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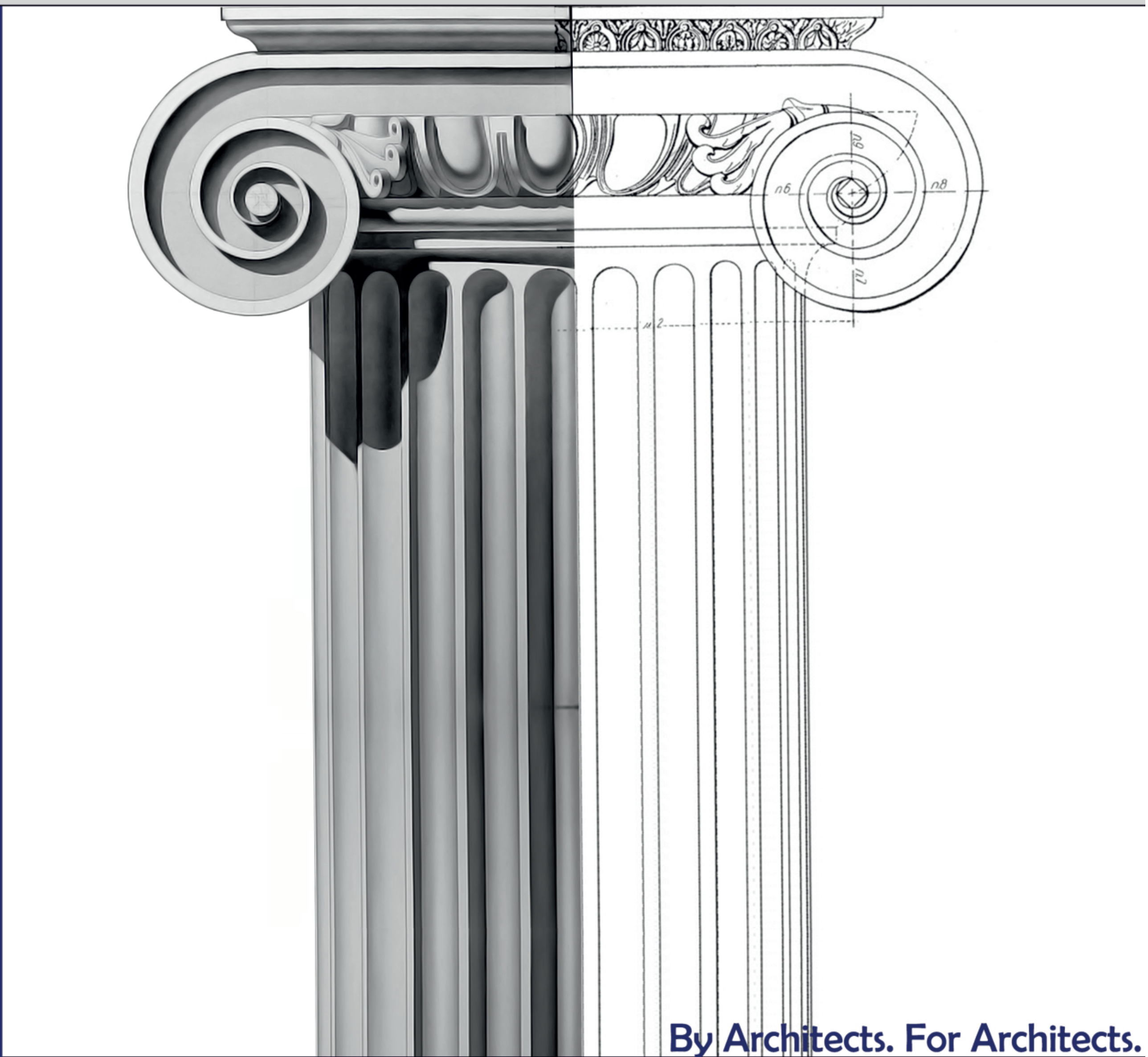
# ARCHITECTURE & ENGINEERING

Volume 6
Issue 3
September, 2021



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# Architecture and Engineering

Volume 6 Issue 3 (2021)

ISSN: 2500–0055





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**Architecture and Engineering**
peer-reviewed scientific journal
Start date: 2016/03
4 issues per year

**Founder, Publisher:**
Saint Petersburg State University
of Architecture and Civil Engineering

**Indexing:**
Scopus, EBSCO, Russian Science Citation Index, Directory of Open Access Journals (DOAJ), Google Scholar, Index Copernicus, Ulrich's Periodicals Directory, WorldCat, Bielefeld Academic Search Engine (BASE), Library of University of Cambridge and CyberLeninka.

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Email: aejeditorialoffice@gmail.com

Date of issue: 29.09.2021

The Journal was re-registered by the Federal Service for Supervision of Communications, Information Technologies and Mass Communications (Roskomnadzor) on May 31, 2017; registration certificate of media organization El No. FS77–70026.

DOI: 10.23968/2500-0055-2021-6-3-03-10

# SOLVING HEAT ENGINEERING PROBLEMS USING THE FINITE ELEMENT METHOD

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**Abstract**
**Introduction:** In the course of the study, we examined energy-efficient and environmentally friendly heat-insulating materials based on gypsum and gypsum-containing primary components. **Purpose of the study:** We aimed to assess the effectiveness of using gypsum materials in wall structures, by using the finite element method based on the ANSYS Steady State Thermal module. Porous materials of different densities (structural, structural and heat-insulating, and heat-insulating gypsum concrete) were used as wall materials. These materials were obtained as a result of the interaction between residual sulfuric acid adsorbed on the grains of "acidic" fluoroanhydrite and carbonate flour. **Methods:** The finite element method based on the ANSYS Steady State Thermal module was used. The thermal conductivity of the structures was evaluated in a three-dimensional coordinate system. The experimental values of thermal and physical characteristics were adopted for the walling fragments. **Results:** The problem was solved numerically, by using the finite element method based on the ANSYS Steady State Thermal module. We established that the developed structural and heat-insulating gypsum concrete is more effective since, under the set design conditions, the temperature of the inner surface of such a wall at the minimum (510 mm) and maximum (770 mm) structure thickness exceeds the temperature of the inner surface of walls made of different materials.

**Keywords**
Fluoroanhydrite, gypsum concrete, calcium compounds, structure formation processes, finite element method, wall material, thermal conductivity.

## Introduction

To implement the strategic tasks of resource and energy saving, we need to search for innovative technologies and justify the likelihood of improving the competitiveness of materials used for walling insulation. Among the currently used materials, energy-efficient and environmentally friendly heat-insulating materials based on gypsum and gypsum-containing primary components can be mentioned. Materials based on gypsum binders are characterized by high strength, heat and sound insulation properties, as well as fire and water resistance (Chernyshov et al., 2016; Pukharenko and Kharitonova, 2018; Zavadsky et al., 2003).

To reduce the average density of gypsum materials, porous aggregates as well as gas- and foam-forming admixtures can be used. Besides, admixtures generating gas in chemical reactions are also quite popular. This method is not new. Many researchers have been exploring this direction (Belov et al., 2012; Garkavi et al., 2018). However, their approaches to gas formation processes differ. We suggest using fluoroanhydrite raw materials as a pore-forming admixture, with sulfuric acid adsorbed on its grains and additional components generating gas in reactions with acid (Anikanova et al., 2020, 2021; Volkova and Anikanova, 2020). The implementation of this approach made it possible to develop structural, structural and heat-insulating, and heat-insulating gypsum concrete. However, evaluation of their effectiveness (as compared with traditional materials) is a labor- and time-consuming task. To assess the effectiveness of using gypsum materials in wall structures, we applied the finite element method based on the ANSYS Steady State Thermal module.

## Materials and methods

Normally hardening gypsum of medium grinding, G-5 AII grade (State Standard GOST 125–2018), was used to manufacture wall materials. As a pore-forming component, "acidic" fluoroanhydrite (Specifications TU 2141–030-07622928–2019) was used together with calcium carbonate (State Standard GOST 32802–2014). According to the results of preliminary studies, without additional processing and chemical modification, fluoroanhydrite cannot be used to manufacture building products due to slow hydration and setting as well as poor strength characteristics. We used acidic fluoroanhydrite modified in a disintegrator, with sulfuric acid adsorbed on its grains, where fluoroanhydrite served as the “carrier” of the acid.

As a plasticizer, we used Steinberg superplasticizers with a concentration of 1, 1.6, 2, 5, and 10%, calculated with reference to the dried substance. They were introduced into the gypsum binder together with mixing water. The technical characteristics of Steinberg MP-4 and Steinberg PR-1S(A) superplasticizers were described by Lesovik et al. (2012) and Ponomarenko and Kapustin (2011). Citric acid (State Standard GOST 908–2004) was used as inhibiting the setting time of gypsum plaster.

The optimal amount of water was determined empirically until the normal consistency of gypsum dough was reached (according to State Standard GOST 125–2018). Using these materials, we formed standard samples of structural, structural and heat-insulating, and heat-insulating gypsum concrete and studied those in combination with masonry.

The problems were solved numerically, by using the ANSYS Steady State Thermal module, which is based on the finite element method. The thermal conductivity problems were solved in a full three-dimensional formulation. The experimental values of thermal and physical characteristics were adopted for the walling fragments.

As part of the calculation of temperature fields, a finite element (FE) mesh was assigned for each of the walling options.

**Results and discussion**

As a result of the research, we obtained samples of wall materials with adjustable characteristics (strength and average density). The porous structure of the material was formed as a result of the interaction between residual acid and carbonate flour. Since fluoroanhydrite represents a waste product of hydrofluoric acid production, and carbonate flour was obtained by grinding natural limestone, the cost of the materials is reduced significantly. Having analyzed the impact of the superplasticizers on the strength of the samples, we established the following: the use of Steinberg MP-4 plasticizer in the amount of 2% of the gypsum weight is optimal to ensure high strength, which is 27 MPa. This is due to a decrease in the water demand of the raw mixture and the participation of polycarboxylate in the gypsum stone structure formation (Fedorchuk, 2005; Garkavi et al., 2018). A gradual decrease in strength with a plasticizer concentration of more than 2% in the mixture is due to the impact of the polycarboxylate component on the hardening kinetics and stone structure. The admixture ensures additional entrainment of air bubbles and, therefore, makes it possible to obtain a less dense composite structure (Anikanova et al., 2018, 2019). The use of Steinberg PR-1S(A) plasticizer reduces the strength characteristics of the samples. The maximum strength, which is 7.4 MPa, was obtained at a plasticizer concentration of 2% of the gypsum weight, which is 2.5 times lower than the reference value (Erofeev et al., 2020; Medvedeva and Sautkina, 2019). The heat engineering characteristics of the structure were studied in accordance with Table 1.

The thermal conductivity problems were solved in a full three-dimensional formulation. Figures 1–3 show options of walling models considered in the study.

The geometric parameters of solid masonry (option 1) (figure 1) are as follows: thickness (a): 510, 640, and 770 mm; the height (b) and length of the samples were taken as 1000 mm.

The geometric parameters of three-layer masonry (option 2) (figure 2) are as follows: total thickness (a): 490, 620, and 750 mm; the height (b) and length of the samples were taken as 1000 mm; thickness of the bearing layer (1, c): 250, 380 510 mm; thickness of the insulation layer (2, d): 120 mm for all cases; thickness of the facing layer (3, c): 120 mm for all cases.

The geometric parameters of masonry with plastering (option 3) (figure 3) are as follows: total thickness (a): 560, 690, and 820 mm; the height (b) and length of the samples were taken as 1000 mm; thickness of the bearing layer (1, c): 510, 640, 770 mm; thickness of the plaster layer (2, d): 50 mm for all cases.

Table 1. Initial characteristics of the wall materials

| Material | Thermal conductivity coefficient, λ (W/(m·°C)) | Heat capacity, c (J/(kg·°C)) | Density, ρ (kg/m3) |
|---|---|---|---|
| Masonry | 0.64 | 880 | 1600 |
| Structural gypsum concrete (type 1) | 0.51 | 1090 | 1900 |
| Structural and heat-insulating gypsum concrete (type 2) | 0.23 | 840 | 1300 |
| Heat-insulating gypsum concrete (type 3) | 0.12 | 840 | 500 |

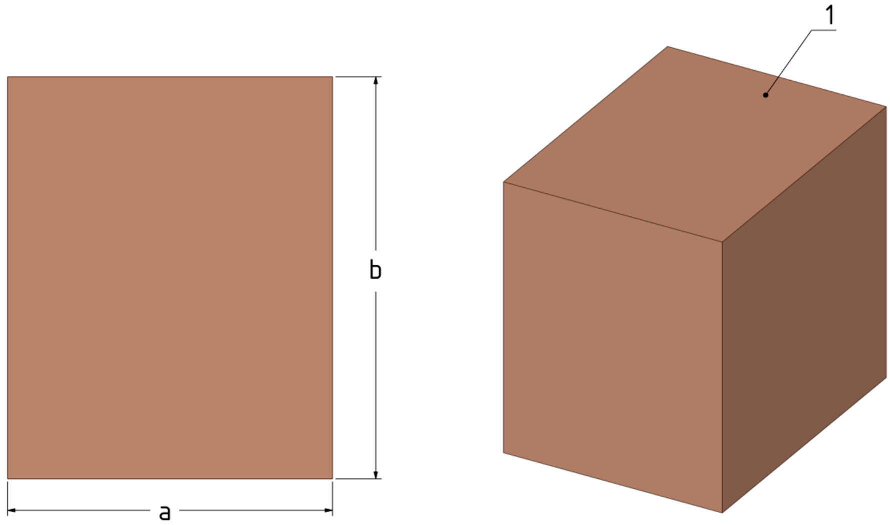


Figure 1. General view of a 3D model of a solid wall (option 1): thickness (a); height (b); solid wall material (1) — masonry, gypsum concrete (type 1, type 2)

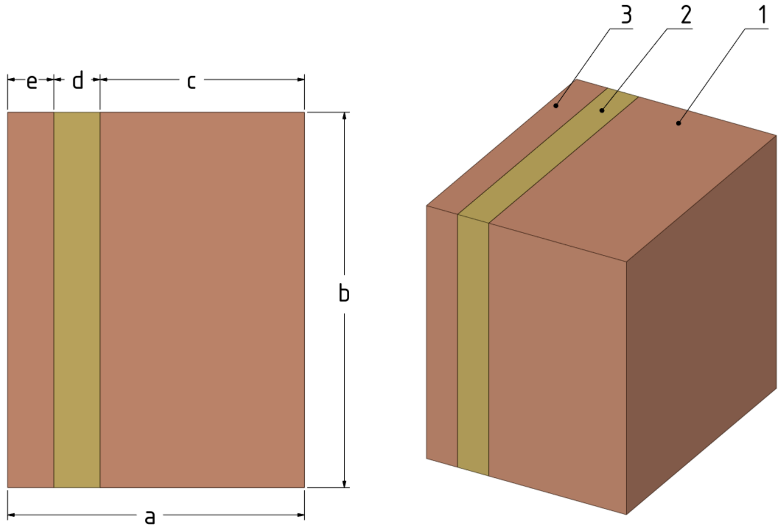


Figure 2. General view of a 3D model of a three-layer wall (option 2): thickness (a); height (b); bearing layer (c); insulation layer (d); facing layer (e); bearing layer material (1) — masonry; insulation layer material (2) — gypsum concrete (type 3); facing layer material (3) — masonry

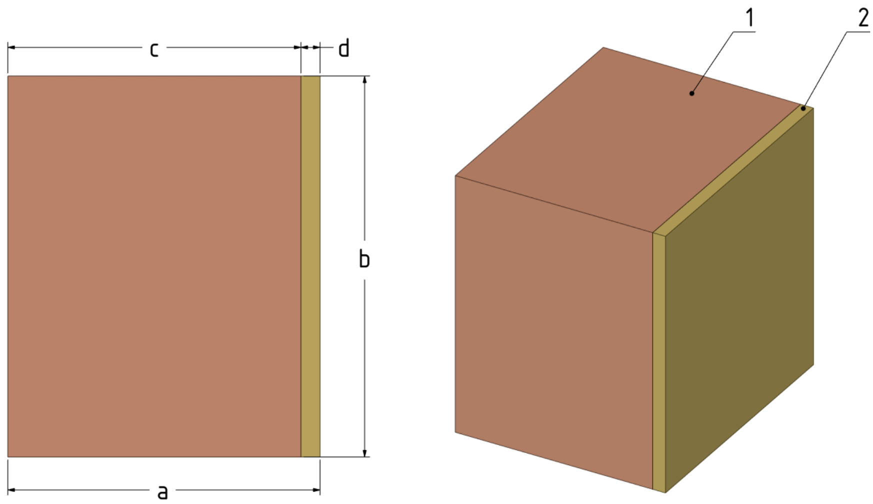


Figure 3. General view of a 3D model of a wall with plastering (option 3): thickness (a); height (b); bearing layer (c); insulation layer (d); bearing layer material (1) — masonry; plaster layer material (2) — heat-insulating gypsum concrete (type 3)

As part of the calculation of temperature fields, a finite element (FE) mesh was assigned for each of the walling options (figure 4). For option 1, the size of the FE mesh was 50 mm; for option 2 (insulation and facing layers) — 60 mm; for option 3 (plaster layer) — 12.5 mm. Thus, depending on the option as well as the varying thickness of the walls and layers, the dimension of the problems ranged from 4000 to 30,964 FEs.

A low order SOLID70 element, which has a 3D stationary or transient thermal conduction capability, was used as a FE (Znobishchev and Shamraeva, 2019). The element has eight nodes with a single degree of freedom (figure 5).

**Initial and boundary conditions**

As initial conditions in the computational domain, a temperature field was determined for each element (layer) of the structure, corresponding to the solution of the following stationary problem:

$$t_i\big|\tau = 0 = t_0\left(x, y, z\right), \quad i = 1, \ldots, N, \quad x, y, z \in \Omega.$$

All inner and outer surfaces of the considered structural fragments are characterized by boundary conditions of the third kind, which take into account heat exchange between these surfaces and the environment. For inner surfaces, they can be written in the following form:

$$-\lambda_{n,m} \frac{\partial t_m}{\partial n}\bigg|_{n=0} = \alpha_{int}\left(t_{int} - t_{surf,ext}\right),$$

where $n$ — the direction of the normal to the corresponding surface; $m$ — the number of the structural element that contacts with internal air; $\lambda_{n,m}$ — thermal conductivity coefficient of the element material; $t_{surf}$ — the temperature of the contacting surface.

At the interface of two adjacent elements, boundary conditions of the fourth kind were applied. In accordance with these conditions, the temperatures and heat fluxes shall be equal:

$$t_{bound,m}\big|_{bound} = t_{bound,m+1}\big|_{bound};$$

$$-\lambda_{n,m} \frac{\partial t_m}{\partial n}\bigg|_{bound} = -\lambda_{n,m+1} \frac{\partial t_{m+1}}{\partial n}\bigg|_{bound}.$$

For all ends of the considered structural fragments, symmetry conditions, corresponding to boundary conditions of the second kind with zero heat flux density, were established:

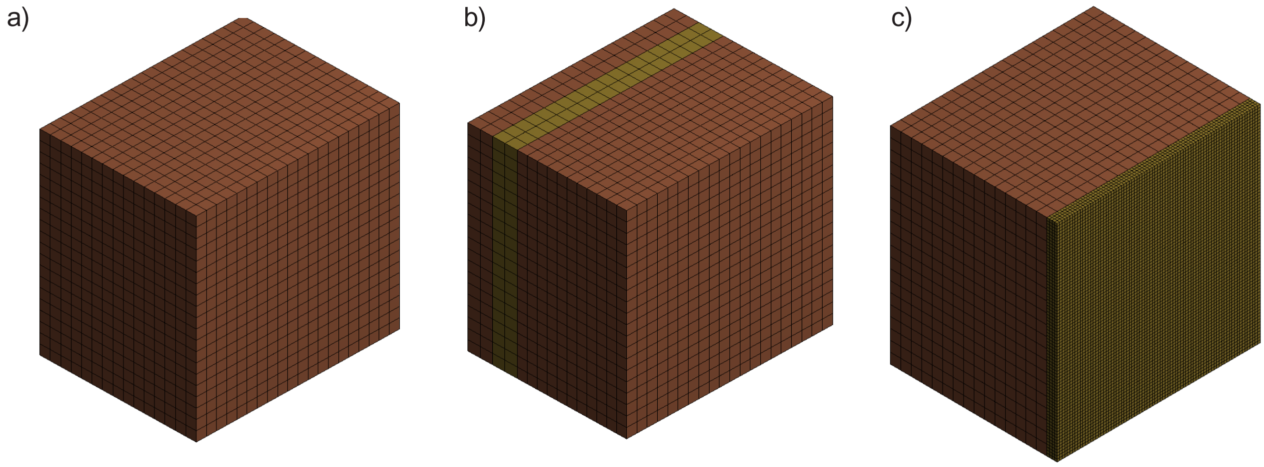


Figure 4. General view of the FE mesh for the options under consideration: option 1 (a); option 2 (b); option 3 (c)

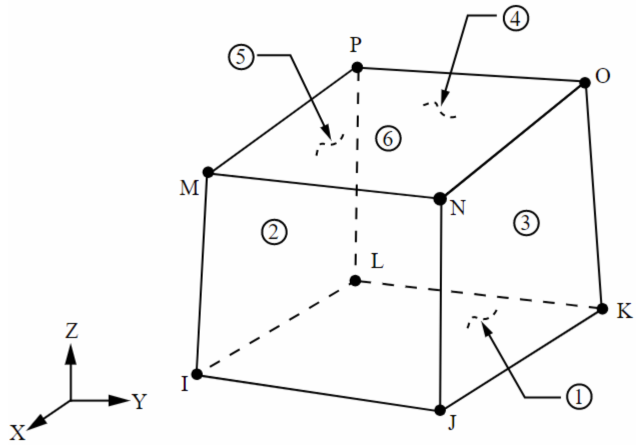


Figure 5. General view of the SOLID70 FE mesh

$$q\big|_{bound} = 0.$$

External temperature was $t_{ext}$ = –39°C and internal temperature was $t_{int}$ = 23 °C. The problems take into account the convection component in accordance with Regulations SP 50.13330.2012 “Thermal performance of the buildings”. The heat transfer coefficients were as follows: on the outer surface — $\alpha_{ext}$ = 23 W/(m2·°C), on the inner surface — $\alpha_{int}$ = 8.7 W/(m·°C) (figure 6).

**Conclusions**

Following the calculations, we obtained temperature fields for each of the considered walling options and materials used. The paper presents the results for design options with a maximum thickness of 770 mm. Figure 7 shows the temperature distribution for three walling options with a thickness of 770 mm. To compare the results of the temperature fields, Figure 7a shows an option of masonry with the required thickness.

According to the results presented in Figure 7, the inner surface of the walls has the following temperatures: in the case of option 1, 17.76 °C (a); in the case of structural and heat-insulating gypsum concrete — 20.97 °C (b); in the case of three-layer masonry with heat-insulating concrete — 19.72 °C (c); in the case of masonry with plastering using heat-insulating concrete — 18.99 °C (d).

Based on the presented research results, the following conclusions can be drawn:

1. Heat engineering problems can be solved numerically, by using the ANSYS Steady State Thermal module, which is based on the finite element method, to assess the effectiveness of using gypsum concrete in wall structures.
2. For the presented types of structural, structural and heat-insulating, and heat-insulating gypsum concrete with the particular thermal conductivity coefficients, heat capacity, and average density (Table 1), we developed three options of 3D walling models, calculated temperature fields for each of the considered walling options and materials used with a thickness of 770 mm, and compared the results with those in the case of masonry.
3. The presented model options in terms of temperature distribution throughout the wall thickness are comparable with masonry and make it possible to increase the temperature of the inner surface of walls from 17.76 (masonry) to 20.97 °C when using structural and heat-insulating gypsum concrete, without masonry of the same thickness.

Thus, in terms of the temperature of the inner surface of walls, the results obtained are comparable with those for masonry with a standard thickness of 770 mm. The developed structural and heat-insulating gypsum concrete (type 2, Table 1) is more effective than masonry since, under these particular design conditions, the temperature of the inner surface of a wall exceeds the temperature of the inner surface of masonry by 3 °C on average.

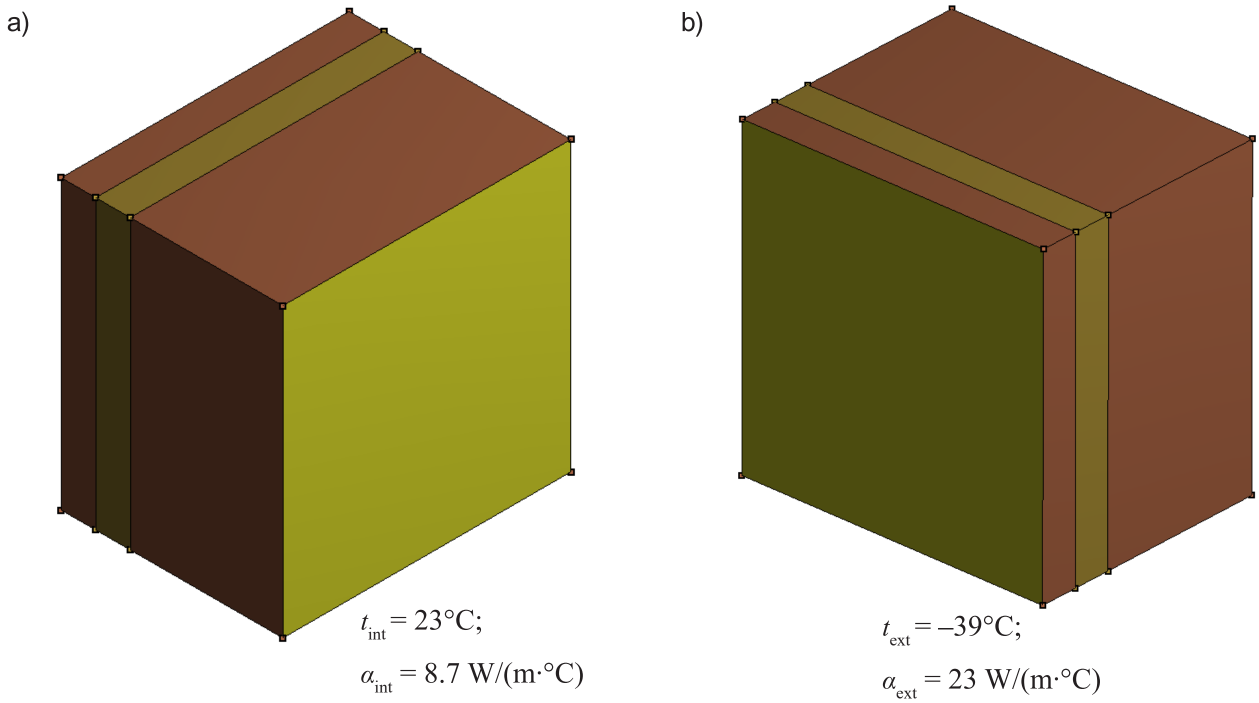


Figure 6. General principle of applying boundary conditions: the inner surface of the wall (a); the outer surface of the wall (b)

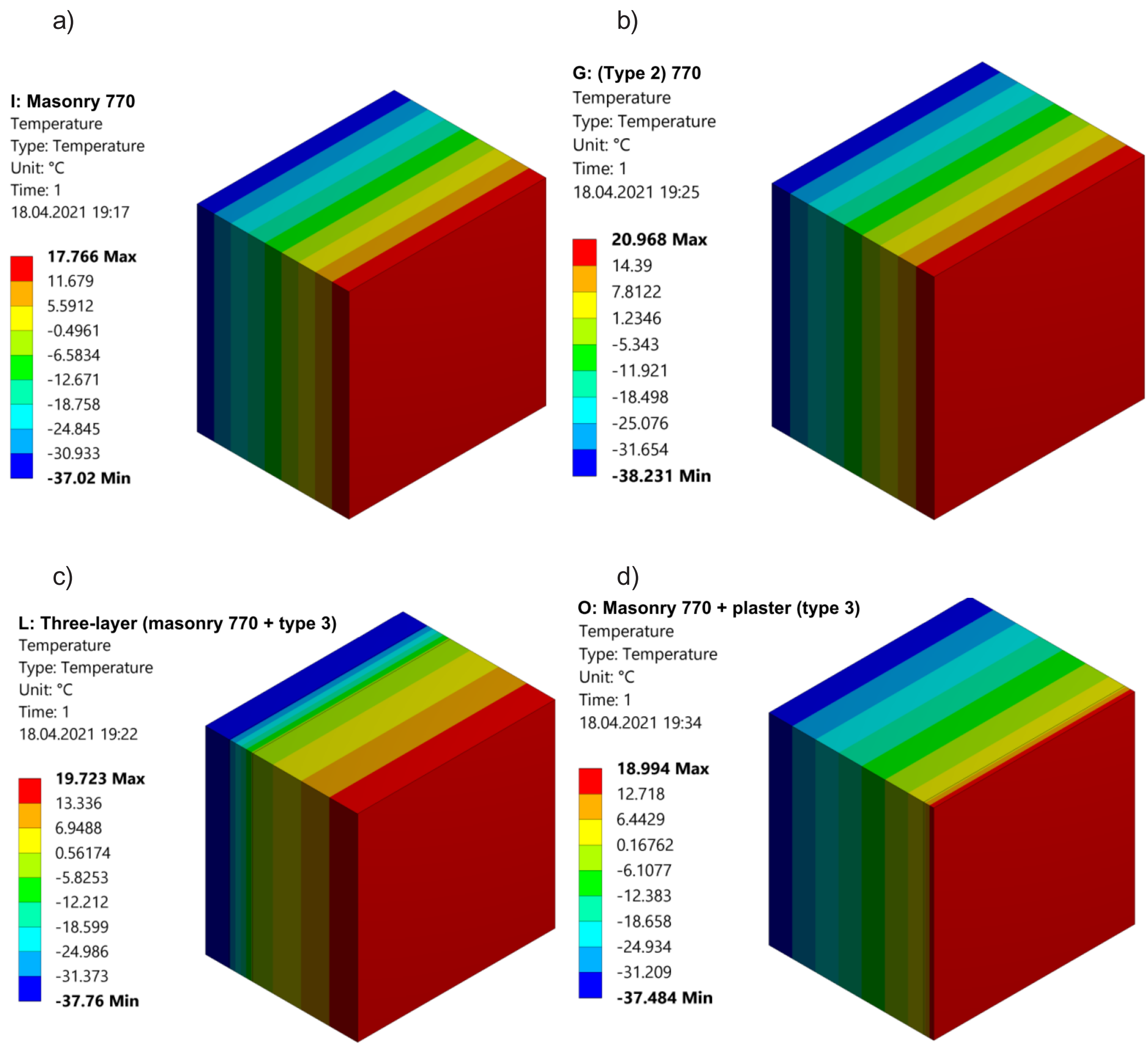


Figure 7. Temperature distribution in a 770 mm thick wall: option 1, masonry (a); option 2, structural and heat-insulating gypsum concrete (b); option 3, three-layer masonry with heat-insulating concrete (c); option 4, masonry with plastering using heat-insulating gypsum concrete (d)

## References

Anikanova, L. A., Kurmangalieva, A. I., Volkova, O. V. and Fedorchuk, Yu. M. (2018). Foamed gypsum materials with fluoride additive. *Vestnik Tomskogo Gosudarstvennogo Arkhitekturno-Stroitel'nogo Universiteta. Journal of Construction and Architecture*, No. 6, pp. 126–137. DOI: 10.31675/1607–1859–2018–20–6–126-137.

Anikanova, L. A., Kurmangalieva, A. I., Volkova, O. V. and Pervushina, D. M. (2020). Gas-gypsum materials properties modified by plasticizing agents. *Vestnik Tomskogo Gosudarstvennogo Arkhitekturno-Stroitel'nogo Universiteta. Journal of Construction and Architecture*, No. 22 (1), pp. 106–117. DOI: 10.31675/1607–1859-2020–22–1–106-117.

Anikanova, L. A., Volkova, O. V., Kudyakov, A. I. and Kurmangalieva, A. I. (2019). Mechanically activated composite fluoroanhydrite binder. *Construction Materials,* No. 1–2, pp. 36–42. DOI: 10.31659/0585–430X–2019–767–1–2–36–42.

Anikanova, L. A., Volkova, O. V., Kudyakov, A. I. and Lotov, V. A. (2021). Hydration processes of anhydrite-containing binders using volumetric phase composition. In: Klyuev, S. V., Klyuev, A. V. and Vatin, N. I (eds) *Innovations and Technologies in Construction. Selected papers of BUILDINTECH BIT 2021. Lecture Notes in Civil Engineering.* Springer International Publishing, pp. 215–221. DOI: 10.1007/978–3-030–72910–3–31.

Belov, V. V., Buryanov, A. F., Yakovlev, G. I., Petropavlovskaya, V. B., Fisher, H.-B., Mayeva, I. S. and Novichenkova, T. B. (2012). *Modification of the structure and properties of building composites based on calcium sulfate*. Moscow: De Nova Publishing House, 196 p.

Chernyshov, E. M., Potamoshneva, N. D., Monastyrev, P. V. and Yartsev, V. P. (2016). Industrial waste recycling for construction purposes as a complex systemic problem. *Problems of Contemporary Science and Practice*, No. 4 (62), pp. 67–86. DOI: 10.17277/voprosy.2016.04.pp.067–086.

Erofeev, V. T., Rodin, A. I., Bochkin, V. S. and Ermakov, A. A. (2020). The formation mechanism of the porous structure of glass ceramics from siliceous rock*,* Issue 8, Article No. 10006. DOI: 10.18720/MCE.100.6.

Fedorchuk, Yu. M. (2003). *Technogenic anhydrite: properties and use.* Tomsk: Tomsk Polytechnic University, 110 p.

Garkavi, M. S., Artamonov, A. V., Kolodezhnaya, E. V., Nefed'ev, A. P., Khudovekova, E. A., Buryanov, A. F. and Fisher, H.-B. (2018). Activated fillers for gypsum and anhydrite mixtures. *Construction Materials*, No. 8, pp. 14–17. DOI: 10.31659/0585–430X–2018–762–8–14–17.

Lesovik, V. S., Chernysheva, N. V. and Klimenko, V. G. (2012). Processes of structure formation in gypsum-containing compositions taking into account the genesis of raw materials. *News of Higher Educational Institutions. Construction*, No. 4 (640), pp. 3–11.

Medvedeva, O. N. and Sautkina, T. N. (2019). Specifics of utilities design using information modeling. *Architecture and Engineering*, Vol. 4, Issue 3, pp. 13–21. DOI: 10.23968/2500–0055-2019–4–3–13–21.

Ponomarenko, A. A. and Kapustin, F. L. (2011). Technology of fluoroanhydrite processing for use in the production of Portland cement. *Chemical Technology*, Vol. 12, No. 6, pp. 329–332.

Pukharenko, Y. V. and Kharitonova, T. V. (2018). Evaluation of usage of carbonate aggregates in the dry mixtures for restoration. *Bulletin of Civil Engineers*, No. 4 (69), pp. 121–125. DOI: 10.23968/1999–5571–2018–15–4–121–125.

Volkova, O. V. and Anikanova, L. A. (2020). Dry mixes for brickwork restoration of old buildings. *Glass and Ceramics*, Vol. 77, No. 7–8, pp. 322–326. DOI: 10.1007/s10717–020-00298–1.

Zavadsky, V. F., Deryabin, P. P. and Kosach, A. F. (2003). Technology of aerated foam concrete production. Construction Materials, No. 6, pp. 2–3.

Znobishchev, S. V. and Shamraeva, V. V. (2019). Practical use of BIM modeling for road infrastructure facilities. *Architecture and Engineering*, Vol. 4, Issue 3, pp. 49–54. DOI: 10.23968/2500–0055-2019–4–3–49–54.

# РЕШЕНИЕ ТЕПЛОТЕХНИЧЕСКИХ ЗАДАЧ С ИСПОЛЬЗОВАНИЕМ МЕТОДА КОНЕЧНЫХ ЭЛЕМЕНТОВ

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**Аннотация**

Изучение энергоэффективных экологически безвредных теплоизоляционных материалов на основе гипсовых и гипсосодержащих исходных компонентов. **Цель исследования:** Оценка эффективности применения гипсовых материалов в стеновых конструкциях, используя метод конечных элементов модуля STEADY-STATE THERMAL программного комплекса ANSYS. В качестве стеновых материалов использован поризованный материал разной плотностью (конструкционный, конструкционно-теплоизоляционный и теплоизоляционный гипсобетон), полученный путем взаимодействия остаточной серной кислоты, адсорбированной на зернах «кислого» фторангидрита и карбонатной муки в процессе протекания химической реакции взаимодействия. **Методы:** Метод конечных элементов модуля STEADY-STATE THERMAL программного комплекса ANSYS. Решение задач оценки теплопроводности конструкций осуществлялось в трехмерной системе координат. Для фрагментов ограждающей конструкции приняты экспериментальные значения теплофизические характеристики. **Результаты:** Численное решение задачи с помощью модуля STEADY-STATE THERMAL программного комплекса ANSYS, работа которого основана на методе конечных элементов, показало, что разработанный конструкционно-теплоизоляционный гипсобетон является более эффективным, поскольку при данных условиях расчета температура внутренней поверхности стены при минимальной толщине конструкции (510 мм) и максимальной (770 мм) превышает температуру внутренней поверхности стен из различных материалов.

**Ключевые слова**

Фторангидрит, гипсобетон, соединения кальция, процессы структурообразования, метод конечных элементов, стеновой материал, теплопроводность.

DOI: 10.23968/2500-0055-2021-6-3-11-18

# RECONSTRUCTION OF THE WATER SUPPLY AND SEWERAGE SYSTEMS OF A CAST-IRON FOUNTAIN IN PAVLOVSK

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**Abstract**
**Introduction:** The restoration of old fountains is essential to the cultural life of society since it preserves the architectural spirit of the past and conveys the historical heritage to the present day. Besides, fountains create a favorable atmosphere in summer, humidifying the air. In the course of the study, we developed an approach to the restoration of the engineering systems and the technology of operation of an old fountain in St. Petersburg. **Methods:** We performed a detailed survey of the cast-iron fountain body and the pits next to it to discover the catchment basin of the fountain and establish its dimensions, assess the operation of similar fountains, analyze historical documents (old photos), and design engineering systems. **Results and discussion:** As a result of the study, the dimensions of the fountain and the catchment basin as well as the diameters of the orifices were obtained. The trajectories of the water jets and the scheme of the fountain's operation were determined. Besides, we performed a hydraulic analysis of the systems and selected the necessary equipment. In this paper, we also present the scheme of the fountain's operation in the following modes: filling with water, normal operation, and shut-down for winter.

**Keywords**
Fountain, reconstruction, water supply, sewerage, survey, hydraulic analysis.

## Introduction

The garden and park ensembles of St. Petersburg are filled with fountains of great cultural and historical value. Fountains have been used as decoration elements in urban and park environments since ancient times (Hynynen et al., 2012; Juuti et al., 2015). In addition to complementing the architectural appearance, they have great practical benefits, humidifying the air in hot weather and creating a pleasant microclimate (Xue et al., 2015), and can be used to supply drinking water (Yenigün et al., 2017) and improve the quality of water in a reservoir (Chang et al., 2015). In some cases, old fountains that have not been in use for a long time get ruined together with the system of water supply. Governments are seeking to pursue fountain restoration projects in order to recreate the architectural appearance of park ensembles. Fountain restoration is a comprehensive process that addresses social, infrastructural, and aesthetic challenges (Alcocer et al., 2017). When reconstructing a fountain, engineers are often faced with a lack of information on the technology of its operation. This work usually includes a field survey and analysis of historical documents related to the fountain's operation (Ďoubal, 2017). In Russia, the implementation of water supply and sewerage projects with regard to fountains is usually complicated by the absence of special regulations. We came up against such a situation during the studies and design of an old cast-iron fountain in Pavlovsk.

This cast-iron fountain (Figure 1A) was cast at San Galli's factory and installed in the garden of the Pavlovsk Music Station in 1864. By the early 1870s, it ceased to function as a fountain and was converted into a flower bed. In 1892, it was converted into an electric street lamp. During the Great Patriotic War, the Music Station was destroyed but the fountain survived. In the 1980s, it was vandalized: parts of the Bacchus sculpture were broken off the top of the structure. The fountain currently remains in this state (see www.kgiop.gov.spb.ru).

In addition to the Bacchus sculpture, there are four mascarons at the base of the large fountain bowl. The use of sculptures for fountain decoration is a fairly common architectural technique (Bonnie and Richard, 2012).

At present, the fountain has a height of 5.8 m. The structure is partially covered with soil. The large bowl, which is the main element of the fountain, has an elongated base and rests on a stone foundation. The Bacchus sculpture is fixed to the large bowl with structural ribs. Before the damage, Bacchus had a smaller fountain bowl in his hand. Some fragments of the catchment basin in the lower part of the fountain have been preserved but now it is covered with soil.

After the reconstruction, the Bacchus sculpture with the street lamp will be reconstructed, the soil around the fountain will be removed, and the catchment basin will be restored. The height of the fountain will amount to 8.6 m.

When examining the mascarons, we found small and large orifices for water discharge (Figure 1B). These orifices were made in all four mascarons located around the perimeter of the large bowl. The large orifices are located in the mouths of the mascarons and the small ones — in the curls. Each mascaron has six small orifices.

Our task was to restore the technology of the fountain's operation. Unfortunately, we found no information about its operation, location of the pipelines, or position of the jets in historical documents (including old photos). Therefore, it was necessary to analyze the technology of operation of similar fountains.

**Methods**

The problem of fountain restoration can be solved in several stages. In the course of our research, we adopted the experience of studying and reconstructing the Fountain of Neptune in Bologna (Apollonio et al., 2017).

At the first stage, we aimed to determine the location of the catchment basin in relation to the orifices in the mascarons. For this purpose, pits were made along the perimeter of the base of the bowl with a depth of up to 0.9 m to discover the structural elements of the catchment basin (Figure 2A). We measured the dimensions of the fountain (including the catchment basin) and determined the diameters of the orifices using a measuring tape (Figure 2B). We also made photos to examine the internal structure of the fountain. Toward that end, a photo camera was placed in the large orifices in the mascarons, and one of the team members was lifted to the large bowl.

The architectural and engineering parts of a fountain are inextricably linked and complement each other (Shakerin, 2004). The water jets unfold the architectural appearance of the structure and enhance its perception, and the architectural

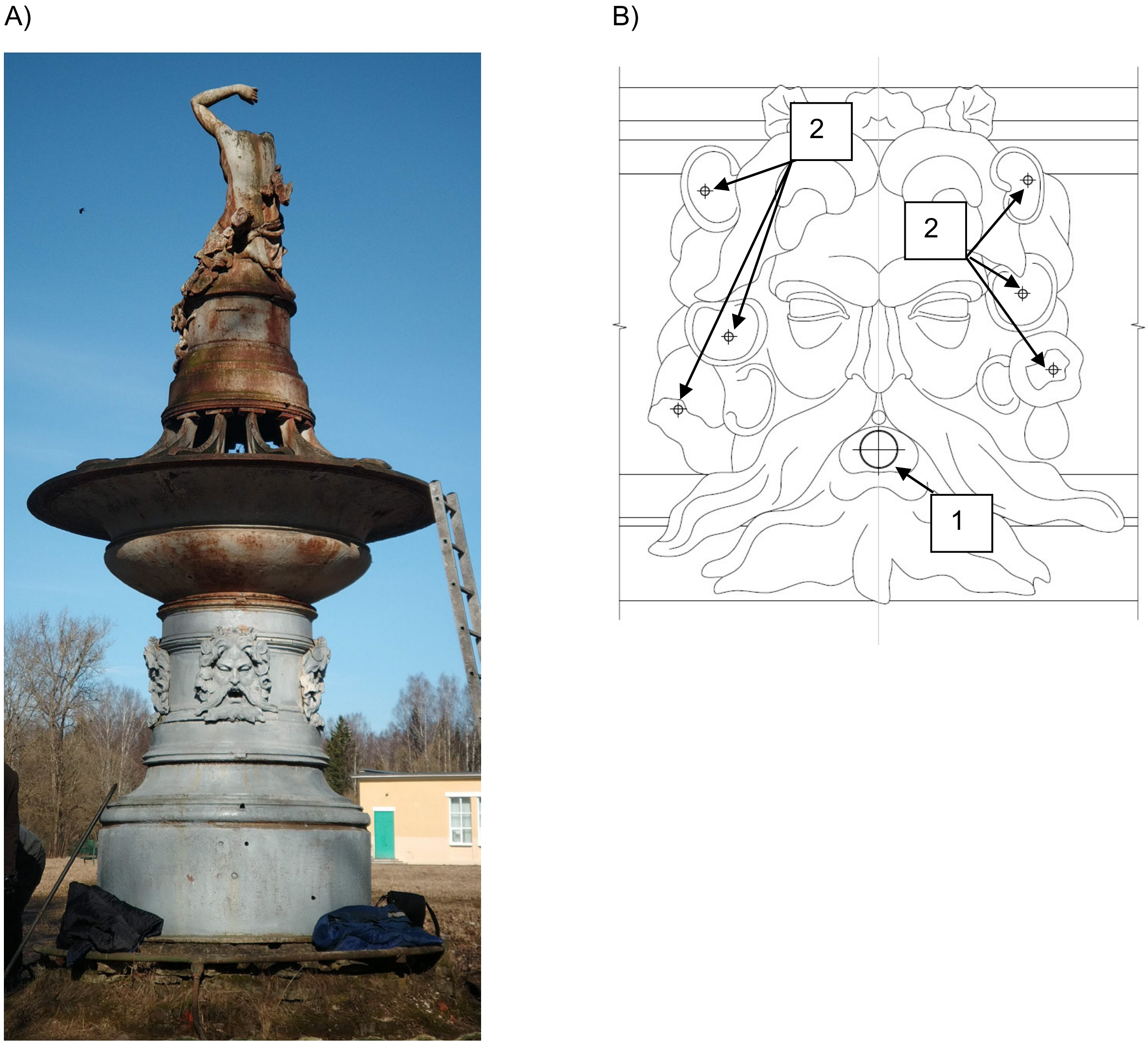


Figure 1. A) cast-iron fountain; B) mascaron: 1 — large orifices, 2 — small orifices

A) B)

Figure 2. Fountain examination

elements hide the engineering mechanisms of the fountain. To reconstruct the equipment of the fountain under consideration, we analyzed similar fountains in St. Petersburg: the Roman Fountains in Peterhof, the fountain on the Universitetskaya Embankment, and the fountain in front of the building of the Military Medical Academy. These fountains have several bowls located throughout the height; water flows out through the orifices and spills over the edges of the bowl. Based on the results of the analysis, several options for the fountain's operation were proposed (Figure 3). According to option A, a water jet, formed above the hand of Bacchus, filled the small bowl with water. Spilling over the edges of the small bowl, water was directed into the large bowl where it accumulated at the base and then flowed out through the large and small orifices in the mascarons into the catchment basin. According to option B, the upper bowl was filled with water in the same manner as described above. Spilling over the edges of the small bowl, water was directed to the base of the large bowl where it accumulated at the bottom and then was discharged into the catchment basin through a special connection element. Water was supplied to the mascarons through a separate pipeline. According to option C, water was supplied to the upper bowl and the mascarons through separate pipelines. However, in contrast to option B, due to the arrangement of deflectors on the structural ribs of the large bowl, water from the small bowl fell directly to the catchment basin and not to the large bowl. According to option D, no water was supplied to the small bowl. Instead of a water jet in the hand of Bacchus, it was proposed to install a street lamp and supply water through separate pipelines only to the orifices in the mascarons.

We also analyzed the territory of the park to discover the location of the pipelines supplying water to the fountain. When examining the plot plan and the pits next to the fountain, we found a cast-iron pipeline with threaded fittings, which came out of the ground near the base of the bowl and was connected to a radical collecting main made of cast-iron pipes. The collecting main had round orifices around the perimeter of the bowl. During the analysis of historical documents, it was determined that the pipeline was intended for the irrigation of green areas, which were located at the catchment basin and the large bowl at certain stages of the fountain's existence. No original water supply pipelines survived. Therefore, we designed the system from scratch.

To calculate the distance of jet travel, Bernoulli's equation was used. To calculate the resistance of the supply pipelines, the Weisbach and Darcy–Weisbach equations were used.

We also needed to determine the points of connecting and emptying the fountain to complete the project. As a connection point, we chose the water supply system of a public toilet, which is located on the square near the fountain. Since the fountain is located in a pedestrian area, which cannot be approached by vehicles for emptying the fountain, it is necessary to develop a system that will allow for water diversion and disposal since it is impossible to discharge water from the fountain into the nearby water body.

**Results and Discussion**

As a result of the survey, we discovered a service opening in the foundation under the base of the large bowl (Figure 4A), which had previously been used to connect the pipelines. When examining the inner cavity of the fountain, we found that the large bowl and the base under it do not have internal partitions between them. A vertical cast-iron pipeline is located along the axis of the fountain, which is presumably left from the plant irrigation system (Figure 4B).

Taking into account the historical experience of using the fountain as a street lamp and following the examination of the inner part of the structure, we decided to restore the fountain according to option D (Figure 3). The combination of water movement and lighting is widely used in modern fountains (Visconty et al., 2016).

As a result of the survey, we clarified the dimensions of the catchment basin and, based on that, calculated the trajectories of the jets and water heads upstream of the large and small orifices (located the highest in the mascaron curls). Remnants of brickwork of an old catchment basin were found in the pits. Thus, the catchment basin has the shape of a ring and is bounded on the outside by a rim, and on the inside — by a stone foundation of the base of the bowl. The diameter of the catchment basin on the outer rim is 4.9 m, and the width of the radial chute is 0.6 m. For the purposes of engineering analysis, we assumed that the jets should fall into the center of the radial chute of the catchment basin. The distance from the center of the chute to the large orifices is 1.7 m, and to the small orifices — 1.57 m. The height of the large orifices located above the chute of the catchment basin is 2.17 m, and that of the small orifices — 2.48 m. Based on the known equation of the jet trajectory (Bistafa, 2015; Gordon, 2013; Peszynski et al., 2019), the required water heads upstream of the orifices were determined. For the large orifices, the water head is 0.354 m, and for the small orifices — 0.264 m. Using Bernoulli's equation, we calculated the water flow rates for each type of orifices. For the large orifices, the flow rate is 1.85 l/s, and for the small orifices — 0.04 l/s.

Since the orifices are located at different heights, we decided to provide separate piping systems for the large and small orifices in order to ensure the required jet trajectories and convenient control

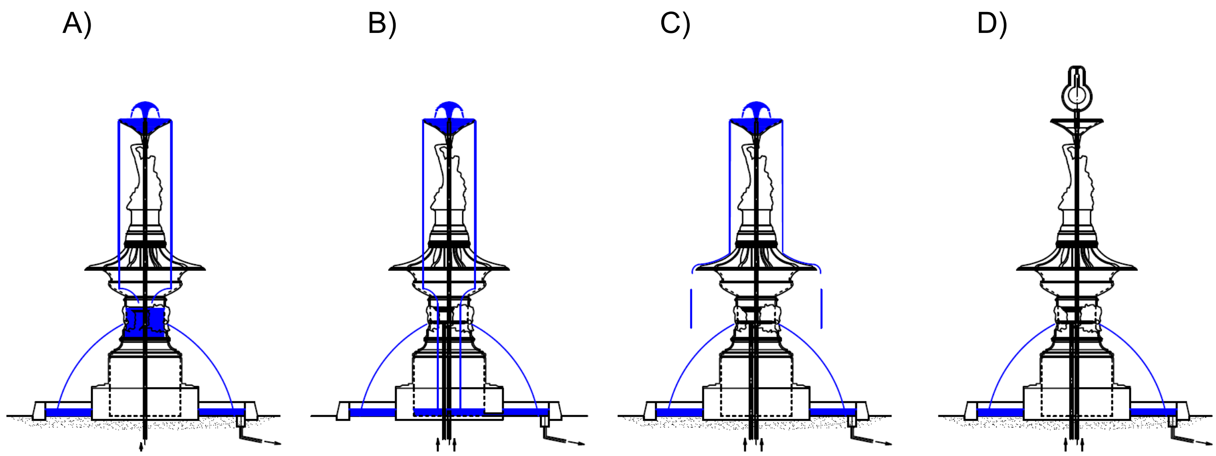


Figure 3. Options of the fountain's operation

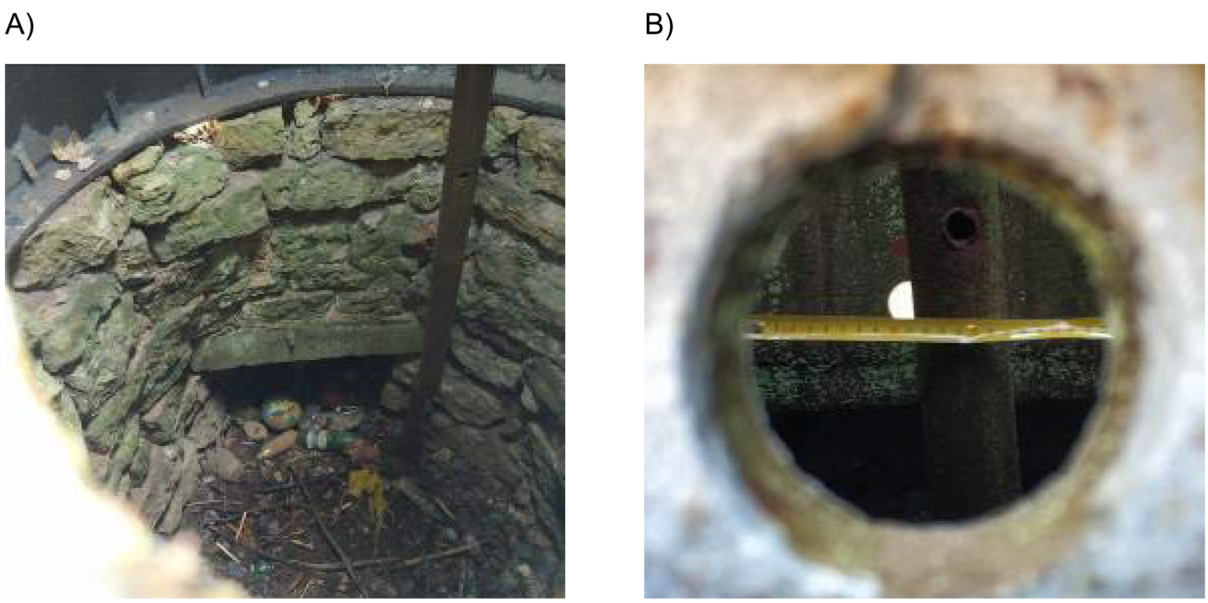


Figure 4. Examination of the inner cavity of the fountain: A) service opening, B) vertical pipeline

of the jet travel distance. We also determined the costs for each system by multiplying the number of the corresponding orifices by the water flow rate. For the system of the large orifices, the flow rate is 7.4 l/s, and for the system of the small orifices — 0.96 l/s. Based on the costs obtained, we performed a hydraulic analysis of the pipeline systems. The pipes inside the fountain were assumed to be made of stainless steel; the diameters of the main supply pipelines are 60 mm for the large orifices and 25 mm for the small orifices. The body of the fountain had four branch pipes on the inside (32 mm for the large orifices, 10 mm for the small orifices). Under the mascarons, the pipelines with a diameter of 10 mm branched out in six directions, and with the help of reducers, they were narrowed for 6 mm orifices in the curls.

The pipelines laid outside from the pumping station to the fountain were made of low-pressure polyethylene.

In the course of the hydraulic analysis for the system of the large orifices, head losses amounted to 3.29 m, and for the system of the small orifices — to 8.60 m.

For each system, a downhole pump was selected, which is quite common in engineering practice (Sanchez, 2004). Both pumps were placed horizontally in the plastic housing of the pumping station, in cooling jackets equipped with meshes for mechanical cleaning. The pumping station is located next to the fountain (Figure 5).

The next important step was to develop systems for supplying water to the fountain and emptying it. It is planned to lay a pipeline (6) with a pipe diameter of 20 mm from the water supply system of the public toilet (1) to the catchment basin of the fountain (2) (Figure 5). To ensure wastewater disposal, we decided to lay a gravity pipeline (7) with a pipe diameter of 200 mm from the drainage well (3) to the collecting well (5) wherefrom water can be pumped out by sewage trucks when shutting down the fountain for winter.

Figure 6 shows a complex of engineering solutions that ensure the fountain's filling with water, operation, and shut-down for winter. The fountain is filled with water in the following way. The ball valve (14) as well as the valves (16), (17), (18), and (19) open. Through the pipeline (6), water is supplied to the catchment basin of the fountain from the toilet. From the catchment basin, water flows by gravity to the pumping station (4) through the pipeline (11). Having reached the design trigger level, the pumps turn on automatically, supplying water to the mascarons: through the pipeline (9) — to the large orifices, and through the pipeline (10) — to the small orifices. Through the orifices, water enters the catchment basin and returns to the pumping station through the pipeline (11). By adjusting the valves (18) and (19), the trajectories of the water jets are controlled. The design level of water in the catchment basin (90 mm from the bottom) is maintained by adjusting the valve (20) on the pipeline (13). The design level of water cannot be exceeded. For that purpose, an overflow pipe (12) is provided, which diverts excess water to the drainage well (3) and further to the sewerage system (7). When the design level of water in the catchment basin is reached, the automation system closes the solenoid valve (15), and the water supply through the pipeline (6) is stopped.

During the fountain's operation, water losses due to evaporation and droplet carry-over are possible. Therefore, the make-up of the circulating water system is ensured with the help of the automation system. When the level of water in the catchment basin drops to 80 mm from the bottom, then, following the signal from the water level sensor in the toilet, the solenoid valve (15) opens, and make-up water enters the catchment basin through the pipeline (6) until the level of water reaches 90 mm from the bottom. Then the solenoid valve (15) closes automatically. At nighttime, the fountain turns off due to the shutdown of the pumping units, and all the water flows to the pumping station (4). In the morning, the fountain turns on due to the forced switching-on of the pumping units. At the moment of the shutdown of the pumping units, the ball valve (14) must be closed.

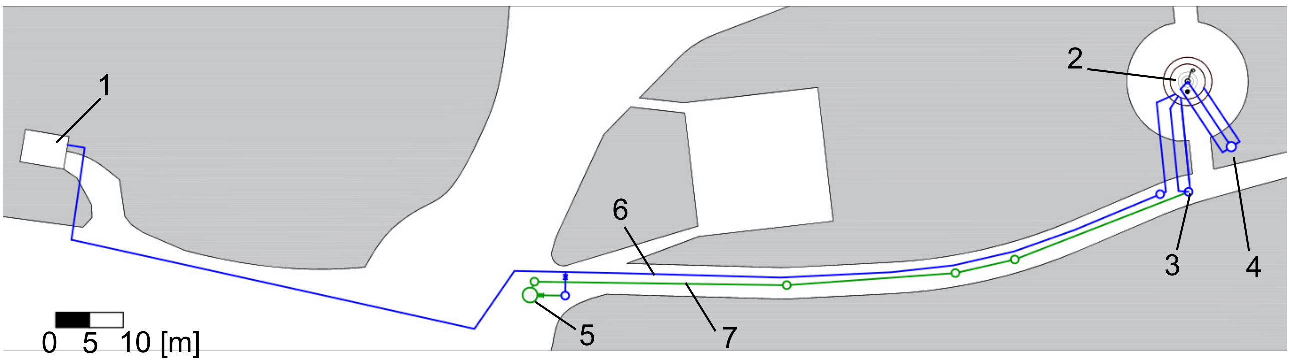


Figure 5. Layout plan of the water supply and sewerage systems of the cast-iron fountain: 1 — public toilet, 2 — cast-iron fountain, 3 — drainage well, 4 — pumping station, 5 — well to pump out wastewater by sewage trucks, 6 — water pipeline, 7 — sewerage system

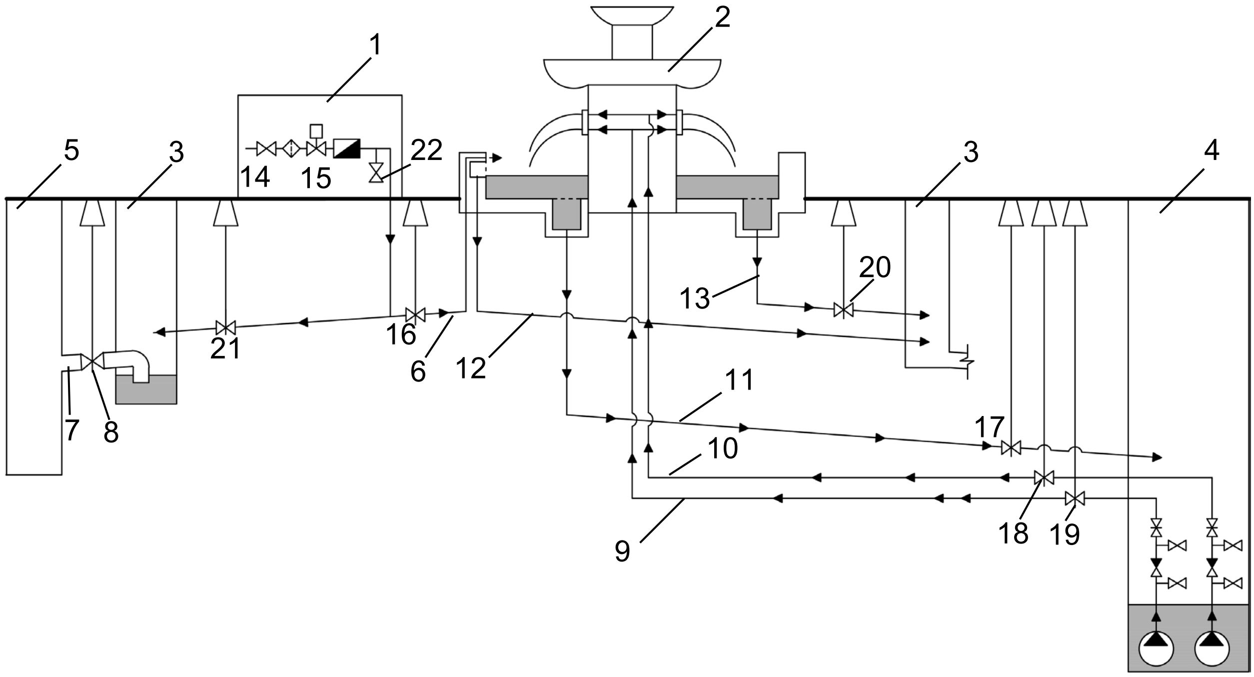


Figure 6. Schematic of the fountain's operation

The fountain is emptied by closing the ball valve (14), closing the valve (17), and orifices the valve (20). In this case, the pumps continue to operate, pumping water into the drainage well (3) through the pipeline (13). The pumps turn off when the level of water at the pumping station (4) reaches the target shutdown level. After that, it is necessary to empty the filling/make-up system (6), the pipelines supplying water to the mascarons (9) and (10), and the pipeline (11). To do this, it is required to open the drain valve (22) in the toilet, the valve (8) at the drainage well, and the valve (17). Then, it is required to open the drain valve at the pumping station. As a result, water from the pipeline (6) enters the sewerage system (7). Water from the pipelines (9), (10), and (11) drains to the pumping station (4). It must be pumped out to the drainage well (3) using a portable pump. Water from the sewerage system (7) enters the well (5) where it accumulates in the settling section. After emptying, all the water is pumped out of the well (5) by a sewage truck.

Since the fountain is located in a park ensemble, no wastewater treatment system was arranged. To prevent pipeline clogging, grates were provided in the pits. In case of water quality deterioration (increase in color or odors), it is recommended to either replace the water in the fountain or use disinfectant tablets.

**Conclusions**

In the course of the study, we examined an old fountain and designed systems ensuring its filling with water, operation, and shut-down for winter. We also developed an approach to the reconstruction of old fountains, which includes the analysis of historical documents, the assessment of the operation of similar fountains, and the use of modern energy-efficient process flow schemes. The restoration of this fountain will enrich the landscape architecture of Pavlovsky Park and create favorable conditions for visitors during the hot season. The experience described in the paper is a clear example of work required for the reconstruction of the engineering systems of the lost fountains.

## References

Alcocer, V. G., Ballesta, J. J. and Hernanz, E. S. (2017). Conservation and restoration works of the Four Sewers Fountain in Daganzo (Madrid, Spain). *Ge-Conservación*, Vol. 11, pp. 172–179. DOI: 10.37558/gec.v11i0.470.

Apollonio, F. I., Ballabeni, M., Bertacchi, S., Fallavollita, F., Foschi, R.and Gaiani, M. (2017). From documentation images to restauration support tools: a path following the Neptune fountain in Bologna design process. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2017 GEOMATICS & RESTORATION – Conservation of Cultural Heritage in the Digital Era, May 22–24, 2017,* Florence, Italy, Vol. XLII-5/W1, pp. 329–336. DOI: 10.5194/isprs-archives-–XLI–5–W1–329–2017.

Bistafa, S. R. (2015). Euler's friction of fluids theory and the estimation of fountain jet heights. *The European Physical Journal H*, Vol. 40, Issue 3, pp. 375–384. DOI: 10.1140/epjh/e2015–60031-2.

Bonnie, R. and Richard, J. (2012). Building D1 at Magdala revisited in the light of public fountain architecture in the late-Hellenistic East. *Israel Exploration Journal*, Vol. 62, Issue 1, pp. 71–88 (1). DOI: 10.5281/zenodo.262938.

Chang, Y.-H., Wu, B.-Y. and Lai, C.-F. (2015). A study of the ecological benefits of the green energy landscape fountain. *Ecological Engineering*, Vol. 75, February 2015, pp. 128–136. DOI: 10.1016/j.ecoleng.2014.11.021.

Ďoubal, J. (2017). The restoration of the Stone Fountain in Kutná Hora: An assessment of the contemporary intervention within the context of repairs throughout history. *Studies in Conservation*, Vol. 62, Issue 7, pp. 371–383. DOI: 10.1080/00393630.2016.1206246.

Gordon, M. (2013). The mathematics of fountain design: a multiple-centres activity. *Teaching Mathematics and its Applications: An International Journal of the IMA*, Vol. 32, Issue 1, pp. 19–27. DOI: 10.1093/teamat/hrs013.

Hynynen, A. J., Juuti, P. S. and Katko T. S. (eds.) (2012). *Water fountains in the worldscape.* Kangasala: International Water History Association and KehräMedia Inc., 222 p.

Juuti, P. S., Antoniou, G. P., Dragoni, W., El-Gohary, F., De Feo, G., Katko, T. S., Rajala, R. P., Zheng, X. Y., Drusiani, R. and Angelakis, A.N. (2015). Short global history of fountains. *Water*, Vol. 7, Issue 5, pp. 2314–2348. DOI: 10.3390/w7052314.

Peszynski, K., Perczynski, D. and Piwecka, L. (2019). Mathematical model of a fountain with a water picture in the shape of an hourglass. *EPJ Web of Conferences*, Vol. 213, 02064. DOI: 10.1051/epjconf/201921302064.

Sanchez, J. (2004). Renovation project returns Chicago fountain to its youth. *World Pumps*, Vol. 2004, Issue 450, pp. 37–39. DOI: 10.1016/S0262–1762(04)00144–0.

Shakerin, S. (2004). Microcontrolled water fountain: a multidisciplinary project. *International Journal of Engineering Education*, Vol. 20, No. 4, pp. 654–659.

Visconty, P., Constantini, P. and Cavalera, G. (2016). Smart electronic system for dancing fountains control capable to create water and lighting scenarios synchronized with a music track. *ARPN Journal of Engineering and Applied Sciences*, Vol. 11, No. 9, pp. 5669–5675.

Xue, F., Li, X., Ma, J. and Zhang, Z. (2015). Modeling the influence of fountain on urban microclimate. *Building Simulation*, Vol. 8, Issue 3, pp. 285–295. DOI: 10.1007/s12273–014–0210–7.

Yenigün, K., Kürkçüoğlu, C., Karakaş, M., Gerger, R., Aydoğdu, M. H. and Gümüs, V. (2017). Historical water structures of Şanliurfa; fountains. In: Baba, A., Gündüz, O. and Tayfur, G. (eds.) *IWA-PPFW 2017. IWA 2nd Regional Symposium on Water, Wastewater and Environment. The Past, Present and Future of the World's Water Resources, March 22–24, 2017*, Çesme - Izmir, Turkey, pp. 430–439.

# РЕКОНСТРУКЦИЯ СИСТЕМ ВОДОСНАБЖЕНИЯ И ВОДООТВЕДЕНИЯ ЧУГУННОГО ФОНТАНА В ПАВЛОВСКЕ

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**Аннотация**
Восстановление старых фонтанов имеет важное значение для культурной жизни общества, поскольку позволяет донести до нашего времени историческое наследие и сохранить архитектурный дух прошлого. Также фонтаны создают благоприятную атмосферу в летний период времени, увлажняя воздух. В данном исследовании разработан подход к восстановлению инженерных систем и технологии функционирования старинного фонтана в г. Санкт-Петербурге. **Методы:** Подход включал в себя подробное обследование корпуса чугунного фонтана и выполнение шурфов рядом с фонтаном для обнаружения сборного бассейна и установления его габаритных размеров, оценку работы фонтанов-аналогов, анализ исторической документации (старинных фотографий) и выполнение проектных работ по созданию инженерных систем. **Результаты и обсуждение:** Получены размеры фонтана и сборного бассейна, диаметры технологических отверстий. Определены траектории струй фонтана и схема его функционирования. Выполнены гидравлические расчеты систем, подобрано необходимое оборудование. Представлена технологическая схема работы фонтана в режимах заливки, функционирования и консервации на зиму.

**Ключевые слова**
Фонтан, реконструкция, водоснабжение, водоотведение, обследование, гидравлический расчет.

DOI: 10.23968/2500-0055-2021-6-3-19-28

# INFRA-BIM FOR BUSINESS PROCESSES' MANAGEMENT IN ROAD CONSTRUCTION AND OPERATION

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**Abstract**

**Introduction:** The article addresses the business processes of the construction and operation of linear road sections. In the course of the study, we analyzed the geographic information system (GIS) of Avtodor company (developer: Indor-Soft, Tomsk) and its use in the operation and maintenance of transport infrastructure facilities at such road sections. In particular, we studied the construction of the Far West Krasnodar Bypass (FWKB), which is part of the North-South transport corridor, and its implementation by means of InfraBIM modeling. **Purpose of the study:** We aimed to describe the structured GIS database of Avtodor company by connecting various InfraBIM tools for the purposes of data generation and road model update. **Methods:** Analyzing the GIS of Avtodor company when using an InfraBIM model of road infrastructure, we studied the following: use of GIS features at the facility; asynchronous editing and selection of data without access to the Internet; database update. **Results:** InfraBIM models of linear road sections, developed in the implementation of such projects as the FWKB, make it possible to optimize time and save money when planning and introducing measures during the operation of transport infrastructure facilities.

**Keywords**

BIM modeling, road information model, geographic information system, transport infrastructure, digital transformation of roads, InfraBIM for road construction and maintenance.

## Introduction

Building Information Modeling (BIM) development and implementation imply the creation of a Common Data Environment (CDE) to obtain the necessary information about transport infrastructure facilities and urban planning (Boykov et al., 2017). The issues of standardization and creation of a database of information models in road construction and urban planning are quite crucial. It is required to develop a regulatory framework that would contribute to the successful implementation of BIM in Russia. The use of BIM models at various stages of the life cycle of capital construction facilities is regulated by Decree of the Government of the Russian Federation No. 1431, dated September 15, 2020, “On approval of the rules for forming and maintaining information models of capital construction facilities, the composition of information, documents and materials included in information models of capital construction facilities and submitted in the form of electronic documents, and the requirements for the formats of these electronic documents, as well as amendments to Paragraph 6 of the Regulations on engineering surveys for the preparation of design documentation, construction, and reconstruction of capital construction facilities”, signed by Chairman of the Government of the Russian Federation Mikhail Mishustin (https://ipbd.ru/doc/0001202009220002/).

A number of road organizations are working on the use of BIM tools: road information models (Shamraeva, 2020b), databases, and automated systems for processing road data banks, including on the Web. In contrast to capital construction facilities and their information models (Hardin and McCool, 2015), in the case of linear transport infrastructure facilities, design and construction are carried out for individual (separate) sections. Such sections may have different implementation periods (e.g., construction, operation, and repair may be carried out on the same road simultaneously), and the project is usually performed by several contractors. Thus, BIM implementation in transport infrastructure differs from that regarding industrial and civil construction facilities: during design, it is required to use InfraBIM for motor roads, transferring data to the GIS during operation so as to obtain a complete BIM model of the road (Shamraeva, 2020a). According to the action plan, dated December 18, 2017, in the direction “Formation of research competencies and technological groundwork” within the program “Digital Economy of the Russian Federation” (action item 03.00.000.001.18.11 — development of software for the instrumentation control of the diagnostic state of roads, intended for the collection, accumulation, storage, consolidation, analysis and interactive visual representation of data on the state of roads, received from various testing and measuring equipment, management authorities, and population), it is necessary to consider the requirements of applicable statutes and regulations in terms of import substitution and gradual transition to the preferential use of domestic software (https://www.sbras.ru/files/news/docs/tex_zadely_d_e_plan.pdf). The tools and software used for the analysis of the business processes at Avtodor company make it possible to optimize time and save money when planning and introducing measures during the operation of facilities.

**Subject, tasks, and methods**

Let us consider the stages of the road facility life cycle in terms of BIM modeling of linear road sections (Fig. 1).

Fig. 1 shows a simplified representation of this cycle. A more detailed scheme was presented by Skvortsov and Sarychev (2015).

**Information modeling at the stage of surveys and design**

The article addresses the business processes of the construction and operation of roads and transport infrastructure at Avtodor company. Specialists of Avtodor company together with contractors and construction supervisors implement InfraBIM to optimize surveys, avoid collisions and errors during geodetic works, control the volume of construction and installation works, and visualize the plan-fact analysis.

At this stage, the following documentation and data on works are introduced to the database:

- detailed design documentation;
- documentation for land cadastral works;
- as-built documentation, including logs, work sheets, drawings, diagrams, and calculations;
- estimate documentation for new types of work;
- main and auxiliary works in accordance with the design, detailed design or other technical documentation for the facility;
- materials, structures, equipment, etc. used during works at the facility.

In particular, we studied the construction of the Far West Krasnodar Bypass (FWKB), which is part of the North-South transport corridor. Its construction is performed by Avtodor company using a number of the following information systems in its work: GIS IndorRoad, WebGIS "Navigation System for Design and Actual Data Management", and S-Info. To ensure communication between information systems, a Common Data Environment is created.

The GIS of Avtodor company ensures accounting and certification of roads, as well as road operation management and life cycle support. On the website https://avtodor-eng.ru/services/arenda-spetstekhniki/geoinformatsionnye-sistemy/, the main GIS tasks and corresponding functions are listed.

Transport infrastructure is intended for safe and comfortable movement of its users. One of the main conditions for its formation is its digitalization (Gibadullin et al., 2020). It is obvious that, with a Common Data Environment, BIM designers will develop design documentation much faster and at a lower cost. To manage transport infrastructure facilities, the following GIS are used: ArcGIS (ESRI company), IndorRoad (IndorSoft company), MapInfo (MapInfo company), free QGIS, DorGIS (Intelnova company), and so on (Shamraeva et al., 2018). Avtodor company develops its own approach to the use of BIM and GIS technologies in construction supervision. We analyzed its business processes with account for the use of GIS in the operation and maintenance of FWKB transport infrastructure facilities. In particular, we studied the following:

• the possibility to use GIS features at the facility;
• asynchronous editing and selection of data without access to the Internet;
• a corresponding set of data on the facilities;
• database update.

To justify the investment in the project, a summary model of the FWKB was developed (Project model_2108018_dop_attributes.nwd) in Autodesk Navisworks in the NWD file format, which is a data exchange format for summary models. This format is static, which means that the data contained in the file cannot be changed or used to create 2D drawings.

During FWKB summary model development, a set of requirements was formulated for each layer of the Construction Work section (coordinate system, accuracy, attributes, stationing, phasing, etc.), including the following layers:

- road center line, junctions, exits and adjoining roads; stationing;

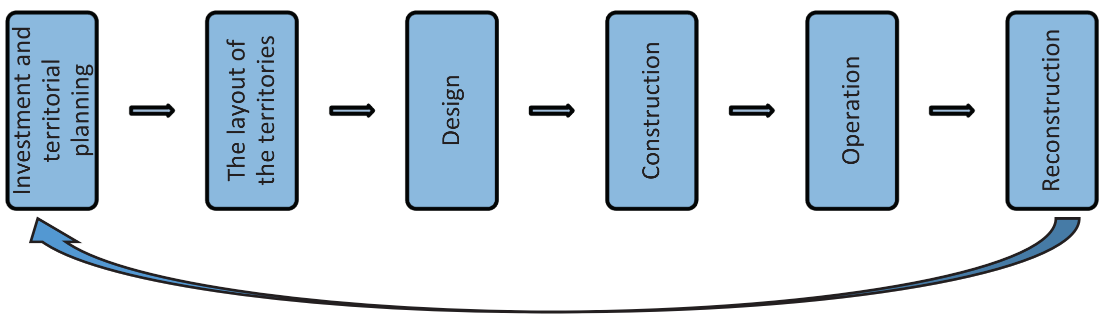


Figure 1. Stages of the road facility life cycle

- road bed boundaries;
- artificial structures: buildings, bridges, pipes, wells;
- protected zones: burial ground for cattle; nature reserve; mineral resources; etc.;
- utilities;
- areas of planned works;
- forest compartments, land plots, boundaries of districts;
- aerial photography.

Thus, the Customer handed over to the construction contractor the information model of the facility as part of the design documentation in the Common Data Environment, meeting the following requirements:

- The structure of surfaces and corresponding data organization shall ensure the creation of files to be uploaded to the system for road construction machinery automated control.
- Data organization in information models shall ensure the creation of data sheets, work sheets, and tables to provide the supply of materials and machinery for road construction.
- The structure of an information model shall ensure the connection between the linear scheduling diagrams and elements of the model, thus visualizing the sequence of road construction works.

The construction contractor shall develop an as-built model of completed construction, equivalent to the design model in terms of the structure of data, and representing the constructed facility's actual state.

Let us take a closer look at the Avtodor GIS features and their use at the facility under consideration. The geometric parameters of the information model elements are completely correct, and the level of detail is very high. The portal with information on facilities has an adaptive web interface optimized for display on a computer or a mobile device. The elements in the GIS database are requested by selecting a multi-level menu or by selecting objects in the map and entering the section of the corresponding facility. Let us list the main disadvantages:

1. Since it is difficult to select elements in the map using the cursor when navigating on mobile devices, an interface is required that would be more adapted to mobile devices and configured to meet the needs of specialists working at the facility.
2. It is impossible to enter information online (perhaps, this is due to the access rights granted for audit). It is obvious that if data are to be uploaded at the site, it is important to ensure that the person generating these data can enter them right away (and not later in the office).
3. 3G/4G network coverage is not available in some areas at the site where specialists work. The availability of only the web version limits the use of the system. Therefore, it is required to consider a solution for extracting data for a specific work area. Besides, if data are to be entered at the site where no Internet access is available, an asynchronous mode of database operation will be required.
4. The Attribute Tables contain a fairly large set of data (more than 250 unique properties of database objects, in addition to geometric characteristics and symbols). However, there is a lack of data required for the GIS use to obtain information about current and future construction projects or serving as a basis for the operation and maintenance of infrastructure facilities. Firstly, there is no information about the validity of data: the source of data, the corresponding accuracy, etc. For instance, it is impossible to know whether the position of a pipe crossing a road was determined during design or geodetic surveys. Secondly, the number of documents on artificial structures is quite limited, and often only photos are available.
5. Finally, in many cases, no data on technical surveys of structures are available. If such data are available, they are contained in a PDF file corresponding to a specific structure rather than presented as object metadata.

Among the portal advantages, the flexible web interface can be mentioned, which includes the following:

1. Viewing of detailed information on the facility and linked documents; going to the map.
2. Map of motor roads with utilities (up to a scale of 1:500) with the interactive change of scale and area for viewing, the formation of a set of layers, the inclusion of auxiliary layers: aerial survey, satellite images, the cadastral map of the Federal Service for State Registration, Cadaster and Cartography (Rosreestr).
3. Distance and area measurement.
4. Analytical functions. Calculation of the quantity, total length and area (if applicable) for the selected types of road facilities (with breakdown by districts, regions, roads).
5. Viewing of panoramic video shots. Point selection, view direction in the map, period selection (year and season), the possibility of moving along the road center line.

Let us describe the possibility of using GIS features at the facility. The portal with information on facilities has an adaptive web interface optimized for display on a computer or a mobile device. The elements in the GIS database are requested by selecting a multi-level menu or by selecting objects in the map and entering the section of the corresponding facility. However, it is difficult to select elements in the map using the cursor when navigating on mobile devices and impossible to select the illumination pole in the map: the corresponding menu section is not displayed in the screen area, and the menu is not drop-down (Fig. 2).

If data are to be uploaded at the site, it is important to ensure that the person generating these data can enter them right away (and not later in the office). An interface is required that would be more adapted to mobile devices and configured to meet the needs of specialists working at the facility. Besides, it is impossible to enter information online (perhaps, this is due to the access rights granted for audit).

The content of the GIS of Avtodor company can be judged by the number of objects in the database and the quality of data entry (seemingly indivisible polygons). The GIS contains a large number of photos of infrastructure facilities with a 360-degree view (Fig. 3). The navigation interface in photos with a 360-degree view is very fast, which makes it possible to significantly improve performance efficiency.

To ensure more efficient management of road facilities, a Common Data Environment (CDE) is required that would timely provide reliable information (Znobishchev and Shamraeva, 2019b). The basic principles of CDE operation include the following:

- verified and reliable information on the facility, obtained from external sources, used by referencing, combining, or direct exchange;
- clearly defined information requirements provided by stakeholders of the project or asset (with a high level of detail) and by the customer (with a higher level of detail);
- the CDE is provided for the management and storage of publicly available information in accordance with the security policy and division of access rights between those generating, using, and supporting this information;
- processes related to information security provision, in place throughout the entire service life of the road (road section), required to resolve problems related to unauthorized access, information loss, theft or damage, and, as far as possible, return to outdated information.

At the stage of construction, the CDE maintains a continuous transition of the Design Model to the Detailed Design and As-Built Models. Upon completion of construction, the information containers required for road management shall be transferred from the information model of the project to the information model of the asset (operation). The remaining information containers related to the project (including those at an archived state) shall be read-only in the case of disputes and for experience gaining.

Thus, it is impossible to use the database to determine the number of objects that need to be supported and maintained in X years. It is recommended to introduce changes in data management to account for support and maintenance of structures.

The database shall be updated with the use of a special program. IndorRoad has the iFC data exchange format implemented for integrating data from BIM models. This function will be necessary in the future for infrastructure construction and reconstruction projects. To update plans and network diagrams, the ETL (Extract, Transform, Load) pro-

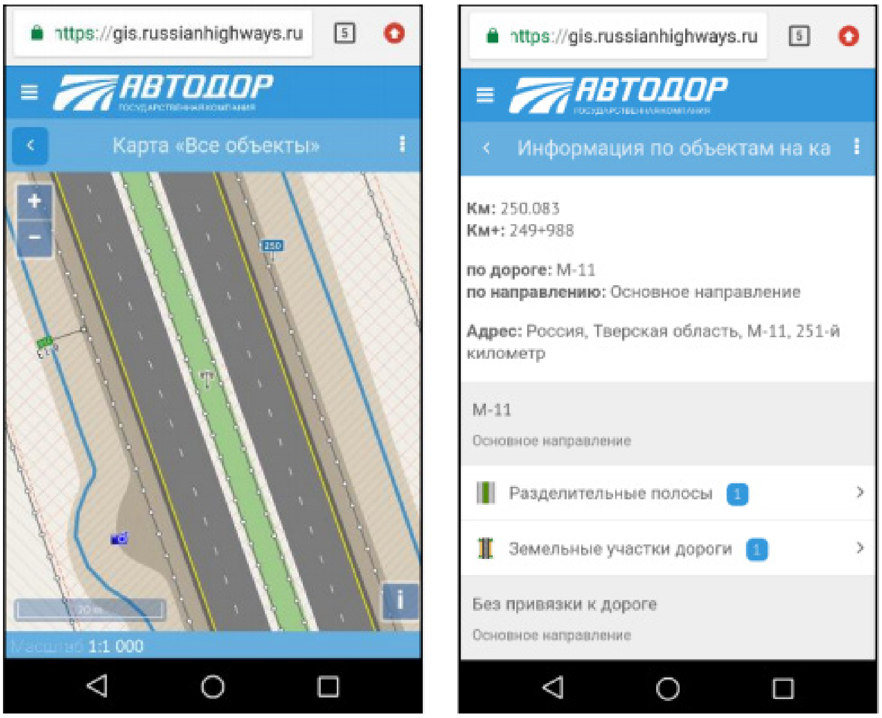


Figure 2. Screenshot from a mobile device

cedure can be used when connecting directly to the CDE without using IndorRoad. This issue should be addressed in order to limit human intervention in data entry.

**Method development**

At the current stage of road digitalization in Russia, the practical use of BIM modeling for road infrastructure facilities plays a significant part. Tools and software developed and used for road diagnostics serve as the information basis that could be integrated into intelligent transport systems (Kazeev, 2020). Let us describe the methods of developing an information model for linear road sections during surveys and design as well as the interaction in the CDE at the stage of project implementation.

**Development of a road information model during surveys and design**

Currently, there are no powerful domestic CAD systems that would make it possible to automate design and surveys and serve as the source of the fundamental data set for building full-fledged BIM models of roads. While in the field of industrial and civil construction, the element base is significantly developed, the field of road construction has a small number of such developments. In many cases, designers have to analyze and redraw the same standard structures without resorting to the capabilities of computer-aided design.

Another BIM issue is the consideration of requirements for the level of detail of the information model at the stage of design documentation development. On the one hand, the level of detail shall not be too high, i.e., the model shall not have elements that will not be used during construction and operation. On the other hand, the level of detail shall be sufficient for construction and installation, construction supervision, and acceptance of deliverables as well as subsequent facility operation.

When planning a project using BIM tools and 3D coordination with the subsequent transfer of the necessary information, the basic levels of detail of information model elements (or the so-called Levels of Development (LODs)) are determined (The American Institute of Architects, 2013). Each LOD (BSI, 2013) contains information about the execution of project tasks that correspond to a particular level of detail. Each project may have five LODs: LOD 100, LOD 200, LOD 300, LOD 400, and LOD 500 (Barannik, 2017). In some cases, LOD 350 (intermediate level) is added to these LODs (Abbasnejad and Moud, 2013). LOD 350 provides contractors with more complete information (Eastman et al., 2011) and is required during bidding organization. Analysis of the business processes related to the construction and operation of linear road sections shows that for the project team to develop clear justified requirements for information models as well as minimum requirements for the information richness of model elements before the commencement of the project, LOD 500 (AIA E203–2013) is optimal (Abbasnejad and Moud, 2013). This LOD reflects the actual dimensions, bindings, etc. to the fullest extent. These data are then transferred to the operation service (Fig. 4).

As a rule, BIM models are developed for the design stage. Therefore, they shall not be used in road operation or maintenance since the model intended for use by the operating organization shall reflect the actual constructed facility. In the current state, BIM models can be used to get an idea of construction and installation works as well as structures under construction. However, they contain a large amount of 3D data and very little attribute data, which makes it impossible to use the project BIM model in its current state for operation and maintenance tasks. The BIM model shall be filled with information throughout the entire life cycle of the project, and the need for its

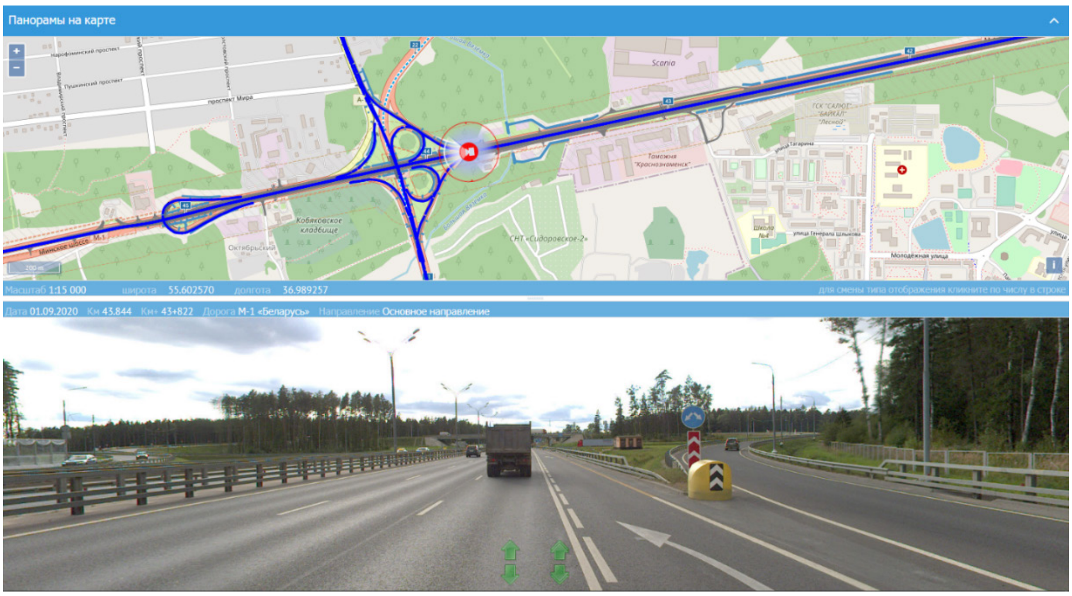


Figure 3. Screenshot of the navigation interface in photos with a 360-degree view

redesign in individual areas due to insufficient level of detail shall be minimized. Based on the initially designed BIM model, through the integration of the financing and progress schedule, a CIM model to optimize construction and installation and, subsequently, an operational AIM model shall be created, supplemented with data on the estimated characteristics of structural elements and installed equipment's operation and wear.

As for the operation stage, information modeling solves the following tasks:

- planning of works and resources for road (road section) maintenance;
- planning of work and resources for works related to road operation, including road (road section) repairs and overhauls;
- planning of works and resources for road (road section) reconstruction;
- procurement of works and resources for road (road section) maintenance and operation;
- collection and accumulation of road (road section) diagnostics data as well as performance monitoring and management of the state of roads (road section) and their utilities;
- automated collection and processing of information from sensors and other systems installed along the road.

These works can also be performed using GIS technologies. The use of these BIM tools in the road industry will not only scale them up but also form a common approach to the structure and library of the digital road model's elements. This is evidence-based reasoning proving the fact that the road GIS reaches the highest level of maturity (in British classification) (BSI, 2007, 2013) — iBIM (Shamraeva et al., 2018) — and demonstrates BIM capabilities during practical application in road infrastructure. Russian specialists are currently developing competitive software solutions that will bring road management to a new environment of economic development.

The use of BIM tools in the implementation of transport infrastructure development projects will optimize time and save money when planning and introducing measures during the operation of facilities.

**Interaction organization using a CDE at the stage of project implementation**

For the FWKB project, specialists of Stroyproekt Institute developed a BIM model in the SINFO environment. According to Avtodor company, this model is suitable for breaking down construction and installation works into stages and getting a general idea of their progress. The company also determined to what extent it could be used for the operation and maintenance of infrastructure facilities (Dmitrienko et al., 2019). In the current state, the InfraBIM model can be used to get an idea of construction and installation works as well as structures under construction. A digital land plot model with an orthophoto could be another advantage.

However, its use without the development of S-INFO to break down construction and installation works into stages is quite difficult and even impossible. Usually, breaking down into stages implies the separation of the original objects. It is impossible to break the selected pavement structure down for a second time (Fig. 5). If the roadbed is to be constructed in two stages, it will be impossible to display only a part of the selected element. Using the model to break down construction and installation works into stages requires access to the original models of each element. Besides, temporary structures were not modeled. Therefore, we cannot control their influence on the boundaries of other structures. If it is required to accurately break down works into stages, we need to model temporary structures. A large amount of data (mainly design and construction data) shall be introduced into the object-related data model. Besides, earthwork structures (excavations and embankments) shall be modeled.

Upon completion of FWKB construction, it is planned to conduct acceptance diagnostics using unmanned aerial vehicles (UAVs) and mobile laboratories of the 5th generation equipped with lidars and mobile laser scanning units (Evstigneev, 2019). In an integration laboratory, 3D models of roads in section view can be developed. Using a scanner, it is possible to collect data from a road section with a width of 7 m (at a speed up to 100 km/h), including from a depth of 7 m under the road pavement. The data obtained are processed automatically by special software and uploaded to the CDE. Concerned individuals and entities can use these data for the design, construction, maintenance, and repair of transport infrastructure facilities. Not only engineers and qualified operators but car enthusiasts as well can join the process of data registration. They will be able to take photos of any road pits and unevenness, violations in traffic sign installation, and, using a special app, send those to the shared database. It is expected that large arrays of information (hundreds of TB) will be accumulated.

Thus, the operational InfraBIM model of the FWKB will ensure uniform principles of data storage, access, and processing for the following applied tasks:

- certification and inventory of roads, artificial structures, and other assets;
- diagnostics of roads and artificial structures;
- collection of information on road traffic accidents;
- registration of traffic intensity and composition;
- evaluation of the level of road maintenance;
- technical registration of road works;
- surveys carried out for the development of traffic management projects;
- surveys and projects of road repairs, construction and reconstruction;

**Model levels in detail**

| **Investment and territorial planning** | **The layout of the territories** | **Design** | **Construction**<br><br>**Operation** |
|---|---|---|---|
| LOD 100 ➪ | LOD 200 ➪ | LOD 300 ➪ | LOD 400 LOD 500 |
| **Attributes:**<br>• Length<br>• Width<br>• Height<br>• Volume<br>• Area<br>............<br>**Result:** territory diagrams with models of existing and planned highways (2-D model) | **Attributes:**<br>• Length<br>• Width<br>• Height<br>• Volume<br>• Area<br>• Shape<br>• Orientation<br>...........<br>**Result:** an area plan with the planned highway in the form of a highway model (number of lanes, configuration of junctions and intersections, etc.) | **Attributes:**<br>• Length<br>• Width<br>• Height<br>• Volume<br>• Area<br>• Profile<br>• Material<br>• Weight<br>• Sectional<br>• Manufacturer<br>............<br>**Result**: engineering model of the highway route, structural lines, road surface and roadbed, road markings, artificial structures, construction site development plan, etc. | **Attributes:**<br>• Length<br>• Width<br>• Height<br>• Volume<br>• Area<br>• Profile<br>• Reference values for profile axes<br>.............<br>**Result:**<br>1) a Production model with a detailed work schedule, logistics for the supply of products and materials, etc. (including 3D models for automated control systems for road construction machines)<br>2) Executive model (models of laser scanning of the highway, etc.)<br>3) Operational model (formed on the basis of the Executive model) |

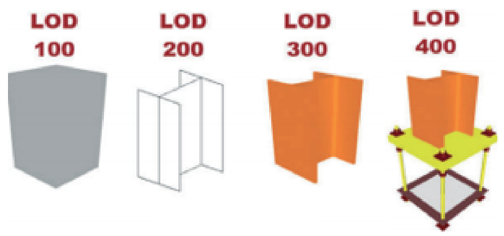


Figure 4. LOD in detail in project development

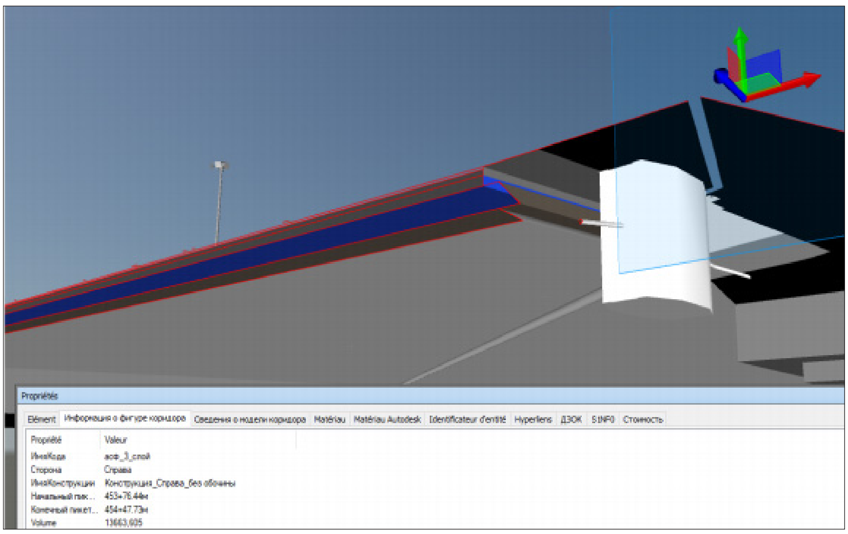

Figure 5. Pavement layer data

- land and property registration.

In many cases, domestic software serves as a means of interaction between the state and business. The GIS of Avtodor company is an example of such interaction, which makes it possible to determine legally relevant data on transport infrastructure facilities and develop common standards and regulations for information exchange (Znobishchev and Shamraeva, 2019a). That is another benefit of BIM modeling when designing transport infrastructure facilities (Bryde et al., 2013).

The issues of using BIM tools in the implementation of transport infrastructure development projects are currently gaining more and more significance. They will help solve the main tasks in the road industry: optimize time and save money when planning and introducing measures at the stage of operation of infrastructure facilities.

The database shall be updated with the use of a special program. IndorRoad has the iFC data exchange format implemented for integrating data from BIM models. This function will be necessary in the future for infrastructure construction and reconstruction projects. To update plans and network diagrams, the ETL (Extract, Transform, Load) procedure can be used when connecting directly to the CDE without using IndorRoad. This issue should be addressed in order to limit human intervention in data entry.

**Conclusion**

The considered InfraBIM model of the FWKB was developed for the stages of design and design documentation development. For the purposes of road operation and maintenance, it shall be modified since the information model intended for use by the operating organization reflects the actual constructed facility. The original models need to be updated. New modeling is required in areas where significant changes were made in the project during construction and installation.

Thus, while there are no projects completely based on InfraBIM processes, the creation of a CDE is conducted in several parallel ways:

- a GIS (“operational BIM”) is formed for the transport infrastructure in operation, which reflects the actual state of the facility and does not require significant costs for update and filling;
- starting from 2021, for all road construction projects, a BIM model is formed that covers the entire life cycle of the road.

However, domestic software solutions are currently suitable for the design stage only since the construction stage requires a decision of the public sector customer for the compulsory use of BIM and a CDE by all participants of the process (designer, contractor, and construction supervisor) with the choice of specific software solutions. Such developments are among the priority areas of information society development, as evidenced by Decree of the President of the Russian Federation No. 203, dated May 9, 2017, “On the Strategy for the Development of the Information Society in the Russian Federation for 2017–2030”. Besides, they support national sovereignty over information flows in the transport sector of the Russian Federation.

## References

Abbasnejad, B. and Moud, H. I. (2013). BIM and basic challenges associated with its definitions, interpretations and expectations. *International Journal of Engineering Research and Applications*, Vol. 3, Issue 2, pp. 287–294.

Barannik, S. V. (2017). Review of the USA national BIM standard NBIMS-US V3. *CAD & GIS for Roads*, No. 1 (8), pp. 4–8. DOI: 10.17273/CADGIS.2017.1.1.

Boykov, V. N., Kuzovlev, Ye. G. and Barannik, S. V. (2017). GIS of the automobile roads in the context of the paradigm of information modeling (BIM). *Dorozhniki*, No. 3 (11), pp. 66–69.

Bryde, D., Broquetas, M. and Volm, J. M. (2013). The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, Vol. 31, Issue 7, pp. 971–980. DOI: 10.1016/j.ijproman.2012.12.001.

BSI (2007*). British Standard BS 1192:2007+A2:2016. Collaborative production of architectural, engineering and construction information. Code of practice.* BSI, 40 p.

BSI (2013). *PAS 1192–2:2013. Specification for information management for the capital/delivery phase of construction projects using building information modelling*. BSI, 68 p.

Criminale, A., and Langar, S. (2017). Challenges with BIM implementation: a review of literature. *53rd ASC Annual International Conference Proceedings, Associated Schools of Construction.* [online] Available at: https://www.researchgate.net/publication/317842173_Challenges_with_BIM_Implementation_A_Review_of_Literature [Date accessed January 11, 2021].

Dmitrienko, V. E., Kuzovlev, E. G. and Shamraev, L. G. (2019). GIS application of the Avtodor State Company for solving practical tasks of road maintenance. *CAD & GIS for Roads*, No. 2 (13), pp. 52–59. DOI: 10.17273/CADGIS.2019.2.8.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011). *BIM Handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors.* 2nd Edition. Hoboken, NJ: John Wiley & Sons, 624 p.

Evstigneev, I. A. (2019). Road infrastructure and highly automated vehicles. *CAD & GIS for Roads*, No. 2 (13), pp. 44–50. DOI: 10.17273/CADGIS.2019.2.7.

Gibadullin, A. A., Morkovkin, D. E., Hutarava, I. I., Stroev, P. V. and Pivovarova, O. V. (2020). Analysis and digital transformation of the transport sector of the Eurasian Economic Union. *IOP Conference Series: Materials Science and Engineering*, Vol. 918, 012231. DOI: 10.1088/1757–899X/918/1/012231.

Hardin, B. and McCool, D. (2015). *BIM and construction management: proven tools, methods, and workflows.* 2nd edition. Indianapolis, IN: John Wiley & Sons, 416 p.

Kazeev, I.M. (2020). Simulation modeling transport and technological complex. *Educational Resources and Technologies*, No. 1 (30), pp. 69–74. DOI: 10.21777/2500–2112–2020–1–69–74.

Linowes, J. and Babilinski, K. (2017). *Augmented reality for developers: build practical augmented reality applications with Unity, ARCore, ARKit, and Vuforia*. Birmingham: Packt Publishing, 548 p.

Shamraeva, V. (2020a). Analysis of business processes of construction and operation of highways on a toll basis using BIM tools. In: *Information Technologies and Mathematical Modelling. ITMM 2020. Proceedings of the 19th International Conference named after A. F. Terpugov, December 2–5, 2020, Tomsk, Russia.* Tomsk: Scientific Technology Publishing House, pp. 429–440.

Shamraeva, V. (2020b). Predicting the effectiveness of implementation of financial models for toll collection on the road. *Transport Business of Russia*, No. 1, pp. 37–41.

Shamraeva, V. V., Kuzovlev, E. G. and Barannik, S. V. (2018). Implementation of geographic information systems in the road sector as one of the directions of information modeling. *Herald of Computer and Information Technologies*, No. 6 (168), pp. 20–26. DOI: 10.14489/vkit.2018.06.pp.020–026.

Skvortsov, A. V. and Sarychev, D. S. (2015). Road project life cycle for information modeling. *CAD & GIS for Roads*, No. 1 (4), pp. 4–14. DOI: 10.17273/CADGIS.2015.1.1.

Stumpf, A. L., Kim, H. and Jenicek, E. M. (2011). *Early design energy analysis using Building Information Modeling technology*. Arlington, VA: Office of the Assistant Chief of Staff for Installation Management, 90 p.

The American Institute of Architects (2013). *E203–2013 Building Information Modeling and Digital Data Exhibit.* [online] Available at: https://help.aiacontracts.org/public/wp-content/uploads/2020/12/AIA–E203–2013–Free-Sample-Preview.pdf [Date accessed 25.02.2021].

Znobishchev, S. V. and Shamraeva, V. V. (2019a). New approaches to construction of linear sections of the transport infrastructure with the use of BIM-modeling. *BIM in Construction & Architecture. Proceedings of the 2nd International Conference, May 15–17, 2019*. Saint Petersburg: Saint Petersburg State University of Architecture and Civil Engineering, pp. 124–129.

Znobishchev, S. and Shamraeva, V. (2019b). Practical use of BIM modeling for road infrastructure facilities. *Architecture and Engineering*, Vol. 4, No. 3, pp. 49–54. DOI: 10.23968/2500–0055–2019–4-3–49–54.

# INFRABIM ДЛЯ УПРАВЛЕНИЯ БИЗНЕС-ПРОЦЕССАМИ СТРОИТЕЛЬСТВА И ЭКСПЛУАТАЦИИ АВТОМОБИЛЬНЫХ ДОРОГ

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**Аннотация**

Предметом исследования являются бизнес-процессы строительства и эксплуатации линейно протяженных участков автомобильных дорог. В статье рассмотрена геоинформационная система (ГИС) государственной компании «Автодор» (разработчик «ИндорСофт», Томск), и ее использование в целях эксплуатации и технического обслуживания объектов транспортной инфраструктуры на таких участках дорог. Объектом исследования является проект строительства Дальнего Западного обхода Краснодара (ДЗОК), являющийся частью транспортного коридора Север-Юг, и его реализация с помощью InfraBIM-моделирования. **Цель исследования:** Описание структурированной базы данных ГИС государственной компании «Автодор» путем подключения различных инструментов InfraBIM для генерации и обновления информационной модели дороги. **Методы:** Предлагаемые программные решения для ГИС государственной компании «Автодор» при использовании InfraBIM-модели дорожной инфраструктуры: применение функционала ГИС на объекте; применение асинхронного редактирования и обработки данных без доступа к Интернету; обновление базы данных. **Результаты:** Разработка InfraBIM-моделей линейно – протяженных участков дорог при реализации проектов типа ДЗОК позволяет решать основные задачи содержания дороги - оптимизировать время и средства при планировании и реализации мероприятий на этапе эксплуатации объектов транспортной инфраструктуры.

**Ключевые слова**

BIM-моделирование, информационная модель дороги, геоинформационная система, транспортная инфраструктура, цифровая трансформация дорог, InfraBIM для строительства и обслуживания дорог.

DOI: 10.23968/2500-0055-2021-6-3-29-41

# INCREASING THE EFFICIENCY OF HEAT LOAD CONTROL IN CENTALIZED HEATING NETWORKS

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**Abstract**
The paper presents the results of studies **aimed** to increase the efficiency of centralized heating networks by improving heat supply control at the plant and at the local level. With this in view, we considered issues of choosing the optimal heat supply schedule and its influence on the efficiency of heat generation, transportation and use, as well as the influence of the heat carrier temperature on heat losses at the corner of the temperature curve. We also studied the influence of the heat carrier temperature in the return pipe of heating networks on the operation of heat generators by using various control methods. Another issue considered in the course of the study was the issue of ensuring the hydraulic and thermal stability of heating networks and heating systems connected to them by using the combined control method. **The methodology of the study** was based on the analysis of heat balance equations for the steady-state operation of a complex including a heating network and a building's heating system. As a **result**, we obtained relationships that make it possible to determine the variation in the heat carrier flow rate and temperature depending on the heat load, as well as the reduction in energy consumption for heat carrier transportation. Recommendations were developed for the introduction of combined heat load control. A scheme for the reconstruction of central heat stations is proposed. **The scientific and practical results** of the study can be used to prevent significant heat losses, ensure optimal operation of heating networks, heat generators, and heating systems, reduce energy consumption, and increase the overall efficiency of centralized heating networks.

**Keywords**
Heat supply, centralized heating networks, energy saving, efficiency, heat load control.

## Introduction

Providing high-quality heat supply while ensuring energy-efficient heat generation, supply and transportation in centralized heating networks (CHNs) is a complex task. The main focus is usually on the efficient use of fuel in heat sources and heat saving directly in consumer systems (Kultyaev, 2017). However, heat carrier supply and transportation as well as the subsequent transformation of heat carrier parameters at consumer connection points account for a significant part of energy losses (Rafalskaya et al., 2019). The efficiency of this complex process is largely determined by the selected methods of CHN operation control at all stages (Magnusson, 2011). Heat supply control at the plant shall be recognized as a key link in this chain (Szkarowski, 2019).

Such control shall ensure the high energy efficiency of CHN operation and improve specific indicators of heat generation and supply. However, these tasks are subordinated to a more comprehensive goal of maintaining particular temperature conditions in buildings at any changes in the external temperature, air infiltration and heat development (Rafalskaya et al., 2018).

Energy losses caused by the low efficiency of control systems during heat generation, transportation and supply in CHNs pose a serious problem. This issue is the main CHN disadvantage when comparing independent and centralized heating networks (Chicherin, 2018).

It is well known that central heat supply quality control at the heat source has a number of drawbacks (Sokolov, 1982). As for local control, energy losses are significant as well, including due to the imperfect design of consumer connection points in buildings and devices for heating unit control.

As a rule, CHN control at the heat source and local control at the heat consumer are considered separately both from the technical and organizational point of view (Chicherin et al., 2018; Cui et al. 2014; Pieper et al., 2017). However, it is obvious that they are bound just as closely (by the common goal, which is to ensure particular temperature conditions in buildings) as the interrelated processes of heat generation, transportation and supply in CHNs. This paper is the first to comprehensively consider the influence of individual stages of heat transformation on the overall efficiency of CHN operation.

**Analysis of the current state of the issue**

The principles of central and local CHN control are in conflict with each other. Issues of improving the energy efficiency of buildings are usually solved before the issues of CHN reconstruction, which are addressed only as a result of reforms in the field of energy efficiency of buildings as heat consumers.

Thermal modernization of buildings reduces the design heat load for heating and hot water supply. Thus, the gap between the rated heat generator capacity and the connected heat load, which is detrimental to the heat source, increases. Equipment of some consumers connected to the CHN heating network with automated individual heat stations (IHSs) including mixing units results in consumers with different requirements for pressure at the inlet. Differential pressure controls at the inlet contribute to the hydraulic and thermal deregulation of the heating network and disrupt heat supply in buildings without automated IHSs. Automatic local control of the flow rate of the heat carrier, entering end-user heating systems, makes it impossible to ensure adequate central heat supply control in boiler houses. The attempts to reduce the heat supply temperature and switch to a low-temperature schedule typical for 4$^{th}$ generation CHNs introduce problems with heat transfer from heating units at the consumer side. In fact, there are many examples of such mutual influence, which is not always useful (Sharapov et al., 2010).

In this regard, the joint consideration of central and local control suggested in the paper seems relevant since it has not been resolved yet at a serious level. The solutions proposed below will likely increase the efficiency of existing CHNs when switching to more efficient alternatives.

The issue of design temperature conditions in a heating network shall be considered separately. As for existing CHNs, a typical approach involves the following: maintaining (if possible) a higher heat carrier temperature in the supply pipe of the heating network and a higher water temperature difference in the supply ($\tau_1$) and return ($\tau_2$) pipes (Sharapov and Rotov, 2007; Sokolov, 1982). An increase in temperature difference will make it possible to reduce the heat carrier flow rate and the hydraulic resistance of the network, as well as the diameter of the pipes. The reduced pipe diameter means less volume of water and smaller leakage areas. All this will reduce water losses as well as the cost of heat carrier pumping and make-up water treatment.

To maintain a high-temperature schedule of heat supply, technically sound mixing units are required at the inlet to buildings, which is not always the case. In this case, low-temperature modes close to the heating schedule are preferable.

The transition to a lower temperature in the supply pipe has a number of advantages. Foreign 4$^{th}$ generation CHNs are oriented towards lower temperature schedules of heat supply (Bhatt and Verma, 2015; Lund et al., 2018). The corresponding European standards are aimed at the same (European Parliament and Council, 2018).

**Subject, tasks, and methods**

Central heat supply quality control (by changing the heat carrier temperature) is the most common method in Russian heating networks. However, this method has a significant disadvantage: inefficient control at the corner (breakpoint) of the temperature curve when heat is used both for heating and hot water supply. From this point on, it is impossible to control heat supply by changing the heat carrier temperature. In this case, the heat carrier temperature in the supply pipe is kept constant (65 °C) to ensure a hot water temperature of at least 60 °C.

We already demonstrated that operation in this period is associated with excessive heating (overheating of premises) and significant inefficient heat losses (Szkarowski et al., 2016). In this case, a decrease in the network heat carrier temperature leads to a decrease in the external temperature, which results in the mentioned corner of the temperature curve, an increase in the duration of system operation in the excessive heating mode, and an increase in inefficient heat losses. Fig. 1 shows this relationship for the following climatic parameters: external design temperature $t_e^d$ = –23 °C at the temperature at the beginning of the heating season $t_e^{hpb}$ = +8 °C

As can be seen, an increase in the design parameters of the heat carrier from 95 to 150 °C increases the external temperature from 0 to +3.5 °C (at which it will be necessary to stop central heat supply quality control), i.e., shifts the corner point to the end of the heating season. The duration of this unfavorable period is reduced from 3600 to 1100 hours. Thus, the annual inefficient heat losses, corresponding to the corner of the temperature curve, decrease with an increase in the design heating water temperature in heating networks.

Fig. 2 shows how the impossibility to carry out quality control affects additional heat losses during heat carrier transportation, corresponding to the corner of the temperature curve, under the same climatic conditions. It follows from the diagram that the increase in these losses is most significant at a heat carrier temperature of 115–95 °C, i.e., at low operating parameters of the heating network.

However, negative economic consequences of high-temperature modes of the heating network should be mentioned as well. For instance, as the difference between the temperatures of the network heat carrier and the ground increases, heat losses through heat insulation increase as well. For the selected climatic conditions, this can be represented by the relationship shown in Fig. 3.

Another reason for an ambiguous assessment of high-temperature modes is the influence of the heat carrier temperature on the performance efficiency and thermodynamic efficiency of heat generators of CHN sources. Higher heat carrier temperatures mean a higher temperature of flue gases and an increase in corresponding heat losses in the heat balance of the boiler. The average temperature of flue gases in the case of standard (non-condensing) hot water boilers in CHNs is 160–180 °C and often even higher. At such a temperature, heat losses with flue gases ($\mathbf{q}_2$ value in the heat balance of the boiler) can account for up to 9–11% of the heat potential of the fuel. This reduces the performance efficiency of the system as a whole.

These losses can be reduced significantly by lowering the temperature of flue gases. A decrease in their temperature from 200 to 100 °C makes it possible to reduce $\mathbf{q}_2$ by 5%. Cooling to 60 °C will ensure more than 7% saving.

An even more effective method of increasing the efficiency of fuel use in CHNs is the condensation of water vapor from the combustion products. In this case, flue gases shall be cooled to 55–56°C (dew point). In addition to reducing physical heat losses $\mathbf{q}_2$, each kilogram of condensed moisture makes it possible to return approx. 2.5 MJ to the heat balance of the boiler.

This could be ensured by the use of condensing boilers. Unfortunately, so far, this task is not feasible in a broad sense. However, it is possible to install condensing heat exchangers at the flue gas ducts. Fig. 4 shows a circuit diagram for the installation of a condensing heat exchanger on the flue gas line of the CHN boiler house.

In any case, to ensure efficient flue gas heat recovery, a sufficiently low temperature of the heat carrier is required in the return pipe of a heating network. For instance, intensive condensation of water vapor on the heat exchange surface is provided at a temperature of network water in the return pipe not higher than 40–45 °C. This is possible only when switching to a low-temperature heat supply, which, at the first glance, contradicts the results of the above analysis. We cannot hope that an increase in the efficiency of heat sources will compensate for long-term unproductive operation in the mode corresponding to the corner of the temperature curve.

In that respect, a radical solution would be to switch to central flow rate control after the moment

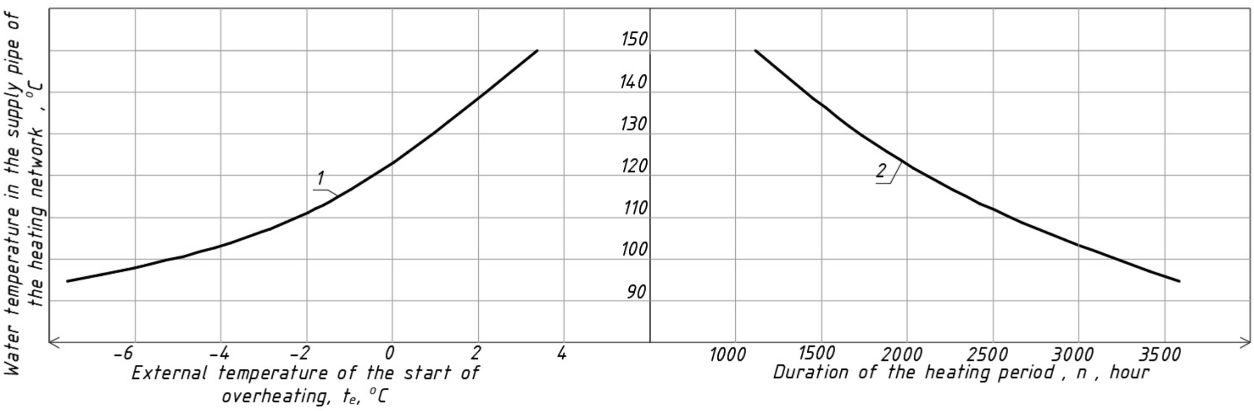


Figure 1. Influence of the design network water temperature on the external temperature, at which excessive heating begins (on the left) and the duration of heating system operation in this mode (on the right) under the selected climatic conditions

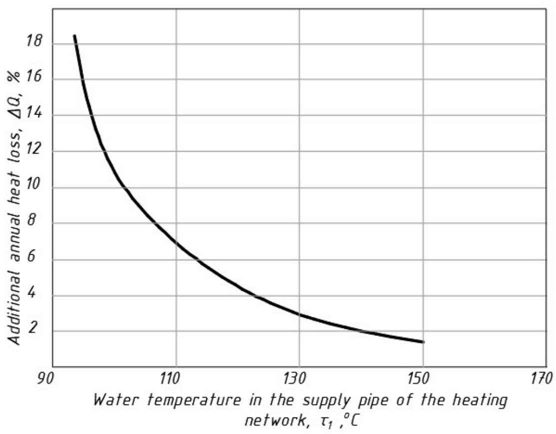


Figure 2. Additional heat losses, corresponding to the corner of the temperature curve, vs. network water temperature

corresponding to the corner of the temperature curve while introducing quality local control of heating systems. Modern automated heat stations provide control of the heat carrier temperature depending on the external temperature by changing the mixing ratio of network and return water in the admix units of heating systems. This also contributes to a decrease in the heat carrier temperature in the return pipe of heating networks.

However, the number of such heat stations is still insufficient, especially in old built-up areas and in small towns. The lack of controlled mixing units in local systems with a high-temperature schedule of heat supply results in a high heat carrier temperature in the return pipe of heating networks, which reduces the efficiency of fuel use at the heat source.

Thus, the issue of choosing the method of central and local control of CHNs and temperature schedule of heat supply remains open and depends on a large number of factors. Preliminary consideration of this issue shows that the transition to a low-temperature schedule of heat supply does not make sense. Without the introduction of condensing boilers or condensing waste heat exchangers and without the transition to central flow rate control of CHN, this will significantly deteriorate the overall performance of the heating network. The reason for that is a significant increase (up to 18% of the fuel potential) in inefficient heat losses during the period corresponding to the breakpoint of the temperature

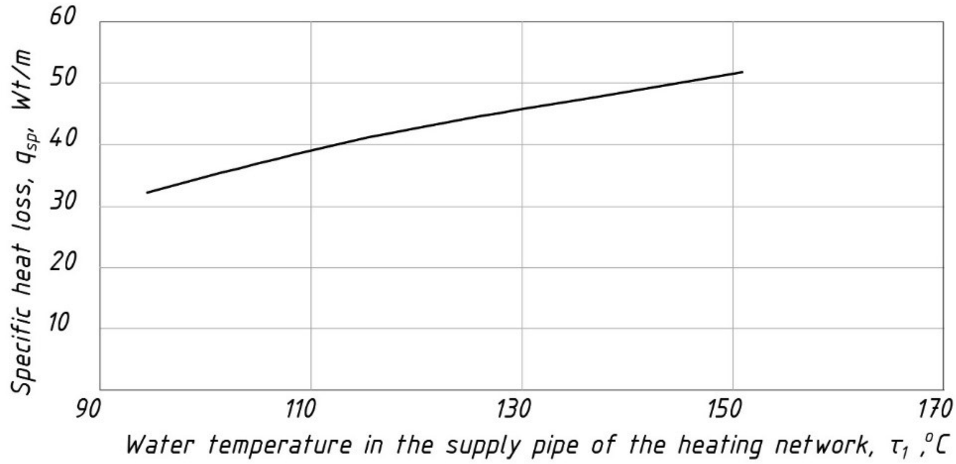


Figure 3. Specific heat losses by heating network pipes vs. network water temperature

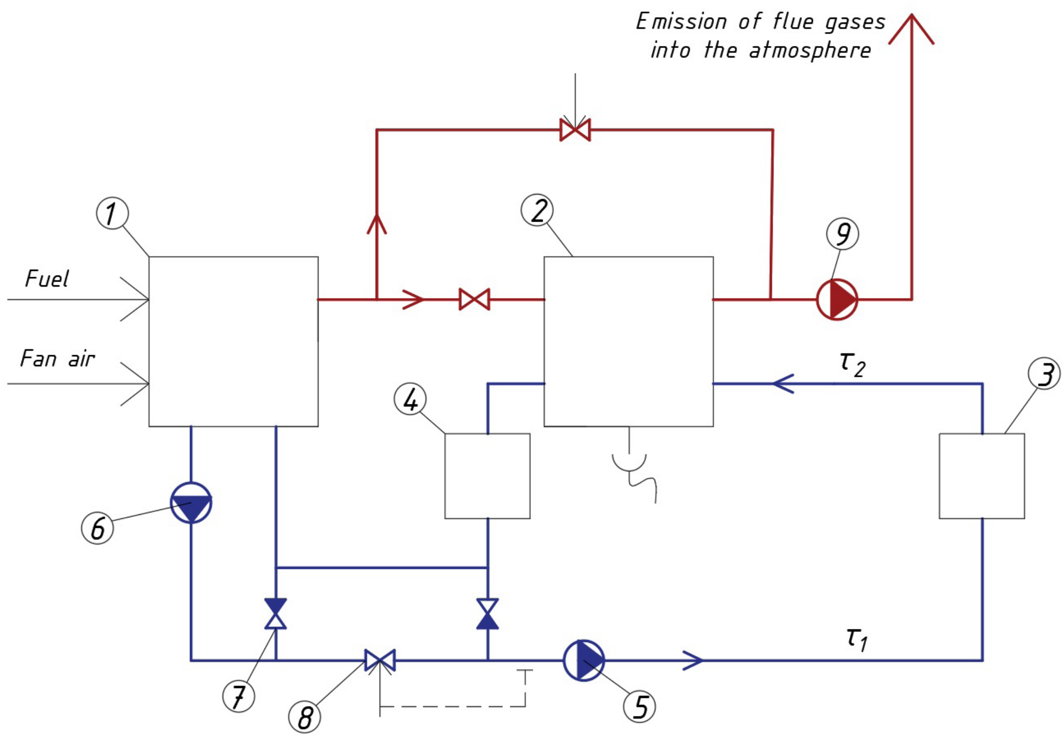


Figure 4. Circuit diagram for combustion products' heat recovery in a condensing heat exchanger: 1 — hot water boiler; 2 — condensing waste heat exchanger; 3 — heat consumer, 4 — calciner, 5 — circulating pump of the heating network, 6 — boiler circuit pump, 7 — check valve, 8 — temperature controller, 9 — flue gas duct

curve when switching to a low-temperature schedule. In our work, we made an attempt to use modeling methods to develop recommendations for choosing the optimal parameters of CHN operation.

**Results and discussion**

Control of heterogeneous heat load can be central (at the heat source) and local (at individual or group consumer connection points). The heat transfer from heating units in heating systems can be controlled by changing:

- the heat carrier temperature in the supply pipe of the heating network $\tau_1$;
- the heat carrier temperature at the input to the heating system $t_1$;
- the flow rate of the heat carrier in the heating network for heating $G_h$;
- the flow rate of the heat carrier circulating in the heating system (after the admix unit) $G_{hs}$.

In this case, a number of the following restrictions shall be observed:

- in case of hot water supply load, the temperature $\tau_1$ cannot be lower than that required for hot water heating (65°C);
- an increase in the flow rate of the network heat carrier for heating $G_h$ is limited by an increase in the hydraulic resistance of the heating network and heating systems as well as network water pressure difference at the inlet to buildings;
- a decrease in the flow rate of the heat carrier in heating systems is limited by a decrease in the hydraulic and thermal stability of end-user heating systems (it is not recommended to reduce the flow rate by less than 60% of the design values);
- a decrease in the temperature at the input to the heating system $t_1$ is limited by disproportionate changes in the heat transfer from heating units (loss of vertical thermal stability) — up to 40% on the lower floors compared to the upper ones.

It seems optimal to introduce **combined quality and flow rate local control**, which has not been applied yet even at modern automated IHSs with control depending on the external temperature (weather control).

Currently, IHSs use quality control by admixing the cooled heat carrier from the heating system to the hot heat carrier from the heating network. The weather control adjusts the mixing ratio so that the temperature $t_1$ would correspond to the current external temperature. In this case, the flow rate of water circulating in the heating system (after the mixing unit) does not change: $G_{hs}$ = const.

An independent circuit for heating systems' connection to heating networks (through a heat exchanger) and a dependent circuit with a mixing pump are also known. In these cases, it is possible to improve the quality of heating system control through local quality control (Bogoslovsky and Skanavi, 1991).

Finally, when CHNs operate according to a heating schedule, no mixing units are available at consumer connection points.

In all cases, it is extremely important to maintain the thermal stability of heating systems, which is the task of central control. From this perspective, we considered the main possibilities of increasing the efficiency and quality of heat supply in CHNs.

**1. Consideration of central control specifics**

**Quality and flow rate control**

The classical approach implies that in order to prevent vertical temperature stratification in heating systems, it is necessary, along with changes in the network heat carrier temperature $\tau_1$, to change the relative flow rate of water for heating $\alpha_h$. This relationship is usually represented in dependence to the relative heat load for heating $\varphi_h$ as follows (Logunova and Zorya, 2020):

$$\alpha_h = \varphi_h^n, \tag{1}$$

where the exponent $n$ is taken equal to 0.33 for two-pipe systems and 0.25 for one-pipe systems.

This method is called optimal quality and flow rate control. Earlier, it was difficult to implement it in practice due to issues with smooth control of the network pump rate. Usually, the flow rate of network water changed stepwise several times during the heating season, and at such a flow rate, quality control was carried out. Modern capabilities of pump rpm control make it possible to optimize CHN operation, thus bringing new life into the principle of quality and flow rate control.

**Central flow rate control**

New technical capabilities change our perception of central flow rate control. Usually, it was recommended only after the point corresponding to the corner of the temperature curve but it was related to the issue of network pump rate control mentioned above. Besides, since it was necessary to prevent temperature stratification in heating systems, the possibilities of flow rate control were limited by the permissible value of the relative flow rate of network water for heating $\alpha_h$ = 0.6.

The rule of flow rate control usually has the following form (Szkarowski, 2019):

$$\alpha_h = \frac{(0.5+u)\,\Delta t_d \varphi_h}{\tau_1 - \delta t_d \varphi_h^n - t_{int}}, \tag{2}$$

where: $u$ is the mixing ratio in the mixing unit of the heating system; $\Delta t_d$ is the design water temperature difference in the heating system; $\delta t_d$ is the design temperature difference between the heating units and internal air; $t_{int}$ is the temperature of internal air; $n$ = 0.75–0.8.

Based on the heat balance equations, using an original method, we simulated central flow rate control for various temperature conditions in the heating network. The results are shown in Fig. 5 in the form of the relationship $\alpha_h = f(\varphi_h)$.

To ensure optimal heat load control, typical for the average temperature in the heating period (about 50% of the design value) at a temperature schedule of 115/70°C, the relative flow rate of the heat carrier will be approx. 30% of the design one. At a load of 20%, typical for the beginning and end of the heating period, the flow rate of the heat carrier will be 10% of the design value.

With flow rate control, the heat carrier temperature in the supply pipe remains constant throughout the entire control range. This solves the problem of inefficient heat losses during the period corresponding to the breakpoint of the temperature curve and excessive heating in the transition period, which is inevitable in the case of quality control. Besides, a decrease in the flow rate of the network heat carrier will significantly reduce the cost of energy for pumping.

**Heat carrier temperature in the return pipe of the heating network**

The calculations performed above do not provide information on the influence of flow rate control on the temperature in the return pipe of the heating network. As shown above, this factor is of key importance for the efficiency of heat generation and the CHN in general, especially when using condensing heat exchangers.

To solve this issue, the heat balance equations were solved with respect to the temperature in the return pipe of the heating network $\tau_2$ for three different methods of central control: quality control (the current case); flow rate control; combined control (quality control up to the corner point and flow rate control after the corner point).

The calculation results are shown in Figs. 6, 7, and 8 in the form of a dependence of the heat carrier temperature in the return pipe and the relative heat load on the external temperature.

The comparative analysis of the calculation results shows the following. With **quality control** (Fig. 6), the heat carrier temperature in the return pipe for high-temperature schedules only approaches the dew point of water vapor in the combustion products but does not reach it, which does not ensure the efficient operation of the condensing heat exchangers.

When switching to a temperature schedule of 80/60°C, the heat carrier temperature in the return pipe at a heat load of about 84% of the design one decreases to the dew point. This guarantees the efficient operation of the condensing heat exchangers and a significant increase in the efficiency of the boilers throughout almost the entire heating period. However, such a temperature schedule is rarely used in domestic heating networks.

With **combined control** (Fig. 7), the heat carrier temperature in the return pipe, required for the efficient operation of the condensing heat

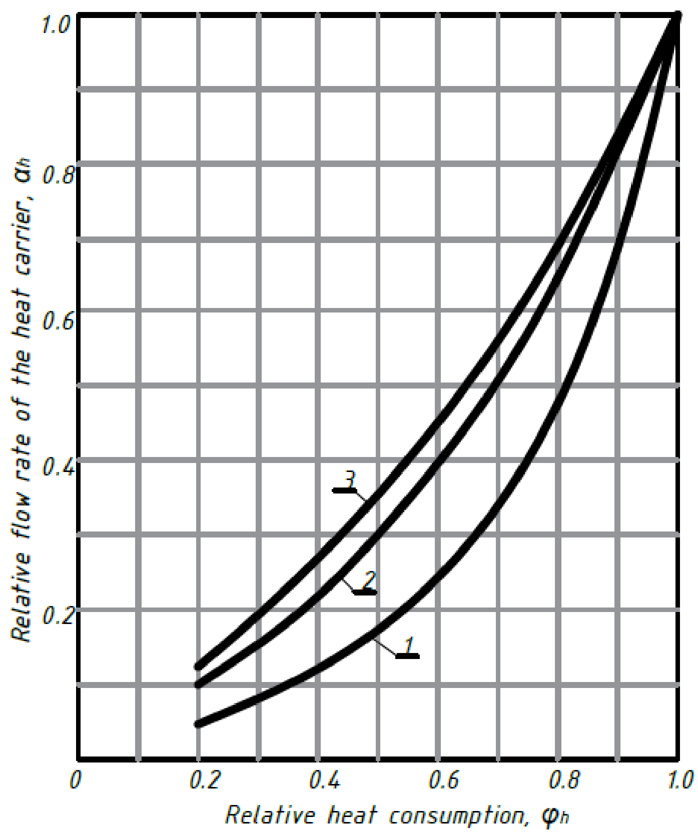


Figure 5. Central flow rate control for various temperature conditions in the heating network: 90/70°C (1); 115/70°C (2); 135/70°C (3)

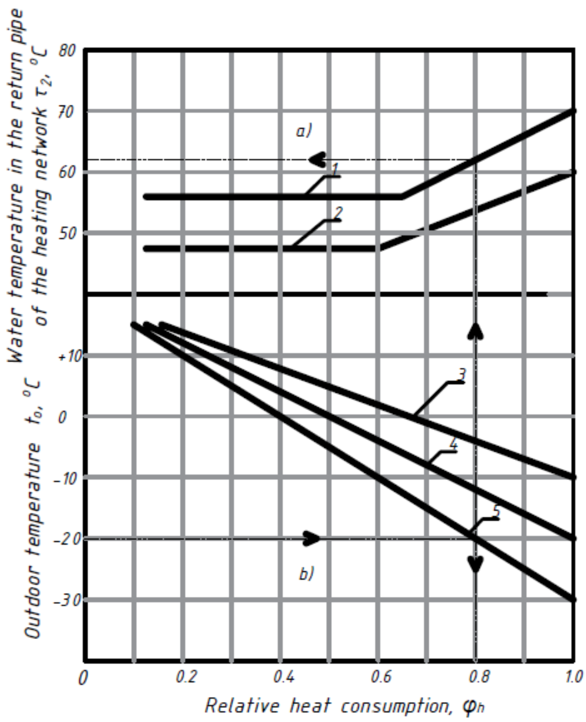


Figure 6. Heat carrier temperature in the return pipe of the heating network (a) and relative heat load for heating (b) vs. external temperature for different temperature schedules of heat supply: 135/70 °C; 115/70 °C, and 90/70 °C (1); 80/60 °C (2), and different design external temperatures: –10 °C (3); –20 °C (4); –30 °C (5), with central quality control

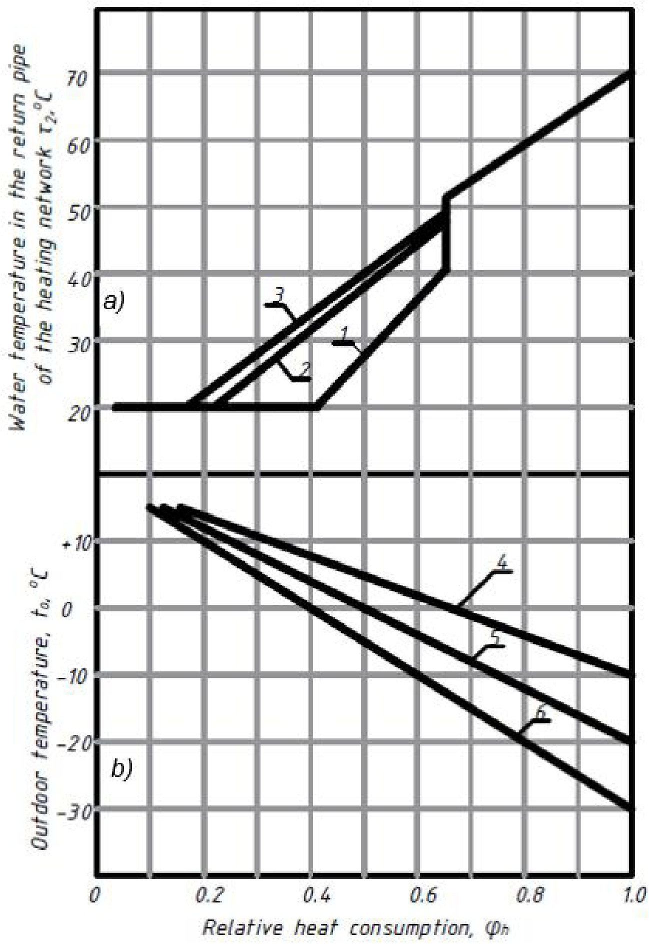


Figure 7. Heat carrier temperature in the return pipe of the heating network (a) and the relative heat load for heating (b) vs. external temperature for different temperature schedules of heat supply: 90/70 °C (1); 115/70 °C (2); 135/70 °C (3), and different design external temperatures: –10 °C (4); –20 °C (5); –30 °C (6), with combined central control

exchangers and CHN in general, is achieved at a heat load below 65–70% of the design one.

At a load of about 50%, the heat carrier temperature in the return pipe will be approx. 40°C even for a temperature schedule of 135/70°C, and with a schedule of 90/70°C, it will drop to 28°C, which will ensure very high performance efficiency of the condensing heat exchangers.

The transition to **central flow rate control** of heat supply (Fig. 8) significantly improves the operating conditions of the condensing heat exchangers and convection heating surfaces of the boilers, increases the depth of heat extraction from the combustion products, and increases the efficiency of the heat generators and CHN in general. This is due to the fact that the temperature in the return pipe of the heating network is significantly reduced. As with combined control, at a load of 50% of the design one, the heat carrier temperature in the return pipe of the heating network is approx. 40°C, even for a temperature schedule of 135/70°C. The transition to temperatures above the dew point for this graph occurs only at an increase in the load to 80% of the design one, which for areas with a design external temperature of –20°C occurs at –12°C. Therefore, for most of the heating season, the water temperature in the return pile will be below the dew point, which guarantees the stable operation of the condensing heat exchangers.

Thus, the transition to central flow rate or combined control makes it possible to prevent excessive heating of buildings during the period corresponding to the breakpoint of the temperature curve, preserve the possibility of generating hot water of the required quality, avoid inefficient heat losses, and ensure the high energy efficiency of the CHN. In this case, the use of low-temperature schedules of heat supply is the most acceptable.

Among other advantages of low-temperature schedules of heat supply, the following can be mentioned:

- reduction of heat losses during transportation;
- reduction of the thermal elongation of pipes and, as a result, a simpler design of heating networks and elimination of hazardous expansion joints;
- an increase in the generation of electrical energy at sources with co-generation of heating and power (CHP plants) due to a decrease in pressure at the heat extraction sections of turbines;
- possibility of CHN operation with alternative and renewable energy sources.

**2. Energy consumption for heat carrier pumping**

In addition to the advantages mentioned above, flow rate and combined control make it possible to

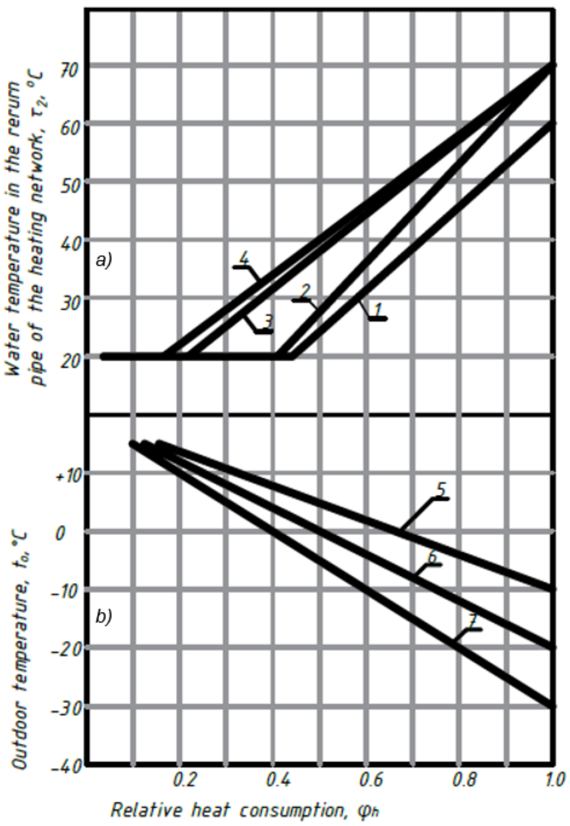


Figure 8. Heat carrier temperature in the return pipe of the heating network (a) and relative heat load for heating (b) vs. external temperature for different temperature schedules of heat supply: 80/60°C (1); 90/70°C (2); 115/70°C (3); 135/70°C (4), and different design external temperatures: –10°C (4); –20°C (5); –30°C (6), with central flow rate control

ensure additional savings in the form of a reduction in energy consumption for heat carrier pumping.

Fig. 9 shows the results of calculating the flow rate of network water with combined control of heat load in comparison with traditional quality control. The connected heat load is 100 MW, and the design external temperature is –23 °C.

Between points A and B, quality control is carried out. At an external temperature of –8°C, the temperature curve is characterized by a breakpoint and it is proposed to switch from quality to flow rate control. This makes it possible to reduce the flow rate of the heat carrier along the B-f-F line.

This, in turn, creates conditions for a significant reduction in energy consumption for network water transportation, which is shown in Fig. 10. It graphically represents an analysis of the required power of network pumps for several options of central heat load control.

The a-b-c-e-d line represents power consumption by network pumps for the current state, i.e., the dependent circuit for the connection of multi-story buildings and central heat load quality control.

The A-B-C-E-D line shows how power consumption by pumps will change after they are replaced with more modern ones (without changing the consumer connection diagram and the control method).

The A-B-f-E-D line shows how power consumption will change when switching to combined central control according to the method proposed in the paper.

The 1–2-3–4-5 line represents the results of the analysis of changes in the power of network pumps at combined central control when switching to an independent circuit for connection of heat consumers.

The results of the analysis show that the transition to the combined central control of heat supply and changes in the method of connecting multi-story buildings can significantly reduce the power of the electric motors of network pumps. This, in turn, reduces fuel consumption for energy generation as well as environmental pollution by harmful substances from the combustion products (Janta-Lipińska, 2020).

The flow rate stage of combined heat load control (along the B-E or 2–3 lines, Fig. 10) requires the installation of automatic drive speed controllers on network pumps, which, in turn, requires significant investments. As an intermediate option, it is proposed to install several pumps (instead of one network pump) with a common flow equal to the replaced one (for instance, three pumps with a capacity equal to 1/3 of the current one). Analysis of the annual heat consumption schedule will make it possible to select the number and specifications of new pumps more accurately. To provide summer load, another pump with the corresponding flow is required. These pumps, running at a constant speed, will be connected in parallel and switched on automatically, depending on the external temperature. This will mean a stepwise implementation of the flow rate stage of combined heat load control.

**3. Consumer connection optimization**

Equipping heat consumers with modern automated IHSs with weather control and the corresponding transition to central flow rate or combined control at the heat sources shall be considered as a long-term perspective of CHN development. This will require the installation of automatic drive speed controllers on network pumps and changes in the thermal-mechanical scheme of boiler rooms.

It will also be necessary to optimize the heat output of boiler units in accordance with the connected heat load and the annual heat

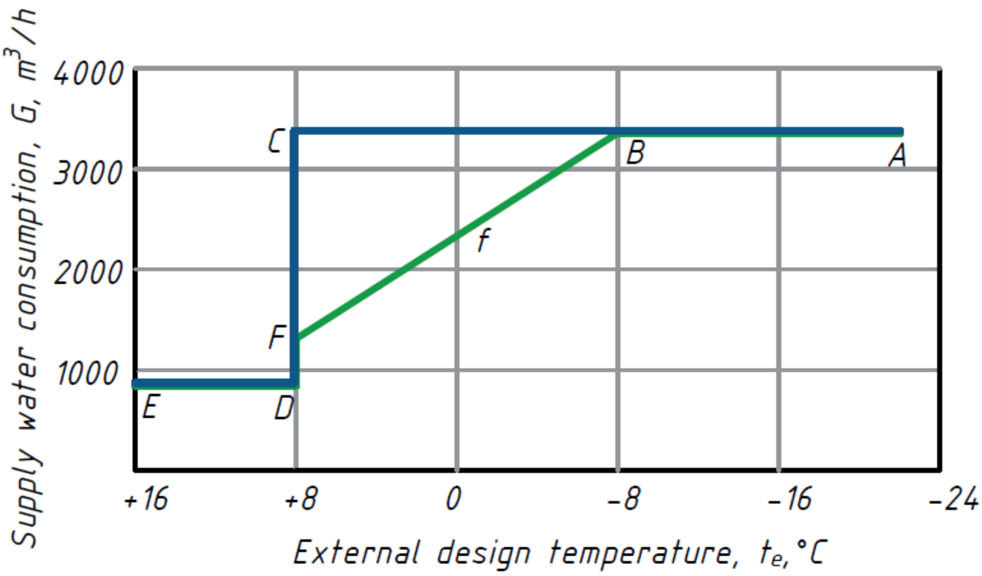


Figure 9. Heat carrier flow rate in the CHN vs. external temperature: A-C-D-E — with quality control; A-B-f-F-D-E — with combined control

consumption schedule. Such modernization of boiler houses shall prevent an excessive decrease in the flow rate of the heat carrier circulating through the boilers. From this perspective, even in the case of hot water boilers, it is preferable to separate the boiler and heating network circuits according to the known schemes.

The main obstacle to the introduction of automated IHSs and central flow rate or combined control is not only in the unreadiness of energy sources. The complete transition to such control can be carried out only after the introduction of an independent connection circuit or automated IHSs with mixing units in all buildings. However, this requires significant investments and time.

Therefore, buildings with obsolete IHSs will remain in the CHN for a long time. This may disturb the hydraulic and thermal stability of end-user heating systems in such buildings. Inevitable changes in pressure difference and flow rate difference at the points of connection to the heating network will be the reason for temperature stratification. The proposed solutions imply significant changes in the flow rate of the network heat carrier.

As an intermediate option, it is proposed to ensure local group control at central (group) heat stations. Until all buildings are fully equipped with automated IHSs, their reconstruction will make it possible to switch to more efficient quality and flow rate local control of heat supply, eliminating inefficient heat losses associated with excessive heating.

Fig. 11 shows a schematic diagram of the reconstruction of a central heat station for the transition to quality and flow rate group control of heat supply in the absence of automated IHSs in the connected buildings.

The reconstruction implies equipment of the central heat station with mixing units, which will ensure constant water consumption in the distributing four-pipe heating network after the connection point. This will prevent the hydraulic and thermal deregulation of end-user systems in the buildings connected to the central heat station.

With such a scheme, the heat flow for heating can vary depending on the ratio between the heat extraction for heating and heat extraction for hot water supply. In short periods of maximum heat extraction for hot water supply, the heat flow for heating will decrease. However, after the end of the peak water draw-off, the heat deficit for heating will be compensated for (Orłowska, 2020).

The annual indicators of the efficiency related to the implementation of such control were calculated for the previously mentioned parameters: heat load of 100 MW and design external temperature of –23°C:

- reduction of inefficient heat losses —**18,806** MWh (6.4% of the annual heat generation before reconstruction);
- equivalent fuel economy (natural gas) — **2.304** million m³;
- energy saving — **2451** MWh (41% of energy consumption during the period corresponding to the breakpoint of the temperature curve before reconstruction);
- corresponding reduction of $CO_2$ emissions — **6426** tons.

**Conclusions**

1. Central quality control in the conditions of

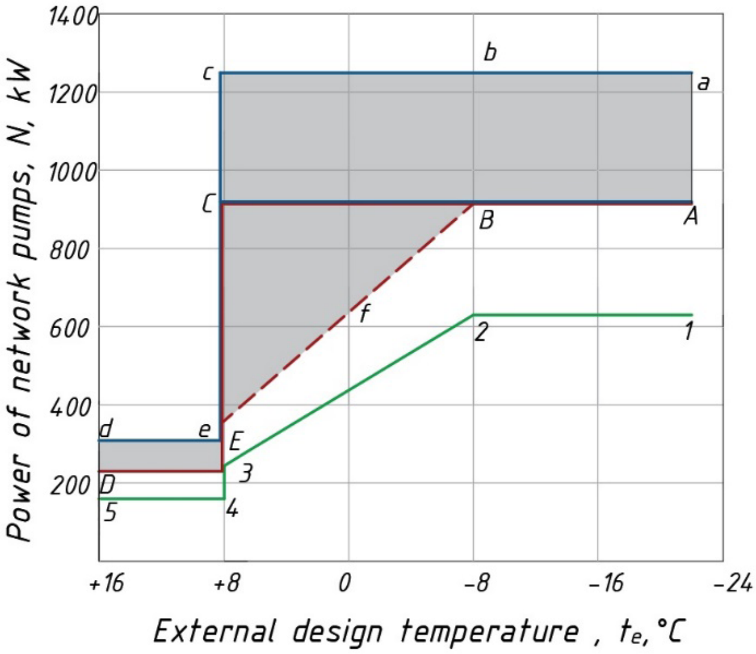


Figure 10. Power of network pumps in the heating network vs. external temperature (the corresponding options are described in the text)

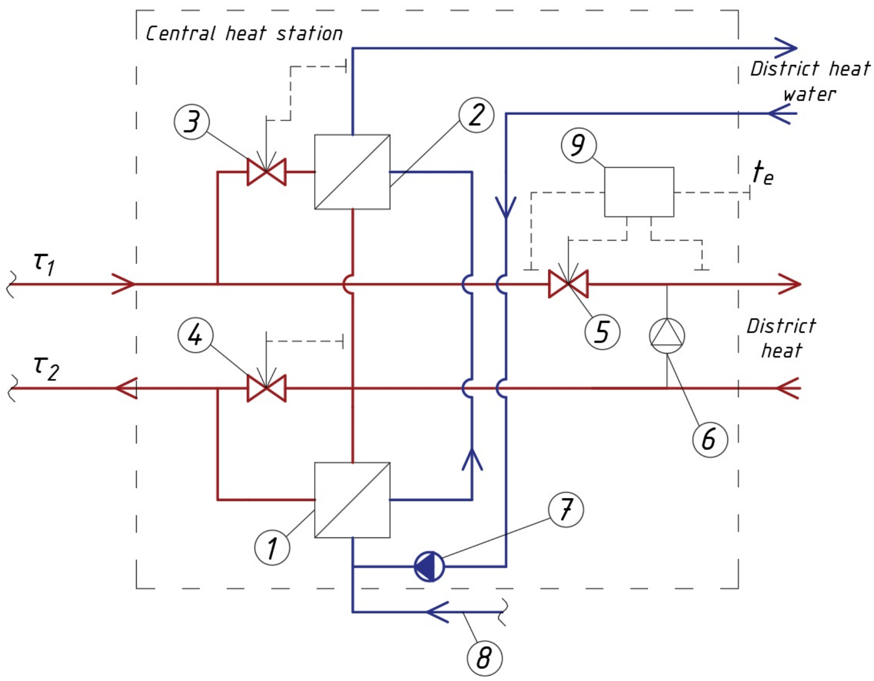


Figure 11. Schematic diagram of the reconstruction of a central heat station for the implementation of quality and flow rate local control of heat supply for heating: 1 — first-stage hot water supply heat exchanger; 2 — second-stage hot water supply heat exchanger; 3, 4 — hot water temperature controllers; 5 — controller of the heat carrier flow rate for heating; 6 — mixing pump with rpm control; 7 — hot water supply circulating pump; 8 — cold water pipe; 9 — controller

equipping end-user systems with automated IHSs, transition to a low-temperature schedule of heat supply, and the lack of condensing waste heat exchangers at the energy sources is characterized by low efficiency and significant disadvantages. The main disadvantage is significant heat losses during the transition periods corresponding to the breakpoint of the temperature curve. Such heat losses reach 18% of the thermal potential of the used fuel. Another disadvantage is inevitable constant changes in the flow rate of the heat carrier in heating networks, which are caused by local quality control of heat supply in automated IHSs.

2. It is proposed to introduce combined control, which, before reaching the breakpoint temperature, ensures quality control of heat supply by changing the heat carrier temperature only. After the corner point, the transition to central flow rate control is performed by changing the flow rate of the heat carrier at its constant temperature.

3. Combined central control makes it possible to prevent significant heat losses as well as hydraulic and thermal deregulation of local systems and provide optimal conditions for heat generators, including in condensing mode. It also reduces energy consumption and increases the overall efficiency of the CHN.

4. The possibility of a complete transition to flow rate control in the entire range of changes in the heat load has been substantiated. Such control is very important for CHNs due to the ongoing thermal modernization of buildings and their equipping with automated IHSs.

5. During the transition period, for buildings connected to the CHN according to a dependent scheme without mixing units and automatic weather control, a combination of combined central control with local quality and flow rate control in group central heat stations is recommended.

6. Central combined and flow rate control have certain disadvantages, e.g., variable hydraulic operation of heating networks. However, with the introduction of a low-temperature schedule of heat supply, such control is characterized by significant advantages.

## References


Bhatt, J. and Verma, H. K. (2015). Design and development of wired building automation systems. *Energy and Buildings,* Vol. 103, pp. 396–413. DOI: 10.1016/j.enbuild.2015.02.054.

Bogoslovsky, V. N. and Skanavi, A. N. (1991). *Heating*. Moscow: Stroyizdat, 735 p.

Chicherin, S. V. (2018). Optimization of thermal energy consumption by buildings: diagrams of changes in the load on weekdays and weekends. In: *Proceedings of the International Conference "Sustainable and Efficient Use of Energy, Water and Natural Resources", November 12–16, 2018, Tomsk*. Tomsk: Publishing House of Tomsk Polytechnic University, pp. 58–60.

Chicherin, S., Volkova, A. and Latõšov, E. (2018). GIS-based optimisation for district heating network planning. *Energy Procedia,* Vol. 149, pp. 635–641. DOI: 10.1016/j.egypro.2018.08.228.

Cui, M., Wang, X. and Liu, J. (2014). The analysis of plate heat exchanger in central heating regulation of indirect connection hot water heating system. *Applied Mechanics and Materials,* Vols. 584–586, pp. 728–731. DOI: 10.4028/www.scientific.net/AMM.584–586.728.

European Parliament and Council (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast) (Text with EEA relevance). *Official Journal of the European Union*, OJ L 328 21.12.2018.

Janta-Lipińska, S. (2020). The method of nitrogen oxide emission reduction during the combustion of gaseous fuel in municipal thermal power boilers. *Rocznik Ochrona Środowiska,* Vol. 22, Part 1, pp. 376–390.

Kultyaev, S. G. (2017). Comparative analysis and optimization of methods for regulating the combined heat load. *Naukovedenie,* Vol. 9, No. 2. [online] Available at: http://naukovedenie.ru/PDF/61TVN217.pdf [Date accessed December 10, 2018].

Logunova, O. Ya. and Zorya, I. V. (2020). *Water heating*. 2nd edition. Saint Petersburg: Lan, 272 p.

Lund, H., Østergaard, P. A., Chang, M., Werner, S., Svendsen, S., Sorknæs, P., Thorsen, J. E., Hvelplund, F., Mortensen, B. O. G., Mathiesen, B. V., Bojesen, C., Duic, N., Zhang, X. and Möller, B. (2018). The status of 4th generation district heating: Research and results. *Energy,* Vol. 164, pp. 147–159. DOI: 10.1016/j.energy.2018.08.206.

Magnusson, D. (2011). Between municipal and regional planning: the development of regional district heating systems in Stockholm from 1978 to 2010. *Local Environment,* Vol. 16, Issue 4, pp. 319–337. DOI: 10.1080/13549839.2011.573472.

Orłowska, M. (2020). Experimental research of temperature distribution on the surface of the front plate, of a flat plate heat exchanger. *Rocznik Ochrona Środowiska,* Vol. 22, pp. 256–264.

Pieper, H., Ommen, T. S., Markussen, W. B. and Elmegaard, B. (2017). Optimal usage of low temperature heat sources to supply district heating by heat pumps. In: *Proceedings of ECOS 2017: 30th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, July 2–6, 2017, San Diego, CA, USA, article #30*. San Diego: San Diego State University.

Rafalskaya, T. A., Mansurov, A. R. and Mansurova, A. R. (2019). Investigation of variable modes of centralized heat supply systems operation with qualitative and quantitative regulation. *Construction and Geotechnics,* Vol. 10, No. 2, pp. 79–91. DOI: 10.15593/2224–9826/2019.2.07.

Rafalskaya, T. A., Rokhletsova, T. L. and Tyusov, S. M. (2018). Central regulation without upper cut: capabilities and prospects. *News of Higher Educational Institutions. Construction,* No. 5 (713), pp. 91–104.

Sharapov, V. I. and Rotov, P. B. (2007). *Heat supply system load control*. Moscow: Novosti Teplosnabzheniya, 164 p.

Sharapov, V. I., Rotov, P. V. and Orlov, M. E. (2010). The improvement technologies of the thermal load regulation for cogeneration systems in urban areas. *Transactions of Academenergo,* No. 4, pp. 70–83.

Sokolov, Ye. Ya. (1982). *Heat and power supply and heating networks*. 5th edition. Moscow: Energoizdat, 360 p.

Szkarowski, A. (2019). *Ciepłownictwo*. Wydanie III uaktualnione. Warszawa: Wydawnictwo Naukowe PWN, 344 p.

Szkarowski, A., Janta-Lipińska, S., Koliienko, A. and Koliienko, V. (2016). Poprawa sprawności scentralizowanych systemów ciepłowniczych przez doskonalenie metod regulacji. *Ciepłownictwo, Ogrzewnictwo, Wentylacja,* Vol. 47, No. 9, pp. 347–351. DOI: 10.15199/9.2016.9.1.

# ПОВЫШЕНИЕ ЭФФЕКТИВНОСТИ РЕГУЛИРОВАНИЯ ТЕПЛОВОЙ НАГРУЗКИ В СИСТЕМАХ ЦЕНТРАЛИЗОВАННОГО ТЕПЛОСНАБЖЕНИЯ

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**Аннотация**

В статье представлены результаты исследований, **целью которых является** повышение эффективности систем централизованного теплоснабжения путем совершенствования процессов центрального и местного регулирования отпуска теплоты. Для этого комплексно рассмотрены задачи выбора оптимального графика отпуска теплоты и его влияния на эффективность выработки, транспортировки и использования теплоты, влияния температуры теплоносителя на потери теплоты в период излома температурного графика. Исследовано влияние температуры теплоносителя в обратном трубопроводе тепловых сетей на работу генераторов теплоты при различных способах регулирования. Рассмотрена задача обеспечения гидравлической и тепловой устойчивости работы тепловой сети и подключенных к ней систем отопления в условиях комбинированного способа регулирования. **В основу методологии работы** положено исследование уравнений теплового баланса для установившегося стационарного режима работы комплекса, включающего тепловую сеть и систему отопления здания. **Получены зависимости,** которые дают возможность определить изменение расхода и температуры теплоносителя в зависимости от тепловой нагрузки, а также сокращение расхода электрической энергии на транспортировку теплоносителя. Разработаны рекомендации по внедрению комбинированного регулирования тепловой нагрузки и предложена схема реконструкции центральных тепловых пунктов. **Научные и практические результаты** работы дают возможность избежать значительных потерь теплоты, обеспечивают оптимальные условия работы тепловых сетей, генераторов теплоты и систем отопления, обеспечивают снижение расхода электроэнергии и повышение общей эффективности систем централизованного теплоснабжения.

**Ключевые слова**

Теплоснабжение, централизованные системы, экономия энергии, эффективность, регулирование тепловой нагрузки.

DOI: 10.23968/2500-0055-2021-6-3-42-48

# EARLY CRIMEAN KHANATE SETTLEMENTS AS THE PRECURSORS OF THE TOWN OF BAKHCHYSARAI

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**Abstract**
**Introduction:** This paper analyzes the formation and development of major medieval settlements that emerged in the 14th–16th century within the boundaries of the modern Bakhchysarai. We studied written and archaeological sources to examine the evolution and structure of these settlements, and provide a general overview of the surviving architectural ensembles and landmarks. Bakhchysarai, the former capital of the Crimean Khanate, is one of those Crimean settlements where the medieval planning structure of the old town and the original organic links to the natural landscape survive to this day. **Purpose of the study:** We aimed to identify the historical background and specifics of how the Old Town and the surrounding historical complexes formed in Bakhchysarai. Our research involved examining historical, archaeological, and contemporary scientific sources and written media, as well as selecting and analyzing theoretical works, normative documents, and architectural designs relevant to the subject at hand. When making a systemic summary of the data that we examined, we used the following **methods**: structural and functional analysis, synthesis, deduction, generalization, and the comparative historical method. **Results:** Our findings show that, at the early stages of statehood in the Crimean Khanate, several settlements thrived in the region: Eski Yurt, which started out as a cultural, administrative, and economic hub and eventually became a major religious center; Qırq Yer, an ancient fortified cave settlement that survived into the early 20th century; and the Salacık settlement at the foot of Çufut Qale, which became the most direct precursor of the new capital in Bakhchysarai. The ruins of these settlements are part of the modern Bakhchysarai's cultural heritage; they lie within its boundaries and greatly influence its modern appearance.

**Keywords**
Crimean Khanate, Bakhchysarai, settlement, architecture, türbe, historical environment.

## Introduction

Bakhchysarai, the former capital of the Crimean Khanate, is one of those Crimean settlements where the medieval planning structure of the old town has been preserved and the organic links to the natural landscape are still being maintained. The new capital of the Crimean Khanate began developing during the first thirty years of the 16th century, reaching its peak in the 17th–18th century.

The town of Bakhchysarai emerged amid the natural terrain of the Çürük Suv River valley. The river valley is "squeezed" between steep rocky plateaus. At the eastern end of the town, stands the Çufut Qale mesa, which splits the ravine into two parts: the Ashlama Dere and Meryem Dere gulches. This creates a unique natural climatic environment where the town grew. The river was highly important for the town's historical development: it cut the urban layout in two and served as the main landmark as town districts formed around it chaotically. Natural forms are the salient element of the urban landscape; they are notable for their size, which dominates over the scale of the architectural environment.

The capital of the Crimean Khanate did not emerge out of thin air. It had a number of key precursors at different points in time: Eski Yurt, Qırq Yer, and Devlet Sarai. All of these settlements have been partially preserved and currently lie within the boundaries of the modern town of Bakhchysarai. Some of the ensembles and individual structures (such as the Eski Yurt and Eski Türbe mausoleums) are located in the middle of residential development areas, having a significant impact on the town's appearance and at the same time being susceptible to environmental factors.

## ESKI YURT SETTLEMENT

In the 14th century, a settlement, later known as Eski Yurt, emerged in the hilly area to the northwest of the Çürük Suv River valley. During the Crimean Ulus era, Eski Yurt was a large, presumably urban settlement, as evidenced by the scale of Qırq Azizler, the largest and oldest Muslim cemetery in the western half of Crimea (dating back to the 14th–15th century), which has been almost entirely lost to time (Zaytsev, 2015). The choice of location was quite deliberate: the open space was highly advantageous, in that a view of the surroundings was clear from all sides. Furthermore, an ancient trade route, linking Chersonesus and the Isthmus of Perekop, passed through the settlement.

Eski Yurt had two large burial sites:

- Qırq Azizler («Forty Saints»in Ottoman) was located in the northwest at the outskirts of the settlement (in the vicinity of the modern Kizyakovy Dachas along Podgorodnyaya Street);
- The other large cemetery, Aziz, lay in the center (in the New Town area, near what is now Budyonny Street). It was known for its mausoleums and the symbolic grave of Malik al-Ashtar en-Nahai, a companion of Rashidun (Rightly Guided Caliph) Ali ibn Abi Talib.

Ottoman explorer Evliya Çelebi described the cemetery as follows (based on a Russian translation by Bakhrevsky (Çelebi, 2008): «In this part of the cemetery, under three lead-coated domes, lie, forever silent, the Kings of Kings...».

S. V. Karlov (2010) theorizes, citing archaeological research data, that the period of Eski Yurt's prosperity falls on the second half of the 14th century, but as soon as by the first quarter of the 15th century, the residents abandoned the area. The most likely version is that they moved from the old settlement to the cave town of Qırq Yer and the nearby Salacık. The road passing through the Bakhchysarai valley connected Eski Yurt and the new capital: the Qırq Yer fortress.

The settlement's name, Eski Yurt, is Turkic in origin and can be translated as "the old seat of power". Eski Yurt did not receive this name until the Khans' residence was moved to Qırq Yer and the old settlement lost its erstwhile administrative and economic influence. The original name of Eski Yurt is unknown.

Either way, the former residents and their descendants did not forget about the sacred landmarks of Eski Yurt. A Sufi sanctuary (tekije) appeared near the Aziz cemetery; the building was eventually destroyed in 1955. Aziz was the final resting place for local nobles. Several of the House Giray türbe mausoleums have survived until today (Karlov, 2010). Eski Yurt remained a prominent spiritual center, where people continued to make pilgrimages all the way into the 1920s (Zaytsev, 2015).

After the war, new districts grew actively in the area. In the early 20th century, part of the medieval Eski Yurt settlement came to be considered a suburb of Bakhchysarai (Karlov, 2010); before long, it was absorbed by the rapidly expanding town. Unfortunately, only very few (see figure 1) of Eski Yurt's numerous landmarks have made it to modern times: a small minaret (the last remaining part of the tekije complex) and four türbe mausoleums.

**QIRQ YER FORTRESS (ÇUFUT QALE)**

Qırq Yer (also known as Gevher Kermen or Çufut Qale) is located on the plateau of a standalone mesa to the southeast of the historical district of Bakhchysarai. The easiest way to access the settlement is from the east. The other three sides of the plateau have steep slopes with a drop of up to 30 m.

What is particularly notable is that this seemingly impossible-to-access area had already been inhabited for a while by the time the Crimean Khanate was founded. Even after the Crimean Tatars left the fortress, it was not entirely abandoned and kept functioning until as late as the 19th century. Today, historians (Gertsen and Mogarichev, 1999) traditionally distinguish the following periods in the evolution of Qırq Yer (Çufut Qale):

- the pre-fortress period (before the 5th century AD);
- the Byzantine-Alanian period (roughly 5th to 14th century);
- the Golden Horde period (14th century to 1441);
- the Crimean Khanate period (1441 to the turning of the 15th–16th century);
- the Karaite Judaism period (early 16th century to 19th century).

The settlement can be divided into three zones: the so-called New Town, which occupies the narrow eastern strip of the plateau; the Old Town, located behind the New Town; and finally, Cape Burunçak, which, unlike the first two zones does not have any surviving medieval structures except for fortifications.

Researchers A. G. Gertsen and Yu. M. Mogarichev (2016) studied the Khanate's jarligs (edicts), giving them a reason to suggest that at the dawn of the Crimean Khanate, Qırq Yer was not just an administrative and political center. Historical sources also point to the local population's ethnic and religious diversity, which is a distinctive feature of eastern trade and craft centers.

The settlement's layout was shaped by the changes in the Main Defense Line. While the development in the so-called Old Town is older, it took place in the section of the plateau where some structures, dating back to the inception of the fortress, already existed (Nabokov, 2016). When Evliya Çelebi (2008) explored the fortress, he saw a "single-layer wall" with three towers, presumably the Middle Defense Wall, which had clearly lost its original defensive function by the 17th century. He also described 1530 homes of the local Jewish residents, with red-brick roofs; notably, 200 of them

Figure 1. Surviving landmarks in the Aziz cemetery in Eski Yurt. Sources (from left to right): https://ru.wikipedia.org/wiki/Файл:EskiYurt.MehmedGiray.JPG (by Oleksa Haiworonski, 2005); https://po-krymu.ru/eski-yurt.html; https://aquatek-filips.livejournal.com/345685.html (by Sergey Anashkevich, 2011); https://mangup.su/travel/bahchisaraj-sledy-ischeznuvshego-goroda.html (by Andrei Vasiliev, 2011); https://aquatek-filips.livejournal.com/345685.html (by Sergey Anashkevich, 2011)

were located between two walls. The explorer also mentions a "small iron gate" (Çelebi, 2008; Nabokov, 2016).

Archaeological evidence and written sources reveal the existence of two-story dwellings with courtyards and cellars, surrounded by stone fences. The Old Town had three large (by Çufut Qale standards) streets that ran lengthwise along the plateau: Burunçak Street, Middle Street, and Kenassı Street (Aqçoqraqlı et al., 1929). There were a number of major religious buildings in this part of the fortress, in the state of ruins: the supposed palace in the west, a mosque, the Djanïke Khanım türbe, and the Greater Kenesa. These structures likely emerged no later than the 14th–15th century (the Smaller Kenesa would be erected in the area later, by the end of the 18th century) (Nabokov, 2016).

Eventually, Qırq Yer became one of Crimea's wealthiest settlements. One of the fortress's colloquial names, Gevher Kermen, i.e., the Fortress of Jewels (Çelebi, 2008), comes from a legend that claimed that the town's walls were inlaid with precious gems. The fortress had its own mint, as evidenced by its coin production, which started around the middle of the 15th century (Lomakin, 2017). Out of the surviving fortress elements, the following date back to the Islamic period: the 15th–16th century Djanïke-Khanım türbe (tomb), the ruined mosque, and various blocks and other building fragments, which were occasionally reused for the construction of more modern structures (Berthier-Delagarde, 1920, Dombrovsky, 1848). Supposedly, the mosque could have been converted into a residential building (Lomakin, 2017). N. I. Repnikov (1940) proposed a hypothesis that there might have been madrasa ruins not far from the mosque.

Even though no traces of the khans' residence have been found in the fortress to date, A. G. Gertsen and Yu. M. Mogarichev (2016) claim that "the Khanate's ruler must have had a palace in town. <...> Oral stories about a palace that once stood near the southern gate, where ruins of monumental structures lie hidden, may be considered evidence of the fact."

Over time, various accumulating factors pushed towards moving the capital to the foot of the mountain range:

1. as the national borders became more secure and foreign conflicts were settled, the fortress-like structure became obsolete;
2. the fortress was confined to the plateau, which ultimately became too constricting for urban development;
3. water supply issues began emerging.

As a result, a new settlement, called Salacık, formed at the foot of the mountain, in the modern Staroselye district. It grew around the khans' residence in Devlet Sarai.

After the Muslims left the town behind, the Karaite community (followers of Judaism) remained in Qırq Yer, earning it the name Çufut Qale (Jewish Fortress). Evliya Çelebi (2008) reported that "...all of Bakhchysarai's Jewish shop keepers and wealthy merchants... descend from this fortress every morning and reach their stores in Bakhchysarai in a single hour."

After the khans' seat was moved to Bakhchysarai, a decision was made to expand the development in the Old Town, which is reflected in the residential districts that are adjacent to the Djanïke-Khanım mausoleum. The atmosphere in Crimea's steppe and mountain foothill regions was relatively peaceful at that point, which affected the role of this fortress type: with time, Çufut Qale completely lost its military significance (Nabokov, 2016).

Evliya Çelebi (2008) explains that Gevher Kermen evolved into a residential and, in part, warehouse complex, which occasionally served foreign ambassadors as lodgings but did not have any infrastructure, such as stores, gardens, active Muslim places of worship, and a properly developed water supply system. "The wealthy Jewish merchants likely resided in properly maintained homes, while their poor neighbors huddled in the nearby caves" (Nabokov, 2016).

The New Town development is also currently represented by ruins, for the most part, except for the residence of Abraham ben Samuel Firkovich and the restored Çal-Boryu House, where Solomon Beym used to live. These structures illustrate what the local residential buildings looked like during the latter period of the fortress's history. Firkovich's house originally used to have just one floor, with an upper floor added at a later point. Other houses in the area were likely subjected to similar renovations (Nabokov, 2016). The New Town has only one major street, Main Street, along with a single important building: the Karaite Community Hall, dating back to 1896 and currently in ruins.

After Crimea became part of the Russian Empire in 1783, the previous restrictions (Shchegoleva, 2005) were lifted from the Karaite and Krymchak residents, but Çufut Qale still remained the center of Karaite culture and religion in Crimea. Cape Burunçak and the Old Town were scarcely used at that point, but the New Town remained full of life up until the end of the 19th century (Troinitsky, 1904).

**DEVLET SARAI: THE KHANS' RESIDENCE**

The core of the terrain in question is formed by the terrace in the upper reaches of the Çürük Suv River and by the intersecting slopes of several gulches at the foot of Çufut Qale Mountain. The gulch sides shield the area from the wind, creating a relatively milder climate and good conditions for economic activity. At the same time, the fact that the residence was located on the bottom of the valley (albeit still very close to the fortress, making it possible to seek shelter there in the event of an attack) testifies to the nascent tendency to forego fortification, which manifested more fully in the later concept of Bakhchysarai.

According to Evliya Çelebi (2008), the settlement of Salacık, which had formed around the Devlet Sarai residence, was surrounded by gardens.

There is reason to believe that the construction of the khan's palace was overseen by Italian architect Aloisio the New, who styled it after a public-type Italian palazzo (Borisov, 2019; Çelebi, 2008). At this stage of history, Devlet Sarai is completely lost: not even its ruins have survived. The only reminder of how opulent the Salacık residence used to be is the lavishly adorned Demir Qapı gateway, which was moved to the Bakhchysarai Palace in the first half of the 16th century. Not far from Devlet Sarai, in the Ashlama Dere gulch, nestled Ashlama Sarai, one of the khan's "smaller" palaces that served as a private residence for his family.

Other structures that have been preserved until this day include a historical mausoleum complex (the final resting place of the first Crimean khans) and the Zincirli Madrasa religious school. In the early 21st century, ruins of the Meñli Giray Mosque, public baths, and a 16th–18th century Muslim graveyard were unearthed in Salacık. Zincirli Madrasa was built during the reign of Meñli Giray, at the beginning of the 16th century. It is one of the oldest and best-known parts of the Salacık ensemble. B. N. Zasypkin's description of Zincirli Madrasa (1927) contains a note that "this small and modest space has served, until almost very recent times, as a hub for Tatar culture and education...".

Throughout the Crimean Khanate's entire existence, the Meryem Dere gulch (located not far from the capital) was home to the main stronghold of the Orthodox Christian faith in central Crimea: the Panagia Monastery, or the St. Anastasia Assumption Monastery (Popov, 1888). A Greek settlement called Mariampol was also located in the same gulch. Aside from the ancient Byzantine Greek community, the local Christian population was also represented by a fairly large Armenian community. The gulch that reached the central part of the town from the north was occupied by the Armenian quarter and the Armenian Holy Mother of God Church, which was located inside a cave (Sargsyan, 2006).

The construction of the Bakhchysarai Khans' Palace began in 1532, further downstream along the Çürük Suv River. Thus, the Crimean Khanate's last and most famous capital was born. Salacık, meanwhile, remained populated, effectively transforming into the eastern suburb of Bakhchysarai.

**Conclusion**

The town of Bakhchysarai took shape over the first third of the 16th century, reaching its peak towards the 17th–18th century, when the Crimean Khanate was flourishing. Presumably, the ruler's residence (and the other residential and public complexes) was built around the initial architectural core: the Grand Mosque.

The towns across the Crimean Khanate, Bakhchysarai included, were characterized by an irregular planning structure. Aside from cultural specifics, the layout of Bakhchysarai was under major influence from the surrounding natural terrain. The core of the town's landscape is formed by the river valley. The districts stretched from east to west, which provided proper ventilation, even though the winds were blocked out by the rock sides (Abibullaeva, 2015).

The northern and southern boundaries were formed by the rocky slopes of the Çürük Suv River valley; and the eastern and western boundaries, by the old seats of power, functionally closely related to Bakhchysarai. Among them, was Eski Yurt, which had transformed into a major cultural hub by the middle of the 16th century and kept receiving pilgrims from all over the region up until the early 20th century, and the Qırq Yer fortress, which, along with the adjacent Salacık, was already considered an ancient residential area as the new capital reached its peak, and yet continued fulfilling some vital administrative functions (for instance, the fortress housed the treasury and had its own active mint for a fairly long time, while Salacık's Zincirli Madrasa served as a major education center).

The main element that formed the urban layout of the medieval Bakhchysarai was the route that passed at the bottom of the valley along the Çürük Suv River bed and connected the administrative units listed above. The main streets all joined this highway. Ottoman explorer Evliya Çelebi reported that "to the east of this gorge, the road leads to Eski Salajik; to the west, the road leads to Eski Yurt <…> of course, there are many other footpaths along the rocks, akin to those goats use. In many places, they are difficult to traverse. Until you climb to the top of the rocks, you will not be able to see Bakhchysarai, which lies in the valley below, from the roads that lead there from four sides."

E. E. Abibullaeva (2015) studied the Kadiasker Notebooks (court records), allowing her to conclude that the expansion of the settlement and the emergence of new districts (mahalle) followed the direction from Salacık to Eski Yurt.

During the construction of Salacık, the capital's architectural core was formed by a set of structures that included the khans' residence, the stone mosque, the khans' graveyard with the türbe (tombs) of the noble families, the madrasa, and the public bathhouses, built as a gift for the residents. The same list was followed during the creation of the Bakhchysarai complex. On top of that, each quarter of the new capital had its own place of worship and, occasionally, an extra public facility like a hammam, a coffee shop, and a school (madrasa or maktab). This gave the quarters certain functional self-sufficiency (Khalit, 2014).

Each house within a quarter had its own (often irregular and asymmetrical) layout that blended organically into the natural terrain. B. A. Kuftin (1925) defines a number of distinguishing features of Bakhchysarai's residential development, including the division of the land plots into terraced levels (lower and upper courtyard) due to the inclined terrain, standard land plot layouts, and the placement of the house in the depths of the courtyard. Even though the individual land plots appeared to be isolated, neighboring courtyards were linked with pathways (Kuftin, 1925), making it possible to move through the town without actually setting foot in the street.

Under the influence of a number of factors, the historical part of the Old Town lost most of the important development elements in the 20th century, while still retaining the historical urban planning structure and the one-of-a-kind ensemble. Most of the structures erected in the historical center of Bakhchysarai have been shaped by the natural terrain and by the medieval planning structure, with the palace complex of the Crimean Khans at the core.

## References


Abibullaeva, E. E. (2015). Mahalle as a territorial unit of the medieval Bakhchisaray: according to Kadiasker Notebooks' materials. *Golden Horde Review*, No. 2, pp. 163–186.

Aqçoqraqlı, O. N. A., Bodaninsky, U. A. and Zasypkin, B. N. (1929). Çufut Qale. Excavation materials study. 1928–1929. *Bulletin of the Tauride Society of History, Archaeology and Ethnography*, Vol. 3 (60), pp. 170–187.

Berthier-Delagarde, A. L. (1920). On certain perplexing questions of medieval Tauride. *Bulletin of the Tauride Research and Archive Commission*, No. 57, pp. 1–135.

Bilyalova, I. Ya. and Bilyalova, L. M. (2017). The Eski Türbe Mausoleum in Bakhchysarai. In: Sukiasyan, A. A. (ed.) *Impact of Science on Innovative Development. Proceedings of the International Research and Practice Conference. February 28, 2017, Yekaterinburg.* Ufa: Omega Science, pp. 255–257.

Borisov, V. N. (2019). *The first palace of the Khans in Eski Salajik, the old district of modern Bakhchysarai. Parts 1–3.* [online] Available at: https://www.archiportal-crimea.ru/images/stories/news/2020/july/B_Borisov_Perviy_hanskiy_dvorec.pdf [Date accessed 31.02.2021].

Çelebi, E. (2008). *A book of travels. Crimea and Surrounding areas: fragments from the book of a Turkish traveler of the 17th century.* 2nd edition. Simferopol: Dolya, 272 p.

Choref, M. M. (2007). On localizing and dating the overground Armenian church in Bakhchysarai. *Historical Heritage of Crimea*, No. 20.

Dombrovsky, F. M. (1848). Historical and statistical overview of the town of Bakhchysarai. *Novorossiya Calendar for 1849*, pp. 380–396.

Gaivoronsky, O. (2016). *The land of Crimea. Essays on the historical landmarks of the Crimean Khanate.* Simferopol: N. F. Ablayeva, 336 p.

Gertsen, A. G. and Mogarichev, Yu. M. (1993). *The Fortress of Jewels. Qırq Yer. Çufut Qale.* Simferopol: Tavriya, 128 p.

Gertsen, A. G. and Mogarichev, Yu. M. (1999). *The ethnic history of Çufut Qale. In: Historical experience of inter-ethnic and inter-religious harmony in Crimea*. Simferopol, pp. 48–52.

Gertsen, A. G. and Mogarichev, Yu. M. (2016). *Qırq Yer. Çufut Qale. Fortress on the seventh climate threshold: research, guide, album.* Simferopol: Antikva, 312 p.

Karlov, S. V. (2010). New data on the medieval settlement of Eski Yurt in Bakhchysarai. In: *Proceedings of the International Research and Practice Conference "Solkhat as the Center of the Golden Horde Culture in Crimea: Research Results and Prospects, Monument Conservation Issues"*. Simferopol, pp. 35–76.

Khalit, N. Kh (2014). Architecture of the Crimean Khanate. *Crimean Historical Review*, No. 2, pp. 243–281.

Lomakin, D. A. (2017). "A large mosque which ruins are still visible": domestic historiography from the last quarter of the eighteenth to the early twenty-first century on the mosque of the mediaeval fortress of Kyrk-Er (Chufut-Kale). *Materials in Archaeology, History and Ethnography of Tauria*, No. 22, pp. 535–551.

Manstein, C. H. (1875). *General Manstein's notes on Russia, 1727–1744.* [online] Available at: https://www.prlib.ru/item/411984 [Date accessed December 22, 2020].

Nabokov, A. I. (2016). Main stages in study of ancient city of Chufut-Kale. *History & Archaeology of Crimea*, No. 3, pp. 348–371.

Osmanov, E. E. (2012). *The religious structures of Bakhchysarai in the late 18th — early 20th century*. [online] Available at: http://kukiit.ru/docs/ts/no2/13.pdf [ Date accessed December 22, 2020].

Osmanov, E. E. (2014). The Madrasa of Bakhchysarai. *Gasyrlar Avazy-Echo of Centuries*, No. 1/2, pp. 243–250.

Osmanov, E. E. (2015). Repair works civil buildings of Bakhchisaray in late XIX - early XX centuries. *Scientific Notes of V. I. Vernadsky Crimean Federal University. Historical Sciences*, Vol. 1 (67), No. 4, pp. 40–58.

Popov, A. N. (1888). *The second educational field trip of the Simferopol gymnasium students to Bakhchysarai and its suburbs*. Simferopol: Tauride Governorate Printing House, 131 p.

Repnikov, N. I. (1940). *Supplements for the archaeological map of the Crimean highlands. Copy of the manuscript from the archives of the Leningrad Department of the Institute of Archaeology*. Fund No. 10, File No. 10, 387 p.

Sargsyan, T. E. (2006). On the Armenian spiritual and cultural centers of Bakhchysarai (17th to 19th century). In: Vishnevskaya, Ye. B. (ed.) *6th Tauride Scientific Readings*. Simferopol: Evrostroy, pp. 136–142.

Shchegoleva, T. (2005). The Karaites of Crimea: history and modern state of the community. *Jews of Eurasia*, No. 1 (8).

Troinitsky, N. A. (ed.) (1904). *Tauride Governorate. First General Census of the Russian Empire, 1897.* Vol. 41. [online] Available at: https://www.prlib.ru/item/436681 [Date accessed December 19, 2020].

Zasypkin, B. N. (1927). Monuments of Crimean Tatar architecture. *Crimea*, No. 2 (4), p. 148.

Zaytsev, I. V. (2015). Islam in the Crimea in the 14th-18th centuries. *Golden Horde Review*, No. 2, pp. 103–128.

Zhuryari, I. (1890). Journey to the nearest surroundings of Bakhchysarai. *Bulletin of the Tauride Research and Archive Commission*, No. 9, pp. 108–111.

# ПОСЕЛЕНИЯ ЭПОХИ РАННЕГО КРЫМСКОГО ХАНСТВА КАК ПРЕДШЕСТВЕННИКИ ГОРОДА БАХЧИСАРАЙ

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**Аннотация**
Статья посвящена анализу формирования и развития крупных средневековых поселений, возникших в XIV-XVI вв. в границах современного Бахчисарая. На базе письменных и археологических источников изучены становление и структура данных поселений, дана общая характеристика сохранившихся ансамблей и памятников архитектуры. Город Бахчисарай – бывшая столица Крымского Ханства – является одним из крымских городов, где сохранена средневековая планировочная структура старого города и первоначальная органическая связь с природным ландшафтом. **Цель исследования:** Выявление исторических предпосылок и особенностей формирования Старого города Бахчисарая, а также окружающих его исторических комплексов. При проведении исследования были изучены исторические, археологические и современные научно-публицистические письменные источники; осуществлен подбор и анализ теоретических трудов, нормативных и проектных материалов по теме исследования. При систематизации изученных данных использованы **методы** структурно-функционального анализа, синтеза, дедукции, обобщения, сравнительно-исторический метод. **Результаты:** Выявлено, что в период становления государственности Крымского Ханства переживают расцвет несколько поселений – Эски-Юрт, изначально культурный и административно-экономический, а затем крупный культовый центр; крепость Кырк-Ер – скальное укрепление и древний пещерный город, просуществовавший до начала XX в.; поселение Салачик у подножья Чуфут-Кале, ставшее ближайшим предшественником новой столицы в Бахчисарае. Остатки этих поселений являются памятниками культурного наследия, и, будучи включенными в городскую черту современного Бахчисарая, оказывают значительное влияние на облик города.

**Ключевые слова**
Крымское Ханство, Бахчисарай, поселение, архитектура, дюрбе, историческая среда.

DOI: 10.23968/2500-0055-2021-6-3-49-61

# GIS METHODOLOGICAL APPROACH TO DEVELOPING AND FORMING A VISUAL IMAGE OF DOWNTOWN AMMAN

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**Abstract**

**Introduction:** Amman's growth expansion was shaped by its topography (valleys and hills), which generated a special character and patterns of the urban form. The city was built on seven hills, which are connected by steep stairs that serve as pathways to the downtown core. The rapid urbanization caused by uncontrolled population growth, as well as random and unplanned formations that were far from following any kind of aesthetic, resulted in the expansion of the center towards the surrounding seven hills. The continuous intersection of these hills caused their boundaries to blur and melt. As a result of the intense transformation, which is causing the hills' appearance to become more uniform, their continuing overlap may completely destroy the unique character and imageability of downtown Amman. **Methods:** This research made use of topographical context analysis and the Geographical Information System (GIS) as well as its 3D modeling function to identify the optimal visibility and viewing angle when looking from the valley towards the hills and between the hills. **Results and discussion:** We identified the main vistas, i.e., highly significant views, which could subsequently be adopted as the locations for proposing landmark scenarios via 3D model GIS analysis. The projection process helped determine the significant views from the valley towards the hills and between the hills. Overall, three scenarios were proposed for the landmarks, out of which, the best one was chosen. It corresponds to the topographical analysis and the community needs, depends upon the local context and urban fabric, and is optimal for decision-making.

**Keywords**
Downtown, hills, visual image, topographical features, landmarks, line of sight analysis.

**Highlights**

- The spread of similar-looking residential buildings over the hills, without concern for the original character, has led to the depersonalization of the downtown environment.
- Visual differentiation between the hills, with no landmarks that distinguish any given hill from the others, has become extremely difficult.
- This research made use of the Geographical Information System (GIS) and its 3D modeling function for assessing and determining the sites for the proposed landmarks on each hill.

## Introduction

Amman, the capital of Jordan, has emerged as a modern Arab city. The physical development of modern Amman has a time frame of only about 135 years. Ancient Amman was occupied by several sequential civilizations — Assyrians, Babylonians, Persians, Greeks, and Romans — but went into decline and was eventually deserted by the year 1400. In modern times, it experienced dramatic growth as a city of migrants, including the periodic influx of migrants from Palestine (1948, 1967, and 1973), Lebanon, and, most recently, Iraq (Ashour, 2016). More recently, some 170,000 Jordanians, including Palestinians who had obtained Jordanian citizenship, relocated to Amman from Kuwait and other countries of the Gulf region as a result of the 1990–1991 Gulf War (Al-Asad, 1997). Refugees have been attracted to the relative political stability of Jordan, and the city of Amman has provided a safe haven for populations in the region suffering from political displacement (Pilder, 2011).

Amman's growth expansion was shaped by its topography, specifically valleys and hills, which have given its urban form a special character and patterns. It has grown along seven successive hills, which formed the topography of early Amman (the downtown). The hills certainly are prominent city landmarks (Potter et al., 2009). They have their own character, inhabitants, and, to a certain extent, their own topography features. The tiny cubic houses, always visible on the slopes of the hills, have stripped the mountain of its original "skin" and settled in there as if they were an intrinsic part of the landscape. The downtown, which is located on these seven hills, naturally has developmental characteristics of its own. The buildings are connected by steep stairs that lead to the downtown core (valley). Gardening activity in the city is very low, insufficient for contributing to the creation of a favorable microclimate (Melnik, 2019).

Modern physical development began in a wellirrigated area at the confluence of several valleys, which evolved as the original downtown core of Amman (GAM, 2008). The residential areas spread gradually from a fertile valley at the downtown core of Amman to occupy the surrounding hills (ESCWA, 2005). These older residential areas borrow their names from the seven hills where they originally developed: Al Akhdar, Al Natheef, Al Ashraffiyyh, Al Taj, Al Qalaah, Al Luweibdah, and Amman hill. The division of these areas is based on a grid pattern, where the hills are physically separated but visually not related. The neighborhoods were once connected to the downtown core by steep stairs as pedestrian links.

The downtown core is the historic center of Amman, it “served as Amman’s central business district with a mixed use pattern of religious institutions, residential neighborhoods, government offices, and commercial streets” (Ashour, 2016). The heritage urban form of the downtown core “is fine grain, small plots of low height structures spreading along the valley <...> Building more than four stories in the downtown valley would remove the strong shape” of the surrounding hills’ profile (Ashour, 2016).

The downtown core has many significant individual buildings, sites, and objects, which are memorable to Amman’s inhabitants and tourists due to their design. It also embraces four main historic sites with many heritage values. The Roman Citadel (Jabal al-Qala’ah), located on one of the hills, is one such site. Another very important monument is the Great Amphitheater at the bottom of the Fortress Mountain. The Al-Hussein mosque, built by king Abdallah I in 1924, is another excellent remaining example of Islamic architecture. The Nymphaeum is a notable landmark as well. According to ADTZSP (Amman Downtown Tourist Zone Sub-Project), despite the presence of ancient sites, such as the Roman Theater and the Citadel, tourists have been neglecting the downtown because of its inadequate promotion and lack of amenities and infrastructure for tourists (JICA, 2000).

The rapid urbanization caused by uncontrolled population growth, as well as random and unplanned formations that did not follow any aesthetic decisions, resulted in a shift from the longitudinal axial development to the gradual vertical multilayer structure, towards the surrounding seven hills. The spread of similar-looking residential buildings over the hills, plus the use of the same types of design techniques, materials and building density without concern for green elements and original character, led to the depersonalization of the urban environment. At the same time, a combination of unharmonized structures and textures also causes the observers to perceive disturbing chaos (Bostanci et al., 2006). In this case, a monotonous (aggressive) environment has been formed, causing emotional hunger, fatigue, and aggression among tourists and especially among residents (as shown in Fig. 1). Landmarks are highly important, as they are symbols that relate and represent the location’s quality and the depth of its traditions and culture, with an enhanced significance over time (Clerici and Mironowicz, 2009).

The expansion of the center towards the surrounding hills, while forming a coherent fabric at the planning level, is actually scattered and chaotic at the aesthetic and visual level, which deprives the downtown of its imageability. The continuing overlap between the hills may completely destroy the unique local character, in the absence of a harmonious spatial composition with visual scenes that impress the viewer and form a unique image of the downtown. Residents and visitors find it hard to find their bearings and often get lost because there is no special character that would help tell each hill apart from the others. Instead, the cityscape melts in a single horizontal line, with no protruding architectural elements, causing confusion. Passini (1992) suggested that any object, even a fountain with a particular meaning, can be a landmark. Amman’s Metropolitan Growth Plan did not offer any clear organizational and formative solutions

Figure 1. Overlap of the hills (on the left); view of the monotonous built form (on the right (source: the author)

related to developing and improving the functional structure in the city center by linking it with its physical surroundings. The focus of the project was on the development of the longitudinal zone, as well as on building rehabilitation and the process of their expansion within the urban space in a longitudinal manner. The idea was to distribute buildings with a large floor density, like in most cities in the world (GAM, 2007). However, the downtown core and its hills, in terms of their spatial characteristics, heritage, and cultural, social, architectural, and historical functions, are not compatible with this proposition, which has negative urban repercussions, leading to the loss of the downtown core's and hills' perception and imageability.

The studies by K. Lynch focused on the identity and structure of city images. He defined "imageability" as "that quality in a physical object which gives it a high probability of evoking a strong image in any given observer" (Lynch, 1960). A city's image is important because it contributes to forming the observers' (or the inhabitants') perception, taste, and behaviors; as well as the language that the observers use and the range of notions that they possess about the environment around them (Zmudzinska-Nowak, 2003). The visual image is intimately related to the mental image, which is retained in the observer's memory, thus helping generate environmental meaning during the evaluation of the city image and sense of place (Silva, 2004).

The preliminary objective of this study is to find a distinctive volumetric-spatial solution, namely a complex of landmarks based on the principles and patterns of architectural composition, through emphasizing the city's character and defining the boundaries of the downtown core and its correlation with the neighborhoods on the surrounding hills. The character of the downtown must be enhanced by focusing on preserving buildings with heritage value, protecting the urban form, improving the green zones in the valley, and especially by creating landmarks. Lynch defines a landmark as an element with distinctive spatial features, which are visible from many angles and distances, including over the tops of smaller elements, and can be used as radial reference to help people orientate or find their way in the surrounding environment (Lynch, 1960). The gradient topography in new development should be respected and the topography of the site should be enhanced through careful positioning of the physical structures (landmarks) and the use of the hill slope to create cityscape perception. The perception influences and helps the observer shape their mental image by way of keeping the attractive and important elements of the city in their mind (Atik et al., 2009). Global Mapper software offers several tools for qualitative and quantitative analysis of visual impact assessment. Terrain analysis is very useful

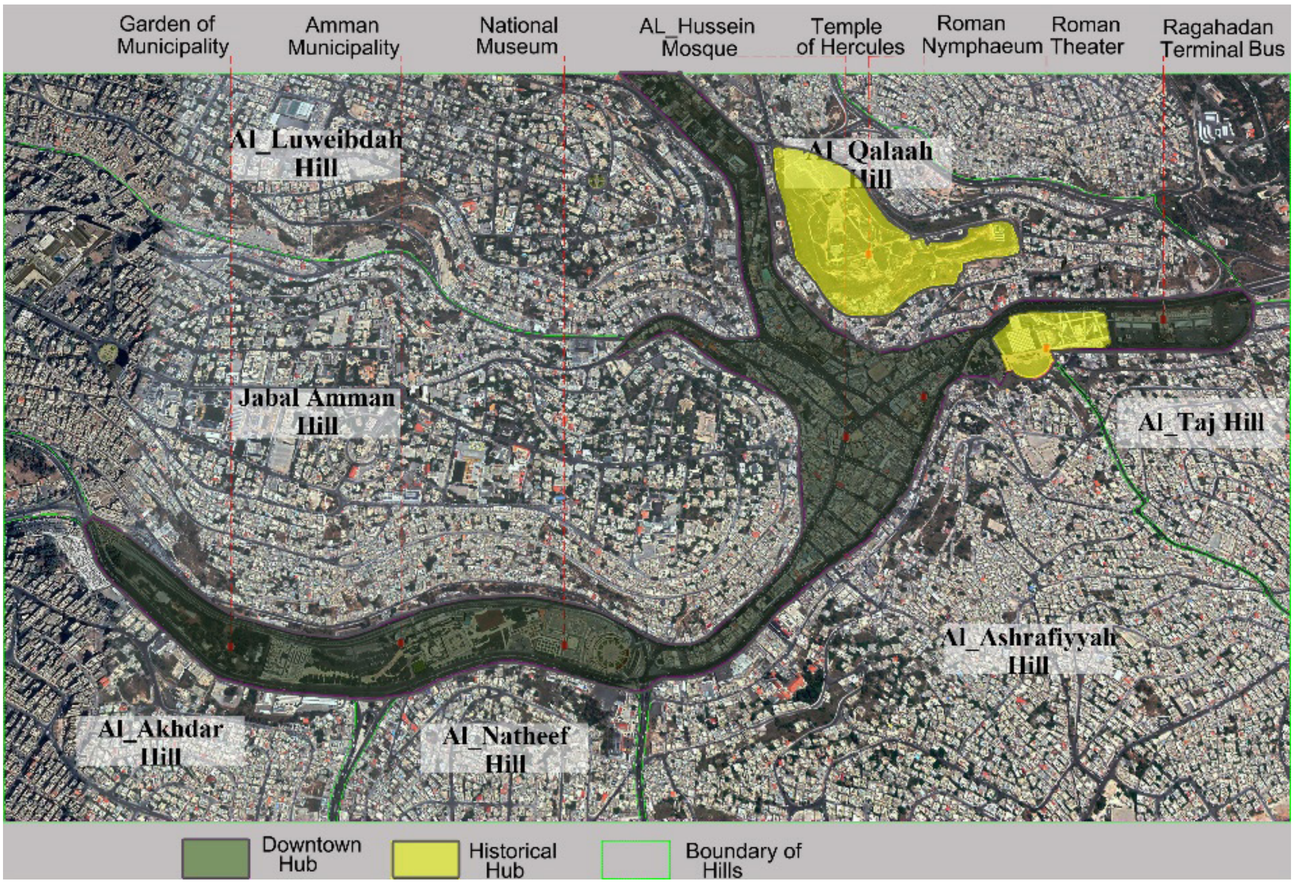


Figure 2. Boundaries of the study area (source: the author)

in this regard. We used viewshed and line of sight analysis to identify the viewing angle and best visible area from the valley, which allowed us to determine the potential locations for the proposed landmarks on each hill, from designated viewer observation points.

**Methodology**

**1.1. Study area**

The study area includes the side slopes of the seven hills in Amman, overlooking the downtown core, as represented in Photo 1. The area extends from the Raghadan bus terminal to the Greater Amman Municipality, totaling 1840 donums. This area represents the origins of Amman and is considered a tourist attraction because it includes important historical sites, such as the Roman Amphitheater, the Citadel, the Al-Hussein mosque, and the Nymphaeum (as shown in Fig. 2).

**1.2. Topographical Context Analysis**

*1.2.1. Field survey*

This survey contributes to understanding the current urban conditions and assessing the significance of the built form. Finally, the survey elicited feedback from residents, visitors, and tourists regarding urban regeneration, new landmarks, and other general suggestions.

*1.2.2. Orthographic physical survey*

A physical survey was conducted for the downtown core and its surrounding hills. It briefly explains the different features and dynamism of the study areas, in addition to providing a series of digital orthoimages of the downtown core and the surrounding hills, for the initial visualization of the valley and its mutual relationship and links with the hills. The survey helped define the topography of various areas, including the distribution of green and vacant urban spaces, the surviving historic topographical features, the ways in which past functions have defined the existing morphology, the dominant building types, the presence of key historic buildings, as well as the construction materials, architectural styles, and specific features.

*1.2.3. Data collection (geoprocessing)*

We collected data on architectural categorization, land use and occupancy, and the hills' elevation, in addition to maps and drawings, through the Greater Amman Municipality and the Royal Geographic Center, using a Geographic Information System (GIS).

**1.3. Line of sight analysis and 3D projection**

The most vital stage in this study involved collecting data with the 3D visualizing and analytical function in the GIS for mapping, as well as analyzing and evaluating the prediction of newly proposed landmarks with sufficient location and elevation accuracy. Line of sight analysis in Global Mapper allows for calculating the visibility along the sight line from the observation point (valley) to the target object (hilltop). We configured the calculations along the selected path, using the path profile line of sight analysis program. A path along the valley was created, then several profiles perpendicular to the valley path (cross-sections) were formed. The spacing of the cross-sections along the path is 25 m; the width is 1750 m, forming 180 cross-sections along the valley path. This width of the cross-section was chosen to cover the largest area between the valley and the surrounding hills from top to top, for study purposes. The 3D visual representation is a combination of the digital terrain model, the orthoimage, and the three-dimensional features for the valley and the hills.

**1.4. Conceptualization of the landmark scenario**

Three designs were proposed for the landmarks on the hilltops, all of which were based on the topographic survey and the physical GIS analysis of the site, in addition to feedback from interviews with the local community regarding urban regeneration and the new landmarks. Each scenario offered a different approach, and all were based on global experiences.

**Results and Discussion**

**2.1. Topographical features**

The Amman downtown is dominated by its distinctive topography, specifically the basin of the valley and the surrounding hills. The Amman valley is surrounded by slopes with a 20% incline, which shape the downtown image and the nature of urban development along the valley's boundaries. The 30–40% slopes, located in some parts along the hillsides, hinder urban development and add to the overlap between the natural and urban fabric. Although early development began in the valleys, it soon climbed up the hills around the downtown to create a dense formation of monotonous built forms, which dominates the slopes. This led to overlaps between the hills, which became difficult to tell apart visually, with no landmarks that distinguish one hill from another. Gaps of open space at the top of the hills are almost nonexistent, as demonstrated in Fig. 3.

There is great variation in the incline of the valley and the surrounding hills, ranging from smooth slopes to steep cliffs, as highlighted in Table 1 below. Exposed slopes are an important visual feature of the surrounding hills. The remaining vegetation is also an important property, especially on the slopes. However, it is extremely vulnerable to urban growth. Poor management is threatening the remaining trees and urban development is threatening some of the most biologically diverse areas within the downtown. The difference in hill elevation is quite notable: Al Qalaah Hill is the lowest, with a height of 835 m, while Al-Ashraffiyyh Hill is the tallest, with a height of 930 m, as seen from the valley. The hill heights are demonstrated in Fig. 6.

Table 1. Physical and topographical analysis of the Amman hills (source: the author).
Elevation of the valley: 740 m

| | Hill name | *Elevation | Topography qualities | Historical value | Heritage value | Land-marks | Vacant lands | Building height | Stairway path Assessments | Land use (on the side slopes) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Al Akhdar Hill | 895 m | Steep slopes | – | – | – | 12% | 2–4 floors | Problematic | Residential |
| 2 | Al Nadtheef Hill | 840 m | Steep slopes | – | low | – | 10% | 2–4 floors | Problematic | Residential |
| 3 | Al Ashraffiyyh Hill | 930 m | Steep slopes and extremely sculpted terrain | Low | medium | Abu-Darweesh Mosque | 22% | 2–4 floors | Problematic | Residential |
| 4 | Al Taj Hill | 890 m | Steep slopes and natural caves | Low | low | – | 18% | 2–4 floors | Good | Residential |
| 5 | Al Qalaah Hill | 835 m | Steep rock face | High | high | The Citadel Temple of Hercules | 30% | 2–6 floors | Problematic | Minimal public land use |
| 6 | Al Luweibdah Hill | 840 m | Steep slopes | Medium | high | Al Weibdah church | 15% | 2–5 floors | Good | Residential and cultural heritage |
| 7 | Amman Hill | 860 m | Steep stone cliffs | Low | high | – | 20% | 2–6 floors | Good | Residential Minimal public land use |

**2.2. Views and Landmarks**

Amman's inhabitants and visitors get lost in the city due to the lack of views and landmarks that could have been located along or seen from its prominent hills and valley corridors, or visible upon entering the city in the direction of the older downtown. The lack of open spaces and formal parks is also a factor. The city needs landmarks, which may be physically or spiritually unique, influential, impressive, and commonly recognized by the people as a sign of place and direction (Hasanuddin, 2004). In the downtown core, there are many individually significant landmarks, like the Great Amphitheater, the Al-Hussein Mosque, and the Nymphaeum. As for the existing hills, they also have a few landmarks that include prominent heritage sites on Al Qalaah Hill (the Citadel), in addition to an extensive network of churches, mosques and minarets on other hills. The latter landmarks melt into the dense residential development zones and include, most prominently, the Abu-Darweesh mosque on Al Ashraffiyyh Hill and the Al Weibdah church on Al Weibdah Hill.

**2.3. Land use and occupancy**

Mixed-use commercial zoning dominates the designated central commercial zone in the downtown core, comprised mainly by the Amphitheater and Citadel sites, with 90% of residential areas located along the surrounding hills.

The side slopes of Al Akhdar, Al Natheef, Al Ashraffiyyh, Al Taj, and Al Luweibdah hills are defined by their residential use. The public land use on Amman Hill and Al Qalaah Hill is minimal, aside from the Citadel, the Roman Amphitheater, and the Al-Hussein Mosque area, albeit the share of these sites does not exceed 4% of the total zoning.

The percentage of land occupancy is very high in the downtown and along the surrounding hills. The average share of vacant plots constitutes approximately 20% of the total land. Al Qalaah Hill has the highest percentage of vacant land, 30%: due to its historical characteristics, it is not permitted to exploit the surrounding lands.

**2.4. Buildings and physical features**

The morphology and the physical character of the downtown core and its surrounding hills are shaped by its topography, the harmonious terraced residential edges, and the containment. The downtown has an architectural historic value, thanks to the Al-Hussein Mosque area, the Roman Amphitheater, the Citadel, and the fact that it is overlooking the valley. This allows for introducing iconic structures in selected, unrestricted zones to enhance attraction for tourism and inspirit the city. Amman's downtown is identified by its significant architectural style, ranging from the modern to the regional to the neo-traditional, which aims to keep Amman's traditional and culturalheritage.

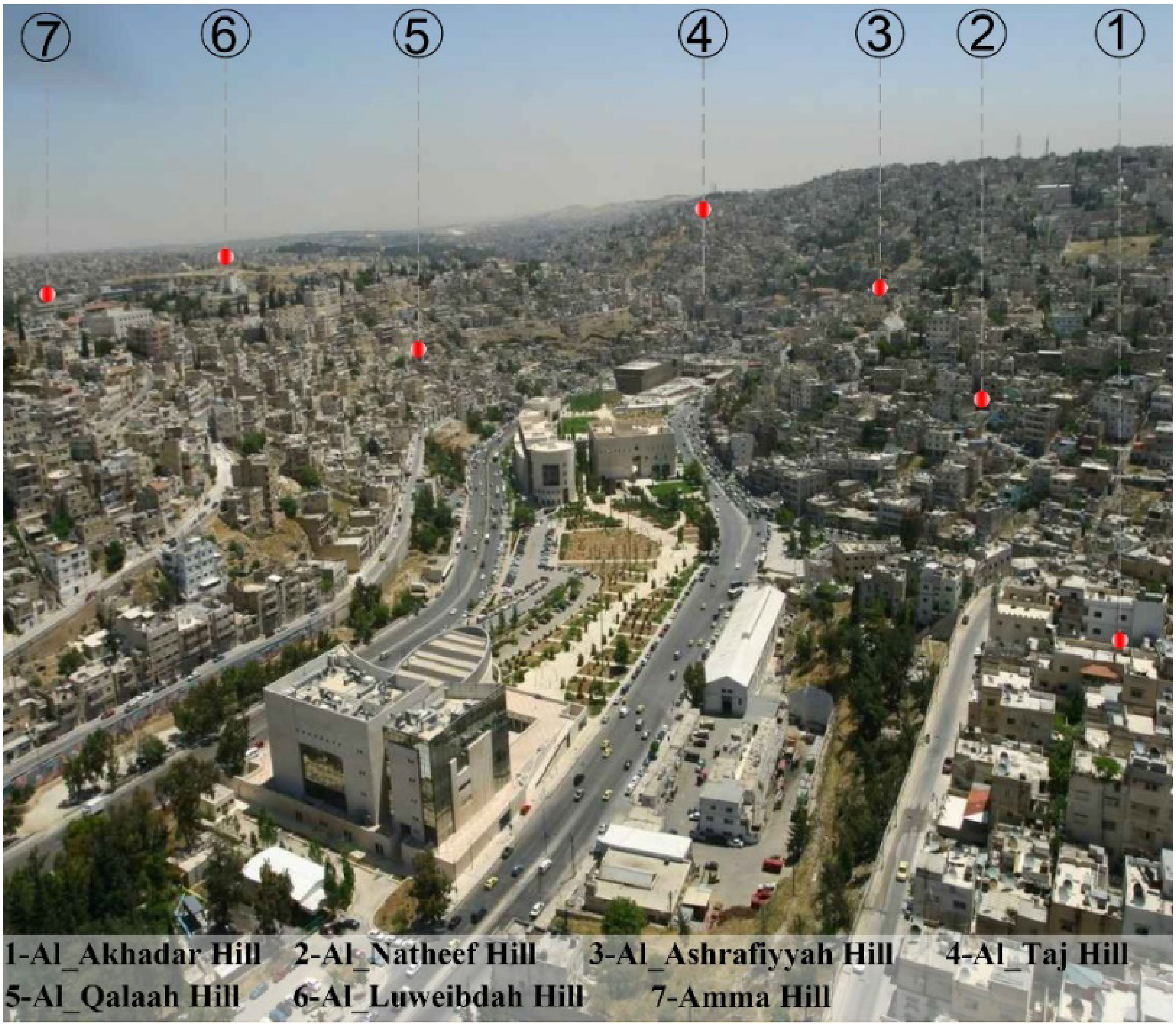


Figure 3. View of the downtown core and the surrounding hills (source: the author)

The buildings are predominantly low-rise, and this height range has remained constant in the downtown over time. Building heights range between 2 and 4 stories, with a few buildings rising to 5–6 stories while not respecting natural gradation and skyline. Residential buildings along the surrounding hills create a harmonious pattern, maintaining open views towards the downtown core. However, many new buildings on the slopes exceed four floors, thanks to the use of additional development rights. If allowed to continue, the construction of such buildings will significantly affect the slope conditions, as well as the image and character of the downtown.

**2.5. Stairway path**

Connections within the downtown core are good, while connections with the surrounding hills are poor. Stairway paths formed spontaneously as a communication element for helping inhabitants reach their homes, and they were not used as an important element in the formation of the urban city plan: they were merely a communication element between the city center and the attractions in open spaces with dominant memorial elements. The downtown is home to many stairways, often hidden from public view. There are more than 600 stairways with at least 75 steps, but previously the downtown had more than 800 total sets of steps in its older parts. The stairs are an integral part of the city's fabric and add to its beauty. Stairways along steep hillsides have been particularly exposed to erosion and pavement cracks over many years.

**2.6. Social characteristics**

In terms of social and cultural characteristics, Amman has been described "as a center of social mix and cultural gathering" (Gharaibeh et al., 2019). "For the first half of the 20th century, Amman neighborhoods were vibrant with diversity, social inclusiveness, and tolerance. People from different socio-economic backgrounds used to frequent the same places" (GAM, 2008). Amman city can be described as a mixture of culturally and socially inclusive areas, where the residents do not form any major socioeconomic, religious, or national group. It has sought to accommodate various groups inhabiting the city, including Iraqi nationals; tens of thousands of Egyptian guest workers, almost exclusively young males; other guest workers from Indonesia, the Philippines and Sri Lanka, primarily young women who are employed as domestic help in households; in addition to other minorities in the city, including the descendants of the original Circassians who inhabited Amman during the late 19th century; and Armenians who fled from Turkey during the conflicts of the 1920s (Al-Asad, 1997).

**2.7. Line of sight analysis and 3D projection**

A strategy is needed to regulate the location of the proposed landmark on the seven hills that would be visible from the valley. In recent years, there have been several proposals to develop landmarks, and it is important for a strategy to be put in place in order to control the landmarks' location and design. Global Mapper software offers several tools for qualitative and quantitative analysis of visual impact assessment. Terrain analysis is very useful in this regard. We carried out line of sight analysis to identify the viewing angle and area with the best visibility from the valley, thus determining the potential locations for the proposed landmarks on each hill. Seven sections were selected for each hill, out of the 180 resulting sections (as shown in Fig. 4). We chose those sections that highlight the best topographical features of each hill.

This image displays the area's contour lines and the elevations of the surrounding hills, in addition to the loop section for all hilltops, allowing us to imagine how the physically separated hills can connect visually with each other (see Fig. 5).

The distance for the entire loop is about 8 km, and the average distance between the hilltops is from 1 to 1.5 km. The difference in the hills' terrain and elevation is also evident.

Fig. 6 illustrates the results of the viewshed analysis for the seven hills, where the X axis represents the distance from the valley to the hilltop, while the Y axis represents the elevation of the hill. The visible areas are highlighted in green and the obstructed areas are highlighted in red. The view elevation from different angles ranges from 14 to 32 degrees. We based the line of sight level on the average person's height, which is 2 m above the sea level. Line of sight analysis in Global Mapper software calculates the visibility along the line of sight from the observer's location in the valley to the target landmark in the hills. Line of sight calculations can be used to visualize any obstructions that may interfere with the view along the profile path. The visible area was determined through the subtraction of the minimum clearance from the maximum clearance, which is based on the intersection of the line of sight path with the terrain surface. The potential locations

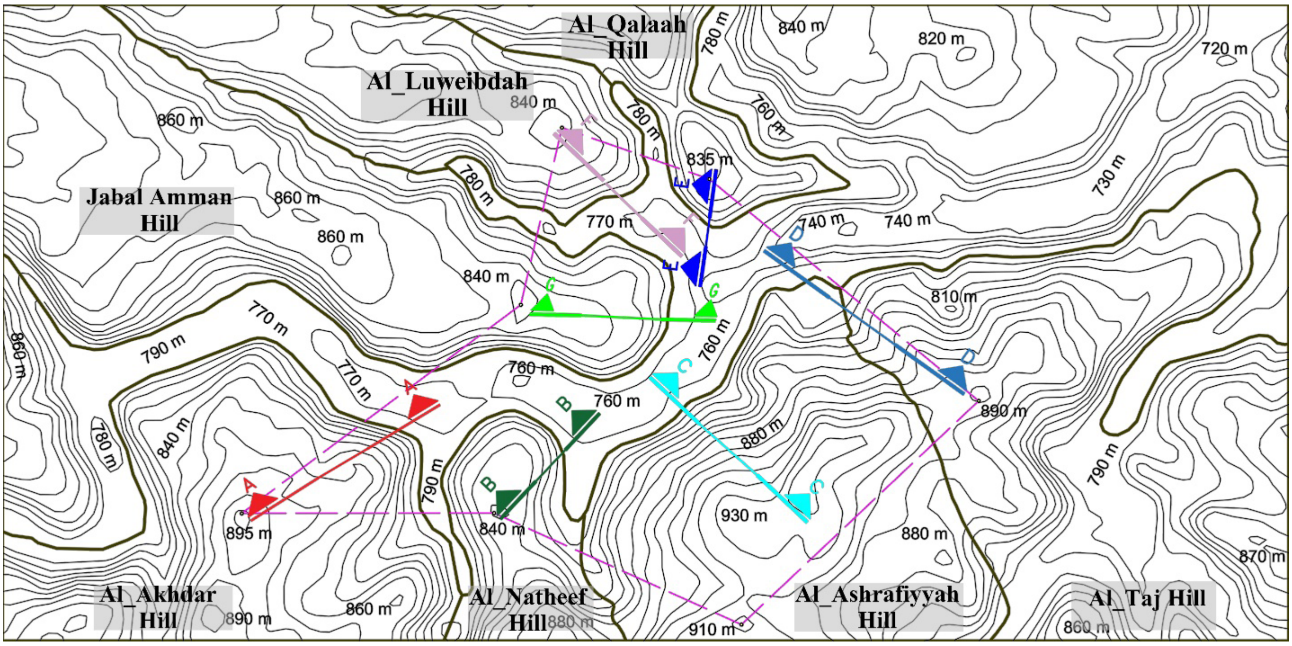


Figure 4. Topographic map of the valley and the hills (source: the author, based on the GIS)

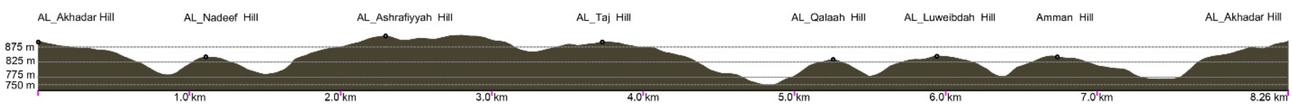


Figure 5. Loop section for the valley and the hills (source: the author, based on the GIS)

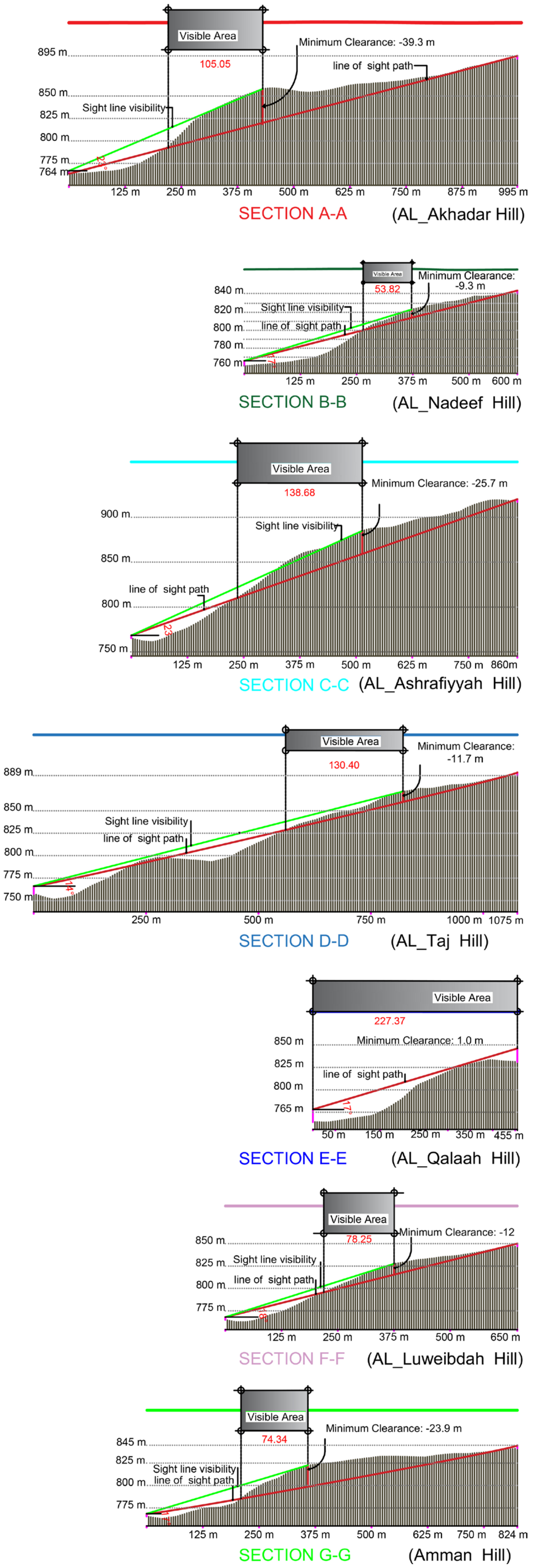


Figure 6. Cross-sections for the seven hills
(source: the author, based on the GIS)

for the proposed landmarks have been identified depending on the minimum clearance readings. We have found more than one location per hill: some hills have nine locations, and some have five, as shown in Fig. 7. When standing on top of one of the hills, the observer can spot more than one potential vacant site where a landmark could be added. After allocating a few vacant sites for each of the hills, the process of making a 3D projection to select the most appropriate ones would be of prime importance.

As evident in Fig. 6, the degrees of hill slopes vary, ranging from a smooth slope to a steep cliff. The most important feature is that they all have a visible area on the side slope but not at the top, which is unexpected. The only exception is Al-Qalaah Hill, which is characterized by the greatest visibility when looking from the valley to the hilltop. The existing historic Al-Qalaah Hill is the optimal choice for a landmark visible from the valley, as the field and angle of view are ideal. The viewshed analysis process, aimed at determining the ideal visibility zone for the rest of the hills, highlighted the accuracy and validity of the methodology that we followed.

From this analysis, it is clear that the proposed landmarks' potential locations were well-exposed and consistent with the urban fabric (Fig. 7).

We applied 3D model GIS analysis to identify the vistas, or highly significant views, which will be adopted as a location for the landmarks. The projection process helped define the significant view when looking from the valley to the hills and between the hills. An optimal observation point must be publicly accessible, visible, easy to reach, and with unlimited distance view (Guney et al., 2012). One location has been selected on each hill in accordance with the vacant plots, as shown in Fig. 8. Notably, most of the locations are on the hillside, not on the hilltops, which means that it would be possible to create a picturesque landmark, visible from vantage points and useful when orientating oneself around the downtown (Al Qalaah Hill is an exception, as it already has the Citadel on top).

Table 2 represents the core of the previously mentioned analyses and 3D projections, which reflect the difference in visibility significance, based on topographical differences between the proposed landmarks, as seen when looking from one hill to another and from the valley towards the hills. This table is a good indication of how to maintain open views and connections between the surrounding hills.

### 2.8. Scenario-based landmark design

The need for spatial reference points (landmarks) for each of the seven hills, which have a larger scale than regular residential buildings, would improve the architectural and artistic perception. Landmarks are defined in physical space as having key characteristics that make them a recognizable and memorable part of the environment (Hasanin, 2007).

Table 2. Visibility significance between the hills (source: the author)

| Name of Hill | AL_Akhadar Hill | AL_Nadeef Hill | AL_Ashrafiy--yah Hill | AL_Taj Hill | AL_Qalaah Hill | AL_Luweibd--ah Hill | Amman Hill |
|---|---|---|---|---|---|---|---|
| AL_Akhadar Hill | — | High significant Visibility | High significant Visibility | significant Visibility | significant Visibility | Low significant Visibility | High significant Visibility |
| AL_Nadeef Hill | High significant Visibility | — | High significant Visibility | Low significant Visibility | significant Visibility | Low significant Visibility | High significant Visibility |
| AL_Ashrafiy--yah Hill | High significant Visibility | High significant Visibility | — | High significant Visibility | High significant Visibility | significant Visibility | High significant Visibility |
| AL_Taj Hill | significant Visibility | significant Visibility | High significant Visibility | — | High significant Visibility | High significant Visibility | High significant Visibility |
| AL_Qalaah Hill | significant Visibility | significant Visibility | High significant Visibility | High significant Visibility | — | High significant Visibility | High significant Visibility |
| AL_Luweibd--ah Hill | Low significant Visibility | significant Visibility | High significant Visibility | High significant Visibility | High significant Visibility | — | High significant Visibility |
| Amman Hill | High significant Visibility | High significant Visibility | High significant Visibility | High significant Visibility | High significant Visibility | High significant Visibility | — |

High significant Visibility | significant Visibility | Low significant Visibility

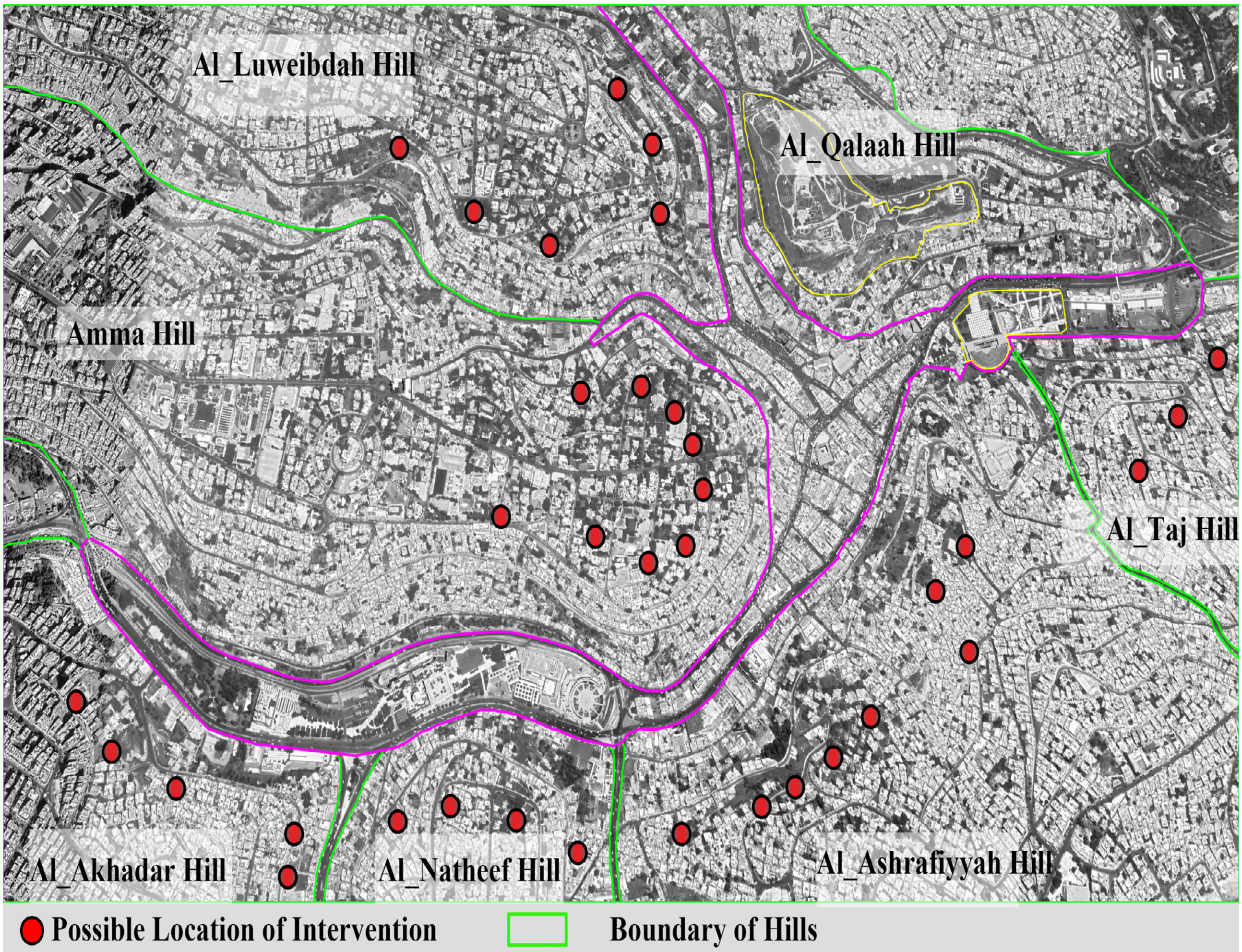


Figure 7. Potential locations for the proposed landmarks (source: the author)

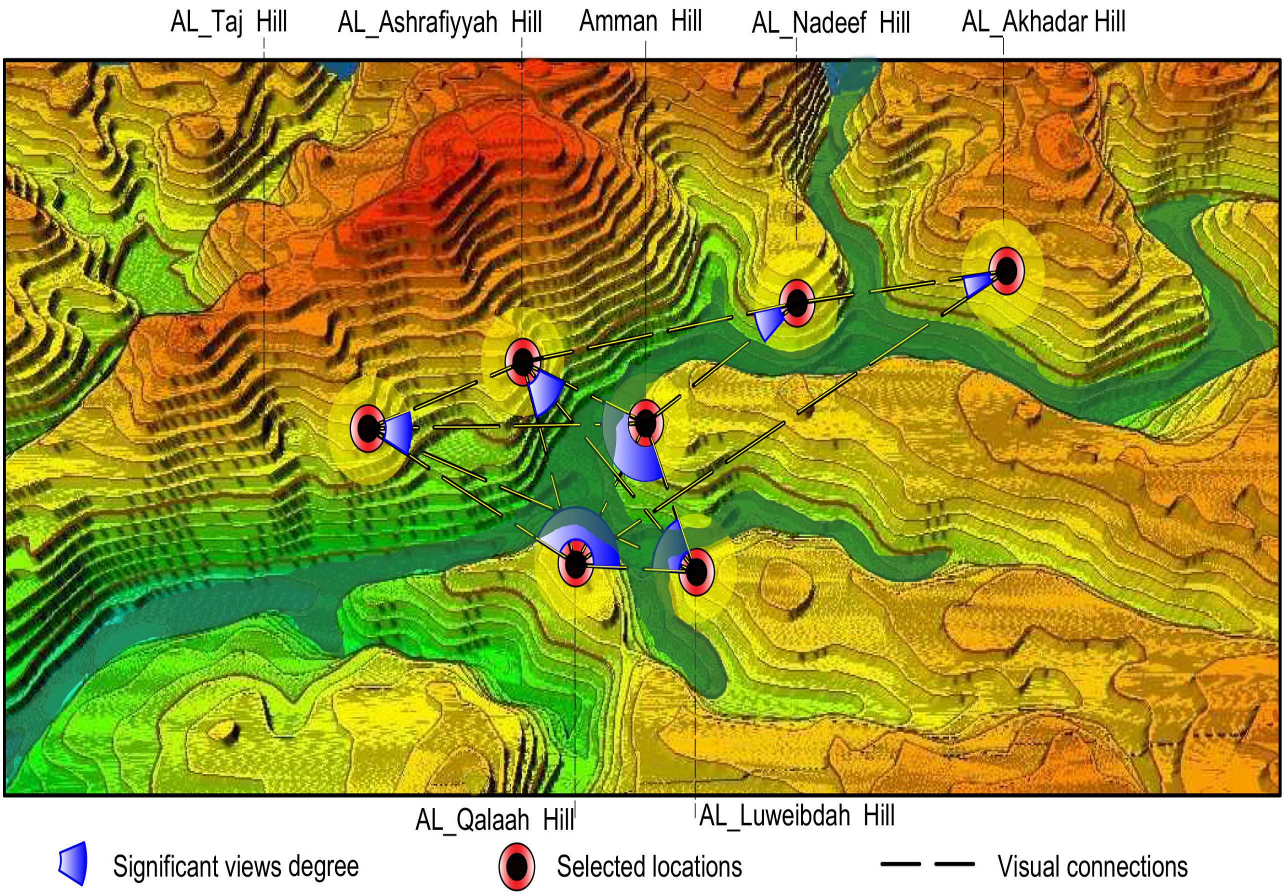


Figure 8. Visual connectivity between the hills (source: the author, based on the GIS)

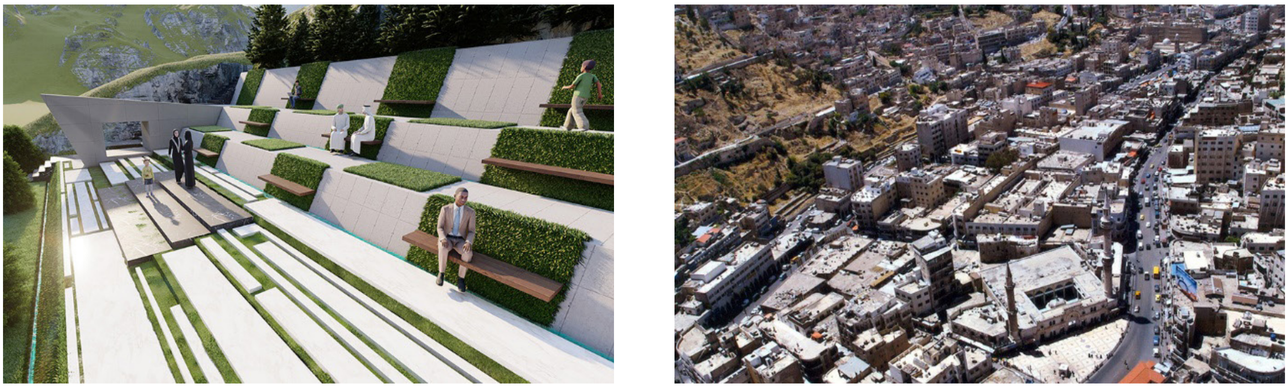

Figure 9. Landscape landmark proposal for Al Ashraffiyyh Hill (source: the author)

Figure 10. Proposal for a coloristic building landmark on Al Akhadar Hill (source: the author)

Consequently, each hill needs an expressive image, not only in terms of aesthetics but also as a functional and volumetric component. Landmark design and construction shall rely on the preservation of the current historical part, which implies eliminating the differences between the historical environment and the modern environment by ensuring that they have a similar regular layout, similar proportions, and, mainly, similar scale.

*2.8.1. Scenario 1. Urban ideology approach*

There are many examples of the relationship between ideology and architecture in urban planning. The Seven Sisters, or “Stalin’s high-rises”, are a group of seven similarly shaped skyscrapers in Moscow, designed in the Stalinist style (socialist ideology) as a symbol of the post-war Soviet Union. Built practically in the center of Moscow, they are visible from almost everywhere throughout the city. Religious buildings, such as mosques, represent this type of approach, for example, the historical city of Istanbul, which is also built upon seven hills and has seven mosques, complex in shape and with various proportions.

The architectural composition of the mosque could be used as a replicable model for the hills, but with different scales, similar to the experience of Istanbul city. This would form a clear visual connection and help distinguish each hill from the others. However, the study of the urban environment contradicts this proposition, given that the vast majority of the hills’ territory, 98% of which is taken up by residential buildings of a monotonous character, is in need of diversity and vitality. The use of such buildings will conflict with the hills’ ecological fabric and increase the urban monotony. Furthermore, the center of Amman is characterized by religious, historical, and national diversity, and imposing a single building model will not reflect this diversity.

*2.8.2. Scenario 2. Urban art approach*

Urban art enhances communication between the hills of Amman. It has the potential to create new trails and cultural paths that will develop different spatial qualities along the hill paths. The idea would be to place one attraction point (landmark) on each of the hills, turning it into a magnet for residents from the other hills and creating reverberation and echoes. All together, the magnets would work as a chain that would initiate communication between the hills. The relevant symbolic landmarks could be toys, sculptures, gardens, fountains, etc. Residents and tourists would enjoy going from one hill to another, and experiencing their different characters while contemplating other hills. The symbolic level of environmental quality represents the higher meaning that corresponds to the nature of the occupants, their beliefs and world views; these include such qualities as status or historical value (Hasanin, 2007). These active cultural elements on each of the surrounding hills would give dynamism to the downtown core and connect with each other to create an icon for the city. Despite the effectiveness of this model at the visual and aesthetic level, it does not meet the social and functional needs of the urban environment and the local community. Nonetheless, the use of some of its elements remains possible.

*2.8.3. Scenario 3. Urban theme approach*

The process of knowing the type and function of the proposed dominant architectural element, just as the method of such elements’ allocation, should not be spontaneous or coincidental. Rather, they must stem from, and be rooted in, the need to maintain each hill as an urban environment, as well as the characteristics that visually distinguish and complement the hill, as compared to the rest of the hills, to form a functionally integrated coherent ring chain. Thus, each hill needs a special expressive image that would be relevant to it not only in terms of aesthetics but also as a functional and mass component.

Here, the coherent scientific approach lies between achieving both the spiritual, aesthetic, symbolic levels, and the utilitarian functional level, which results in a diverse, attractive, and vibrant urban media environment. By analyzing the topography, architectural planning, and the peculiarities of each hill, we found out how to reach the shape and type of each functionally dominant structure so that it corresponds to the location and merges with it. This scenario was adopted because it meets community needs, as shown in the interviews and in the questionnaire, due to its satisfactory functional and aesthetic solutions.

In this scenario, an architectural proposal organizes landmarks as a visual system of buildings, integrating coloristic, historical, cultural, religious, and landscape features, in accordance with the needs of life and society. The system carries a certain ideological and artistic content, organically combines utilitarian and informational values, as well as general cultural, aesthetic, and figurative artistic values. This project a dynamic, lively, and enjoyable image of the downtown, distinguishing each hill from the others from the residents’ and visitors’ points of view.

Suggested manipulation was done for some hills as a sample, making it possible to create preliminary visualization of the dominant structures (landmarks).

*Al Ashraffiyyh Hill (landscape landmark)*

We have mapped out a study of possible future landscape area interventions. Considering the unique topography of the site, as well as the number of undeveloped parcels on steep slopes that are challenging for building construction, new opportunities present themselves for the creation of future gardens that will benefit the inhabitants of the district. The site occupies an important location, overlooking the Citadel, and shall be integrated into the open-space system of the downtown. The proposal is to create landscaped parks and terraced courts embedded into the surrounding hill, to be accessible by stairways and footpaths (as displayed in Fig. 9). The exposed slopes, which form an integral part of the surrounding hills, were used as a landmark by creating a formal park overlooking the downtown core, reused as an open public space. Turning these planned spaces into green usable ones will exploit the open space and provide green connections between the surrounding hills and the downtown core.

*Al Akhadar Hill (coloristic building landmark)*

This hill's name means "The Green Hill" in Arabic. It is considered the most populous, urban, and chaotic; its buildings do not have any distinctive architectural value. Many residents experience boredom and psychological distress, especially since the urban environment needs to be restructured, and many of these buildings now need a structural re-examination, due to the danger of collapsing. Multiple studies have highlighted the importance of a comprehensive re-examination of this area, strongly encouraging demolition and appropriate redevelopment. It was suggested to make the changes at the lowest financial costs and to find a distinctive, dominant, and expressive landmark consistent with the "Green Hill" name. That can be achieved through the process of re-painting the buildings in a variety of energetic colors, which will affect the community psychologically in a positive way and become a synthetic method. The most chaotic location was chosen for rehabilitation (Fig. 10)

*Jabal Amman Hill (multi-purpose landmark)*

Amman Hill is famous for its steep rock cliff. The image of the cliffs between the buildings is something very familiar and commonplace for the residents of Amman Hill. The site for the landmark was chosen between two existing streets, due to the difference in elevation. The proposal was to design a multi-purpose building characterized by panoramic views overlooking the downtown core. To complete the image of the buildings surrounding the cliff, stone and glass units were installed and repeated at different distances to embody the concept and break the elevation monotony.

*Al Qala'ah Hill (historical landmark)*

The new enhancement will represent a responsible new interpretation of Al Qala'ah Hill (the Citadel), taking into consideration both the significance of the context and the needs of the community. This new interpretation of the existing Citadel will be informed by the specificity of the site between the hill (the Citadel) and the valley (the downtown core), including a public open-space framework with several pathways, many markets, walkways, public access points, and a viewing platform, all aimed at enhancing tourist activity.

**Conclusion and recommendations**

This research has revealed that an efficient approach is necessary to preserve and sustain the existing landmarks like the Citadel, as well as to create new landmarks in the seven hills to complete the high-end downtown image and identity. In assessing new navigation landmark development proposals, especially for the seven hills forming the topography of the downtown, the local authorities should utilize an array of assessment and decision-making support tools. Three landmark navigation scenarios have been demonstrated, out of which the urban theme approach scenario has been adopted, as it meets the needs of the community and reflects the functional and aesthetic values. GIS technologies evidently serve as an efficient tool set that bears significant potential for urban planners and decision-makers. Such technologies can assist with planning, mapping, and managing the new landmarks that are unusual for the specific physical setting, as well as with developing, testing, and evaluating the uniqueness of the downtown image. The analysis performed also carries the imperative potential for future research stages, in terms of the evaluation and enrichment of urban aesthetics visualization, as well as tests of the proposed new landmarks in the hills of Amman.

**Acknowledgments**

This research was supported by Applied Science Private University, Faculty of Art and Design.

## References

Al-Asad, M. (1997). Ruptures in the evolution of the Middle Eastern city. Amman. In: Bonine, M. E. (ed.) *Population, Poverty, and Politics in Middle Eastern Cities*. Gainesville: University Press of Florida, pp. 46–63.

Ashour, K. (2016). Urb*an regeneration strategies in Amman's core: Urban development and real estate market.* DSc Thesis in Engineering. Dortmund: Dortmund Technical University.

Atik, D. Z., Çakir, H. K. and Benian, E. (2009). The importance of city image elements through recognizing and introducing of cities: Edirne example. *Trakia Journal of Sciences*, Vol. 7, No. 2, pp. 246–251.

Bostanci, S. H., Ocakçi, M. and Şeker, S. (2006). Kentsel siluetin çeşitlilik açisindan değerlendirilmesinde entropi yaklaşimi. *Journal of Istanbul Kültür University*, Vol. 2, pp. 83–95.

Clerici, A. and Mironowicz, I. (2009). Are landmarks essential to the city – its development? In: Schrenk, M., Popovich, V. V., Engelke, D., Elisei, P. (eds.) *REAL CORP 2009: CITIES 3.0 – Smart, Sustainable, Integrative. Proceedings of 14th International Conference on Urban Planning, Regional Development and Information Society.* Schwechat: CORP, pp. 23–32.

ESCWA, 2005. *Urbanization and the changing character of the Arab city.* New York: Economic and Social Commission for Western Asia, United Nations, 36 p.

GAM (Greater Amman Municipality) (2007) Resource Center. Retrieved Dec 6, 2016, from GAM announced fourth phase of master. Plan. [online] Available at: file:///C:/Users/RTX/Downloads/ammanplansummaryreport-110129134939-phpapp01.pdf [Date accessed December 6, 2021].

GAM (2008). *The Amman Plan Metropolitan Growth.* Amman: Greater Amman Municipality.

Gharaibeh, A. A., Al.Zu'bi, E. M. and Abuhassan, L. B. (2019). Amman (City of Waters); Policy, land use, and character changes. *Land*, Vol. *8, Issue* 12, 195. DOI: 10.3390/land8120195.

Guney, C., Akdag Girginkaya, S., Cagdas, G. and Yavuz, S. (2012). Tailoring a geomodel for analyzing an urban skyline. *Landscape and Urban Planning*, Vol. 105, Issues 1–2, pp. 160–173. DOI: 10.1016/j.landurbplan.2011.12.016.

Hasanin, A. (2007). Urban legibility and shaping the image of Doha: visual analysis of the environmental graphics of the 15th Asian Games. *International Journal of Architectural Research*, Vol. 1, Issue 3, pp. 37–54. DOI: 10.26687/archnet-ijar.v1i3.36.

Hasanuddin, L. (2004). Redefining landmarks. *Jurnal Alam Bina*, Vol. 6, No. 1, pp. 66–76.

Jalouqa, K. (2016). *Urban planning of Amman*. Amman: Lecture at Jordan Engineers Association.

JICA. (Japan International Cooperation Agency) (2000, August). JICA Library. From Amman Downtown Tourist Zone Sub-project. [online] Available at: https://openjicareport.jica.go.jp/759/759/759_307_11605615.html. [Date accessed April 14, 2020].

Kuala Lumpur City Hall (2008). *Draft Kuala Lumpur City Plan 2020. Vol. 1.* Kuala Lumpur: Percetakan Nasional Malaysia Berhad.

Lynch, K. (1960). *The image of the city*. Cambridge, MA: MIT Press, 194 p.

Melnik, V. (2019). Urban identity of Amman (a dialogue between tradition and modernity). *Journal of Engineering and Architecture*, Vol. 7, No. 1, pp. 68–82. DOI: 10.15640/jea.v7n1a8.

Passini, R. (1992). *Wayfinding in architecture*. 2nd edition. New York: Van Nostrand Reinhold, 229 p.

Pilder, A. D. (2011). *Urbanization and identity: the building of Amman in the twentieth century*. MA Thesis in History. Oxford, OH: Miami University.

Potter, R. B., Darmame, K. Barham, N. and Nortcliff, S. (2009). "Ever-growing Amman", Jordan: Urban expansion, social polarisation and contemporary urban planning issues. *Habitat International*, Vol. 33, Issue 1, pp. 81–92. DOI: 10.1016/j.habitatint.2008.05.005.

Silva, K. D. (2004). *Mapping meaning in the city image: towards managing the imageability of urban cultural landscapes*. PhD Thesis in Architecture. Milwaukee: The University of Wisconsin.

Zmudzinska-Nowak, M. (2003). Searching for legible city form: Kevin Lynch's theory in contemporary perspective. *Journal of Urban Technology*, Vol. 10. Issue 3, pp. 19–39. DOI: 10.1080/1063073032000175390.

DOI: 10.23968/2500-0055-2021-6-3-62-69

# SUSTAINABILITY IN THE PROCESS OF DEVELOPMENT PERMIT ACQUISITION (ARMENIA)

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**Abstract**

**Introduction:** Sustainability is becoming more integrated into different fields in many countries. Architecture and urban development are no exception. International agreements, charters, and national strategies have already been adopted around the world. Nonetheless, the relevant procedures and applications are just as important. In Armenia, despite the existence of several National Standard upgrades and the development of the Buildings' Energy Passport, there is still no building sustainability assessment system. **Methods:** This article analyzes development documentation, particularly the application form and acquisition of design permits, in terms of its sustainability, based on legal research, the Developers Guide, and the author's own professional experience. **Results and discussion:** This analysis shows that generally, applications and permits include sustainable aspects, but need several improvements in order to make development more sustainable. In turn, the main issues affecting the process are timing, communication, and project presentation capacity.

**Keywords**

Sustainable architecture, sustainable development, documentation, environment, society, economy.

## Introduction

Buildings produce 40% of the total waste in many countries of the world (John et al., 2000) and consume nearly the same part of the total energy produced in the world, accounting for, once again, about 40% of total carbon dioxide emissions (UNEP, 2019). To reduce these consumption levels and control the environmental degradation caused by these problems, international organizations, unions, and separate countries address the matter as something requiring an urgent solution.

The United Nations' Rio Conference in 1992 (United Nations, 1992), the Kyoto Protocol in 1997, and the European Union's Gothenburg meeting on sustainable development were aimed at finding a way to reduce the impact of human activities, including construction and development, on the natural environment, as well as a way to ensure a healthy future for the next generations, as mentioned by the Brundtland Commission in its definition of sustainable development. As a result, programs like HABITAT were formed and executed. In the European Union, the European Norms were created as well, each addressing separate aspects of construction and design. On top of the European Norms, each country can use its national norms simultaneously (as of the moment of writing this article).

Many professional organizations have created rating systems to assess buildings' environmental footprint. This includes the American LEED, the German DGNB, the Australian Green Star, the Japanese CASBEE, the French HQE, the British BREEAM, and many others. According to Vierra (2011), there are nearly 600 different rating systems in the world. Each has its own methodology, limitations, and advantages. Some of the systems became obligatory in different countries only partially, or are applicable to some types of buildings. For example, BREEAM is obligatory in the United Kingdom for the projects financed by ministries responsible for health and education (Schweber,2013), San Francisco requires LEED Silver for high-rise residential development and LEED Gold for new large commercial development (City and County of San Francisco, 2019).

Despite international agreements and charters, various countries have their own national standards, requirements, and strategies for sustainable development and the urban environment. For example, Singapore's authorities have Master Plans, which include many projects relevant to sustainable construction. In 2009, they announced a program for fostering new and existing buildings to help them achieve the Green Mark. The aim was to transform 80% of all buildings into sustainable ones by 2030 (Low et al., 2014).

In 2008, the Russian Government decided to assess all buildings for the Olympics by BREEAM. In so doing, they wanted to spread ideas about sustainable architecture and sustainability (Brodach, 2013). It is very likely that the same initiative was used for PR campaigns promoting the Olympics as well. Several standards were updated in the country later on, like the GOST R 54963–2012, or the STO NOSTROY 2.35.4–2011, which now include some components similar to BREEAM standards. The government even created a rating system. Known as the Green Zoom, it still stays far behind BREEAM and LEED, with only 70 registered projects, 23 of which are under construction and 47 are in the design stage.

In Armenia, there are no national rating systems, but there are standards and norms that regulate the construction and design processes. Most of them have been updated, with tangible improvements. In addition, the country also developed the Buildings' Energy Passport, as part of UNDP/GEF (2014).

Despite the absence of a national rating tool, in Armenia, there are three buildings assessed by LEED and BREEAM. One more has already been registered in the BREEAM dictionary (Vardanyan, 2021). The low number of certified projects reveals the need for a national strategy or rating system.

However, standards and strategies alone do not assure sustainability. Procedures are equally important for the development of a sustainable project, and processes involving application forms can play a crucial role in project execution. For this reason, this article will analyze sustainability-related design permit application processes and forms used in the Republic of Armenia.

**Methodology**

This article studies the requirements for the design permit acquisition process, as well as its limitations and specifics in Armenia. The aim was to understand if any of the above is relevant to the sustainable aspects of architecture, construction, and urban development. For the purposes of the study, we applied qualitative research methodology, particularly desk research and case studies. During desk research, we reviewed literature and analyzed Armenian legislation. While organizing the structure of this study, the literature review was given the first priority. To create a list of possible literature on the subject, we searched the archives of the National Library of Armenia and Google Scholar to find potentially relevant materials. As the second priority, we studied the legislation describing the design and construction permit issuance process, using the Armenian Legal Information System (ARLIS) and the website of the Ministry of Urban Development (MUD). Unfortunately, we did not find any literature publications that were relevant to the research topic and could be useful for answering the research questions of the study. We did carry out a separate study of the main legislative acts and other related materials from the ARLIS and MUD databases. Specifically, we studied Government Decision of the Republic of Armenia No. 596-N dated March 19, 2015, the Developers Guide published by the Ministry of Urban Development in 2016, and the accepted forms of Design Permits (DP). We will start by briefly describing the development and DP issuance process. Later, we will present the sections of the DP form as the first and guiding document of the whole project, discussing them in terms of social, economic, environmental, and institutional aspects of sustainability to understand if they reflect sustainability and how much they support and foster sustainable design and development. In order to understand how legislation is applied in practice, we carried out a case study. The current project, which is being managed by the author, with sustainable features during the design permit acquisition process, will be subject to analysis based on professional experience. Recommendations will be given for updating the process and the form for issuing design permits.

**General Process of Development**

All the development processes depend on the building's category, which reflects the risk level. There are five levels in all. The low-risk level includes maintenance works, landscaping, minor construction tasks that do not require projects, and emergency works on infrastructure (however, such works must be done after notifying the local authorities). The average risk level includes sites where project documentation does not require expert assessment, which is replaced by recommendations of the designing company, while the technical construction inspection is replaced by respective recommendations as well. The above-average risk level includes sites with characteristics between category II and IV, where project documentation is subject to a basic expert assessment (done by the client). The high-risk level includes special and important sites, which require comprehensive government assessment (done anonymously and coordinated by the authorities) for project documentation. The highest risk level includes projects that are particularly hazardous and technically complex and also projects where other countries are involved. Project documentation for projects of this kind is subject to special comprehensive expert assessment. All the permits and construction timing are decided by the government for each project separately (Government of the Republic of Armenia, 2015).

Generally, a development project includes the following phases: design permit (DP; or architectural planning task), project development, project expert assessment, construction (demolition) permit, completion certificate (occupation permit).

The DP defines the obligatory requirements and limitations according to the community's (city's or village's) spatial planning documents. These matters are defined by the aforementioned law. To get the DP, the developer must apply to the head of the community again, using an accepted form. The DP must be issued within a period of 5 to 20 days, depending on the building's risk level.

After the DP is given, a licensed architect/firm starts developing the project according to standards and norms. Documentation undergoes an expert assessment adequate to its risk level. With the expert conclusion, the developed project is handed to the authorities, whereupon the construction permit is given (Ministry of Urban Development of the Republic of Armenia, 2016).

This is a quite general description. It does not go into too many details, as they do not relate to this research. Below are the discussions for typical buildings, usually under categories II, III, or IV. Particularly, the case study that we discuss here is a category IV building according to N596 List 3.

**Design Permit Application**

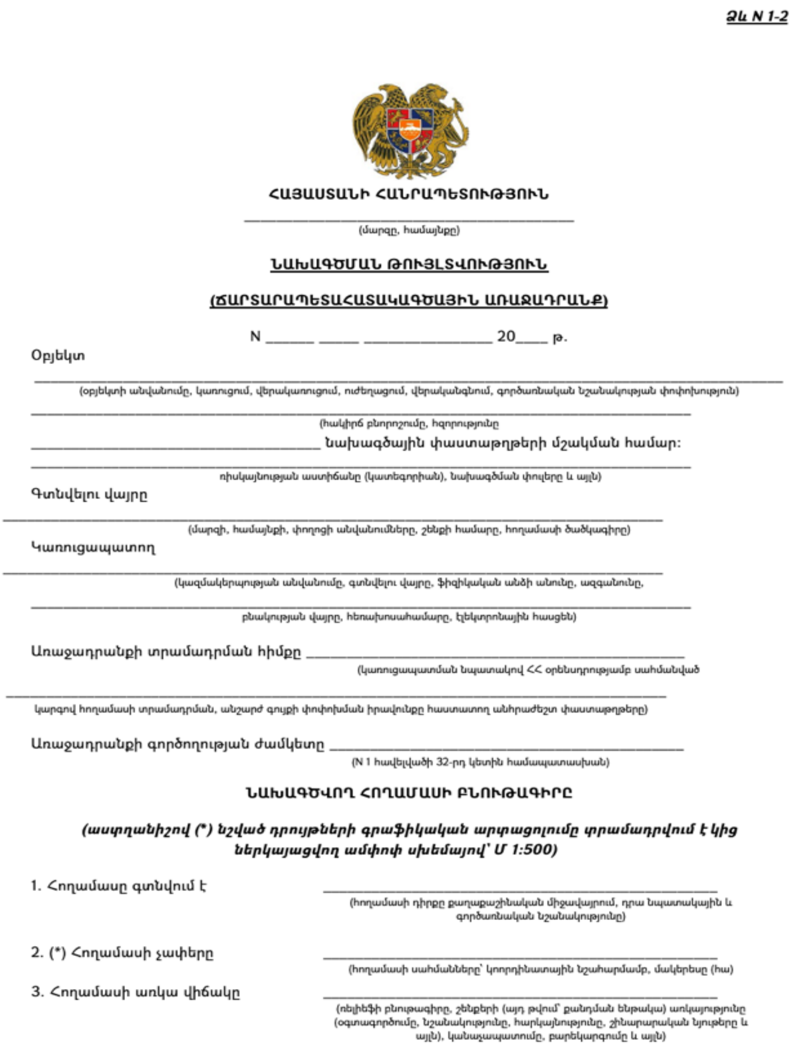
In the DP application, the developer asks for a permit to design a new building at the lot address and asks to be provided with technical requirements for the utility infrastructure (water, sewage, gas, electricity). Later on, there are two lines to describe what is to be built. Underlined, are the guidelines for function, external measures, height, lot and construction area, and power. Then, the following documents must be attached: the lot plan, specifying the location of the proposed development, as well as coordinates and the neighboring lots' functions and buildings; the floor plan in case of functional changes of the lot; and the ownership certificate for the area.

**Design Permit Form**

The form consists of four sections, including general information, lot characteristics, project requirements, and additional requirements. Altogether there are 27 clauses, with subclauses (Figure 1).

General information must be provided, such as the description of the site with its name, construction type if it is new, and information on renovation, reinforcement, or conservation and functional changes if there are any. Furthermore, the address of the lot, the developer's contact information, and the ownership certificate must also be provided.

Lot characteristics cover eight clauses. The first clause is location. The guidelines indicate that this implies "lot location in the urban environment, its aim, and functional meaning". The second clause is


Ձև N 1-2

ՀԱՅԱՍՏԱՆԻ ՀԱՆՐԱՊԵՏՈՒԹՅՈՒՆ

(մարզը, համայնքը)

ՆԱԽԱԳԾՄԱՆ ԹՈՒՅԼՏՎՈՒԹՅՈՒՆ

(ՃԱՐՏԱՐԱՊԵՏԱՀԱՏԱԿԱԳԾԱՅԻՆ ԱՌԱՋԱԴՐԱՆՔ)

N ___ ___ ___ 20___ թ.

Օբյեկտ

(օբյեկտի անվանումը, կառուցում, վերակառուցում, ուժեղացում, վերականգնում, գործառնական նշանակության փոփոխություն)

(հակիրճ բնորոշումը, հզորությունը

___ նախագծային փաստաթղթերի մշակման համար:

ռիսկայնության աստիճանը (կատեգորիան), նախագծման փուլերը և այլն)

Գտնվելու վայրը

(մարզի, համայնքի, փողոցի անվանումները, շենքի համարը, հողամասի ծածկագիրը)

Կառուցապատող

(կազմակերպության անվանումը, գտնվելու վայրը, ֆիզիկական անձի անունը, ազգանունը,

բնակության վայրը, հեռախոսահամարը, էլեկտրոնային հասցեն)

Առաջադրանքի տրամադրման հիմքը ___

(կառուցապատման նպատակով ՀՀ օրենսդրությամբ սահմանված

կարգով հողամասի տրամադրման, անշարժ գույքի փոփոխման իրավունքը հաստատող անհրաժեշտ փաստաթղթերը)

Առաջադրանքի գործողության ժամկետը ___

(N 1 հավելվածի 32-րդ կետին համապատասխան)

ՆԱԽԱԳԾՎՈՂ ՀՈՂԱՄԱՍԻ ԲՆՈՒԹԱԳԻՐԸ

***(ասրղանիշով (*) նշված դրույթների գրաֆիկական արտացոլումը տրամադրվում է կից ներկայացվող ամփոփ սխեմայով՝ Մ 1:500)***

1. Հողամասը գտնվում է ___
(հողամասի դիրքը քաղաքաշինական միջավայրում, դրա նպատակային և գործառնական նշանակությունը)

2. (*) Հողամասի չափերը ___
(հողամասի սահմանները՝ կոորդինատային նշահարմամբ, մակերեսը (հա)

3. Հողամասի առկա վիճակը ___
(ռելիեֆի բնութագիրը, շենքերի (այդ թվում՝ քանդման ենթակա) առկայությունը (օգտագործումը, նշանակությունը, հարկայնությունը, շինարարական նյութերը և այլն), կանաչապատումը, բարեկարգումը և այլն)

Figure 1. Accepted Form of the Design Permit

the size of the lot, which must include its coordinates and area. The third clause describes the lot's current situation, from the general terrain to the existing buildings with their description, including function, height, materials, green areas, and landscaping. The fourth clause is the transportation requirements: here, all the roads and other means of transportation must be mentioned, including railways. The utility infrastructure networks in the lot or in the neighboring area, including underground ones, must be mentioned in the fifth clause. Borders with neighboring lots and their names are to be given in the sixth clause. The seventh clause concerns any special natural and/or historical protected areas or cultural landmarks if located within the lot or overlapping with it. The name and status of the area/landmark(s) must be indicated. And the eighth and final clause in this section is about floor plan limitations, in case there are industrial sites in the area, as well as protected objects or utility infrastructure, or limitations against other sites, including servitudes.

Project requirements are covered in clauses 9 to 21, with their subclauses. The ninth clause is about spatial architectural requirements, with subclauses 9.1–9.7: distance from the building line, distance from the neighboring lots (sites), maximum height (in case the height exceeds the maximum, additional measures, including calculations and reinforcement methods must be taken to follow the requirements of Seismic Construction Design Norms), development density (construction area/lot area, waterproof area/lot area), and green areas in percentages. The last subclause, 9.7, is for additional requirements. The tenth clause is about the demolition or movement workflows of existing projects; the eleventh clause is about the usage conditions of underground or basement floors. The twelfth clause is about utility networks and equipment. It has six subclauses, including: water, sewage, hot water, electricity, gas supply, digital communication cables, and corresponding manholes near the lot. These have to be attached separately, as the relevant documentation is issued by the supplier companies. Clauses 12.5 and 12.6 describe low streams and waste collection. The thirteenth clause pertains to the lot's preparation, including water draining and utility protection measures. The fourteenth clause concerns landscaping, which includes hardscape elements, fences, lawns, etc. The fifteenth clause lists suggested construction materials. The sixteenth clause includes safety structures for protecting people and buildings during emergencies.

All fire safety requirements and measures are covered in the seventeenth clause. Under the eighteenth clause, all accommodations for people with disabilities must be mentioned. The nineteenth clause is about environmental protection. Serving as a guideline, it instructs the applicant to write down all the measures taken to avoid any harmful effects on the surrounding environment. The twentieth clause covers construction organization, aiming to avoid negative effects and to assure uninterrupted flows of the urban economy and transport. Dates for the DP validity are indicated under the twenty-first clause.

The Additional Requirements section has six clauses, specifically: type of expert assessment, intermediary agreements, public audit, agreements or professional opinions, postal box installation, and other requirements (under the twenty-seventh clause). Intermediary agreements might be required by some interested parties. Public audit is, once again, regulated by law. Agreements and professional opinions under the twenty-fifth clause apply to natural, historical, or cultural heritage and must be discussed with the authorities responsible (Government of Armenia, 2015).

**Case Analysis**

A well-known charitable public organization, which provides dental, ophthalmological, and social services to children and their families in Armenia and Artsakh, is currently working on a development project for a new center to provide better services. The site was chosen in the downtown, near a metro station, a walkable distance away from the main public transport hub, so the stakeholders of the services would have multiple opportunities to use public transport to reach the center, which is currently difficult as the existing center is located in the part of the city where only one minibus line operates.

Before the site purchase, the organization's representatives had a meeting with the chief architect of the city, who was responsible for new developments at the time. They described what they wanted and how that could be accomplished, as they wanted to be certain that the lot was worth buying. The developers even hired an architect to sketch a building for them. In the list of clauses we just discussed, one thing was clear: before the purchase, nothing specific could be recommended to the developer. Taking the risk, the developers purchased 10 separate neighboring lots with residential buildings, over a total area of about 1500 sq. m.

After selecting the architect, a project sketch was developed and a decision was made to have a sustainable building with all possible facilities that could benefit a charitable organization. The architect considered design strategies, while the developers aimed to get certified by LEED or BREEAM. Discussions were had with consultants in order to understand which possible efficient solutions could be implemented to have a healthier environment and to save money while operating the building.

After the workflow was established, a decision was made to apply for the demolition permit and the design permit separately to gain more time. Over the course of several team meetings with the owners, the architect, the lawyer, and the real estate agent, two main procedural problems were revealed:

- Land unification: going into the permit issuance process with 10 separate lots could cause difficulties; on the other hand, unifying the lots into one would require taking measurements of all the buildings. The team concluded that measurement and the following processes were too expensive in comparison with the possible difficulties. The unification process could be done after the demolition when the unified lot would be free of any buildings.
- Neighbors' permit: usually, the municipality asks for neighbors' permits to assure smooth workflow in the future. Some clauses in the law require this, but they are not specific and, in most cases, they can be bypassed with the right approach.

A DP application was prepared and filed, including a demolition project, which had been developed by the project's architect and had passed an expert assessment by a licensed company. 10 days later, the project manager and the architect had a meeting at the municipality with the Head of Urban Development Projects, to present the project sketch and discuss the DP application. During the project meeting, the neighbors' issue was discussed, among other questions. There seemingly were no other problems, except that the submitted demolition permit had to be recalled because there was no reason for demolition. The head of the department listed the three options available. Each could cost the charitable organization a certain amount of money, which was not preferable. While discussing this issue, the head of the department suggested another possible option for obtaining a demolition permit, which was to apply for a DP and make it the basis for demolition.

The DP application was submitted on the following day. After a week, the architect talked over the phone to municipality representatives, discussing the issue of the neighbors' permit. During sketch development, the law and standards were strictly followed by the design team, to avoid any need of involving the neighbors in the project in any way. The distances, openings, heights, and entrances were all adjusted to comply with the law in a way that would make a permit unnecessary.

Another week later, the municipality sent out notices, asking for technical requirements to be issued for the project. This process took an additional three weeks, until every utility company sent its answer, including site visits with the project manager. The project was even sent to the National Security Agency, due to the lot's proximity to the National Assembly.

After the technical requirements were met by the utility suppliers, the municipality experts found some disparities in the ownership certificates for the lots, and the issue of unification was brought up again. However, since it had previously been decided to do the demolition and later unify the lots, that issue was also resolved.

By the time of writing this article, despite all internal processes being agreed upon and all approvals being obtained, the DP has still not been issued after 2.5 months of discussions, agreements, meetings, and site visits.

**Discussion**

The process of permit acquisition starts with the DP application. Its content must be presented properly. The accepted form for the application is a one-page document, with limited space for filling in the answers. Except for the information about the lot, there is only one line, where the developer is supposed to write what they want to get, also noting the external sizes. In case of functional changes, the master plan is required by the law, however, it is often limited to a project sketch submitted alongside with main architectural drawings: the master plan, the floor plans, the facades, the sections, and the roof. This requires the developer to have an architect at hand in situations when they do not yet know if they will be able to complete the project. For some groups of developers — public organizations like in this case study — this can be a barrier for taking steps, as the process involves additional costs, while the companies do not know if there will be an opportunity to develop something that matches their vision. This represents economic and social issues, preventing transformation and development.

There are no guidelines on the planned approaches to be implemented in projects in terms of sustainability features. Such approaches can include PV panels, geothermal pumps, glazing types, construction workflow, and anything that is mentioned in the DP. The use of renewable energy on-site affects the use of the grid, as well as the "power" parameter that needs to be mentioned in the application form.

The later-stage phone conversations and site visits take much longer than assumed, which is incompatible with the deadlines set in the laws and community regulations. The uncertainty of these deadlines creates many risks for developers and likely leads to changes in the plans.

The DP comes with the name filled in and with the buildings' risk level mentioned, along with the contact information. The validity period is specified in the first part of the application.

The second part, which characterizes the lot, also has transportation access information. This is a helpful point that can be used for sustainability assessment. In this aspect, the sixth clause (the one about neighboring plots) provides a good explanation of the urban environment and can serve as a starting point for an assessment of social integrity and zoning. The form goes even beyond that and mentions specially protected areas under its seventh clause, which implies that the project has to undergo a comprehensive government assessment. The eighth clause puts limitations on the floor planning and can include exits, windows, and fence restrictions, based on the neighboring site functions and development. These limitations have a strong social impact, usually subject to contention, but by providing and reinforcing the associated limitations or agreements, social solidarity can be achieved among all stakeholders, leading to social sustainability in some aspects.

In the project requirements, clauses 9.1–9.4 are typical urban development regulations. Clauses 9.5 and 9.6 cover the percentages of the construction area and the green areas, which are probably among the most important environmental factors of development. Clause 9.7 includes additional points, which are not common for usual building and development types and conditions. Clauses 12.1–12.6 include the requirements for utility services, most of which are attached and provided by the supplier companies. However, these clauses do not allow for any limitations, and everything is left for companies to fill in. Clauses 13 and 14 govern engineering preparation and landscaping works, both of which correlate strongly to the environmental footprint. Under the thirteenth clause, a water drainage system and other measures can be applied, while the landscaping section can include concrete tasks relevant to sidewalks, lawns, and lighting. Clause 15 is about the usage of the materials and finishes; however, recycling and local materials are not presented in the requirements, despite being vital for sustainable architecture and construction. Special attention must be given to these clauses, as the Armenian market strongly depends on local natural materials, and the physical and thermodynamical characteristics of those can change over time as they are excavated from deeper levels of the soil (Vasilyeva, Vardanyan, 2017). Following this, there are emergency and fire protection requirements under clauses 16 and 17, which are regulated and checked by the Ministry of Emergency Situations. The eighteenth clause of the DP only mentions accommodations for the disabled. The idea of separating the abled from the disabled is negative from the social standpoint, however, the municipality usually makes a point to ensure that everyone is serviced at the building properly. The nineteenth clause considers the protection of the surrounding environment from hazards; but when it comes to sustainability, the environmental footprint and influence must be assessed throughout the building's entire existence, from "cradle to grave", not just at a given moment. Thus, more specific steps can be mentioned or additional subclauses can be added, including not only the activities during the construction period but also the life cycle activities of materials and buildings in their entirety. The twentieth clause is about construction technology, organization, and workflow. This part also needs to be expanded to include more specifications, because many factors are affecting this, and in case of wrong or deficient supply, urban economy or transportation can be disturbed, or the rights of the neighboring areas' residents can be violated. The last, twenty-first clause in this section mentions a validity period for developing the project and possible phases. The phases are a good option for developers to gain time, by getting the permit for different parts of the development separately. This is a truly economic aspect of sustainability, which can foster the execution of big and complex projects, thus boosting the economy.

The additional conditions section poses requirements generally relating to official procedures. In other words, if we count the institutional component as one of the aspects of sustainability, which many researchers do (Doan et al., 2017; Littig and Grießler, 2008; Spangenberg, 2002), this whole section relates to this aspect. It mentions the type of expert assessment and the need for integral agreements with different stakeholders, including public audits. For additional points, there's the last clause, which can be applied very broadly, depending on the project.

**Conclusion**

Analysis of primary and secondary data shows that the design permit application process has both gaps and strong points. Obviously, in case of some adjustments, the process of issuing a DP and the DP form itself can become a well-defined guideline for sustainable design and construction in all of its aspects: the social, the environmental, the economic, and the institutional. Generally, the form and applications are well-made and can cover all the necessary aspects; that said, some strong institutional and procedural updates should be implemented. The institutional aspect of sustainability ought to be more integrated and effective in the field, in case the timing and procedures need to be revised. For better performance, preliminary meetings with municipality representatives from the development department can be organized on a mandatory basis, in order to discuss possible developments. It is only after these meetings that the developer will be able to invite an architect and pay for sketches to apply for a DP; otherwise entering into an agreement with an architect can cause financial losses, affecting the economic aspect of sustainability. The economic aspect is not covered or considered by the current procedures, while in reality, there is a significant need to refer to this aspect. This aspect can be enhanced through simple tax and state fee exemptions or property tax reductions. In the general perspective, as mentioned above, regulated institutional processes can be viewed as tools to foster economic growth. The social aspects, despite the existing clauses on neighbors' permit and disability access, do not fully assure the social sustainability of new development, if not to say that the aspect is covered superficially. Legislation related to real estate and ownership rights must be updated to avoid contradictions and contentions. The environmental aspect is a field where the public authorities have a strong toolkit to use. Already existing clauses and procedures can reduce environmental harm by covering information about all types of roads, accesses, and parking requiring specifications, rather than leaving these details for the developers to figure out. The latter can lead to non-sustainable solutions in some ways. Some vital environmental aspects, such as renewable energy usage, recycling, local material usage, as well as dust, noise and waste control, are missing from the process of permit acquisition entirely.

**Limitations and Future Research**

This article attempted to give a general notion of the sustainable aspects' integrity in the documentation and requirements for new development in Armenia. The lack of literature and research in the field confined the author to legislation review and case studies. Most of the organizations addressed were not open to sharing their experience with the municipality or considered it private information.

Future research can be done in two ways: by reviewing more case studies, and by going deeper into legislation and standards in search of sustainability aspects.

## References

Brodach, M. (2013) Green Building Market in Russia. *REHVA Journal*, No. 3, pp. 50–51.

City and County of San Francisco (2019). San Francisco Green Building Standards Code. [online] Available at https://up.codes/viewer/san_francisco/ca-green-code-2019. [Date accessed May 10, 2021].

Doan, D. T., Ghaffarianhoseini, A., Naismith, N., Zhang, T., Ghaffarianhoseini, A. and Tookey, J. (2017). A critical comparison of green building rating systems. *Building and Environment*, Vol. 123, pp. 243–260. DOI: 10.1016/j.buildenv.2017.07.007.

Government of the Republic of Armenia (2015). *Decision No. 596-N dated March 19, 2015.* [online] Available at: https://www.arlis.am/DocumentView.aspx?DocID=112490 [Date accessed May 10, 2021].

John, V. M., Agopyan, V., Abiko, A. K., Prado, R. T. A., Gonçalves, O. M. and Souza, U. E. L. (2000). Agenda 21 for the Brazilian construction industry–a proposal. In: *Construction and Environment: from Theory into Practice, November 23–24, 2000*. São Paulo: CIB PCC USP.

Libby Schweber (2013) The effect of BREEAM on clients and construction professionals, Building Research & Information, 41:2, 129-145, DOI: 10.1080/09613218.2013.768495.

Littig, B. and Grießler, E. (2008). Social sustainability: a catchword between political pragmatism and social theory. *International Journal of Sustainable Development*, Vol. 8, Nos. 1/2, pp. 65–79. DOI: 10.1504/IJSD.2005.007375.

Low, S. P., Gao, S. and Tay, W. L. (2014). Comparative study of project management and critical success factors of greening new and existing buildings in Singapore. *Structural Survey*, Vol. 32, No. 5, pp. 413–433. DOI: 10.1108/SS-12–2013-0040.

Ministry of Urban Development of the Republic of Armenia (2016). *Developers Guide.* [online] Available at: http://www.mud.am/maps/Karucxapatoxi_Uxecuic_NEW.pdf [Date accessed May 10, 2021].

Spangenberg, J. H. (2002). Institutional sustainability indicators: An analysis of the institutions in Agenda 21 and a draft set of indicators for monitoring their effectivity. *Sustainable Development*, Vol. 10, pp. 103–115. DOI: 10.1002/sd.184.

UNDP/GEF (2014). Improving Energy Efficiency in Buildings: Report on Activities Performed in 2014, Yerevan. Available at: http://www.nature-ic.am/en/projects/Improving-Energy-Efficiency-in-Buildings/2.

UNEP (2019). *2019 Global Status Report for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector.* [online] Available at: https://www.unep.org/resources/publication/2019-global-status-report-buildings-and-construction-sector [Date accessed May 04, 2021].

United Nations (1992). *Earth Summit: Agenda 21.* United Nations, 300 p.

Vardanyan, E. G. (2021). Case study of first certified sustainable buildings in Armenia. In: Rybnov, E., Akimov, P., Khalvashi, M. and Vardanyan, E. (eds.) *Contemporary Problems of Architecture and Construction*. London: CRC Press, pp. 101–106.

Vasilyeva, A. and Vardanyan, E. (2017). The need for sustainable buildings in Armenia. *Bulletin of Builders' Union of Armenia*, Vol. 3. p. 68-72.

Vierra, S. (2019). Green building standards and certification systems. [online] Available at: https://www.wbdg.org/resources/green-building-standards-and-certification-systems [Date accessed September 10, 2021].

# Technique and Technology of Land Transport in Construction

DOI: 10.23968/2500-0055-2021-6-3-70-76


## ADAPTATION OF THE TRAFFIC SIGNAL CONTROL DESIGN METHOD TO A HAMBURGER ROUNDABOUT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**Abstract**

**Introduction**: Currently, hamburger roundabouts with traffic signal control have limited application in the road networks of large cities. During analysis of scientific and technical literature, we established that it does not contain any systematic information on the possibility of their application or methods to determine their parameters. **Purpose of the study:** We aimed to adapt Webster's method of traffic signal design to hamburger roundabouts with traffic signal control, considering the specifics of traffic management. **Methods**: In the course of the study, we used methods of traffic analysis and simulation in the field-proven Aimsun software, recommended for use by scientific and technical literature on traffic management. We also assessed the efficiency of the adapted method by using the simulation results and comparing average transport delays at intersections considering the standard and adapted methods. **Results:** It was established that the adapted method of traffic signal cycle design reduces the average transport delay by 28% on average.



**Keywords**

Traffic, hamburger roundabout, transport delay, traffic signal cycle.


### Introduction

There are several methods of traffic signal cycle and phases design, proposed by P. Koonce (2008), V. M. Polukarpov (Zyryanova and Filimonova, 2017), V. A. Vladimirov (Zyryanova and Filimonova, 2017), A. A. Vlasov (Vlasov et al. 2009), and F. Webster (1958). In Russian scientific and technical literature as well as practice, Webster's method became the most widespread (Rosavtodor, 2012, 2013).

Currently, hamburger roundabouts with traffic signal control have limited application in the road network of such cities as Fairfax (USA), Minsk (Belarus), Samara (Russia), and some others. Such a transport junction is intended to ensure traffic management by giving priority to those moving in the main direction, allowing them to go through the central island.

During analysis of regulations as well as scientific and technical literature (Central Research and Design Institute for Urban Development of the National Committee for Civil Engineering and Architecture, 1980; Garant, 2020; Kaligin et al. 2019; Ministry of Motor Roads of the RSFSR, 2004; Redington, 1995; Rosavtodor, 2012, 2016; Tollazzi, 2015; Tollazzi and Renčelj, 2014; Tollazzi et al., 2011, 2016; US Department of Transportation, Federal Highway Administration, 2010), we established that they do not contain any systematic information on the possibility of hamburger roundabouts' application or methods to determine their parameters, transport delays, etc. The Guidelines for Road Marking (Ministry of Motor Roads of the RSFSR, 2004) recommend using a two-phase traffic signal cycle, and the Guidelines for the Development and Implementation of Traffic Management Measures "Improving the Efficiency of Using Roundabouts" (Garant, 2020) recommend using the basic theory of traffic signal control management in relation to roundabouts. According to Tolazzi (2015), the diameter of the island in a hamburger roundabout with traffic signal control shall be 60 m or more. The Guidelines for the Design of Roundabouts During the Construction and Reconstruction of Motor Roads (Rosavtodor, 2016) recommend using roundabouts with a complex (non-standard) layout (e.g., roundabouts with a straight-through section, including hamburger roundabouts) at intersections where five or more streets come together at an estimated traffic intensity of 15,000–50,000 of normalized units per day. The circular area in the middle shall have 1–3 lanes.

The number of lanes at the entrance/exit to/from a roundabout shall be from 1/1 to 3/3. The estimated speed at such a junction shall be 10–20 km/h. In these Guidelines, transport junctions without traffic lights are considered. The Guidelines for Road Marking (Ministry of Motor Roads of the RSFSR, 2004) recommend using traffic lights at signalized roundabouts and signalized roundabouts with a straight-through section. In the case of signalized roundabouts, traffic flows approaching the intersection pass it at a green light (as in the case of standard intersections), and left-turning traffic flows move simultaneously with those moving straight ahead. In the case of signalized roundabouts with a straight-through section, prevailing traffic flows in one or two streets, moving straight ahead, move along the shortest path (diameter), and in the points of intersection with the roundabout, traffic lights are installed. The Guidelines provide examples of sign posting, traffic lights arrangement, and road marking.

The following recommendations for the use of traffic signal control at roundabouts are given:

- high vehicle traffic intensity;
- heterogeneous traffic flows;
- the share of left-turning vehicles in the prevailing direction is more than 0.25–0.3;
- high pedestrian traffic intensity.

**Purpose of the study**

We aimed to adapt Webster's method of traffic signal design to hamburger roundabouts with traffic signal control.

**Study**

Fig. 1 shows a hamburger roundabout with traffic signal control in Fairfax (USA). Fig. 2 shows traffic management facilities.

Komarov et al. (2021) and other researchers (Rosavtodor, 2016) studied the influence of transport as well as organizational and planning factors on the efficiency of traffic management (with transport delays as the main criterion) at

Figure 1. Hamburger roundabout with traffic signal control in Fairfax (USA)

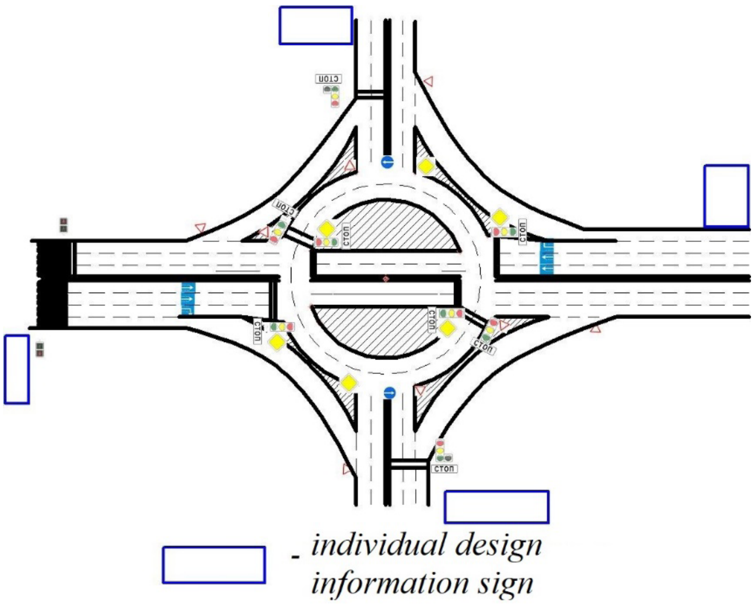


Figure 2. Traffic management facilities at the roundabout

hamburger roundabouts with traffic signal control. It was established that, as for the main direction, the estimated and experimental data (transport delays) agree with each other at the saturation degree $\chi \le 1$ (in this case, transport delays will be less than 38 s), and as for the minor direction, the data agree with each other at the saturation degree $\chi \le 0.72$ (in this case, transport delays will be less than 30 s).

To develop recommendations for traffic signal control at a transport junction, it is necessary to solve the following system of inequalities:

$$\begin{cases} \chi_{main} \le 1 \\ \chi_{minor} \le 0.72 \end{cases}. \quad (1)$$

The saturation degree can be determined by the following equation (Rosavtodor, 2012, 2013):

$$\chi = \frac{N_i * T_{cycle}}{M_i * t_{green}}, \quad (2)$$

where $N_i$ — traffac intensityon the main road in the straight direction (normalized units/hour);
$M_i$— saturation flow for the main road (normalized units/hour);
$T_{cycle}$— duration of the traffic signal cycle (s);
$t_{green}$ — duration of the green interval (s).

Since a two-phase traffic signal cycle is used at the junction (Garant, 2020; Komarov et al. 2021; Ministry of Motor Roads of the RSFSR, 2004; Rosavtodor, 2016), then:

$$T_{cycle} = t_{g\_main} + t_{g\_minor} + t_{change}, \quad (3)$$

where $t_{g\_main}$ — duration of the green interval for the main direction, s;
$t_{g\_minor}$— duration of the green interval for the minor direction and the circular area, s;
$t_{change}$— duration of the change intervals that can be determined by the corresponding recommendations (Rosavtodor, 2012, 2013).

Let us shift to phase coefficients $y_i$ (Rosavtodor, 2012, 2013; Webster, 1958) that can be determined by the following equation:

$$y_i = \frac{N_i}{M_i}. \quad (4)$$

Then we obtain the following system of inequalities:

$$\begin{cases} t_{g\_main} \ge T_{cycle} \times y_{main} \\ t_{g\_minor} \ge 1.39 \times T_{cycle} \times y_{minor} \\ T_{cycle} \ge \dfrac{t_{change}}{1-(1.39 \times y_{minor} + y_{main})} \end{cases}. \quad (5)$$

To ensure simultaneous fulfillment of all inequalities, let us replace all inequality signs with equal signs.

$$\begin{cases} t_{g\_main} = T_{cycle} \times y_{main} \\ t_{g\_minor} = 1.39 \times T_{cycle} \times y_{minor} \\ T_{cycle} = \dfrac{t_{change}}{1-(1.39 \times y_{minor} + y_{main})} \end{cases}. \quad (6)$$

When Eq. (6) is used, the resulting values of the traffic signal cycle duration and the duration of the intervals are quite small. In terms of essence, this equation is close to Webster's method (Rosavtodor, 2012, 2013; Webster 1958). Let us adapt Webster's method for the minor direction by using the resulting coefficient of 1.39. Then we obtain the following equations for traffic signal control:

$$\begin{cases} T_{cycle} = \dfrac{1.5 \times t_{change} + 5}{1-(1.39 \times y_{minor} + y_{main})} \\ t_{g\_main} = \dfrac{(T_{cycle} - t_{change}) \times y_{main}}{1.39 \times y_{minor} + y_{main}} \\ t_{g\_minor} = \dfrac{1.39 \times (T_{cycle} - t_{change}) \times y_{minor}}{1.39 \times y_{minor} + y_{main}} \end{cases}. \quad (7)$$

The efficiency of traffic management in Russia is assessed by the criterion described in Federal Law No. 443-FZ dated December 29, 2017 "On Traffic Management in the Russian Federation and on Amending Relevant Legislative Acts of the Russian Federation" (Silchenkov et al. 2020) as the ratio of time losses (delays) in vehicle and/or pedestrian traffic before and after the implementation of traffic management measures given that traffic safety is ensured.

Then, using the upgraded traffic model in the Aimsun software (Rosavtodor, 2016), we assessed the efficiency of the adapted method in comparison with the standard one as relative changes in the average transport delays. The upgrade of the traffic model implied changes in the number of lanes so that to ensure that the junction is symmetrical.

In the course of the study, the following assumptions were made:

- traffic flows include passenger cars only;
- the diameter of the island is 60 m;
- the approaches to the junction in the main direction are characterized by the same intensity (the same is true for the minor direction);
- in the main direction, the traffic flow moves only straight ahead since the influence of the left-turning flow on transport delays is insignificant (Komarov et al. 2021);
- the approaches to the junction in the minor direction are characterized by the following: 50% of vehicles move straight ahead, and

50% of vehicles turn left;
- the lane width is 3.75 m;
- the longitudinal slopes are 0‰;
- the distribution of the traffic flows in the software is set in a random manner (without user's participation);
- and so on.

**Procedure:**
- the following phase coefficients were taken: for the main direction, $0.2 \leq y_{main} \leq 0.8$; for the minor direction, $0.2 \leq y_{minor} \leq 0.5$ ;
- saturation flows were determined for the approaches to the junction by the corresponding recommendations (Garant, 2021; Kremenets et al. 2005; Redington, 1995; Rosavtodor, 2012); intensities for each pair of $y_{main}$ and $y_{minor}$ were determined as well;
- traffic signal control cycles were determined by the standard and adapted methods;
- the traffic flow intensity values and data on the traffic signal control cycles were introduced in the traffic model; transport delays were determined for each approach; the average transport delay at the intersection was determined;
- for each pair of $y_{main}$ and $y_{minor}$, 10 simulations were performed, and the average transport delay was determined;
- for some pairs of $y_{main}$ and $y_{minor}$, it was impossible to determine the average transport delay since vehicles could not move due to high traffic intensity values. These pairs of $y_{main}$ and $y_{minor}$ are not presented in comparative Table 1.

Table 1 shows the results of the study.

Table 1. Comparison of traffic signal cycle design methods

| Phase coefficient, main road, $y_{main}$ | Phase coefficient, minor road, $y_{minor}$ | Adapted method: Duration, s: Green interval, main road | Adapted method: Duration, s: Green interval, minor road | Adapted method: Duration, s: Duration of the change intervals | Adapted method: Duration, s: Traffic signal control cycle | Standard method: Duration, s: Green interval, main road | Standard method: Duration, s: Green interval, minor road | Standard method: Duration, s: Duration of the change intervals | Standard method: Duration, s: Traffic signal control cycle | Average delay, adapted method, s | Average delay, standard method, s | Relative difference, % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.2 | 0.1 | 9 | 6 | 6 | 21 | 9 | 5 | 6 | 20 | 7.1 | 6.4 | 10.1 |
| 0.3 | 0.1 | 13 | 6 | 6 | 25 | 13 | 4 | 6 | 23 | 7.7 | 6.2 | 20.3 |
| 0.4 | 0.1 | 18 | 6 | 6 | 30 | 18 | 4 | 6 | 28 | 9.2 | 10.1 | –10.4 |
| 0.5 | 0.1 | 26 | 7 | 6 | 39 | 24 | 5 | 6 | 35 | 11.5 | 19.1 | –65.7 |
| 0.6 | 0.1 | 39 | 9 | 6 | 54 | 35 | 6 | 6 | 47 | 14.4 | 23 | –59.2 |
| 0.7 | 0.1 | 68 | 13 | 6 | 87 | 56 | 8 | 6 | 70 | 21.8 | 38.3 | –43.1 |
| 0.2 | 0.2 | 9 | 12 | 6 | 27 | 9 | 9 | 6 | 23 | 10.4 | 9.9 | 5 |
| 0.3 | 0.2 | 14 | 13 | 6 | 33 | 13 | 9 | 6 | 28 | 11.1 | 11.4 | –2.8 |
| 0.4 | 0.2 | 22 | 15 | 6 | 43 | 19 | 10 | 6 | 35 | 13.8 | 16.4 | –19.3 |
| 0.5 | 0.2 | 37 | 20 | 6 | 63 | 29 | 12 | 6 | 47 | 19.1 | 32.9 | –72.4 |
| 0.2 | 0.3 | 10 | 21 | 6 | 37 | 9 | 13 | 6 | 28 | 13.1 | 20.5 | –56.1 |
| 0.3 | 0.3 | 18 | 25 | 6 | 49 | 15 | 15 | 6 | 35 | 30.1 | 52.3 | –73.6 |
| 0.2 | 0.4 | 14 | 38 | 6 | 57 | 10 | 19 | 6 | 35 | 7.7 | 7.4 | 3.8 |
| | | | | | | | | | | | Average difference | –28 |

**Results and discussion**

As can be seen from Eq. (7), in the case of the adapted method, the duration of the green interval for the minor direction and the circular area increases. This is due to the existing recommendations for traffic management (namely, the use of two-phase traffic signal control).

The adapted method of traffic signal cycle design, applied to the traffic model built in the Aimsun software, reduces the average transport delay at the intersection by 28% on average, and in the most probable case when the sum of the phase coefficients for the main and minor roads is in the range of 0.5...0.7 — by up to 40%. At low traffic intensity values, when the sum of the phase coefficients is less than 0.4, it is preferable to use standard Webster's method of traffic signal control design.

This study can be useful in the development of recommendations for the use of a hamburger roundabout with traffic signal control and the update of recommendations for the use of roundabouts and traffic signal control design.

## References

Central Research and Design Institute for Urban Development of the National Committee for Civil Engineering and Architecture (1980). *Guidelines for the design of urban streets and roads*. Moscow: Stroyizdat, 222 p.

Garant, 2020. *Guidelines for the development and implementation of traffic management measures "Improving the efficiency of using roundabouts".* [online] Available at: http://base.garant.ru/71802764/ [Date accessed January 13, 2020].

Garant, 2021. *Federal Law No. 443-FZ dated December 29, 2017 "On Traffic Management in the Russian Federation and on Amending Relevant Legislative Acts of the Russian Federation".* [online] Available at: https://base.garant.ru/71848756/ [Date accessed January 22, 2021].

Kaligin, N. N., Uvaysov, S. U., Uvaysova, A. S. and Uvaysova, S. S. (2019). Infrastructural review of the distributed telecommunication system of road traffic and its protocols. *Russian Technological Journal*, Vol. 7, No. 6, pp. 87–95. DOI: 10.32362/2500–316X-2019–7-6–87-95.

Komarov, Yu. Ya., Ganzin, S. V. and Silchenkov, D. D. (2021). Determination of the conditions for the application of the F. Webster formula for determining the transport delay at a circular intersection with traffic light regulation and a cut-through central island. *Intellect. Innovation. Investments*, No. 1, pp. 76–86. DOI: 10.25198/2077–7175-2021–1-76.

Koonce, P. (2008). *Traffic Signal Timing Manual. Report No. FHWA-HOP-08–024.* [online] Available at: https://ops.fhwa.dot.gov/publications/fhwahop08024/doc_page.htm [Date accessed 25.02.2021].

Kremenets, Yu. A., Pechersky, M. P. and Afanasyev, M. B. (2005). *Traffic management facilities.* Moscow: Akademkniga Publishing and Book-Trade Center, 279 p.

Ministry of Motor Roads of the RSFSR (2004). *Industry-Specific Construction Standards VSN 23–75. Guidelines for road marking.* Moscow: Center for Design Deliverables in Construction, 127 p.

Pugachev, I. N., Gorev, A. E., Oleshchenko, Ye. M. (2009). *Traffic management and safety.* Moscow: Academia Publishing Center, 272 p.

Redington, T. (1995). The modern roundabout arrives in Vermont. *AASHTO Quarterly Magazine*, Vol. 75, Issue 1, pp. 11–12.

Rosavtodor, 2012. *Industrial Road Guidance Document ODM 218.2.020–2012. Guidelines for the evaluation of the traffic capacity of motor roads.* Moscow: Federal Road Agency (Rosavtodor), 143 p.

Rosavtodor, 2013. *Industrial Road Guidance Document ODM 218.6.003–2011. Guidelines for the design of traffic lights on motor roads.* Moscow: Federal Road Agency (Rosavtodor), 69 p.

Rosavtodor, 2016. *Industrial Road Guidance Document ODM 218.2.071–2016. Guidelines for the design of roundabouts during the construction and reconstruction of motor roads.* Moscow: Federal Road Agency (Rosavtodor), 168 p.

Silchenkov, D. D., Lemeshkin, A. V., Komarov, Yu. Ya. and Metlev, V. S. (2020). Research of transport delays at the hamburger through-about intersection. *Construction and Road Building Machinery*, No. 4, pp. 27–30.

Tollazzi, T. (2015). *Alternative types of roundabouts. An informational guide.* Cham: Springer, 206 p. DOI: 10.1007/978–3–319–09084–9.

Tollazzi, T., Mauro, R., Guerrieri, M. and Renčelj, M. (2016). Comparative analysis of four new alternative types of roundabouts: "Turbo", "Flower", "Target" and "Four-Flyover" roundabout. *Periodica Polytechnica Civil Engineering*, Vol. 60, No. 1, pp. 51–60. DOI: 10.3311/PPci.7468.

Tollazzi, T. and Renčelj, M. (2014). *Modern and alternative types of roundabouts – state of the art.* The 9th International Conference "Environmental Engineering", May 22–23, 2014, Vilnius, Lithuania. Article No. enviro.2014.137.

Tollazzi, T., Renčelj, M. and Turnšek, S. (2011). New type of roundabout: roundabout with "depressed" lanes for right turning – "flower roundabout". *Promet – Traffic&Transportation*, Vol. 23, No. 5, pp. 353–358.

US Department of Transportation, Federal Highway Administration (2010). *Alternative Intersections/Interchanges: Informational Report (AIIR). Publication Number: FHWA–HRT–09–060.* [online] Available at: https://www.fhwa.dot.gov/publications/research/safety/09060/006.cfm [Date accessed December 4, 2020].

Vlasov, A. A., Akimova, V. Yu. and Shirokov, M. V. (2009). Evolutionary methods for estimation of traffic lights operating conditions. *Bulletin of Kharkiv National Automobile and Highway University*, No. 47, pp. 97–99.

Webster, F. V. (1958). *Traffic signal settings. Road Research Technical Paper No. 39.* London: HMSO, 45 p.

Zyryanova, S. A. and Filimonova, O. A. (2017). Automation of calculations for traffic signal control parameters using various methods. In: *Performance and Safety Issues of Complex Technical and Information Systems. Proceedings of the International Research and Practice Conference, November 4, 2017, Orenburg, Russia.* Sterlitamak: Agency of International Research, pp. 40–43.

# АДАПТАЦИЯ МЕТОДИКИ РАСЧЕТА СВЕТОФОРНОГО ЦИКЛА ДЛЯ КРУГОВОГО ПЕРЕСЕЧЕНИЯ СО СВЕТОФОРНЫМ РЕГУЛИРОВАНИЕМ И ПРОРЕЗАННЫМ ЦЕНТРАЛЬНЫМ ОСТРОВКОМ

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**Аннотация**
Кольцевые пересечения со светофорным регулированием и прорезанным центральным островком нашли ограниченное применение на улично-дорожной сети крупных городов. В ходе анализа научно-технической литературы установлено отсутствие системной информации о возможности их применения, методик расчета параметров данного типа кольцевого пересечения. **Цель исследования:** Адаптировать существующую методику Ф. Вебстера расчета светофорной сигнализации для кругового пересечения со светофорным регулированием и прорезанным центральным островком с учетом особенностей организации дорожного движения. **Методы:** В исследовании использовались методы анализа, моделирования дорожного движения в программном комплексе Aimsun, неоднократно апробированный в этой области знаний и рекомендованный для применения в научно-технической литературе по организации дорожного движения. Оценка эффективности адаптированной методики проводилась по результатам моделирования сравнением средних транспортных задержек на пересечении при адаптированной и существующей методике. **Результаты:** Адаптированная методика расчета светофорного цикла дает снижение средней транспортной задержки в среднем на 28 %.

**Ключевые слова**
Дорожное движение, кольцевое пересечение со светофорным регулированием и прорезанным центральным островком, транспортная задержка, светофорный цикл.

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