} * k_h / \gamma_M = 24 * 0,9 * 1,1 / 1,25 = 19\ N/mm^2$

Checking of bending stresses

$\sigma_{m.d} / (k_{crit} * f_{m.d}) = 0,9 / (1 * 19) = 0,05 < 1$

Shear strength

Design value of the end shear force

$V_d = 0,7\ kN$

Design shear stress

$\tau_{v.d} = 3 * V_d / 2 * b * h = 3 * 700 / 2 * 100 * 200 = 0,05\ N/mm^2$

Design shear strength

$f_{v.0.d} = f_{v.0.k} * k_{mod.short} / \gamma_M = 2,5 * 0,9 / 1,25 = 1,8\ N/mm^2$

Checking of shear stresses

$\tau_{v.d} / f_{m.0.d} = 0,05 / 1,8 = 0,03 < 1$

Deflection

Instantaneous deflection due to loading

$u_{Ginst1} = (5 * G_k * l_1^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 0,88 * 300^4) / (384 * 116 * 10^4 * 6666,67) = 0,012\ cm = 0,12\ mm$

$u_{Qinst1} = (5 * Q_k * l_1^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 1,05 * 300^4) / (384 * 116 * 10^4 * 6666,67) = 0,014\ cm = 0,14\ mm$

$u_{Ginst2} = (5 * G_k * l_2^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 0,88 * 600^4) / (384 * 116 * 10^4 * 6666,67) = 0,192\ cm = 1,92\ mm$

$u_{Qinst2} = (5 * Q_k * l_2^4) / (384 * E_0 * I_{eff}) =$

$= (5 * 1,05 * 600^4) / (384 * 116 * 10^4 * 6666,67) = 0,23\ cm = 2,3\ mm$

Instantaneous deflection at the mid-span of the slab

$u_{Ginst1} + u_{Qinst1} = 0,12 + 0,14 = 0,26\ mm$

$u_{Ginst2} + u_{Qinst2} = 1,92 + 2,3 = 4,22\ mm$

Limitation of deflection at the instantaneous state

$w_{inst1} = l_1 / 300 = 3000 / 300 = 10\ mm$ – the slab does not exceed the limit

$w_{inst2} = l_2 / 300 = 6000 / 300 = 20\ mm$ – the slab does not exceed the limit

Final deflection due to permanent actions

$u_{finG1} = u_{Ginst1} * (1 + k_{def}) = 0,12 * (1 + 0,6) = 0,19\ mm$

$u_{finG2} = u_{Ginst2} * (1 + k_{def}) = 1,92 * (1 + 0,6) = 3,07\ mm$

Final deflection due to variable actions

$u_{finQ1} = u_{Qinst1} * (1 + k_{def}) = 0,14 * (1 + 0,6) = 0,22\ mm$

$u_{finQ2} = u_{Qinst2} * (1 + k_{def}) = 2,3 * (1 + 0,6) = 3,68\ mm$

Final deflection due to permanent and variable actions

$u_{net.fin} = u_{finG} + u_{finQ} = 0,19 + 0,22 = 0,41\ mm$

$u_{net.fin} = u_{finG} + u_{finQ} = 3,07 + 3,68 = 6,75\ mm$

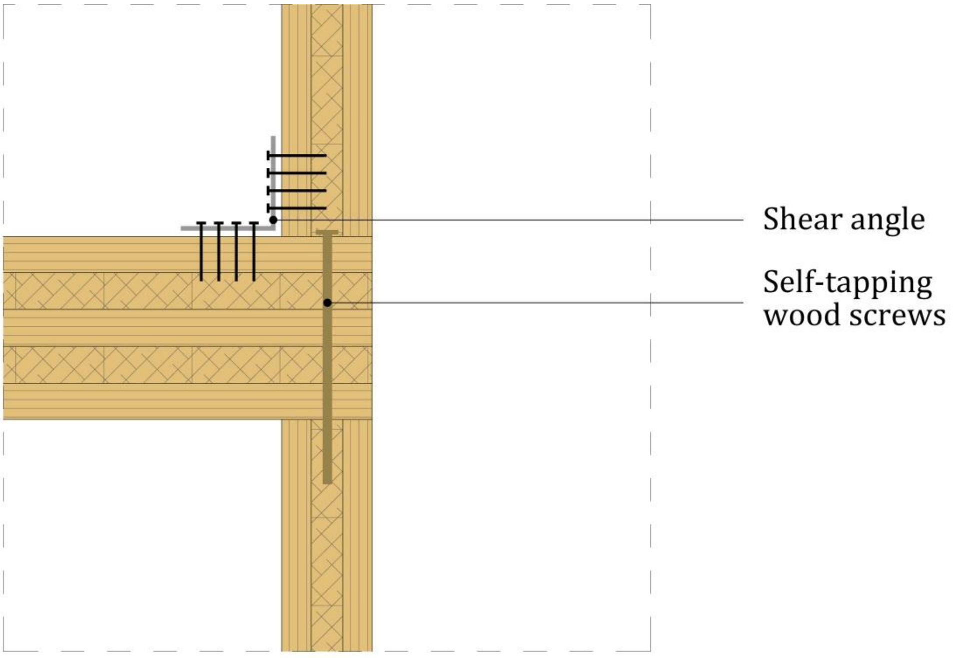
Adopting EC5 limitation on deflection

$w_{inst1} = l_1 / 250 = 3000 / 250 = 12\ mm$ – the slab does not exceed the limit

$w_{inst2} = l_2 / 250 = 6000 / 250 = 24\ mm$ – the slab does not exceed the limit

5.6. CONNECTIONS

Figure 5.33. Vertical connections



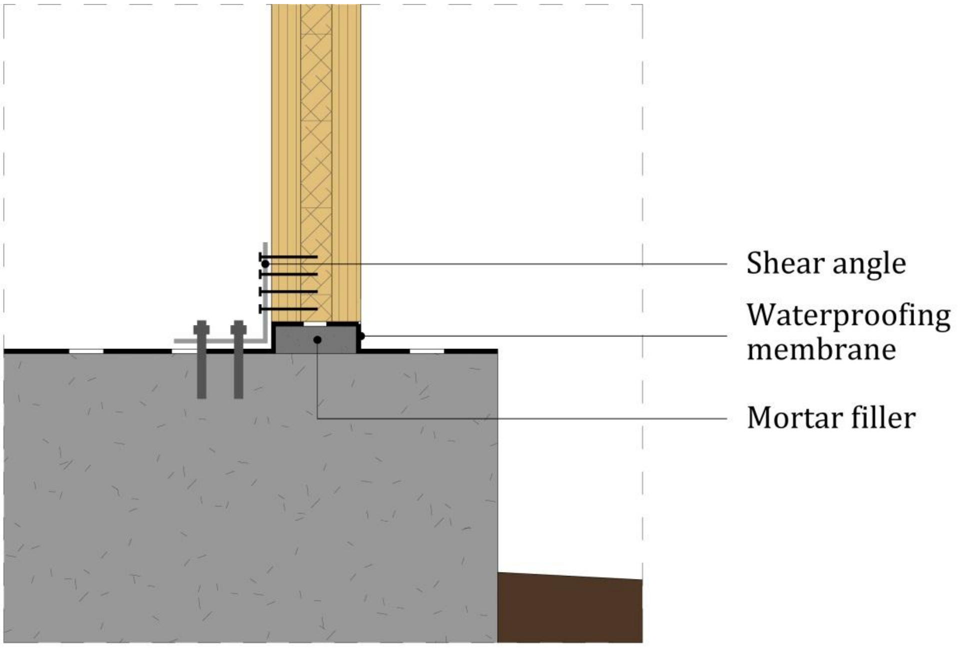


Figure 5.34. Horizontal connection

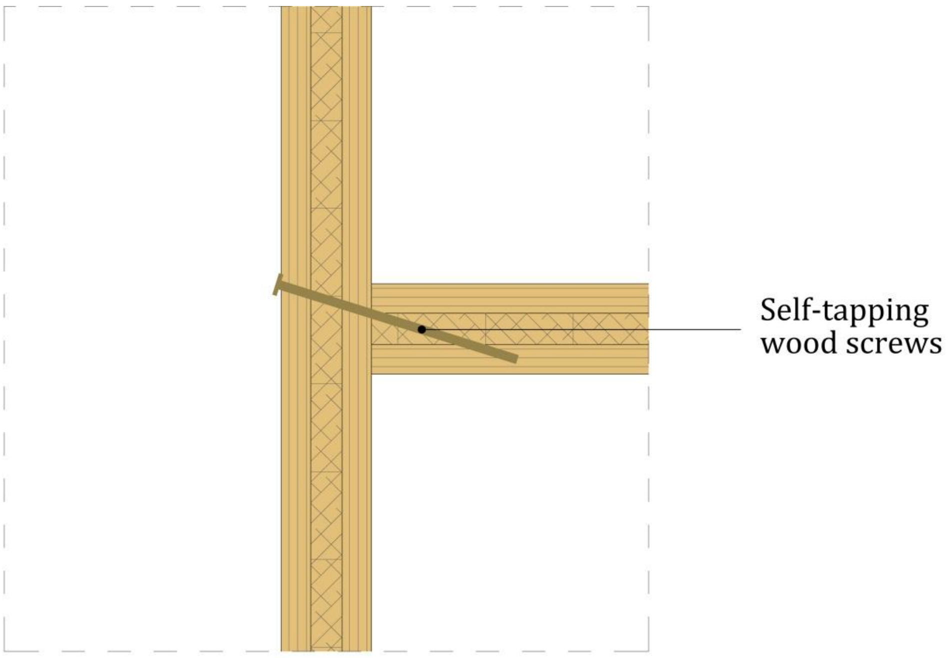
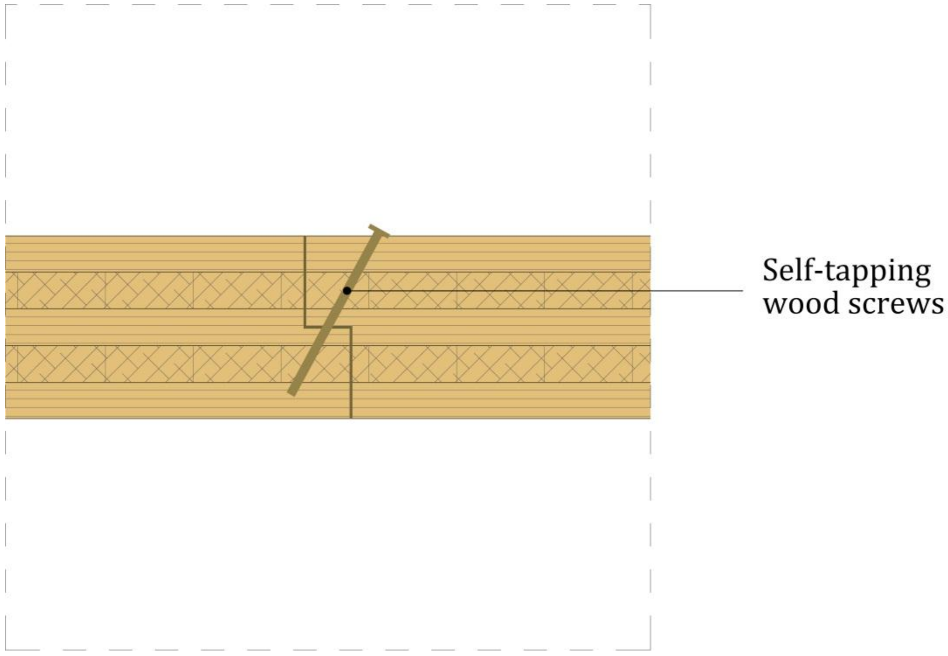


Figure 5.35. Connection between slabs



6. CONCLUSION

The main aim of the project consists of two parts: improvement of Russian family's life and familiarization with Russian traditions and life values.

Solving of the problem was started on the level of urban design. The project of residential settlement includes residential zone, consisting of different types of housing for solving the problem with accomonation of different groups of people, which are in need, as well as public, offices, educational and sport zones for proving high standard of living. Special zone in the project is the zone of sanatorium for medical aid to pregnant women and children with disabilities and for taking care about old people.

On the level of architectural design the second part of the problem was solved. The project of the center of the settlement includes three main parts: Church complex for familiarization with Russian world-view, Center of Russian Traditional Arts for familiarization with Russian traditions and Russian Cultural Center, created as link between these two parts and inhabitants and visitors. In the project of Russian Cultural Center it is important to create the space with harmonic combination of different types of activities. It consists of educational building, museum buildings, auditorium building and winter garden, which links them together.

For technological design the main Russian traditional materials – brick and timber – were chosen. Educational building consists of reinforced concrete bearing frame and non-bearing brick walls. For museum and auditorium buildings timber technologies were applied. One of museum buildings was chosen for detailed elaboration. For reaching indor environmental quality geothermal heating and cooling system with hydronic radiant floor and heat recovery ventilation system were applied. The important element in the climate with big quantity of rains is rainharvesting system. For generating electricity photovoltaic system is used.

For structural design of museum building cross-laninated timber panel are used. The panels have excellent strength and stiffness to weight ratio, very good load distribution and allow to minimize swelling and shrinkage. Its structural performance is compatible with pre-cast concrete.

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