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Geoinformation Technologies in the Reconstruction of the Social Space of Siberian Cities at the Turn of the 19–20th Centuries (Case Study of the City of Tobolsk)

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This article presents the experience of creating the historical geographic information system “Siberian Cities at the Turn of the 19–20th Centuries” (Case Study of the City of Tobolsk) focused on presenting online results. The structure of the article corresponds to the main stages of GIS creation.

At the first stage, the main attention was paid to the methods of preparation and input of cartographic material, due to the lack of a mathematical framework for historical maps. The affine transformation algorithm has been chosen as the main algorithm for working with the map of the city of Tobolsk, which allows to place the map sheet in a modern coordinate system (WGS84), with a limited number of fiducial points, correctly. The second stage was aimed at determining both the sources of demographic, social, economic, and spatial data, which will become the basis of the basic vector-raster layers. The source was a set of census forms of the First General Population Census of 1897 for 8 cities in the Tobolsk Province. The third stage is devoted to the Web-GIS creation. A pilot version of the project with the reconstruction of the urban space of Tobolsk at the turn of the 19–20th centuries was created on the platform NextGISWeb.

It is concluded that geoinformation technologies application is aimed not only at visualization and presentation of data from different sources, but also at creating a tool for spatial analysis of demographic, social and economic factors, studying the features of the various social groups resettlement and reconstruction of the social space of the city as a whole.

Keywords: social space, census of 1897, historical geographic information system, Web-GIS, cities of Siberia.

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Research area: history.

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Project description

Having relative boundaries and demarcated space in the form of streets, squares and buildings, a city is a unique object of multidimensional spatial analysis, including in historical retrospect (Rygalova, 2015: 135–136). The study of social aspects of the urban space formation is of particular interest. Was there a kind of “territorial principle” for the social groups resettlement within the city? How was this principle defined: by employment and workplace, by social or territorial background, etc.? These issues are of particular relevance for the cities of Siberia at the turn of the 19th and 20th centuries. Whether forced and voluntary migrations, as well as ethnic features of the region were determinant for the social composition of the cities? How did the urbanization processes (temporary and intra-provincial migration) determine the “image” of the city? The aforementioned issues became the basis for the project “Social Topography of Siberian Cities at the Turn of the 19th and 20th Centuries: GIS Spatial Analysis of Employment” which goal is to reconstruct the social space of the city of Siberia on the basis of comprehensive methodology for analyzing social structure and its representation in an interactive geoinformation system. Creating a historical geoinformation on-line system is one of the main tasks of the project, and, at the same time, a technology that allows to accumulate and analyze various data: demographic, cartographic, social, economic, etc.

Spatial approach to the study of social aspects of urban settlements has become widespread in the process of studying ancient and medieval cities. Thus, studies by T.D. Panova (2013), L.E. Zueva (2012) and L.D. Mazur (2010) based on archaeological excavations, cadasters, census and sentry books represent the reconstruction of the social space of the medieval cities of the Moscow and Vladimir-Suzdal principalities (Moscow, Vladimir, Suzdal, Shuya and Yuryev-Polsky). An interesting experience of the historical socio-topographical reconstruction of Polotsk, based on the data of the revision of 1765, is presented by the researcher D.V. Duk (2015).

The social space of the cities of the 19th century was studied by such researchers as V.Yu. Kozlova (2011), A.A. Akasheva (2006), E.V. Baranova and R.B. Konchakov (2005). But whereas V.Yu. Kozlova used cartographic material as an illustrative one, the studies by A.A. Akasheva, E.V. Baranova and R.B. Konchakov are based on the use of geoinformation technologies that allow to carry out spatial analysis of statistical and mass sources (censuses, police reports, etc.) in the information and digital environment.

In addition, projects devoted to the studies of social urban space, created on the basis of the web-GIS technology and introduced on the Internet, were of special interest. In the practice of international research, such projects were created both for medieval cities (e.g. Mapping Edinburgh's...), London (Politics, Literary Culture...), as well as for the cities of the 19–20th centuries (GISHistorical Antwerp II) and Istanbul (Istanbul Urban Database). In most projects, the basis for web-GIS was modern maps “synchronized” with the historical plans of the cities of different periods. Localized objects were accompanied by the information in accordance with the idea of the resource: virtual reconstruction of castles, historical photographs, cadastral data or information about residents. Such projects are means for data visualizing and data sources (for example, census or cadastral data of the 19– early 20th centuries that are usually stored in archives and not accessible to the general public), as well as a tool for spatial analysis. There are no similar projects in the practice of Russian studies.

This article presents the experience of creating the historical geoinformation system “Siberian Cities at the Turn of the 19–20th Centuries” (Case Study of the City of Tobolsk), focused on introducing the results on-line. The structure of the article corresponds to the main stages of GIS creation: 1) preparation and input of cartographic data; 2) basic vector-raster layers development; 3) data publication with the use of a cartographic web server.

Methods of preparation and input of cartographic material

This procedure was carried out along with georeferencing and transformation of rasters. Registration of maps and plans was carried out with the help of ArcGIS desktop cartography system using fiducial points and modern vector layers of blocks, houses and other structures, as well as hydrographic elements. When working with old maps, it is important not only to link, but also to transform the image, which, whenever possible, gives an opportunity to eliminate distortions throughout the map field. The transformation methods are based on comparing the coordinates of the source points

and fiducial points, which are combined into special graphic elements – displacement links in ArcGIS (Fig. 1).

To build mathematical equations (dependencies) in the process of transformation, the source points and the displacement links target points are used. The most common methods are: affine transformation and the “rubber sheet” method. The algorithm of affine transformation gives an opportunity to differentiate the image, to scale, to set the incidence, to rotate, to move, etc. The transformation parameters are obtained based on the best matching of the source and target fiducial points. In the course of its application, the program determines an error, which is a measure of matching for the actual and calculated positions for the fiducial points. The error is generated for each displacement link, then the root-mean-square error (RMS) is determined for each transformation performed. RMS represents the measure of deviation between the target fiducial points and initial fiducial points obtained as a result of the transformation.

A detailed description of the “rubber sheet” algorithm for solving similar problems was applied by a group of researchers including A.A. Frolov, A.A. Golubinsky and S.S. Kutakov (2017). Working with the drawings of Moscovia, which were made

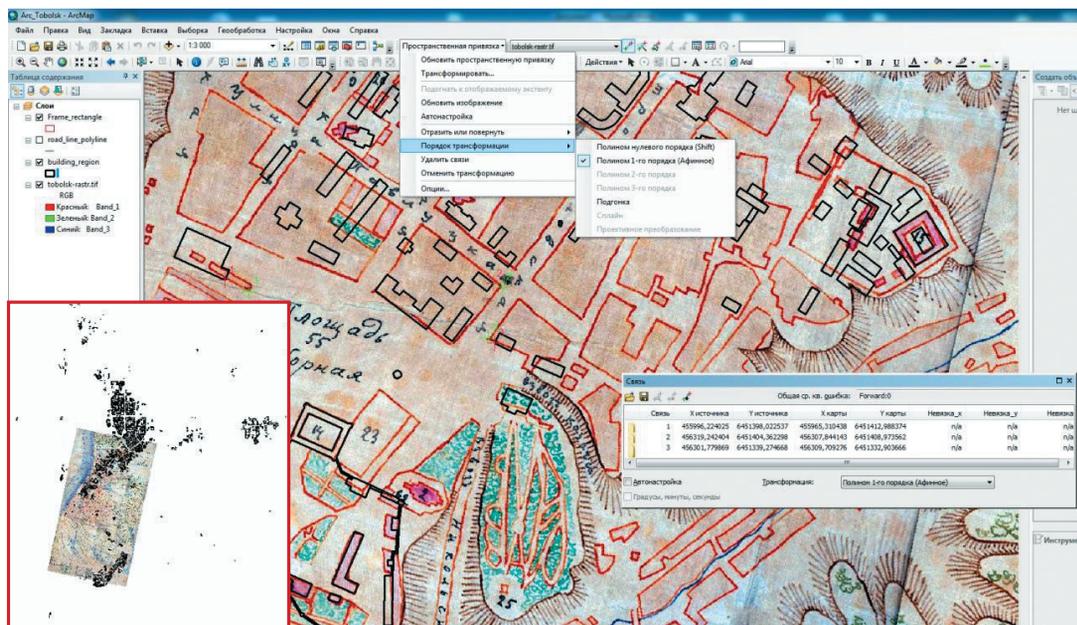


Fig. 1. Georeferencing and raster transformation (map of 1860) using fiducial points and vector layers in ArcGIS. *Note:* black contours are a vector layer of modern buildings, red contours are buildings on the 19th century map

without the strict observance of the mathematical framework, the task of geo-linking of these drawings with the preservation of the location and basic proportions arose. The attempts to connect the drawings as accurately as possible demonstrated poor results, thus, the authors subsequently abandoned this idea and opted for the “rubber sheet” algorithm (thin plate spline). The latter provides the most flexible deformation of the whole raster field, taking into account the correspondence of each of the given benchmarks to the points on the terrain and flexibly distorting the drawing between them (Frolov, 2017). Since the “rubber sheet” algorithm transforms images more flexibly, one part of the plan can remain practically unchanged, and the other, on the contrary, can change beyond recognition. Meanwhile, according to A.A. Frolov and A.A. Golubinsky “... more than 700 drawings have resulted in a link to the terrain, however, about 140 drawings have not been localized yet” (Frolov, 2017: 81). Therefore, it is unfeasible to speak about the universality of this technique, it is necessary to take into account the state of the drawings (maps), the degree of correspondence to the mathematical basis, and a number of other factors.

For example, the map of Tobolsk (the author is not defined) was created carelessly in terms of the mapped objects and cartographic fonts precision. However, according to the authors’ experience, this did not affect the correctness and precision of conveying proportions and following basic scale. Therefore, with a limited number of fiducial points, it was possible to position the map sheet in the modern coordinate system (WGS84) correctly, using a rigorous mathematical relation in the form of affine equations. In addition, the method itself does not exclude interactive work/links correction and allows to change the target position of fiducial points on the basis of visual analysis.

An important element in evaluating the results of a mathematical framework development is the quality of georeference and transformation, which is expressed quantitatively in the form of deviations of coordinates from the true values. Considering the wide variety of projections in the ways of their creation and the criteria that assess the distribution of distortions in the process of digital maps development (Ivanov, 2012), the authors used a geocentric coordinate system (WGS84 datum). Without delving into the analytical transformations parameters, one should speak of its universality and practicality, as well as the possibility of rapid modification/transformation from a given coordinate system into any other system (Bugayevsky, 1998).

To assess the quality of the initial plans and maps georeferencing, errors in the raster registration were detected using the following formula (Chibisov, 2017: 87):

$$M(m) = \frac{m}{\left(\frac{R_{DPI}}{2.54}\right) \times 100},$$

where $M(m)$ is the value of the registration error expressed in meters; m is the denominator of the map scale; R_{dpi} is the initial raster resolution; 2.54 is the value of division of one inch in centimeters.

Given that the scale of the basic plan of Tobolsk was 50 sazhen in 1 English inch (Fig. 2), it is easy to know the value of division of 1 inch in meters: 1 inch = 2.16 sazhen. Thus, it constitutes 8.5 m/1 mm., which implies the value of the basic map scale equal to 1: 8,500 (i.e., 1 cm = 85 m, or 1 mm = 8.5 m). Provided that $R_{dpi} = 300$ dpi and the basic map scale is 1: 8,500, the following weighted error values are obtained for one point: $M = 8500 / (300 / 2.54 \times 100) = \pm 0.72$ m.

At that, before the transformation the error limit averaged 13 points, which corresponds to ± 11 m; after the transformation procedure the error limit value was 5 points maximum, which corresponds to the error of ± 3.6 m (Table 1).

This indicates, first, about the need for preliminary processing and geometric correction of raster data (which also includes the old city plans). Secondly, in addition to the well-chosen, the most accurate and detailed cartographic materials, one should pay attention to the details of the image itself, preserving the features of the landscape, hydrography or terrain. The latter are particularly stable in time; thus, individual elements can also be used for the prototype reference. Thirdly, according to the authors' experience, the situation with the quality of the plan (its content) drawing, as well as proportions and, hence, the mathematical framework observance, is quite

Table 1. Distribution of raster data georeference errors for the GIS project “Siberian Cities at the Turn of the 19–20th Centuries”

Methods for raster data spatial coordination	
Without transformation procedure, <i>Dm, m</i>	With the use of affine transformations, <i>Dm, m</i>
In the centre	
$\pm 5,0$	$\pm 2,5$
Along the sheet edges	
$\pm 17,0$	$\pm 4,7$
Average values	
$\pm 11,0$	$\pm 3,6$

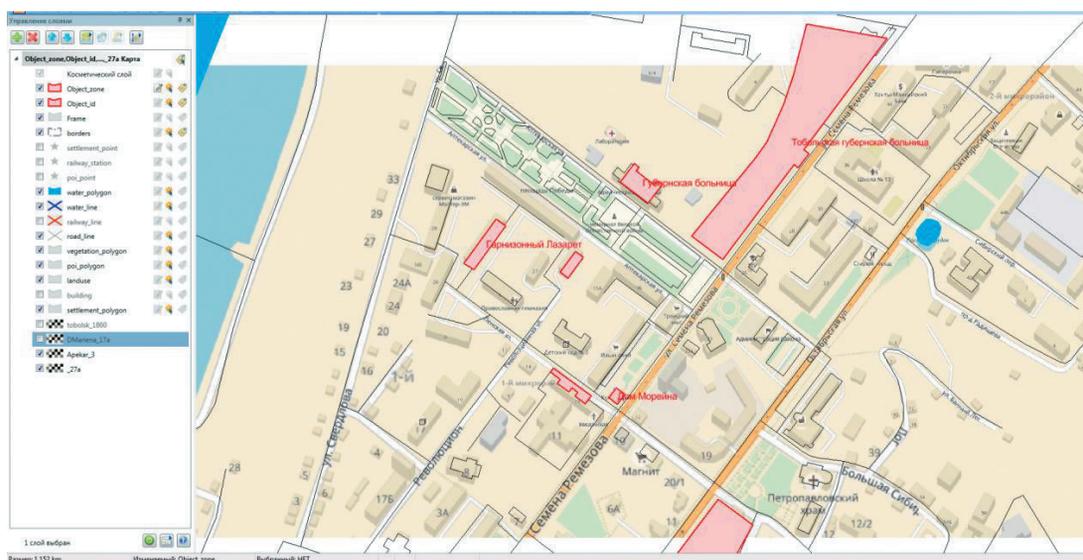


Fig. 2. Digitization of layers based on georeferenced substrate (source: <https://2gis.ru/tobolsk>)

ambiguous. For instance, the plan used for Tobolsk is not at all a prototype in terms of its representation, style, design, correctness and clarity of lines, etc. Meanwhile, the city buildings and blocks displayed in the plan are planimetrically accurate and largely observe the proportions, shapes and sizes of objects.

It is also worth noting that the process of the aforementioned original cartographic materials transformation and georeferencing does not provide the required accuracy in itself. For this, it is recommended to use prototype vector datasets (GIS layers), borrowed from other sources. In this project, for example, the authors used vector layers obtained as a result of digitization in a modern coordinate system based on the following sources: 2GIS on-line (<https://2gis.ru/tobolsk>), Open Street Map Russia (<http://openstreetmap.ru>), as well as raster substrates downloaded with the use of SAS. Planet service (Fig. 2).

In addition to these recommendations, it is necessary to take into account what type of data the obtained vector layers belong to – topological (geometrically correct) or nontopological (incorrect from the point of view of geometry and planimetric position). In the latter case, additional transformations of the topology and geometric correction of vector data provide the greatest opportunities for the further procedures for using the system and, what is especially important, for the correct integration of all its elements into the Web-GIS.

Data sources for vector-raster layers

Basic vector-raster layers are understood as sets of spatial, demographic and social data, developed and used in desktop (local) GIS. At this stage, the cartographic vector-raster basis was prepared by digitizing the linked maps and plans for the towns of the Tobolsk Province in the modern coordinate system WGS84.

In addition, this stage includes the development of electronic maps, groups of layers and their transition into the formats, convenient for their transfer to cartographic web services. According to the presentation format, the resources can be divided into two general groups: 1) raster data, 2) vector data.

The towns of the Tobolsk Province for the implemented version of the desktop GIS included Tobolsk, Ishim, Kurgan, Tara, Turinsk, Tyukalinsk, Tyumen, Yalutorovsk. The following layers are included into the list of the vector layers for the GIS digitization:

- Roads and transport network;
- Street network;
- Hydrography;
- Vegetation;
- Blocks;
- Infrastructure objects;
- Institutions of management, culture, religion, production, trade;
- Residential buildings.

Raster format is a fairly simple way to represent spatial data. A raster map is a digital image from a set of pixels with a coordinate reference. The drawbacks of this format are: a larger amount of memory (in comparison with a vector image); the absence of some functions and capabilities that are available when working with the vector format data; difficulty of actualization; limited zoom capabilities; the impossibility of dumping (removing unnecessary content elements and their attributes); difficulty of attribution; impossibility of addressing to the content elements; large amounts of data, complexity of any operations with elements, etc. (Kikin, 2014). However, raster layers give an opportunity to preserve the “image” of historical maps.

In addition, at this stage, the localization of objects, primarily residential buildings and institutions, which were accompanied by their characteristics, as well as a list of residents/employees, took place. The source of such information is the database on the urban population of Siberia at the turn of the 19–20th centuries. The basis of the database was the original census forms of the First General Population Census of 1897, preserved in the State Archives in the city of Tobolsk (Fund 417). The peculiarity of

the set of census forms is the fact that they contain not only demographic (gender, age, marital status, etc.), social (class, position in the household, literacy) and economic (employment status) information about the residents, but also spatial data, namely information on the address of residence (street, house, apartment), the owners of real estate and the description of residential and non-residential buildings (what it was built of, what it was covered with). It should be noted that household buildings, detached wings or pavilions were often not designated on historical maps, and a complex of buildings belonging to a particular institution could be designated as a single landfill. At present, the identification of objects on the historical maps of cities continues.

On-line representation of the results

A separate task of the project was to create a possibility of presenting GIS results on-line. A fundamentally important point is the choice of a methodical approach to solving the problem of cartographic visualization and the publication of interactive historical maps. This approach is based on the technology of freely distributed data and “free GIS”, i.e. open source GIS. NextGISWeb platform has been chosen as a constructor of the Web-GIS proposed to the users. A pilot version of the project with the reconstruction of the urban space of Tobolsk at the turn of the 19–20th centuries is currently represented at this resource (<http://history.nextgis.com/resource/25/display>).

In the authors’ opinion, there are following useful and promising features of the proposed Web-GIS: support for data uploading and visualizing in the form of both raster and vector type of layers; the convenience of data editing through the exchange protocols (import-export) in the normal desktop GIS mode; the possibility to enter and edit new attributes, geocoding new (heterogeneous) data in the Web-GIS through an understandable and convenient NextGISConnect module; possibilities of publishing in the old maps system without a mathematical framework (or having a poor mathematical framework) through the preliminary procedures of images referencing and transformation, which made the first stage of the project; the possibility of adding photographs and other graphic images to the cloud database (Fig. 4), etc.

Despite some of the drawbacks noted in relation to raster data, it is a necessary group of resources for the Web-GIS, as it is this group that provides qualitative mapping and the possibility for the spatial analysis of retrospective map, along with modern data (Fig. 3). So, on the represented map we see the plan of the city of Tobolsk, and we also have an opportunity to see what exactly is located today on the sites of the 19th century

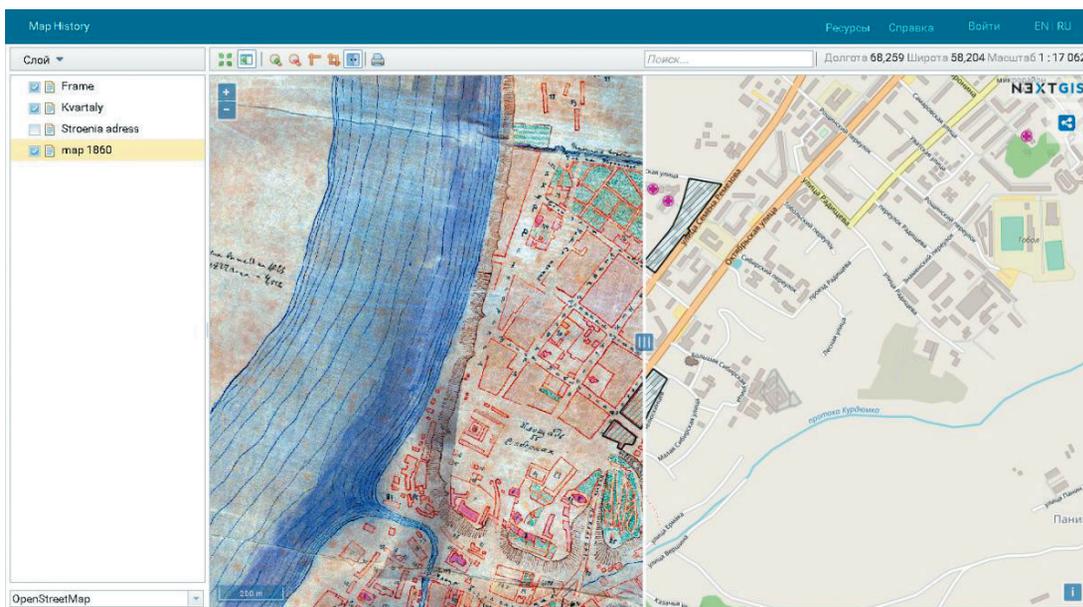


Fig. 3. Visualization of Tobolsk's cartographic basis in the "curtain"/combination mode (<http://history.nextgis.com/resource/25/display>)

objects. Due to new tools, it became possible to analyze and study the dynamics of historical processes retrospectively.

In addition to cartographic visualization and queries, the system provides the ability to download and publish historical data and the photos of objects. Thus, when choosing an object on the integrative map "Public Assistance Institution", information about all the people registered in it at the time of the census and belonging to different categories – from the sick ones to the civil servants, officials and their family members will be displayed. In addition, another useful function is displaying photos and other graphic files attached selectively to the most interesting objects and stored in a cloud resource on the Web server.

One of the most important aspects of the work done is the ability to provide the potential users of the proposed Web-GIS with an ability to connect to the system not only as an information user, but also as a developer. The authorization procedure provides: full-fledged work with entering/adding new objects to the existing layers; the ability of editing the attributes and geocoding new data, as well as other operations. Such opportunities will be implemented at the next level of the system use, technically from 2018 onwards. In the authors' opinion, the most acceptable way to solve the aforementioned problem is to connect using special WFS protocol (WebMapService). With its help, it will be possible to fully complete the Web-GIS with new spatial

The screenshot displays a Web-GIS interface with a blue header containing navigation links: 'Ресурсы', 'Панель управления', 'Справка', and 'Администратор'. The main content area is titled 'Объект #4' and includes a breadcrumb trail: 'Основная группа ресурсов > Old City Resours > Stroenia adress > Объект #4'. Below the title, there is a section for 'Атрибуты' (Attributes) with a table:

Name	Богадельня общественного призрения

Below the table is a section for 'Описание' (Description) containing a list of names and professions, such as 'Кирилова Вера Ивановна, Крест. гос. служанка при Богадельне общественного призрения; Терентий, уменьшенный со дня рожд.; Тукнов Александр Николаевич, слепой и глухой; Ковряков Афанасий Осипович, Мещанин; Якимов Петр Панкратович, Крест. гос. на оба глаза слепой; Муромцев Василий Александрович, Чиноничество; Нестеров Михаил Егорович, Бродяга, слепой; Черепанов Николай Петрович, Мещанин; Усольцев Петр Филиппович, Крест. гос.; Захаров Иван Дмитриевич, Крест. гос.; Южанкин Павел Васильевич, Мещанин; Кардаполов Иван Ильич, Мещанин; Ефимов Федор Ильич, Мещанин; Чехович Иосиф Андреевич, Крест. гос.; Каренгин Егор Прокопьевич, Мещанин; Симашко Антон Антонович, Мещанин; Романовская Ольга Николаевна, Крест. гос.; Прадедова Евдокия Ефимовна, Чиноничество; Глазкова Евфимия Николаевна, Крест. гос.; Толмачева Евдокия, Чиноничество;'. To the right of the main content is a sidebar with options: 'СОЗДАТЬ РЕСУРС' (Create Resource) with 'Стиль MapServer' and 'Стиль QGIS'; 'ДОПОЛНИТЕЛЬНО' (Additional) with 'Представление JSON' and 'Дерево ресурсов'; 'ВЕКТОРНЫЙ СЛОЙ' (Vector Layer) with 'Таблица объектов', 'Загрузить GeoJSON', and 'Загрузить CSV'. At the bottom right, there is a map window showing a photograph of a large, multi-story brick building (a 19th-century barrack) overlaid on a street map.

Fig. 4. Means of historical and graphical (photographic) data visualization in the Web-GIS: 1 – the list of people of all categories living in the Public Assistance Institution at the time of the census in 1897, 2 – a photograph of the 19th century barrack belonging to the military garrison

and statistical data characterizing the cities of Siberia at the turn of the 19th and 20th centuries. Taking into account the multi-user mode of this protocol, several specialists can simultaneously work with the system which will diminish time costs and provide data cross-checking in the system.

Creation of the urban space geoinformation systems requires a combination of cartographic, descriptive and mass sources. At the same time, work with historical maps requires special attention. Preparation and input of cartographic data into the GIS requires the use of special methods and approaches. It should also be taken into account that historical map's objects may not correspond to the descriptions in the available sources. Whole complexes of structures, for example, can be marked on the map as one polygon. Nevertheless, the amount of details of most historical maps allows to localize both residential and infrastructure facilities, as well as accompany them with characteristics.

The Web-GIS technology allows to significantly expand user capabilities, as well as to use them as a means of the project implementing due to the remote administration function. Thus, the use of the geoinformation technologies, both new and classic ones (for instance, the development of a GIS project using the “shrink-wrapped” version of

the geographic information system) is aimed not only at visualization and presentation of data from different sources, but also at creating promising tools for spatial analysis of demographic, social and economic factors, studying the features of various social groups resettlement and reconstruction of the social space of the city as a whole.

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Геоинформационные технологии в реконструкции социального пространства сибирского города на рубеже XIX–XX вв. (на примере города Тобольска)

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В данной статье представлен опыт создания исторической геоинформационной системы «Города Сибири на рубеже XIX–XX вв.» (на примере г. Тобольска), ориентированной на представление результатов on-line. Структура статьи соответствует основным этапам создания ГИС.

На первом этапе основное внимание уделялось методам подготовки и ввода картографического материала, обусловленным отсутствием математической основы у исторических карт. В качестве основного для работы с картой города Тобольска был выбран алгоритм аффинного преобразования, позволяющий при ограниченном количестве контрольных точек довольно правильно расположить лист карты в современной системе координат (WGS84). Второй этап был направлен на определение источников как демографических, социальных, экономических, так и пространственных данных, которые станут основой базовых векторно-растровых слоев. Таким источником стал комплекс переписных листов Первой всеобщей переписи населения 1897 года по 8 городам Тобольской губернии. Третий этап посвящен созданию Web-ГИС. На платформе NextGISWeb была создана пилотная версия проекта с реконструкцией городского пространства Тобольска на рубеже XIX–XX вв.

Делается вывод о том, что применение геоинформационных технологий направлено не только на визуализацию и представление данных разных источников, но и на создание инструмента пространственного анализа демографических, социальных и экономических факторов, изучения особенностей расселения различных социальных групп и реконструкции социального пространства города в целом.

Ключевые слова: социальное пространство, перепись 1897, историческая геоинформационная система, Web-ГИС, города Сибири.

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