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3D artistic mapping of the urban environment for tourism information support

Abstract. With the development of the tourism sphere, its information support is also developing, in particular, represented with cartographic works. One of the forms of cartographic support for tourism is three-dimensional artistic maps (3D-maps, panoramic maps) and cartographic web applications. By our understanding *the panoramic map* of the city is a cartographic image of the urban environment, made with regard to linear and aerial perspectives on the principle of artistic painting and created an illusory sense of volumetricity. Such maps illustrated the historical parts of cities, park zones, museums-estates, individual architectural monuments become popular souvenirs, but their handwritten creation is rather labor-intensive and requires high artistic skills.

The research proposes the author's methodology and technology for creating and updating of three-dimensional artistic maps mainly of small and medium cities and towns using modern information technology, which involves a rational combination of works done manually (handwritten) and with the usage of graphic editors (automated). The preferred cartographic projections for mapping of different territories have been determined (external perspective projection with positive image, taking into account the curvature of the globe surface – for vast territories, central projection – for small territories, including individual monuments). The most optimal conditions for three-dimensional illusory representation of cities have also been established (the constant height of the observation point, the projection with parallel rays at an angle of 60° to the picture plane, the display only the front and middle parts of the map). Special attention is paid to the usage of automated libraries of signs, textures and colors, developed by the author in digital form and containing individual constructive elements of urban environment objects, which greatly simplifies the process of panoramic map creating.

The proposed combined handwritten-automated methodology involves several stages: preparatory, field and office. At the last stage, the visualization of objects is carried out, including the construction of the plan of the mapped territory, transforming it into the perspective projection, the construction of building frames and filling them with structural elements, color design and drawing detailing.

This methodology is also used for updating of artistic maps (actualization of their content).

Keywords: urban environment, artistic cartography, sign, texture and color libraries, combined handwritten-automated methodology and technology, web application

1. Introduction

The development of the tourism industry in the context of globalization and digitalization requires new approaches to its information support. From this point of view, special attention is paid to both large tourist areas and individual cities which have their own unique appearance, determined by their rich history, by the presence of numerous architectural monuments, historical buildings, and natural resources. The increasing of their tourist attractiveness in order to popularize them for tourists and give impetus to the development

of these settlements can be achieved through the development of new forms of cartographic support for tourism – three-dimensional artistic maps and cartographic web applications.

An analysis of the historical development of 3D images of cities, from the Middle Ages to modern period, led to the conclusion that medieval artistic panoramic maps of cities play an important role in the history of cartography. *Panoramic map of city* in my opinion is a cartographic image of the urban environment, made according to the linear and aerial perspectives rules as well as the principle of artistic painting and created an illusory sense of volume.

Since the middle of the 20th century cartographic art has been reviving: during this period, 3D cartography received a scientific basis. A great contribution to the development of the theory of three-dimensional mapping (mainly in the relief displaying) was made by representatives of foreign (C. Häberling, E. Imhof, Z. Kozieł, E. Raisz, etc.) and Soviet (R.V. Atoyan, O.V. Kovaleva, P.A. Skvortsov, L.E. Smirnov, T.V. Vereshchaka, etc.) scientific schools.

Raisz developed more than forty perspective drawings for different landscapes for geomorphological maps (Raisz, 1948). E. Imhof was engaged in realistic representation of relief on maps, justified methods of perspective image construction (Imhof, 1982).

Häberling deals with the methodology of interactive three-dimensional maps. In his article (Häberling et al., 2008) he considers some features of 3D maps – their perspective projection view, which is depicted on two-dimensional mediums but is perceived as a representation of three-dimensional reality. He also briefly reviews cartographic research on the compilation of 3D representations of terrain, suggesting specific cartographic techniques for constructing such products.

The work written by Kozieł (2003) is devoted to relief modeling. Review and classification of methods and ways of depicting relief on maps (from handwritten images to electronic maps) are considered by Vereshchaka and Kovaleva in their book (2016).

In the monography written by Smirnov (1982) a number of issues of space representation in cartographic works are considered, classifications of three-dimensional models in relation to terrain relief are given and various principles and methods of reproducing three-dimensionality of objects on maps are analyzed.

The development of the school of artistic cartography in the USSR is associated with the name of P.A. Skvortsov, who made a significant contribution to the development of map design. Landscape maps created with his participation are made in oil colors according to the laws of perspective and painting (Biktimirova & Bugaevskij, 2015).

The works of Vasmut (1983; Vasmut et al., 1991) and Tikunov (1997) are devoted to automated and mathematical methods in cartography.

R.V. Atoyan was engaged in the issues of improving the methodology and technology of tourist maps creating on the basis of scientific principles of construction, cartographic modeling and artistic design, as well as the implementation of automation means in separate production processes of tourist maps creation (Atojan, 1999; Atoyan, 1989).

At the present stage, much attention is paid to three-dimensional mapping of terrain for the purpose of online visualization and the usage of maps in mobile applications. Panoramic maps of historical parts of cities, park areas, museums, and individual architectural monuments are also becoming popular. In addition to the fact that they are considered as souvenir cartographic products, they also serve practical purposes: orientation, planning excursions, observing historical and cultural heritage.

Currently, mostly traditional (2D) mapping techniques are used to compile city maps – such cartographic works have mathematical accuracy and a certain degree of clarity, however, they are inferior to three-dimensional artistic maps, where special importance is attached to visual illusions of volume. Handwritten three--dimensional panoramic maps are characterized by expressiveness and ergonomics, especially for an inexperienced user, however, their creation requires a significant investment of time and certain artistic skills. At the same time, panoramic maps do not have a unified theoretical and methodological basis or common approaches to graphic construction and color schemes.

The research proposes new scientific approaches to three-dimensional artistic mapping and, on their basis, a unified methodology and technology for creating and updating three--dimensional artistic maps using modern infor-

mation technologies in order to provide the tourism industry with cartographic products.

To achieve this purpose, the following objectives were solved:

– to substantiate the scientific and practical aspects of improving the theoretical foundations of three-dimensional artistic mapping of the urban environment;

– to formulate the principles of construction and evaluate the functionality of usage of automated symbols, textures and colors libraries;

– to implement a comparative analysis of handwritten and automated methods for creating a three-dimensional artistic panoramic map, to determine the advantages and disadvantages of each of them;

– to develop an original method for creating of three-dimensional artistic maps of cities using a combined handwritten and automated method in order to rationalize the usage of art techniques and methods of graphic construction of images via information technologies;

– to substantiate the levels of visualization of the urban environment elements, to develop an original technology for creating and updating three-dimensional artistic panoramic maps using a handwritten and automated method;

– to summarize promising directions for the practical usage of three-dimensional artistic maps, to design a navigation structure and to develop a design layout for a cartographic web resource.

The *objects* of the research are mainly small and medium cities and towns, individual architectural monuments, and tourist areas; the *subject* of the research is the techniques and methods of processes automation (computerization) which deal with constructing of three-dimensional artistic cartographic images of cities.

The information base of the investigation consists of statistical data, materials from open cartographic Internet services and my own field surveys of the mapped territories, as well as literary and cartographic sources, and electronic resources.

2. Theoretical foundations of three-dimensional artistic mapping

Consideration of mapping objects and the basic elements of the content of panoramic maps, inherent in the natural and anthropogenic environment, made it possible to identify various types of three-dimensional cartographic images (Figure 1). The main features of their classification are scale, territorial coverage, transmitted content and the purpose of use, which determine the degree of generalization of the displayed objects. Maps of nature reserves

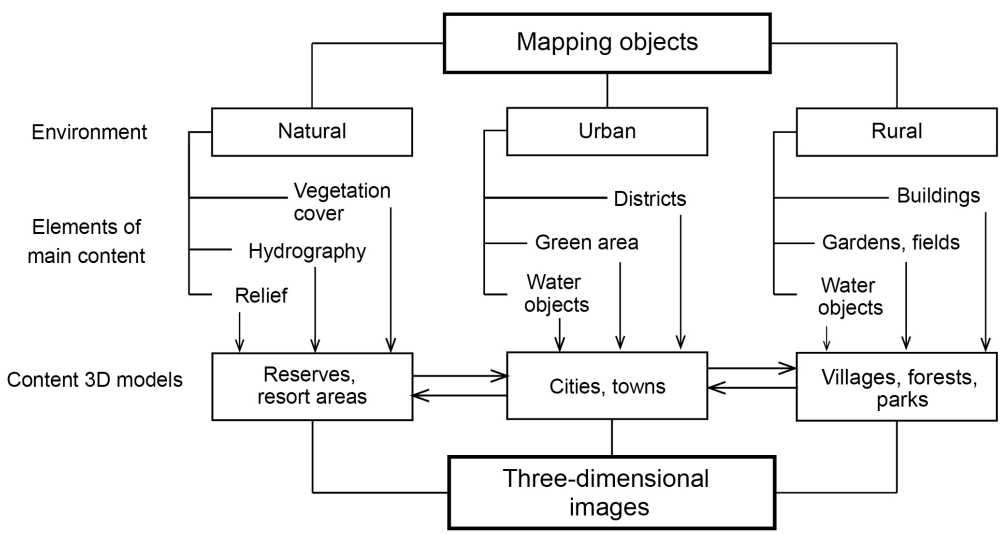


Figure 1. Classification of 3D images based on the basic content model of mapping objects

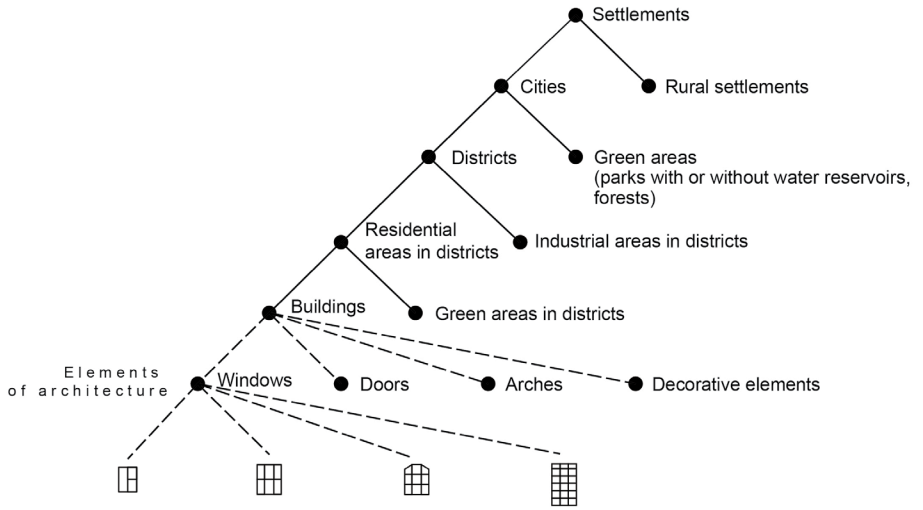


Figure 2. The part of the directed graph-tree in relation to the elements of the urban environment

and resort areas as well as other significant areas can be created only on small and medium scales, while panoramic maps of cities can cover all scales depending on the territory being mapped. 3D images of castles, monasteries, estates, parks are created only on a large scale. The purpose of panoramic maps can also be different: they can be used for studying the area and orientation, as a basis for information, advertising or souvenir products.

Natural and anthropogenic objects depicted on panoramic maps are interconnected in content-temporal and spatial aspects. In a cartographic image, a distinction is made between content (information about objects and natural phenomena), elements of content (hydrography, relief, vegetation, settlements, roads) and form (image of the specified content). The data array identified on the basis of logic and content analysis for a visual representation of the urban environment on a panoramic map was divided into homogeneous classes, and within the class groups of characteristics and categories (genus and type of object) were identified. Thus, conceptual and content classification models in the form of a directed graph-tree have been formed (Figure 2). These models serve as the basis for creating of cartographic symbols systems for panoramic maps with significant territorial coverage and libraries of structural elements (visual signs, textures and colors) in relation to artistic 3D maps of small areas.

When creating a panoramic map, it is necessary to obtain the illusion of a three-dimensional image on a plane, which is achieved using color effects and graphic techniques. There is a variable scale on artistic 3D maps. The multifaceted nature of the image is conveyed through interposition (overlapping some objects with others) and the relative size of objects located at different distances from the viewing point (Atojan, 1999). The importance of different types of perspective is also great. There are physical, or aerial perspective (the influence of air on the clarity of the outlines of objects, as well as their color depending on the distance), and geometric, or linear perspective (decreasing the size of objects with increasing distance from the object watching by the observer).

The creating a panoramic image begins with determining of the territory coverage, and as a result, with the selection of a map projection (Figure 3).

For vast territories (hemispheres, continents, parts of the world, large states), the external perspective projection with a positive image is used (this projection takes into account the curvature of the globe surface). As a mathematical basis for creating of panoramic 3D

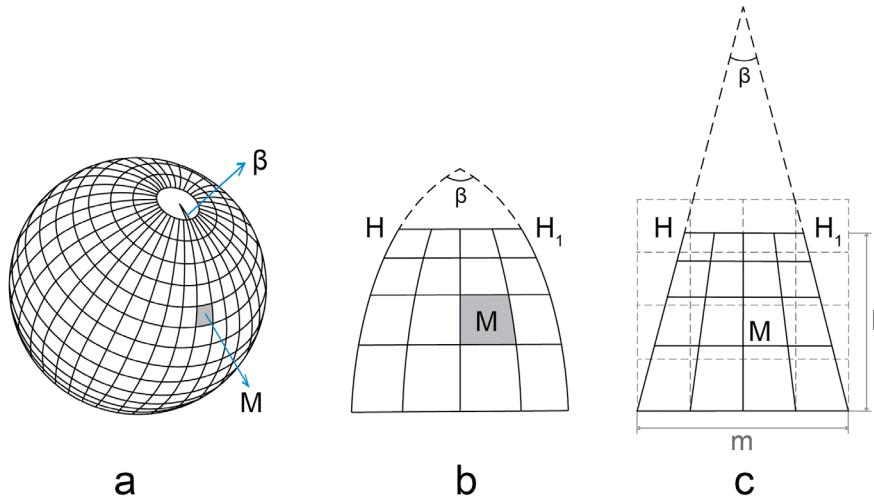


Figure 3. Selection of perspective projection depending on territorial coverage:
a – for large areas, b – for medium-sized areas, c – for small areas,
M – the mapped surface, HH1 – the horizon line, l – the image depth (longitudinal dimension),
m – the size of the map base (transverse dimension), β – the viewing angle

maps of small areas, such as individual settlements, small recreation areas, national parks, a type of external perspective projection with a positive image (Bugaevskij, 1980; Vahrameeva et al., 1986) – the central projection – is used. This is due to the insignificant amounts of distortion associated with curvature of the earth's surface (Smirnov, 1982).

Experimental works implemented by author to determine the angle of inclination of the projection beam and the visibility parameters of objects located on the surface helped to define the most optimal conditions for mapping of small and medium-sized cities: the constant height of the observation point, constructing of projection with parallel rays at an angle of 60° to the picture plane, displaying only the front and middle plan (Figure 4).

The artistic component in panoramic maps creating, including the well-known laws of graphics and painting, is considered from the view of obtaining a realistic panoramic image. Since the fact that in nature form and color exist as parts of a whole, in unity with the environment in which they are located, in relationship between themselves and space, which has depth, near objects are perceived as larger than distant ones, which lose the intensity of their color and detail.

The colorful design of panoramic maps in this aspect is considered as a complex process of artistic execution of the author's original. Each artist-cartographer retains his own individuality, however, the number of aspects can be formulated that should be taken into account during creating picturesque maps:

1. To determine the general color scheme; to highlight primary colors, bright and dark areas mentally; to pay attention to the overall balance of color spots. For example, if cold tones are used for the forest, it is also recommended to use cold colors for water spaces.

2. To determine the direction of lighting. It must also be correct from a geographical point of view. For example, in the northern hemisphere, the sun cannot illuminate the Earth's surface from the northwest or the northeast.

3. To display image depth. For this purpose, you should conditionally divide the surface of the sheet into foreground, middle and background, and also use the laws of aerial perspective.

4. To use the law of contrast to highlight objects of primary importance (for example, architectural monuments).

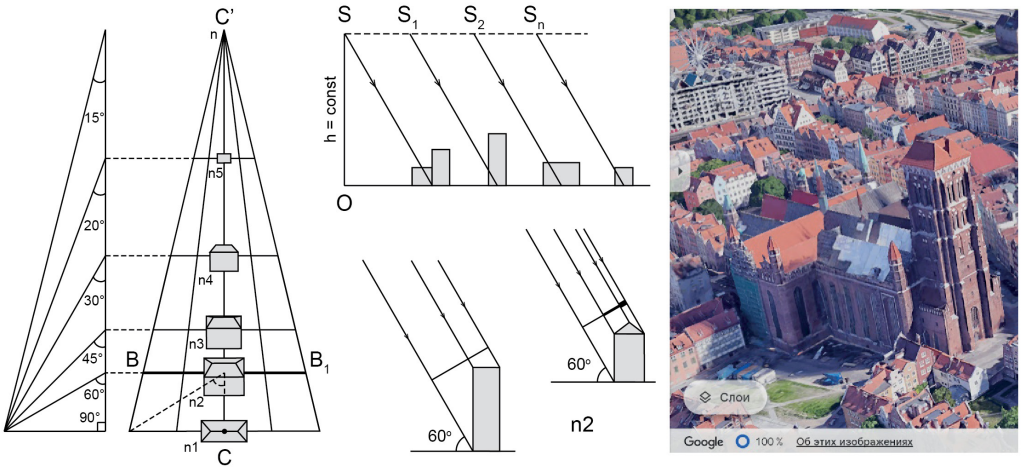


Figure 4. Optimal conditions for a three-dimensional illusory representation of cities (using the example of the Church of the Virgin Mary in Gdańsk, Poland):
n1…n5 – conventional architectural forms, CC' – the central axis, C' – vanishing point of the rays of the central projection, BB1 – the line of optimal parameters, S…Sn – observation points. On the right is the part of the 3D model of an urban environment (source: Google Earth, Data providers: Landsat / CopernicusData SIO, NOAA, U.S. Navy, NGA, GEBCO)

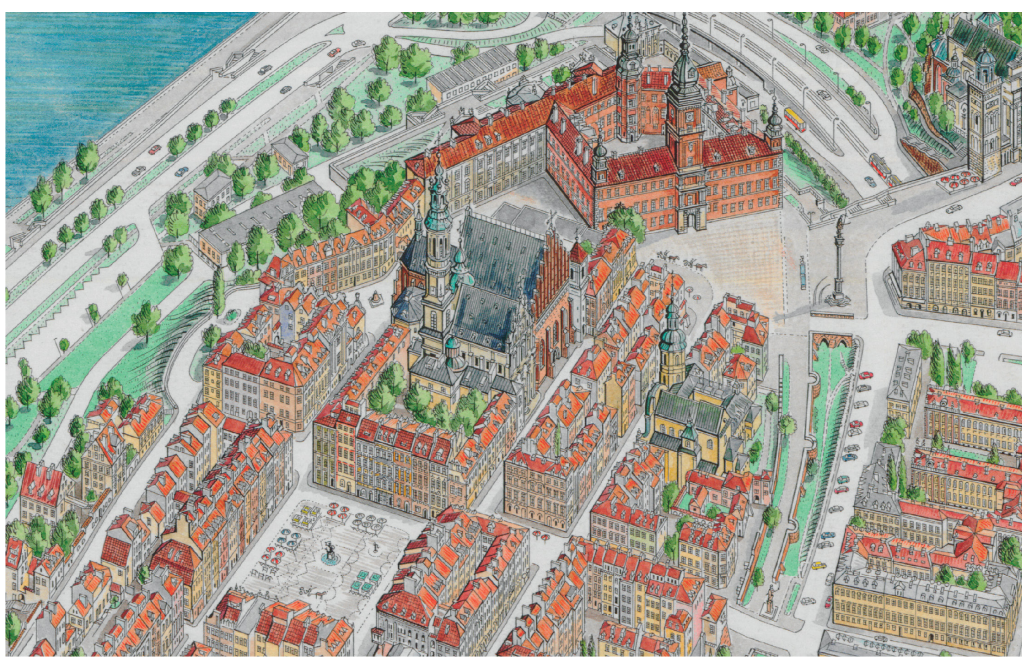


Figure 5. The part of the city of Warsaw, Poland, made in handwriting way (2000).
Artist – R. Atoyan, Terra Nostra Publishing House (Poland, Atoyan & Kuźmiuk, 2003)

5. It is necessary to give volume to the object and emphasize the surface structure.

3. The methodology and technology for constructing a three-dimensional artistic cartographic image of the urban environment

For a long time, three-dimensional artistic panoramic maps were compiled by hand: the cartographic image was drawn on paper with pencil and ink, and then painted in color using watercolors (Figure 5). This is a rather labor-intensive process that requires high artistic skills.

However, it can be simplified by automated (with partial human participation) creation of panoramic maps. Various libraries developed digitally and containing individual structural elements of urban environment objects are served for this purpose. Such libraries include:

− sets of architectural forms that are used to fill facades and detail the image (Figure 6);

− variants of vegetation elements, created manually and differentiated by shape, size, contour, color (Figure 6, Atoyan & German, 2017b, p. 47);

− textures and colors created taking into account the illuminated and shadow sides of the object (facades, roofs, vegetation). With some modifications, these samples are used for background filling of area objects during the color design of three-dimensional artistic panoramic maps (German & Atoyan, 2017).

Using the developed library samples, visualization of objects is carried out, which involves several levels. They are built according to the principle from general to specific, from simple to complex and reflect the gradual transition from two-dimensional maps to three-dimensional images (Atoyan & German, 2017a, p. 36; German, 2023).

To minimize the disadvantages of the handwritten method and to emphasize the advantages of the automated method, a combined handwritten-automated method of constructing of three-dimensional artistic cartographic works is proposed. This method consists of a rational combination of works performed manually and with the usage of graphic editors (Figure 7). On its basis the technology of creating of three-dimensional artistic panoramic maps is proposed, which includes several stages.

At the first stage – *preparatory* – various materials are collected and analyzed in order to study the territory to be mapped. Here, the choice of a viewpoint and determination of the coverage of the area to be represented on the 3D map are decisive.

For panoramic maps of cities, the area, intended for mapping, is selected taking into account certain conditions:

1. The main sights of the city should be concentrated in the foreground of the panorama or in the center and shouldn't be overlapped by other buildings;

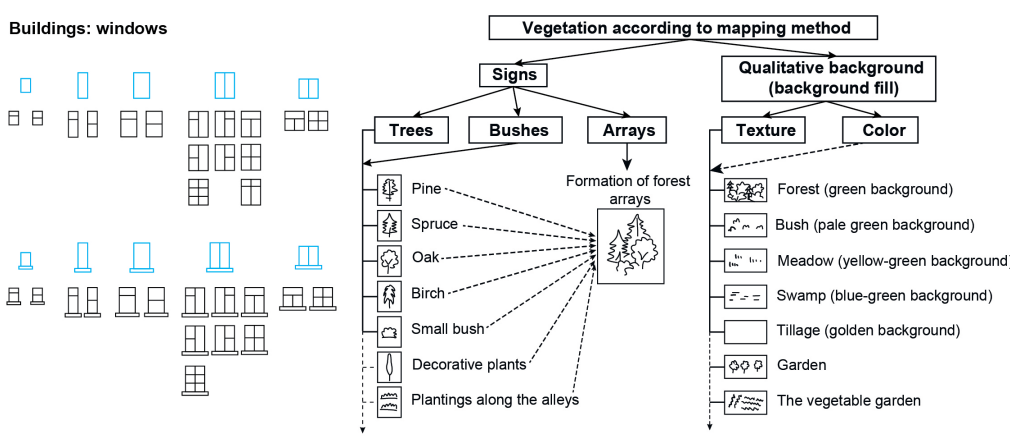


Figure 6. The part of the library of automated symbols (using windows as an example) and the principle of constructing of the library of vegetation symbols

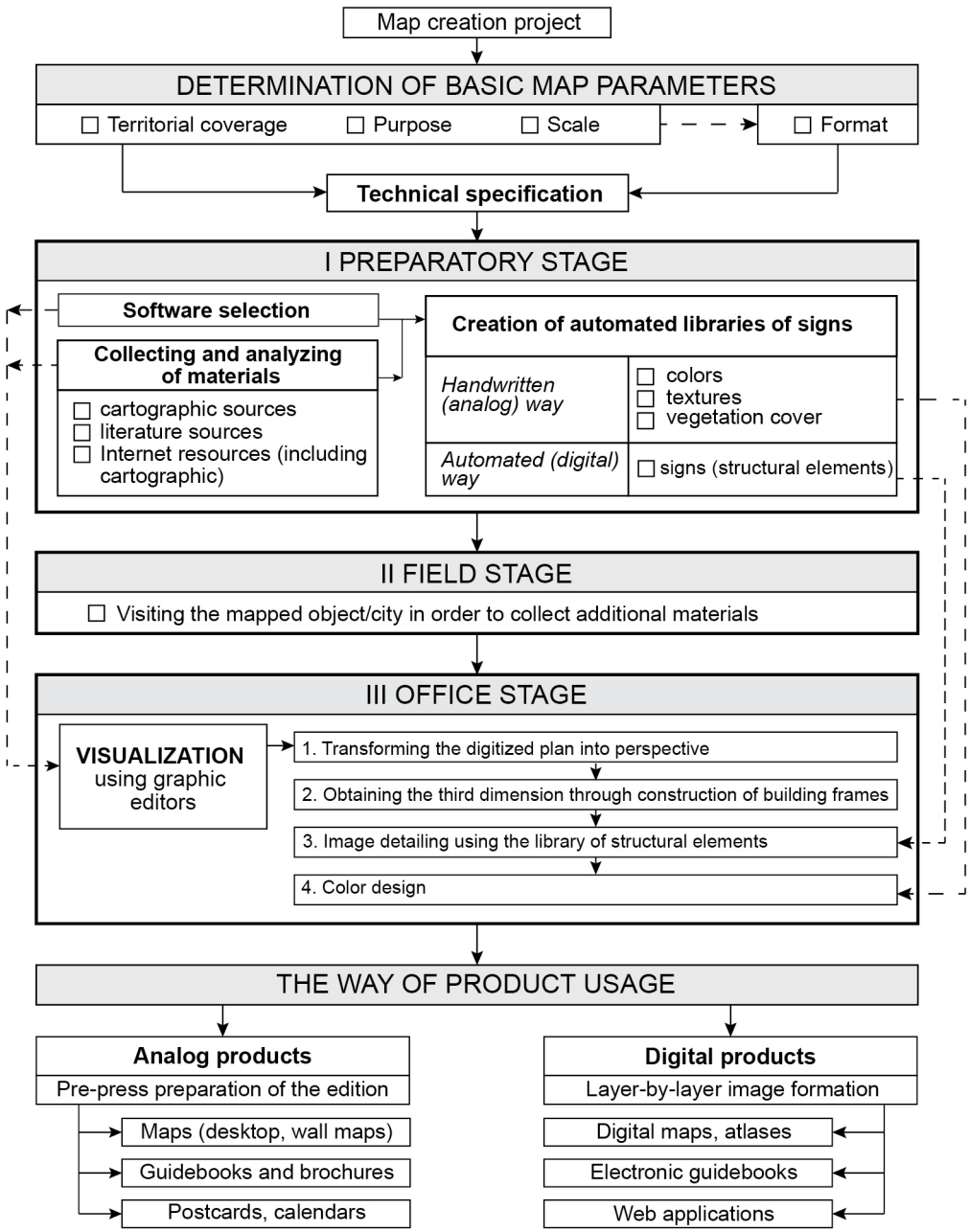


Figure 7. The technological scheme of creating of a three-dimensional artistic map of urban environment by handwritten-automated method and the ways of its usage (German, 2023)

2. Orientation of the main roads is preferable in perspective, “at an angle”; in this way, the buildings will not line up in a “chain” and significantly overlap each other. The resulting direction of the roads will give the buildings located along them an additional volume due to the

visibility of two faces (the facade and the wall which is perpendicular to it).

On the basis of images provided by cartographic information services (Google Earth, Яндекс.Карты (Yandex.Maps), GoogleMaps, OpenStreetMap, dzz.by, map.nca.by, etc.), a rough terrain plan is prepared in a pre-selected software – vector graphics program Adobe Illustrator or CorelDRAW. At this stage outlines of buildings, road network, hydrography, park areas are vectorized. Further this plan will be used as a basis for the field survey. If it is necessary, new libraries of symbols, textures, colors and vegetation elements are created; the existing libraries can be supplemented.

The second stage involves *field inspection of the territory*: during the visiting of the mapped object, all buildings are photographed from the visible side; on the working plan (scheme) of the city, if necessary, the features of the configuration of buildings, the presence of decorative elements, the color of facades and roofs, the number of storeys of the buildings, etc. are recorded.

The third stage of 3D image creation – *office stage* – consists of the visualization of urban environment objects assuming several levels.

First of all, the working plan of the mapped area is corrected and supplemented on the basis of field survey materials (photographs, schemes, sketches). Then this plan is converted into perspective in the selected vector graphics program (unlike the handwritten method, where the perspective grid is built manually, and the plan is transferred to the paper “by cells”). Empirically, it has been revealed that the most rational display of object faces is possible at an inclination angle between the mapped surface and the projection beam equal to 60°, so the plan transformation into perspective is carried out up to this value simultaneously with the image depth reduction (German, 2019b, p. 45, 2023).

The third dimension is obtained by constructing of building frames based on the materials of open Internet map services and photographs taken during the field survey. Due to the perspective, the height of buildings differs in the front, center and far plan (along the centerline), so specific values corresponding to one storey are selected to convey their relative magnitude (that means the change in linear dimensions depending on the distance between the object ant the observation point).

Next, the building frames are detailed, i.e. filled with structural elements. Using satellite images,

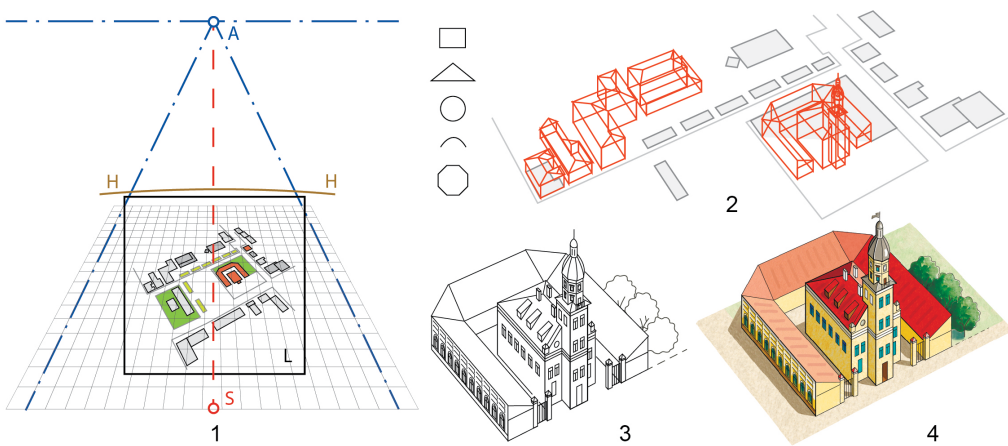


Figure 8. Visualization of 3D-image of an architectural monument by the combined handwritten-automated methodology (on the example of the town hall of Niasvizh, Belarus):
1 – plan transformation (A – point of ray convergence in perspective projection;
S – observation point; HH – horizon line; L – picture plane);
2 – building frame construction; 3 – facades filling with elements from the library of signs;
4 – color design using texture and color libraries

the type of roof is determined (sloping or flat, with or without ledges); the location of the entrance door, columns, arches, annexes, staircases and other elements is marked; facades are filled with windows of the required configuration from the previously created library of signs. For these purposes, the corresponding tools of the graphic editor are used, which allow to scale and distort standard structural elements, as well as to distribute the required number of windows with equal spacing between them within the contour of the facade. In some cases, the number of windows in a row has to be neglected due to the small scale of the image. The storey of the building is retained.

At the final stage of the visualization the color design of urban environment elements is carried out (Figure 8). For this purpose, texture and color libraries are used, including samples of the area filling of the map content elements (illuminated and shadow sides of roofs, facades, sidewalks, lawns, the color of the falling shadow, etc.): made in watercolor on a paper and further digitized for subsequent use in the raster graphics program (Adobe Photoshop), they allow to preserve the artistic aesthetics of the image (German, 2019a).

The proposed methodology and technology speed up the process of panoramic map compilation, compared to the exclusively handwritten method. In addition, the analysis of various software products has shown that the joint use of graphic editors (vector and raster) and fine art techniques allows to make the cartographic image more colorful, expressive and ergonomic, especially for the inexperienced user. This is achieved by artificial enlargement of the main sights, which contributes to their visual highlighting against the background of other structures; expansion of the main roads in order to place explanatory captions; slight displacement of buildings relative to each other in order to avoid undesirable overlapping of differently distant objects; colorful design of the map-panorama using natural shades of colors (watercolor paints, German, 2023).

4. The technology of actualization (updating) of the panoramic map content

Over time, the appearance of cities is transforming: vacant lots are being built up, new structures are being constructed, building facades and roof profiles are being updated. All this entails the actualization of the content and, as a consequence, the updating of panoramic maps created earlier by handwriting. However, it is practically impossible to make many graphical changes manually on the original image of the urban environment, and the creation of a new cartographic work, not fundamentally different from the original, seems impractical due to the large amount of required time. The solution was found in the usage of raster graphics editor – Adobe Photoshop. Working with the digitized image, it is possible to easily “erase” a tree or, on the contrary, “plant” an entire alley, “repaint” the facade of a building, “replace” a sloping roof with a flat one, and many other things that cause certain problems when updating a cartographic work manually (Atoyan & German, 2015).

In addition to making minor changes, Adobe Photoshop allows to place separate new drawings on the basis, which is a scanned handwritten original of the panoramic map. The selected fragment can be corrected in terms of color, brightness, contrast, its size (increase or decrease), as well as can be aligned with the main landmarks (corners and road lines, roofs and walls of neighboring buildings).

In general, the process of updating a panoramic map can also be divided into several stages. First of all, the materials that are necessary to identify changes during the field survey are prepared. During the visit to the city, in particular all its streets, neighborhoods and parks represented on the map, a lot of photographs are taken; the most significant changes are indicated on the city plan for convenience; image numbers and the direction where the survey was taken from are marked. All field materials are processed and systematized in the office conditions.

The updates that should be made to the new edition of the panoramic map can be roughly divided into two main groups in terms of complexity: a) new constructions; b) private changes in individual fragments of larger objects (e.g., color and structure of roofs and facades of buildings, parks and individual trees, roads and trails, Atoyan & German, 2015).

It is most efficient to draw new buildings separately, manually, from the same viewpoint, so that the image does not break out of the

overall style of the map. Subsequently, such a drawing, previously scanned in high resolution (at least 300 dpi), is overlaid on the digitized panoramic map in the appropriate place in Adobe Photoshop (Atoyan & German, 2015). filled with appropriate textures using available tools (Figure 9).

The actualization of the content of the cartographic representation can be observed on the panoramic map of the Niasvizh Palace (Belarus)

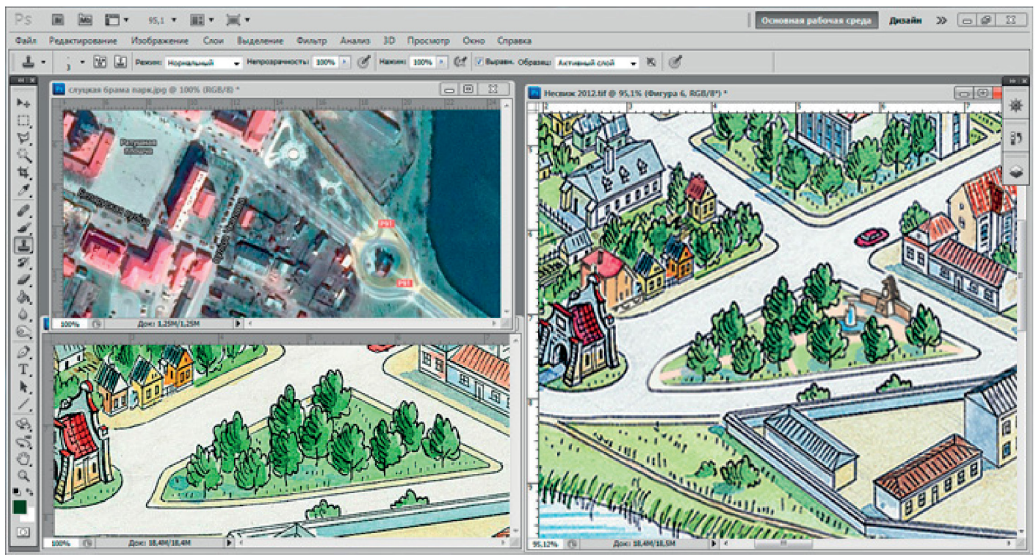


Figure 9. Adding paths into a park zone in Adobe Photoshop graphic editor

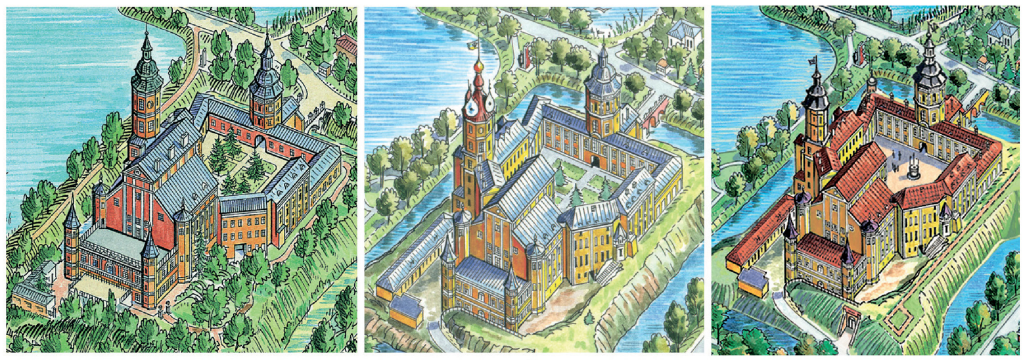
Then the necessary color and contrast, which are closest to the original image, are given to the drawing.

Smaller changes are made directly in the program, without previous manual drawing. These changes include editing of individual objects and their parts: color and structure of roofs and facades of buildings, road junctions, park plantings, individual trees, etc. Depending on the specifics of the object, the following technical methods are used: copying objects, editing color balance and color replacement, filling a map section with a texture, etc.

Some new content elements or changes have to be made manually using a graphic tablet, such as changes in the road network (new interchanges, streets, pedestrian and park paths) or the filling of significant areas (e.g. with grass). Key lines (curbs, sidewalks) in this case are drawn manually, on a separate layer placed on top of the original, and all “white spots” that appear when changing the environment are presented in editions of different years. After the reconstruction, the appearance of the palace and the adjacent territory changed significantly, which influenced its graphic representation. The new artistic image of the castle became more vivid and expressive due to more saturated bright colors and their combinations, the presence of halftones, the effects of shadow plasticity, the overlay of falling shadow, which was not taken into account in previous editions (Figure 10).

Most of the changes were made to the original panoramic map in the Adobe Photoshop, some were made by overlaying of individual fragments on the scanned original (e.g. a new configuration of the moat or a rebuilt eastern tower).

Thus, the usage of computer graphic programs has a number of advantages over the manual way of updating maps: it allows to make changes to the cartographic work promptly, with high quality and without damage to the



a b c

Figure 10. The Radziwiłł Palace on the panoramic maps of Niasvizh (Belarus) of different years of publication: a – 1998, b – 2008, c – 2015 (Atoyan & German, 2015)

original document, making it up-to-date and suitable for mass consumers.

5. Modern and perspective ways of usage of three-dimensional cartographic images

The most popular in the masses, perspective and dynamically developing areas at present are navigation mapping, mobile mapping, web mapping, etc. Some geoinformation reference systems, including a detailed city map and information about companies, also contain elements of three-dimensional graphics (e.g. 2GIS application).

The development of a cartographic web application has the following features: the lack of universal languages and interfaces for different mobile platforms; the possibility of several implementation options (a website adapted for mobile devices; native application based on a specific programming language; joint usage of web technologies, web browser and software shell of the device); its own nuances of preparation and implementation of images

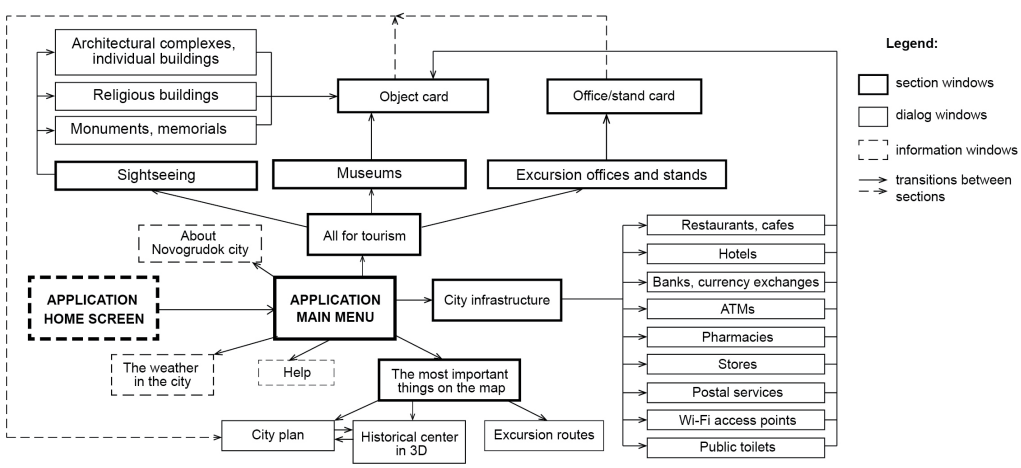


Figure 11. Simplified layout scheme of the navigation structure of the Novogrudok tourist infrastructure web-application

a b c d

Figure 12. Screens of the web-mapping application: the main menu (a), the map of the city (b), the part of 3D-map of the historical center (c), the card of the object (d)

in different graphic formats in the application. From my point of view, the most rational option for including a map image into a web application is a combination of vector and raster formats, providing optimal performance and functionality of the resource.

In the framework of this research the navigation structure is designed and the design layout of the cartographic web application is proposed on the example of the tourist infrastructure of Novogrudok city (Belarus, Figure 11, Figure 12).

In the developed design layout, the historical center of the city is represented as the artistic three-dimensional drawing in vector, without detailing of buildings, but with retaining of their general color design (Figure 12c). Such three-dimensional image has a higher visibility in comparison with the city plan or frame representation of buildings, but at the same time it has a small size due to the peculiarities of vector graphics construction (German, 2023).

6. Conclusions

The combined handwritten-automated method of creating and updating of three-dimensional artistic panoramic maps of cities, based on the principles of perspective image construction applied to the urban environment, has a number of advantages compared to the handwritten and automated methods of map creation used separately. It includes the reduction of the technological cycle due to universal libraries of signs, textures and colors; saving of time; significant reduction of manual labor through the usage of graphic editors. The ratio of the volume of work performed by handwritten and automated methods depends on the scale of the created map, its purpose, theme, etc.

The author's technology of creating of a three-dimensional artistic map has also been developed within the framework of the research. It includes four levels of 3D image visualization, representing a step-by-step transition from two-dimensional to three-dimensional representation (transforming the plan into a perspective projection, obtaining the third dimension, image detailing and color design using the developed libraries of structural signs, colors and textures).

The principles of construction and stages of visualization with the usage of graphic editors, presented within the framework of these methods and technology, with minor modifications can be applied to the construction of a three-dimensional artistic panoramic map of any city or architectural monument.

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