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A comparative analysis of urban development and the tram line network in Lviv in 1932−2016

Abstract. This article presents a comprehensive analysis of changes in urban development (including certain types of public buildings) and changes in the routes of Lviv's tram lines over the last 80 years, related to the territorial and demographic development of the city. For this purpose, maps comparing these elements of urban infrastructure between 1932 and 2016 were developed. The analysis was carried out based on a plan of Lviv from 1932, contemporary vector data taken from *OpenStreetMap*, ArcGIS basemaps, *Google Street View* panoramic images, information contained in interwar Lviv guides, and supplementary information from other sources.

Keywords: Lviv, old maps, calibration, urban development changes, tram lines

1. Introduction

Studies on the spatial development of cities are relatively rarely devoted to changes in buildings important for Polish culture and identity of the so-called Eastern Borderlands, such as Lviv. This city was the heart of Polish culture for a long time. Urban concepts of spatial development have changed over the last century in Lviv as a result of frequent political and socio-economic changes. In the 20th century, Lviv was part of five countries (the list includes only those that governed the city for more than a year): Austria-Hungary, the Republic of Poland, the German Reich, the Soviet Union, and Ukraine (L. Podhorodecki 1993). Each country implemented a slightly different concept of the city's spatial development.

Many books and articles have been written about the spatial development of Lviv. Some of the most detailed studies are atlases on the history of the city. One of the most recognised publications is an atlas prepared by the publishing house "Kartohrafiya" (O. Shabliya 2012), which is the first comprehensive atlas of Lviv in independent Ukraine. The subject of the urban development of Lviv was discussed by B. Posatsky (2014), L. Podhorodecki (1993), A. Bonusiak (2007) and B. Tscherkes (2000). There were also many publications on the development of the tram network. One example is the research conducted by S. Tarkow (1994).

An analysis of the changes in the city's urban development in a graphic form can be found on the website of the "Lviv Building Age Map" project[1]. This site includes information on the dates of construction of around 50% of Lviv's buildings. They have been grouped into 50-year intervals. Analyses of changes in the city development range and the street layout can also be found on the "Old City Maps" portal[2]. This project presents old city maps by means of an overlay on *Google Maps*. There are three maps of Lviv available on the website: from 1932, 1939, and 1944. Apart from the previously mentioned portals, the issue of visualizing changes in the range of Lviv has not been widely discussed in literature. The aim of this study is to fill this gap.

As part of the research, comparative maps of the state of buildings in Lviv between 1932

[1] http://opengeo.intetics.com.ua/buildingage/

[2] https://stareplanymiast.pl/wg-miast/lwow/

and 2016 were prepared, using a map from 1932, contemporary satellite images, and vector data. The time frame between 1932 and 2016 was chosen for several reasons. The first is the wealth of content in the 1932 map and the fact that 1932 represents the beginning of the 1930s, the middle of the period between the First and the Second World War. Thanks to this, it was possible to show the spatial changes which took place between Polish Lviv and the present-day Ukrainian city. The "present" is represented by the year 2016 in which the research was carried out. In order to fully take advantage of the potential of the map from 1932, the maps show not only changes in urban development, but also in the layout of cultural institutions – theatres, museums, universities and sacred buildings, as well as changes in the routes of tram lines.

The research covered the city area presented on the map from 1932, i.e. 44.29 km^2 (fig. 1). However, the map does not show the outermost parts of the suburbs, which have a low density of buildings.

2. Source data

2.1. Primary data

The map of Lviv at the scale 1:15,000 from 1932 was published by the Cartographic Institute of E. Romer. It is available as a scan in the Mapster database[3] (fig. 2). The map shows the outlines of buildings, with some links to an index with information about the function of the building. Thanks to this, the location of e.g. schools, public administration buildings, hospitals, and churches can be found. This

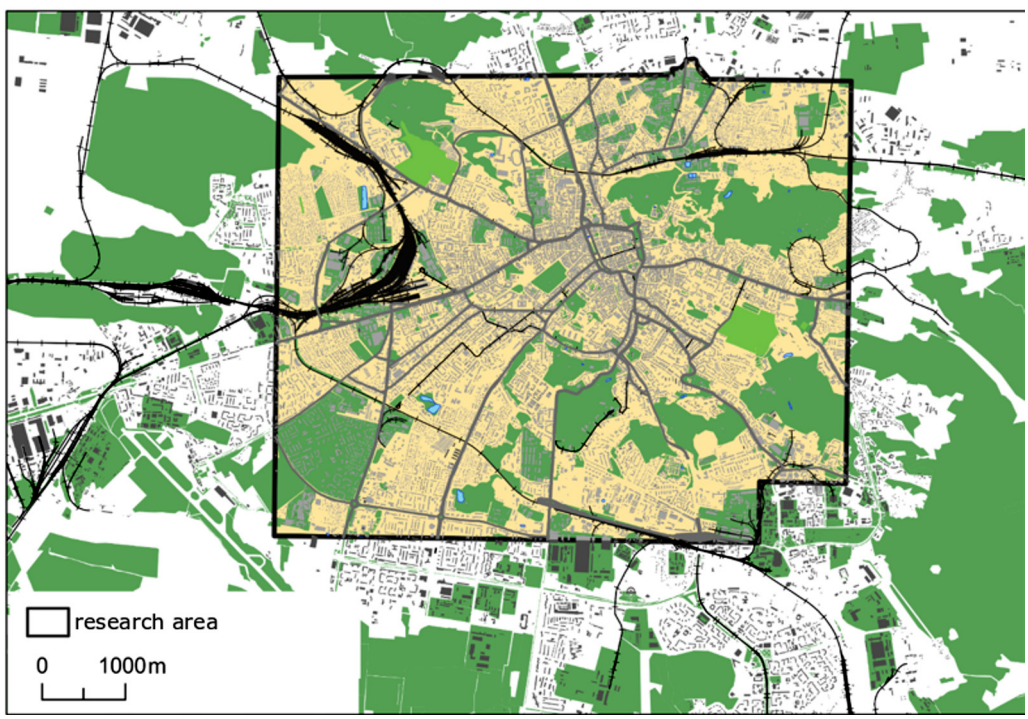

Fig. 1. The range of research (own work based on *OpenStreetMap* vector data)

[3] http://igrek.amzp.pl

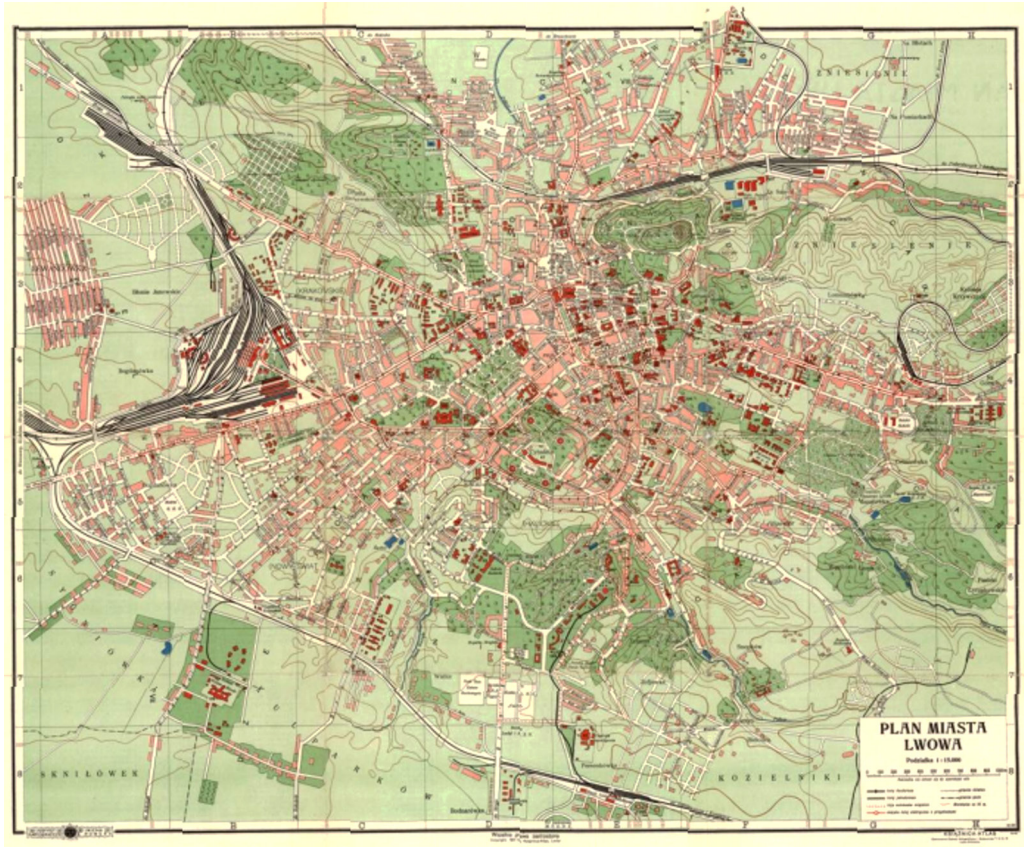

Fig. 2. Map of the City of Lviv, 1932, Cartographic Institute of E. Romer, Książnica Atlas, Zjednoczone Zakłady Kartograficzne i Wydawnicze TNSW Lviv−Warsaw

makes it possible to view changes in the location of individual buildings and quantitatively analyse these changes within each category.

A drawback of the map is the lack of a geodetic network and its non-cartometric nature, as well as the widening of streets in relation to buildings (it is, however, necessary to maintain good readability of the map). In terms of the development range, a major disadvantage of the map is the non-uniform generalization of building outlines. Historic buildings, which are the city's greatest tourist attraction, and those that have a significant public function, e.g. universities, are presented in more detail than residential and residential-service buildings, although some of the latter are also historic buildings. As a result, most of the buildings are not presented individually, but as built-up areas with homogeneous areas demarcated by streets.

Vector data from the *OpenStreetMap* portal (as of 1 November 2016) was used to illustrate the current state of urban development and the tram line network[4]. This data includes the "*buildings*" layer and the "*railways*" layer, which includes tram lines. These layers were the main element of the comparative analysis. An important information was the attribute data on the functions of the buildings, thanks to which it was possible to visualize the changes in the distribution of churches, schools, offices and universities (buildings with such functions are also marked on the map from 1932). The vector

[4] http://download.geofabrik.de

data was used as a reference layer to calibrate the 1930s map.

The *OpenSteetMap* database maintained and developed by volunteers, who often lack necessary expertise, therefore its quality has been criticized (M. Wang et al. 2013). One of the disadvantages is the inability to verify the accuracy of the data in the database. Therefore, the accuracy of the vector layer was verified using the *ArcGIS World Imagery* basemap available in ArcMap 10.3.1. The base map consists of aerial and satellite photos from several satellites. The spatial resolution of the photos of Lviv is 1 m[5]. It was decided to use *OpenStreetMap*, as it is the most up-to-date, which makes it superior to city plans offered by cartographic publications available on the market.

2.2. Verification data

The data supporting the analysis of changes in urban development and its functions as well as changes in the tram line network was provided by six pre-war Lviv tourist guides. The scans are available on the website of the National Digital Library Polona[6] (A. Gojawiczyński 1926, *Pamiątkowy przewodnik…* 1927, *Ilustr. przewodnik* 1933, *Ilustrowany przewodnik…* 1936, E. Hora 1937, A. Medyński 1938). They contain information about the routes of tram lines and the location of buildings with specific functions, e.g. universities. The guides were used to verify and supplement the data on the map. Four plans of Lviv from 1900, 1925, 1927 and 1939 were also used. These plans were available on the website of the National Digital Library Polona and in the Mapster database.

The course of modern tram lines has been verified using the information provided on the website "Lviv.Travel Official City Travel Site"[7]. In addition to the above-mentioned data, two basemaps processed in the ArcMap program were also used to verify the research methodology – *ArcGIS World Imagery* and *OpenStreetMap*. They were used to verify the location of museums, theatres, university buildings, and religious buildings. The research also used the "Lviv Interactive Map" from the website of the Center for Urban History of East Central Europe,[8] as well as Google Street View panoramic photos to help divide buildings into those built before and after 1932.

3. Research methodology

The methodology of work was divided into several stages (fig. 3). The first step involved completing and verifying the vector data, which was done using the *ArcGIS World Imagery* basemap. In places where the data turned out to be incomplete (the building was not vectorized or the vectorization was inaccurate) the vector data was modified. In the case of the rail transport layer, the tram lines layer was separated based on the information contained in the attribute table. The level of detail of the buildings was considered appropriate in terms of the target map scale (1:15,000), so it was decided not to generalize vector data.

The next stage involved calibrating the map of Lviv from 1932 and then verifying this process. For calibration, reference data in the form of three vector layers from the *OpenStreetMap* portal was used – the layers of buildings, railroads, and roads. Spline transformation (rubber-sheeting type) was used, which is intended for the calibration of maps not based on the geodetic network (A. Affek 2012). Twenty-two control points were defined and distributed evenly throughout the map area. The quality of the performed calibration was assessed by visual analysis of the map's geometrical distortions. For this purpose, a distortion mesh was generated and the vectors of displacement of control points were determined in MapAnalyst[9]. The distortion mesh allows to analyse the spatial diversity of map fitting errors (A. Affek 2012). The greater the distortion on the map sheet, the more distorted the grid. This is due to the fact that the most distorted parts of the map are those located in the eastern and north-eastern part of Lviv in that time, and in the eastern part of the city centre. Analysis of the displacement vectors showed that the greatest displacements of control points are on the edge

[5] http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

[6] https://polona.pl

[7] http://lviv.travel/en/index/information/transportation/tram

[8] http://www.lvivcenter.org/en/lia/map/

[9] http://mapanalyst.org/download.html

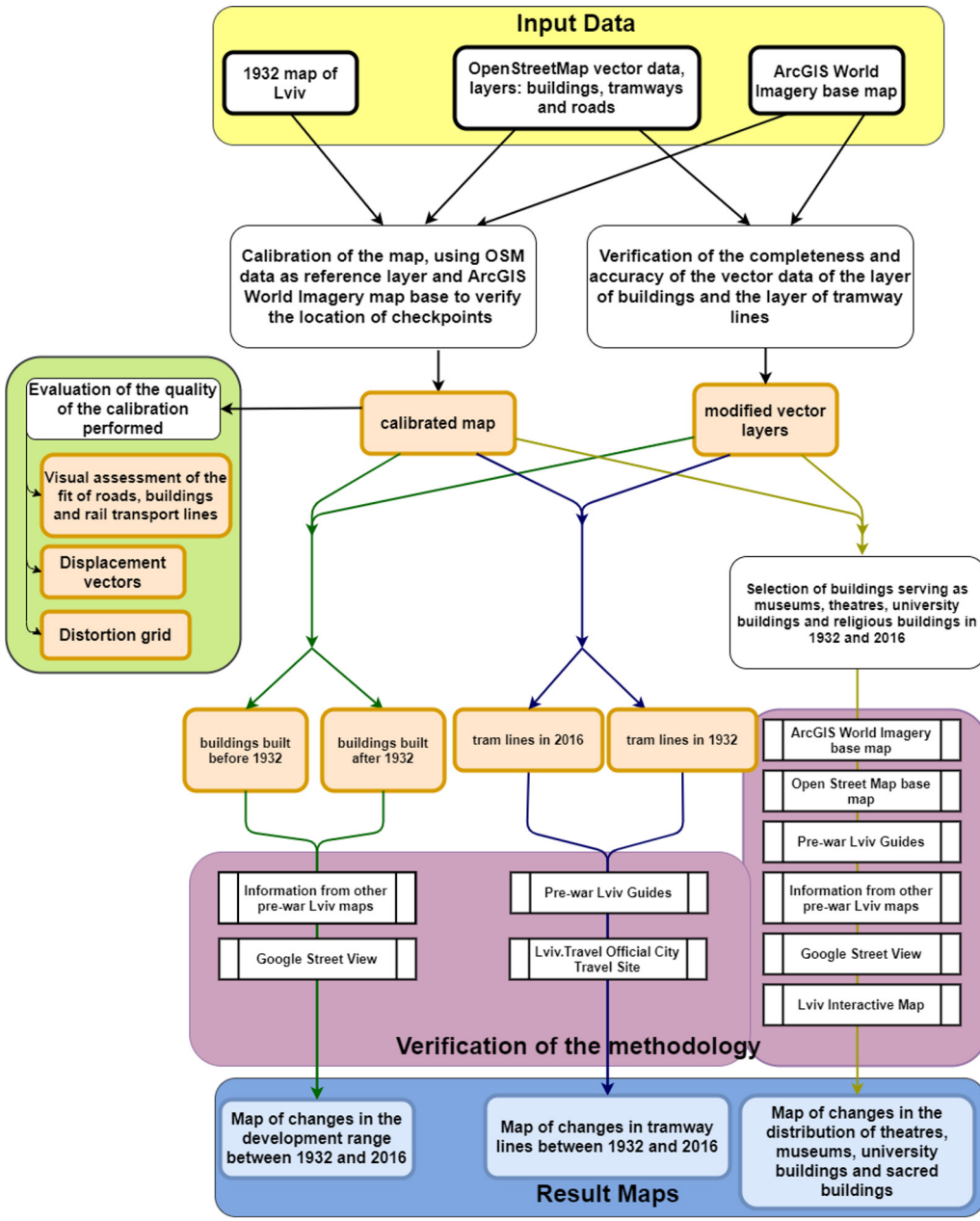

Fig. 3. Research methodology (own work)

of the map, although some points in the centre of the map have also been significantly displaced. Despite local large distortions, the calibration was considered acceptable.

The next, fundamental stage of research involved dividing buildings into those existing in 1932 and those constructed later. At this stage, a visualization of tram lines operating in 1932

and 2016 was prepared, as well as a visualization of religious buildings, theatres, museums and higher education buildings in 1932 and 2016. The implementation of this stage included comparing the modified vector data with the image of the old map. If the shape of a building had changed, the shape according to the newer source (vector data) was adopted.

When dividing the buildings by age, it was assumed that the buildings overlapping in both layers were built before 1932. Some of them, however, were built after World War II, in the place of pre-war buildings, so the image of the target layer – "buildings built before 1932" − should be treated more generally, as a reconstruction of the former Lviv. This layer showed buildings which were actually built before 1932 and buildings located in the urban development area of Lviv that year. In the case when the "old" and "new" range of the building coincided only to a small extent and had a significantly different shape and orientation, it was assumed that it was built after 1932. The analysis of building changes was also influenced by changes in the street layout. In situations where today's street runs in a place where there used to be buildings before and there was no street, the buildings next to it were considered to be built after 1932. When analysing "isolated buildings" located away from the main urban area, in places where map calibration generated significant distortions (pre-war suburbs) *Google Street View* was used as an auxiliary tool for locating buildings.

The mapping of changes in the distribution of cultural centres − museums, theatres, universities, and temples, required the use of information from many sources. This included information contained in the attribute table of the modified *OpenStreetMap* vector data, where some buildings were assigned the "type" attribute. Those marked as *cathedral*, *chapel* or *church* were classified as religious buildings, and buildings marked as *university* were classified as higher education buildings. Information on the layout of today's buildings was taken from two basemaps: *ArcGIS World Imagery* and *OpenStreetMap*, from *Google Street Map* panoramic photos, and information from an interactive map of Lviv[10]. When analysing the distribution of buildings in 1932, reference was made to the aforementioned pre-war plans for Lviv and tourist guides from the 1920s and 1930s. On the basis of *ArcGIS World Imagery*, an additional layer, the so-called Shevchenko Hai, was created. It is an open-air museum of several dozen hectares in the eastern part of Lviv, which serves both as a museum and as a green area in the city.

Tab. 1. Number of buildings with selected functions

	1932	2016	1932 and 2016
Sacral buildings	111	123	101
Theatres	5	4	10
Museums	6	5	36
Universities	7	10	5

The layer illustrating the tram lines operating in 2016 was verified using data published on the Lviv.travel website[11]. These data were the same, so there was no need to modify them. On the basis of the pre-war map, a layer of tram lines operating in 1932 was developed. Their route was verified on the basis of information contained in pre-war guides to Lviv and other pre-war city plans. The tram line network was consistent with the information on the map, except for one section located in the southern part of the city.

4. Research results

The research resulted in maps comparing urban development (fig. 4), the arrangement of buildings serving as temples, museums, theatres and buildings of higher education (fig. 5) and the course of tram lines (fig. 6). All three maps show changes which took place between 1932 and 2016. On all maps, the topographic background is *OpenStreetMap* and layers made on the basis of the *World Imagery* basemap: streets, pavements, paths, railroads, greenery, and cemeteries.

While compiling a comparative map of the state of urban development, a layer of buildings erected after 1932 and a layer of buildings erected probably before 1932 were illustrated. In the case of maps of changes in the arrange-

[10] http://www.lvivcenter.org/en/lia/map/

[11] http://lviv.travel/en/index/information/transportation/tram

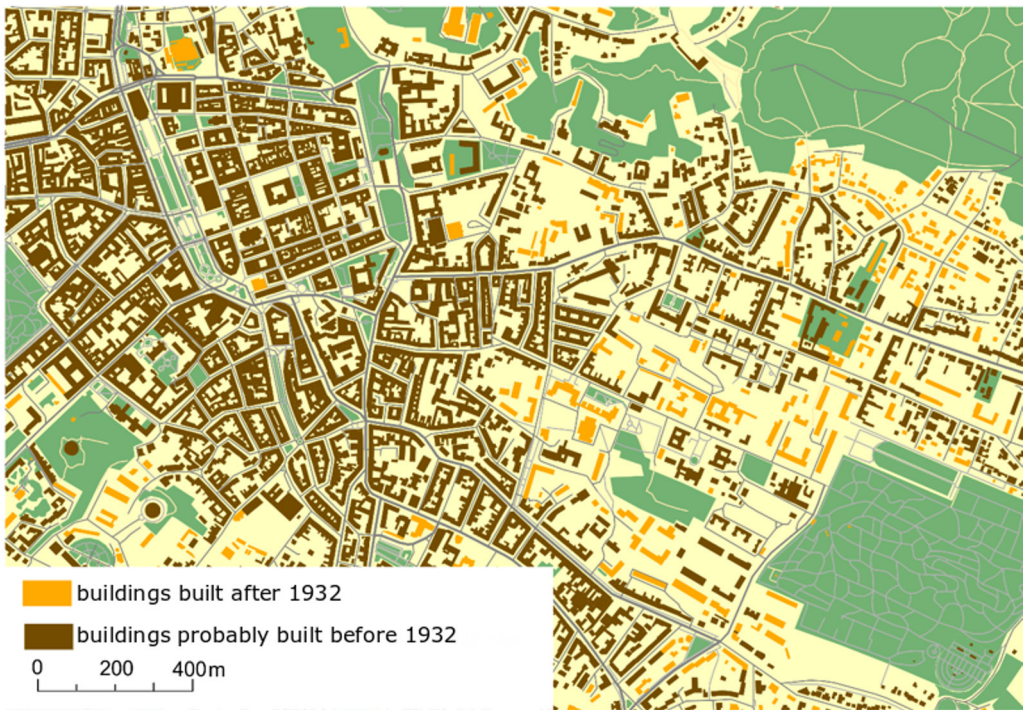

Fig. 4. Buildings erected before 1932 and in the years 1932−2016 (part of the map; own work based on *OpenStreetMap* vector data)

ment of characteristic buildings, 14 layers were created. For each of the four building types, three surface layers were developed: buildings with a given function in 2016 (yellow), buildings with the same function in 1932 and 2016 (red), and buildings with a given function in 1932, but not in 2016 (burgundy). In the case of religious buildings, an additional layer of buildings existing in 1932, which did not survive until 2016, was created. When developing a comparative map of the tram line network, three main layers were distinguished: tram lines operating in 2016, lines operating in 1932, and a section of tram lines that probably operated in 1932. The fourth layer consists of tram lines operating both in 1932 and in 2016.

5. Analysis of test results

5.1. Age analysis of buildings

The area of all buildings located in the research area is 756.3 ha. 56% of the buildings are buildings constructed after 1932 (420.5 ha), and 44% are buildings probably built earlier (335.8 ha). Pre-1932 buildings are concentrated in five areas: in the central part of *Śródmieście*, which is the historic centre of the city, in the southern part of *Przedmieście Żółkiewskie*, in the south-eastern and central part of *Przedmieście Krakowskie*, in the northern part of *Przedmieście Halickie* and in the western part of *Przedmieście Łyczakowskie*. There have been no significant changes to the street layout in these areas.

The regions of Lviv with a majority of buildings built after 1932 (mainly in the Soviet era and later) are the pre-war suburbs, where there used to be single buildings or undeveloped areas. In the south of the city, these are pre-war districts and housing estates: Sygniówka, Kulparków, Skniłówek, Kozielniki and the so-called Pasieki Halickie; in the east: Lonszanówka, Cetnerówka and a part of Łyczaków located near the inactive railway line Lwów-Winniki and Kolonia Krzywczyce; in the north: west

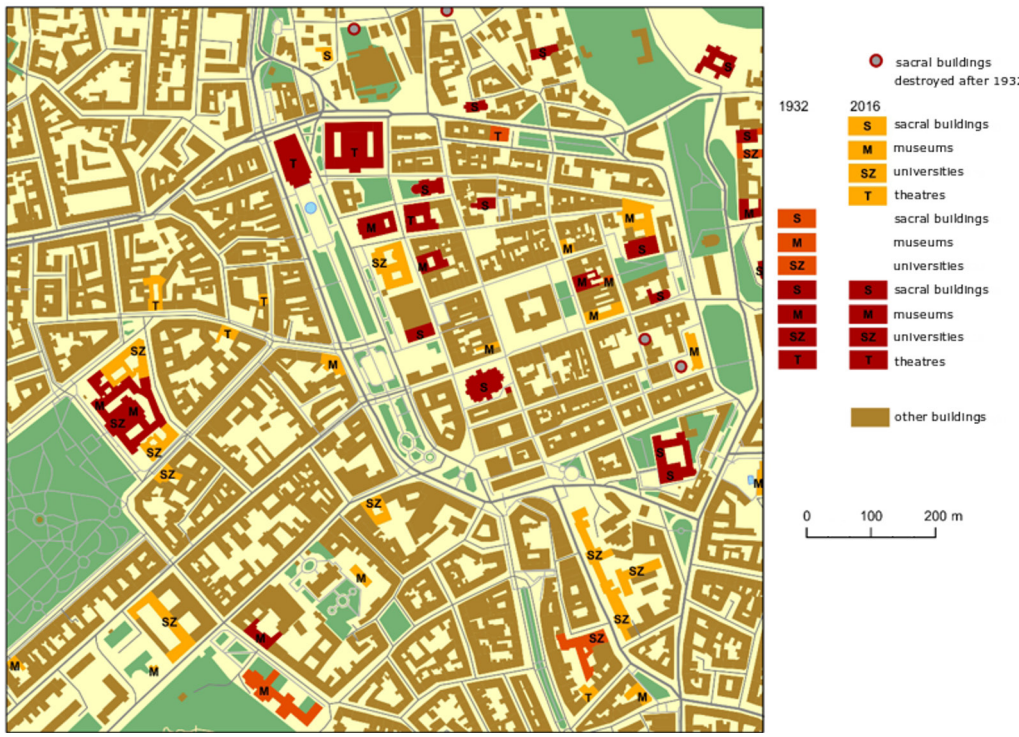

Fig. 5. The location of buildings with selected functions in 1932 and 2016 (part of the map; own work based on *OpenStreetMap* vector data)

Zamarstynów, northern Zniesienie, and Kleparów. The buildings are located mainly along streets that did not exist in 1932 but were built later. In the remaining areas, buildings from before 1932 are mixed with newer buildings.

The analysis of the age of the buildings in Lviv allows us to conclude that buildings built before 1932 are mainly concentrated in the city centre and along major communication lines.

5.2. Analysis of changes in the arrangement of buildings with selected functions

In 1932, there were 111 religious buildings in the studied area, including 106 Christian ones, as well as 6 synagogues and Jewish prayer houses. Even then, there were churches that did not fulfil their primary sacred function, e.g. the Church of St. Wawrzyniec with the Monastery of Bonifratri, which was a hospital from 1785. Six sacred buildings were demolished during the war and the Soviet era (Great City Synagogue, Progressive Synagogue, Golden Rose Synagogue, Old Synagogue − all in the center, St. Andrew and Vladimir Orthodox Church in Bogdanówka, and the Church of Our Lady Queen of Poland in Zniesienie), and four of them became museums. In 2016, there were 123 religious buildings: 121 churches and orthodox churches, the Cori Gilod synagogue of the Beit Aaron community in Israel, and the House of Prayer of Jehovah's Witnesses. Religious buildings are the most evenly distributed category of buildings, despite their strong concentration in the city centre. The concentration of churches in the city centre has historical reasons (funded by kings, nobility, and townspeople), and also results from minor damage during both world wars.

In 1932, there were five theatres in the city, of which only one (Teatr Nowości) did not survive until 2016. In addition to the four old theatres, six others were open in 2016, all of which were located in the city centre.

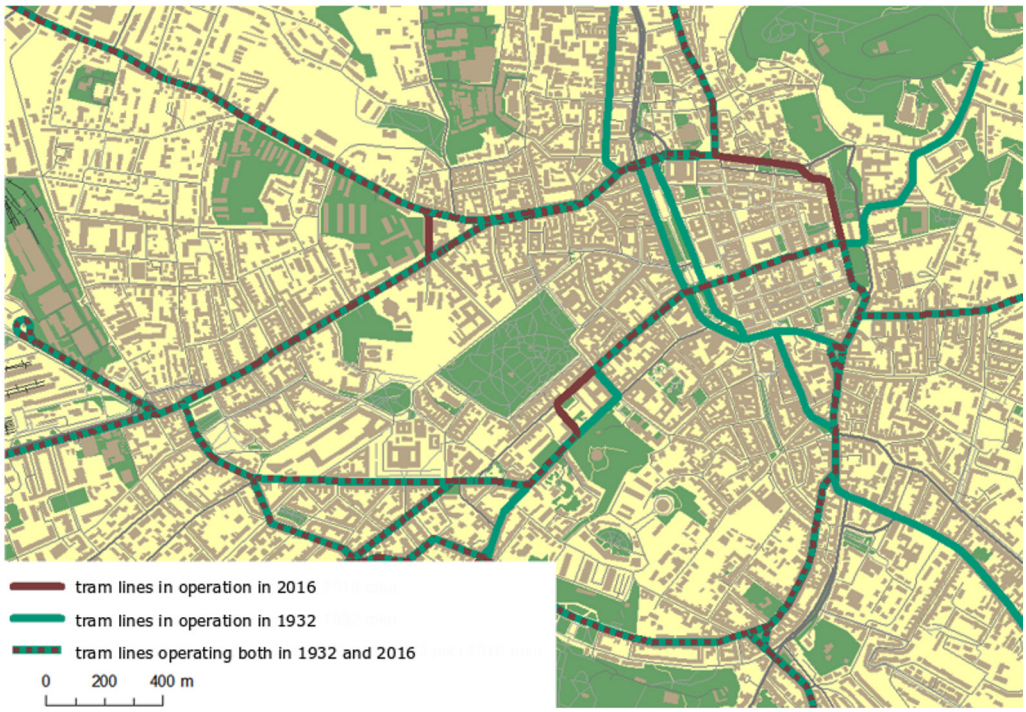

Fig. 6. Tram lines operating in 1932 and 2016 (part of the map fragment; own work based on *OpenStreetMap* vector data)

Museums are more evenly distributed. In 1932, there were six of them, five of which have survived to this day. After the Second World War, the Lubomirski Museum located in the so-called Ossolineum was closed. In 2016, there were 36 museums, most of them in the city centre, and a dozen or so far away from the centre. A special type of museum is the Shevchenko Hai open-air museum, which consists of several dozen historic buildings of Western Ukrainian folk architecture, located in the forested area of Zniesienie. In 1932, there were 7 higher education buildings in Lviv, 5 of which were still in operation in 2016: The Ivan Franko National University of Lviv, the Lviv University of Technology, the National Forestry University of Ukraine, the Lviv University of Trade and Economics, and the Ground Forces Academy. After the Second World War, two universities were closed: the Higher Theological Seminary of the Lviv Archdiocese and the Academy of Veterinary Medicine (currently operating as a university). The buildings of the faculties of Lviv universities are located mainly in the southern part of the city centre. Most of them belong to the Ivan Franko University and the Lviv University of Technology. All the buildings of Lviv universities are located no more than 1 km in a straight line from the historical centre.

5.3. Analysis of changes in the tram line network

The analysis of the tram line network shows that about 60% of today's lines coincide with those that operated in 1932. In 1932, the total length of tram lines was 48.3 km, and in 2016 it was 38.3 km (including 4.1 km outside the studied area), which indicates a reduction by 18.6%. This decrease − despite the city's demographic growth and spatial development − is associated with the development of other forms of urban transport: trolleybuses and city buses. The route of the tram lines differs significantly in several places, mainly in the city

centre and in the southern part of Łyczaków, where new routes were created after World War II, and some were closed (fig. 6).

The analysis of the entire city area shows that the tram lines have been extended most towards the south, beyond the research area, reaching the present-day suburbs of Lviv. The length of the tram lines increased to a lesser extent to the north and east. A few sections existing in 1932 were no longer functioning in 2016. In addition, the tram lines in today's Prospekt Svobody and Vysokyi Zamok were dismantled. In addition to these changes, there were several minor modifications in the western and northern parts of the city.

6. Conclusions

The conducted research allows us to conclude that the analysis of building changes on the basis of maps of old and modern vector data requires the use of numerous materials verifying the research methodology (satellite photos, information from websites, other old maps from a similar period, archival guides, and even panoramic photos from *Google Street-View*). Numerous auxiliary materials were used due to the difference in the degree of data generalization (this especially applies to those elements that change the form of presentation when the scale is modified, such as urban buildings), the nature of vector data (the non-uniform accuracy of *OpenStreetMap*), and the accuracy and detail of the analysed old maps. Historical knowledge is a key factor influencing the correctness of the analysis.

The developed maps make it possible to analyse changes that took place over 80 years in Lviv, a city belonging to Poland in the interwar period, and now to Ukraine. This makes the historical exploration of the city more attractive. The visualization of the age of the buildings, changes in their location, and changes in the routes of tram lines should be treated as an extension of the existing research on the spatial evolution of the city.

The maps presented in the article would be worth publishing in the future in the form of a website. The visualization could include animations showing changes in important elements of urban infrastructure.

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