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GENERATING AN IMAGE OF THE CITY STRUCTURE WITH THE USE OF MOCK-UPS, 3D MODELS AND ARTIFICIAL INTELLIGENCE ON THE EXAMPLES OF MODELS OF THE STRUCTURE OF SELECTED CITIES OF THE GZM METROPOLIS

GENEROWANIE OBRAZU STRUKTURY MIASTA Z WYKORZYSTANIEM MAKIET, MODELI 3D I SZTUCZNEJ INTELIGENCJI NA PRZYKŁADACH MODELI STRUKTURY WYBRANYCH MIAST METROPOLII GZM

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Abstract

Spatial analysis of cities and regions in the field of urban-architectural planning is usually presented in the form of drawings and diagrams. With the development of spatial information and the capabilities of GIS software and the use of database resources, the creation of illustrations of spatial analysis has become more accessible and easier. According to Kevin Lynch's theory, the image of a city cannot be determined in an automated way, and their identification requires an authorial approach and research. The article presents a series of experiments series, in which an attempt is made to represent the image of the city using mock-ups, 3D models, using augmented reality, as well as artificial intelligence. The authors put forward the thesis that a contemporary, proprietary representation of the city image in the form of models can be an alternative to traditional diagrams representing the basic elements that make up the city image.

Keywords: city image, spatial analysis, 3D models in analysis, artificial intelligence, city structure

Streszczenie

Analiza przestrzenna miast i regionów w zakresie planistycznym i urbanistyczno-architektonicznym najczęściej jest przedstawiana w postaci rysunków i schematów, które bazują na podkładach mapowych. Wraz z rozwojem informacji przestrzennej i możliwościami stosowania oprogramowania GIS i wykorzystywaniem zasobów baz danych tworzenie ilustracji analiz przestrzennych stało się bardziej dostępne i łatwiejsze. Według teorii Kevina Lyncha na obraz miasta składają się krawędzie, dominanty, obszary, ścieżki oraz punkty węzłowe, których nie można jednak wyznaczyć w sposób zautomatyzowany, a ich identyfikacja wymaga autorskiego podejścia oraz badań. W artykule przedstawiono serię eksperymentów realizowanych w ramach cyklu modele struktury miasta, w których podjęto próbę reprezentacji obrazu miasta z wykorzystaniem makiet, modeli 3D, z wykorzystaniem rzeczywistości rozszerzonej, a także sztucznej inteligencji. Autorzy stawiają tezę, że współczesne, autorskie przedstawienie obrazu miasta w formie modeli może być alternatywą dla tradycyjnych schematów przedstawiających podstawowe elementy składające się na obraz miasta.

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Wnioski z badań mogą mieć zastosowania w analizie przestrzennej miast i regionów oraz być wskazówką do rozwoju metod prezentacji ich struktury.

Słowa kluczowe: obraz miasta, analiza przestrzenna, modele 3D w analizie, sztuczna inteligencja, struktura miast

1. INTRODUCTION, STATE OF RESEARCH

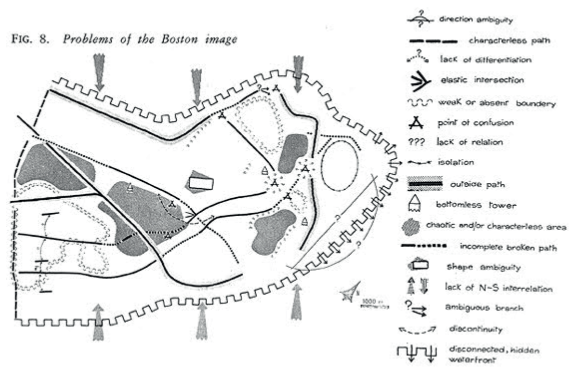
Spatial analysis of cities and regions used in spatial planning and urban design is undergoing a major evolution nowadays thanks to the development of tools (most often based on GIS) and the widespread availability of data (shared informally, e.g. social media, or published as databases (big data). Mapping and graphical representation of spatial data nowadays is implemented in a systematic way, and its presentation in some cases is even possible in real time. The images generated in the above way can be considered new informal icons that create the image of cities. This is shown by a number of studies, of which those that allow imaging the structure of cities were considered key.

Abesinghe et al. examine how, with the help of social media data, a city's image changes, and with it its popularity in supralocal and international rankings. To achieve this, the study adopted the Capture-Understand-Present (CUP) model. The researchers emphasize that in the digital age there is no need to adopt complex methods for studying the image of a city. Social media messages, which allow for a deeper and closer understanding of the community's attitude to the city's image, prove to be sufficient [1].

A study using a similar approach to the use of geocoded social media data is also presented in the article by Huang et al. [2]. The perception of images of cities in the Tri-City Region in Poland was studied. Benchmarks established based on the official GIS database, surveys and map sketches made by residents were used to evaluate the results. The study proved the relevance and importance of Lynch's theory in the digital age, and that GSM technology and Instagram and Twitter data are a good complement to his original methods. The development of this type of survey method, also reduces the amount of field work and allows the measurement of images of cities on a much larger scale [2].

Another of the methods of studying the image of cities is the process proposed by Jinag B [3]. It consists, on automatic calculation of the image of the city from geospatial databases of the city, taking into account the hierarchy of scaling, grouped on layers of urban artifacts, e.g. streets, buildings, parks. Hierarchy of artifacts is done as a process of ranking in terms of semantic, geometric and topological information. This ranking makes it possible to divide the artifacts and the spaces adjacent to them into two parts: above and below the norm. This allows the

a)



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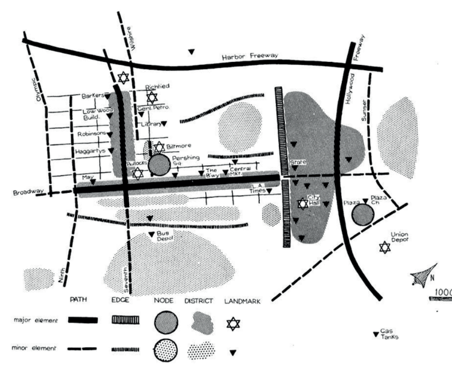

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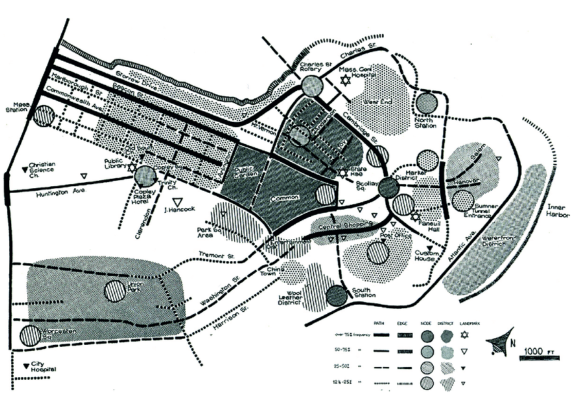


Fig. 1. A mental map of the city of Boston (a), Los Angeles (b), New Jersey (c), Kevin Lynch, Image of the City.

Source: a) https://architectureandurbanism.blogspot.com/2010/09/kevin-lynch-image-of-city-1960.html, b) https://flic.kr/p/nTb77, c) https://urbandesignlab.in/the-image-of-the-city-by-kevin-lynch/

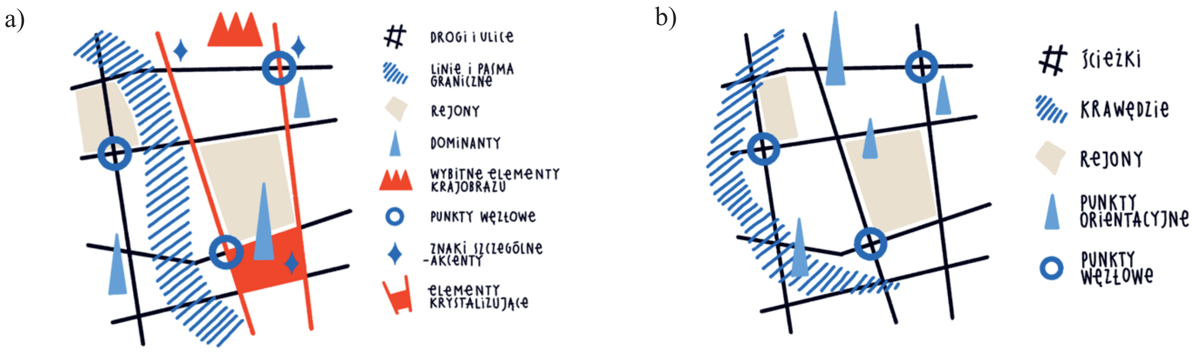


Fig. 2. Elements of city structure according to Kazimierz Wejchert a): roads and streets, border lines and strips, districts, dominants, prominent landscape elements, nodes, special characters, elements crystallizing the city plan and according to Kevin Lynch b): paths, edges, districts, landmarks, nodes

Source: https://ade.niaiu.pl/archipediapl/elementy-miasta, authors: Elżbieta Kusińska, Weronika Reroń

study to distinguish spaces that form important parts of the mental map and image of the city [3, 4].

Tang, Yang et al. [6] conducted experiments with image analysis of Wuhan city using a method that examined differences in respondents' attitudes toward the city's image and the relationship between attitude ratings and basic information about the respondents. Using a survey questionnaire, respondents' basic information and attitudes toward the city were collected. SPSS (Statistical Package for the Social Sciences) was also used for descriptive statistical analysis, correlation analysis, and ANOVA analysis on the data, in order to obtain information on the associations and relationships between images of the city and basic information about the respondents. Lynch also argued that image and the image of a city are shaped through people's perceptions and experiences [5]. The Wuhan study by categorizing the evaluation into three aspects i.e. degree of liking, degree of intimacy and degree of importance allowed for more in-depth analysis on the evaluation of the city's image and more importantly the image of the city itself through its relationship with its residents [6].

Referring to Kevin Lynch's method, Polish urban planner Kazimierz Wejchert [7] notes new factors shaping the image of a city. In addition to those corresponding to the components indicated by Lynch (Fig. 2b), Polak additionally distinguishes: elements crystallizing the city plan (EK), prominent landscape elements, and special characters (Fig. 2a). The first factor is found in cities mostly in the form of a market, often also as a compositional axis in the form of a main street. It must be a strong enough feature that makes the resident immediately associate it with the entire city. Prominent landscape elements are the most distinctive views, which are often the hallmark of a place. A landmark in a city's image can be, for example, a monument or sculpture, but also distinctive details of buildings or even temporary colorful advertisements.

Photos are a natural representation of a city's image, and are a fixation on the perception of the actual city. Sussana Moreira [8] describes the use of aerial photographs of selected cities to illustrate elements of Kevin Lynch's city image. Paths were shown through the street layouts of Brussels and the English town of Dagenham. Edges were illustrated through the example of the historic walls of the city of Lucca in Italy and the buildings of the city of Antofogasta in Chile, which is separated by a coast on one side and a mountain range on the other. The author showed the areas using the city centers of Madrid and Thessaloniki, Intersections and squares in Argentina's La plata and Spain's Plaça de Tetuan are good examples of nodes. As landmarks, the author presented photos of the Statue of Liberty and the Asinelli and Garisenda towers in Bologna, Italy. The author emphasizes the connection of Lynch's highlighted elements to the whole city and their setting in context: "(...) none of the elements proposed by Lynch exist in isolation in the real case, and therefore the author concludes that although his analysis begins with the differentiation of the data into categories, it must end with their "reintegration into the whole image" [8].

The mental mapping method that Lynch uses when creating a city image was used by Milena Stettner in her research on "building a city image by residents of selected small cities in the Lower Silesian province" [9].

It consisted of confronting mental maps created by the urban planner and residents of selected cities. Three cities were selected: Trzebnica, Siechnice, Świeradów-Zdrój. The city of Siechnice fared best in this comparison. The simple layout and small size of the city allowed it to be mapped very accurately with elements such as nodes, landmarks and edges. In the case of the last city, the respondents mapped all the city's landmarks and nodes in accordance with reality, while the drawings of the rest of the city's structure differed among the respondents. This was due to the respondents' different places of residence. The most important conclusion drawn by the author of the conducted research is that the legibility and perception of the city by its users is very much influenced by the diversity of space and characteristic elements in the city.

Milena Stettner used the same survey method for the residents of Wroclaw Angles [10]. She collected 22 residents and visitors, including people connected and familiar with urban issues, e.g. planner, official. The respondents started their drawing with the 3 most characteristic elements of the city: the Market Square, the main street and the edge in the form of the railroad tracks, the river and the highway. The worst in the juxtaposition of elements of the city image was the mapping of streets. Juxtaposition of the results showed that the respondents most remember their activities in the urban space, distinguishing, for example, the route to work, home or school.

Another author's method of research was proposed by Beata Komar [11] using the example of the Tysiąclecia housing estate in Katowice. An urban audit was conducted, which involved examining the estate according to 11 guidelines. They concerned issues of sustainability, including, among others, the urban composition and legibility of the settlement's spatial layout according to Kevin Lynch's theory. The author adopted separate criteria for this issue and evaluated them. After analyzing all elements of the structure, the estate received the highest score, the criteria of which were: "holistic fulfillment of the theory's assumptions, i.e. the settlement has all the elements mentioned in the theory: edges, nodes, paths, landmarks, neighborhoods" [11]. A survey was then conducted with 12 seniors living in the settlement, during which the audit results were confronted. The two-phase nature of the research made it possible to confront the results. The most important of the conclusions drawn by the author is the introduction of additional objects with different functions into the structure of the settlement, in addition to buildings with a residential function. The author also notes the need to maintain a legible urban space, for example, by not cluttering existing pedestrian routes with new elements or introducing a visual identification system.

Despite the growing popularity of artificial intelligence, it is not yet as widely used in the field of urban planning as it is in other fields. However, as outlined in the article "The Sustainability of Artificial Intelligence: An Urbanistic Viewpoint from the Lens of Smart and Sustainable Cities", in recent years, AI applications have become an integral part of the city, where, for example, artificial intelligence manages transportation systems or monitors the state of air quality. Researchers emphasize the increasing use of AI in city planning, and thus its greater impact on sustainability [12].

Bibri, Krogstie et al. [13] analyzed the links between artificial intelligence and smart cities, and as a result observed rapid development in sustainable green smart cities between 2016 and 2022. This is related to the digitization program and the development of data-driven technologies, which is characteristic of AI in smart city analysis.

Cugurullo et al. [14] point out, artificial intelligence is having an increasing impact on the management of 21st century cities. AI applications can be found in cities that are most suitable for its implementation, due to the concentration of high-tech infrastructure and high population density that determines the need for new AI technologies. Artificial intelligence can be a tool used by urban planners to generate scenarios for the future of urban development. According to Peng, Lu, Liu and Zhai [15], this is expected to optimize urban planning and design, and direct attention to sustainable development. For planners, AI-processed textual information from various plans can be important to facilitate and streamline data analysis and improve the efficiency of city planning. As Parasa [16] points out, one of the main functions of AI in urban planning is also predictive modeling, i.e. collecting and analyzing data, such as historical data, to predict future trends in urban development and its infrastructure needs. Despite the use of AI for various urban planning purposes, no attempt has been made before to generate images of cities using it.

2. MATERIALS AND METHODS

For the purpose of the research, the following were implemented: literature search, in situ research,

research using GIS software and quantitative data, experiment, research by design and comparison method. During the series of classes entitled. “Models of city structure” conducted in the Department of Urban and Spatial Planning at the Faculty of Architecture at the Silesian University of Technology, students have been performing analyses on the structure of various Polish and European cities for several years now. These are classes conducted as part of the course “Urban Design – City Structure”. The series began with analyses on the city of Bologna in Italy (2019) [17], then Aachen in Germany was studied (2020) [18]. Subsequent editions focused on Polish cities and included Zabrze (2021) [19], Gliwice (2022) [20], as well as the Upper Silesian and Zagłębie Metropolis (2023) [21]. The studies are of a scientific nature: the research and experiments carried out by students together with their supervisors are based on theory, and their results are published.

The research used information from local databases, such as the Municipal Spatial Information System (MSIP) [22] and the Study of Land Use Conditions and Directions [232 for a given city, as well as national databases such as the Central Statistical Office (CSO) [243, Geoportal [25] and OpenStreetMaps [26]. The geo-information software QGIS was also used, which allowed the creation of many analytical maps with preset criteria. One of the more specialized tools, for example, was Databout. LIS – Locate It Smart [27], a program that analyzes the accessibility and surroundings of selected locations (Gliwice). The program was previously used, among others, during the creation of the Development Strategy of the City of Kutno 2030 [28]. Using it, accessibility models of social infrastructure were made. For example, pedestrian accessibility to bus stops or city bike stations was checked, and the data obtained was incorporated into the draft City Strategy.

Various tools such as Cadmapper, Autocad were used in developing the acquired data. Sketchup and Blender were used to work on 3D models. The use of dedicated applications Sketchfab.com and Augment.com, as well as working with VR goggles, made it possible to make the created 3D models available in virtual and augmented reality. In addition to traditional photos, photographic documentation was made in the form of photopanoramas in the Teliportme.com application, as well as with images taken by drone. Other tools used to create physical mock-ups include a Styrocad thermal plotter and a 3D printer.

In the case of the development of the Upper Silesian Metropolis, attempts were also made to create development scenarios using artificial intelligence “Midjourney”. Places such as the highway interchange, the Silesian Stadium and the Market Square in Gliwice, for example, were selected, and then positive and negative versions of the development of the selected locations in 100 years were created and compared.

3. CASE STUDY

For the purpose of preparing the case study, analyses of the city’s structure carried out as part of the research are presented. These include historical, share of built-up area, technical and blue-green infrastructure, road communication, accessibility of public transportation or land use taking into account residential, service and industrial areas separately. Analyses of public spaces and inspired by Kevin Lynch’s methodology were also prepared. These formed the basis for further research discussed in the article.

3.1. Models of the Bologna city structure

The analysis of the city of Bologna according to Kevin Lynch’s method is presented using a large-scale physical mock-up (Fig. 3). It shows the outline of the city’s boundaries, along with a simplified sub-image of the solids of the buildings. Roads are depicted on the mock-up using orange threads. Depending on the frequency of use of a given road, the amount of line/thread guidance was increased or decreased. Nodes, or key communication links, were depicted on the mock-up with vertically placed sticks of different heights. High sticks mark the most significant nodes while low sticks indicate the less significant ones.

Fig. 3. Mock-up showing analysis of the city of Bologna according to Kevin Lynch’s method

Source: https://www.polsl.pl/rar/ps_aktualnosci/nietypowe-modele-miast-wystawa-modele-struktury-miasta-bolonia-28-maja-informacja-prasowa/

Areas are depicted as cut-out 3d solids, the edges of which are the boundaries of the areas, while the edges are depicted on the mock-up with black threads. In the case of Bologna, these include railroads, airport runways, the city's ring road and selected roads. Landmarks were visualized on the mock-up with photos of selected points, and then pasted in their corresponding locations. The authors highlighted the following landmarks for Bologna, among others: Ducati Factory and Museum, Bologna Airport, Navile Canal, Park di Via dei Giardini, Sacred Heart Church, Fiera District, Fico, CUS Bologna Sports Club, Monumento Brigata Partigiana Maiella historical site, Polish War Cemetery.

3.2. Models of the Aachen city structure

3.2.1. Analysis of the city of Aachen according to Kevin Lynch's method

The analysis of the city of Aachen according to Kevin Lynch's method was presented using a spatial model (Fig. 4), which was then made available in augmented reality.

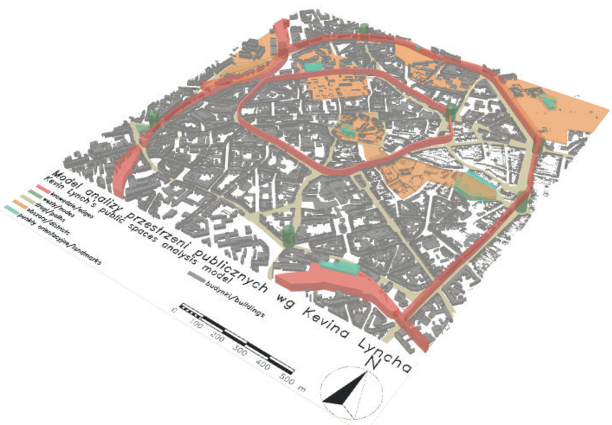


Fig. 4. Analysis of the city of Aachen according to Kevin Lynch's method – 3D model

Source: https://agmt.it/m/zL3d9gm9

The model shows a section of the city center with gray building blocks. Roads are depicted in the model as light green lines, and are mostly the main streets of the city. The nodes, or intersections of the main roads, are depicted in the model as green rollers. Areas are depicted in the model as orange outline fills. Areas highlighted are the inner city (around the city hall), Elisengarten Park, the commercial zone in the eastern part of the center (includes a house and a department store), the RWTH Aachen Polytechnic Campus, Ludwigsalle Park and school with sports areas, Campus Campus Mitte, and Kurgarten Park. The edges are depicted in the model as red, continuous lines. These included Road 57 and 264, the city's ring road (Road 1), as well as railroads (especially near the train station and the northwestern part of the center). Landmarks of the city of Aachen include the Aachner Dom Cathedral, Elisenbrunnen, RWTH Aachen University, Aquis Plaza Aachen, Neues Kurhaus Aachen, Marienturm and the main train station. The listed building blocks have been turned blue.

3.2.2. Analysis of selected public spaces in Aachen

Studying the public spaces of the city of Aachen, it was decided to check their accessibility on a section of the city center. In the 3D model (Fig. 5) that was made, in addition to the underlay containing buildings and railroad lines, areas of places/markets/squares (red fill), green areas (green fill), pedestrian spaces (orange fill), and spaces for all types of transportation (light green lines) were marked. The study selected several specific public spaces for each city district. These included the Elisengarten park, the Market Square with the town hall and cathedral, the Brander Wald nature reserve, the Indemann viewpoint and the former Walheim quarry.

Fig. 5. 3D model presenting the accessibility model of public spaces in the city of Aachen

Source: https://agmt.it/m/YwrSnzD7

3.3. Models of the Zabrze city structure

Zabrze was the first city in the Upper Silesian Metropolis to be analyzed.

3.3.1. Analysis of the city of Zabrze according to Kevin Lynch's method

The analysis of Zabrze according to Kevin Lynch's method was presented using maps of the entire city and a spatial model of a selected part of the city, which was then made available in augmented reality.

Four maps of the city were drawn up showing separately the location of landmarks (Fig. 6a), areas (Fig. 6b), edges (Fig. 6c), and nodes and roads (Fig. 6d). A section of the city was then selected to create a 3D model. The area includes the vicinity of the House of Music and Dance, identified as one of the city's landmarks.

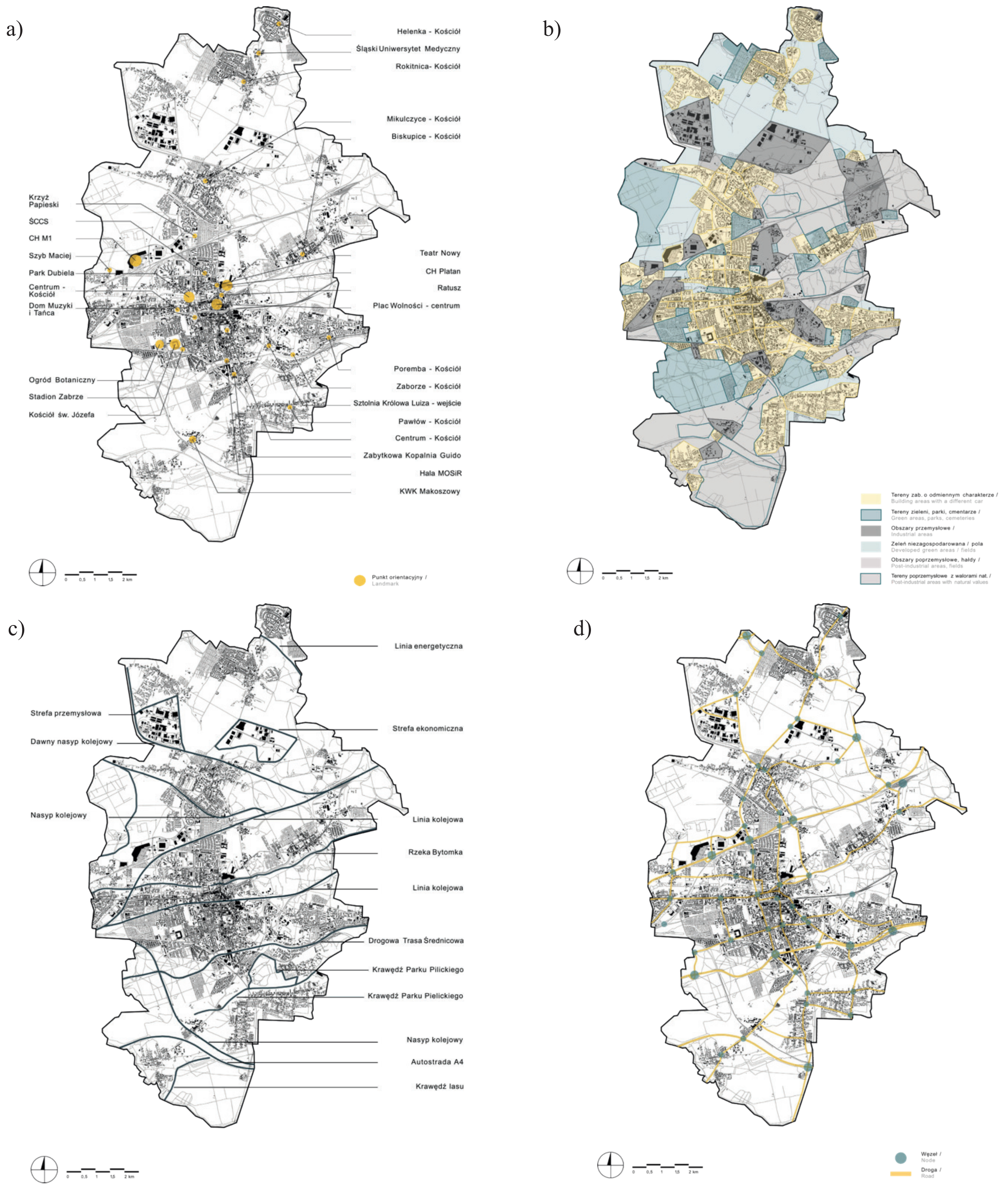


Fig. 6. Analysis of the city of Zabrze according to Kevin Lynch's method – landmarks (a), districts (b), edges (c), nodes and roads (d)

Source: Modele struktury miasta Zabrze [18], authors: Paweł Białas, Michał Ciebień

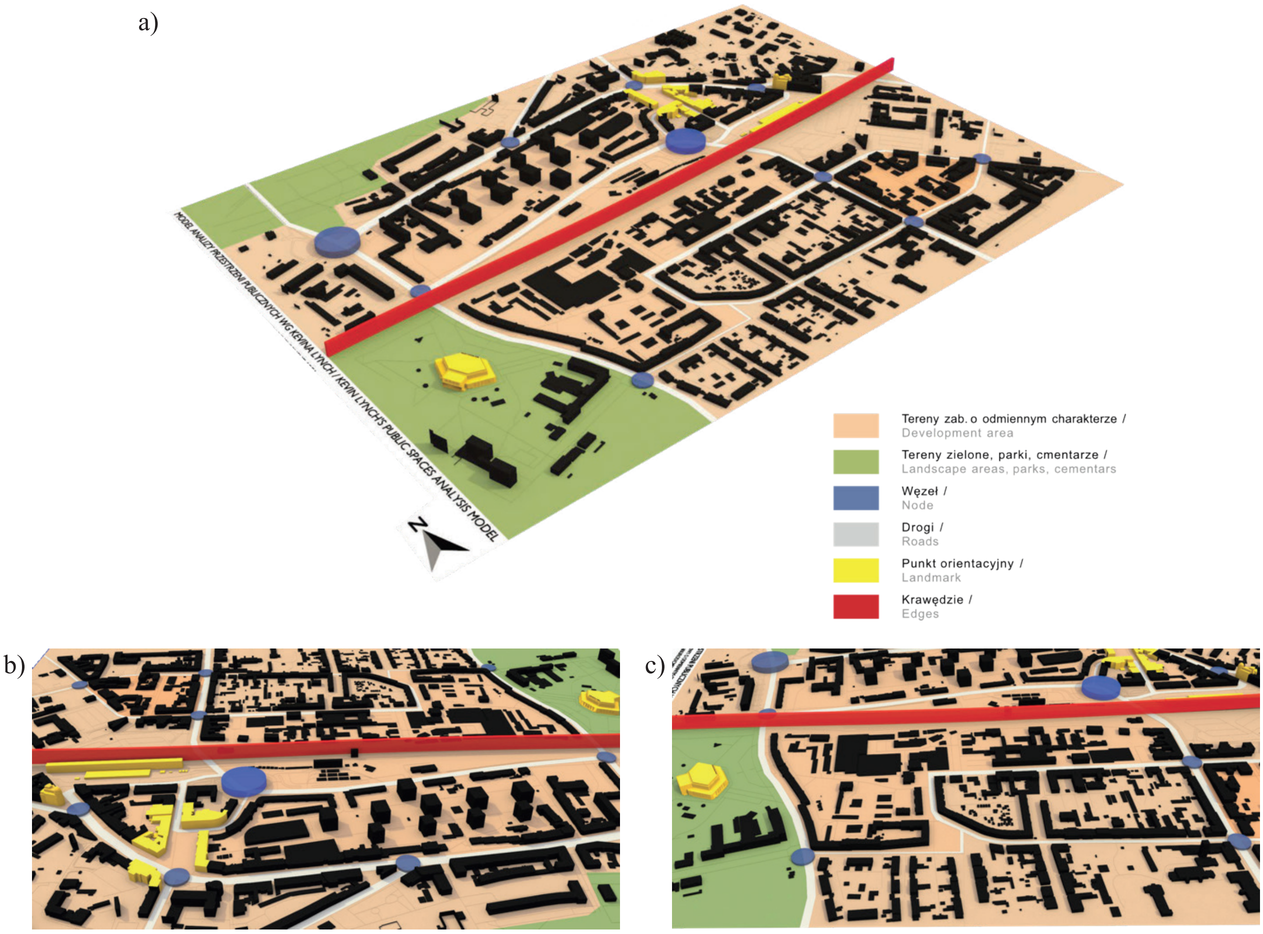


Fig. 7. Analysis of the city of Zabrze according to Kevin Lynch's method – 3D model (a), close-ups of the model (b, c)
Source: Modele struktury miasta Zabrze [18], author: Kamil Bryłka

Roads are depicted in the model as gray, continuous lines. Three national roads are indicated: 88, 78, 94, the Drogowa Trasa Średnicowa, as well as a section of the A4 highway running through the city and Wojciech Korfanty Avenue, one of Zabrze's most important streets. The nodes are depicted in the model as blue cylinders. Areas were depicted in the model as outline fills of corresponding color. The following areas were distinguished: buildings of a different character, green areas, parks, cemeteries, undeveloped greenery and fields, industrial and post-industrial areas, dumps, and post-industrial areas with natural values. The edges are depicted in the model as red, continuous lines. For Zabrze, these are railroad lines, main roads, railroad embankments, remnants of former mines (heaps), an economic and industrial zone, power lines, the Bytomka River, the Drogowa Trasa Średnicowa, the edges of Pilecki Park, a section of the A4 highway and the edge of the forest. Landmarks are depicted in the model as yellow solids. Such places are indicated as, for example, the Silesian Medical University, the New Theater, City Hall, Liberty Square, the Królowa Luiza Adit, the historic Guido Mine, Maciej Shaft, Dubiel Park, the House of Music and Dance, Zabrze Stadium and churches.

3.3.2. Analysis of selected public spaces in Zabrze

A spatial model and corresponding mock-up were drawn up for each public space in Zabrze. Several squares (Traugutta, Theater Square, Wolności Square, Krakowski Square), public buildings (AdmiralsPalast Hotel, House of Music and Dance), and former mine buildings (Guido Mine, Queen Luisa Adit) adapted for a museum were selected.

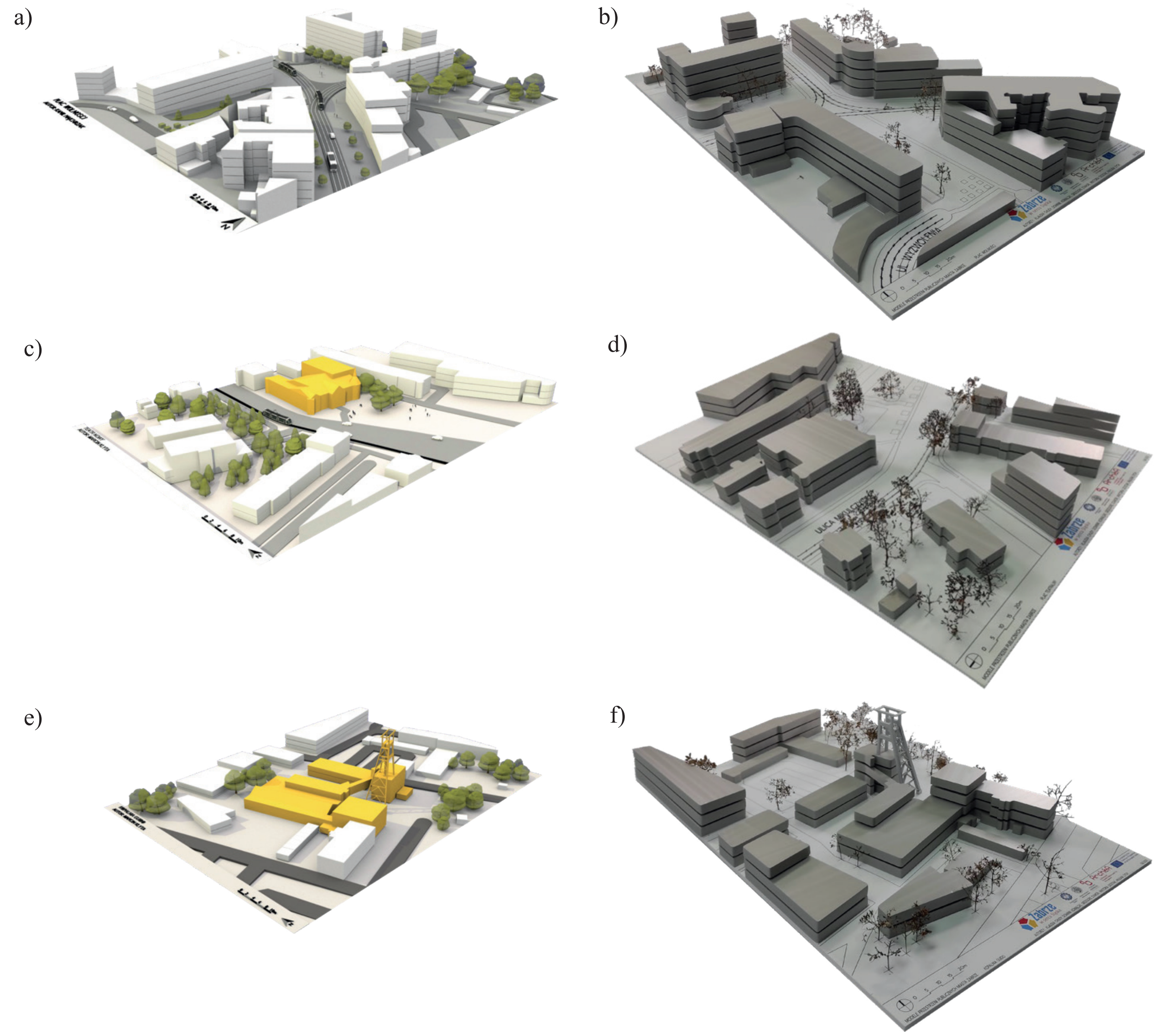


Fig. 8. Wolności Square – 3D model (a), mock-up (b), New Theater – 3D model (c), mock-up (d), Guido Mine – 3D model (e), mock-up (f)

Source: Modele struktury miasta Zabrze [18], authors: Kamil Majchrzak (a), Paweł Białas (a, c, e), Marcin Klyta (c, e), group work (b, d, f)

3.4. Models of the Gliwice city structure

During the study of Gliwice, two distinctive areas were selected in addition to analyses of the entire city. These were the Academic District of the Silesian University of Technology and Nowe Gliwice, an area formerly occupied by the Gliwice coal mine, which was rehabilitated and where the "Nowe Gliwice" Education and Business Center was built.

In addition to performing basic analyses of the city's structure on the basis of the map, such as the analysis of residential areas, service and industrial areas or blue-green infrastructure, analyses were also performed with the help of spatial 3D models, which were made available in augmented reality and virtual reality, as well as mock-ups which were their physical representation. Using mock-ups, it was also decided to depict several selected public spaces of Gliwice, such as the aforementioned area of New Gliwice, the Academic District, the Gliwice Market Square or the Gliwice Radio Station with its surrounding area.

3.4.1. Analysis of the city of Gliwice according to Kevin Lynch's method

Using Kevin Lynch's method for creating a "city image", it was examined how the elements he highlighted apply to the city of Gliwice. A 3D model

Fig. 9. Analysis of the city of Gliwice according to Kevin Lynch's method – map (a), 3D model (b)
Source: Modele struktury miasta Gliwice [19], authors: Agnieszka Bonczek, Natalia Hulbój

was drawn up showing the listed features of the city's structure (Fig. 9b). Roads were depicted in the model with black lines. Roads include the Drogowa Trasa Średnicowa and the A1 and A4 highways. Nodes were depicted in the model with blue cylinders. They included the highway interchange and public spaces such as the Market Square, the square in front of Arena Gliwice, Piast Square and the railroad station. The areas were depicted in the model with gray outlines. The area of the Silesian University of Technology campus and the Gliwice Aeroclub are highlighted here. The edges are visualized in the model with blue lines. For Gliwice, they are: Drogowa Trasa Średnicowa, A1 and A4 highways, railroad lines and the Klodnica River. Landmarks are depicted in the model as gray cylinders and are: Gliwice Radio Station, Gliwice City Hall and Arena Gliwice.

3.4.2. Analysis of selected public spaces in Gliwice

In the compiled model of accessibility of public spaces (Fig. 10), in addition to the primer containing buildings, areas of squares/markets (orange fill), green areas (green fill), pedestrian spaces (light orange fill), pedestrian and roadways (light orange fill), as well as spaces for all types of transportation (gray lines) are marked.

A spatial model and corresponding mock-up were drawn up for each public space in Gliwice. Two main areas were selected: Nowe Gliwice and the Campus of the Silesian University of Technology, as well as the Market Square, areas near the Gliwice Radio Station and the Mickiewicz and Grunwald Parks. Photos and 360 panoramas were also used during the analysis.

Fig. 10. A map presenting the model of accessibility of public spaces in the city of Gliwice
Source: Modele struktury miasta Gliwice [19], author: Daria Bal

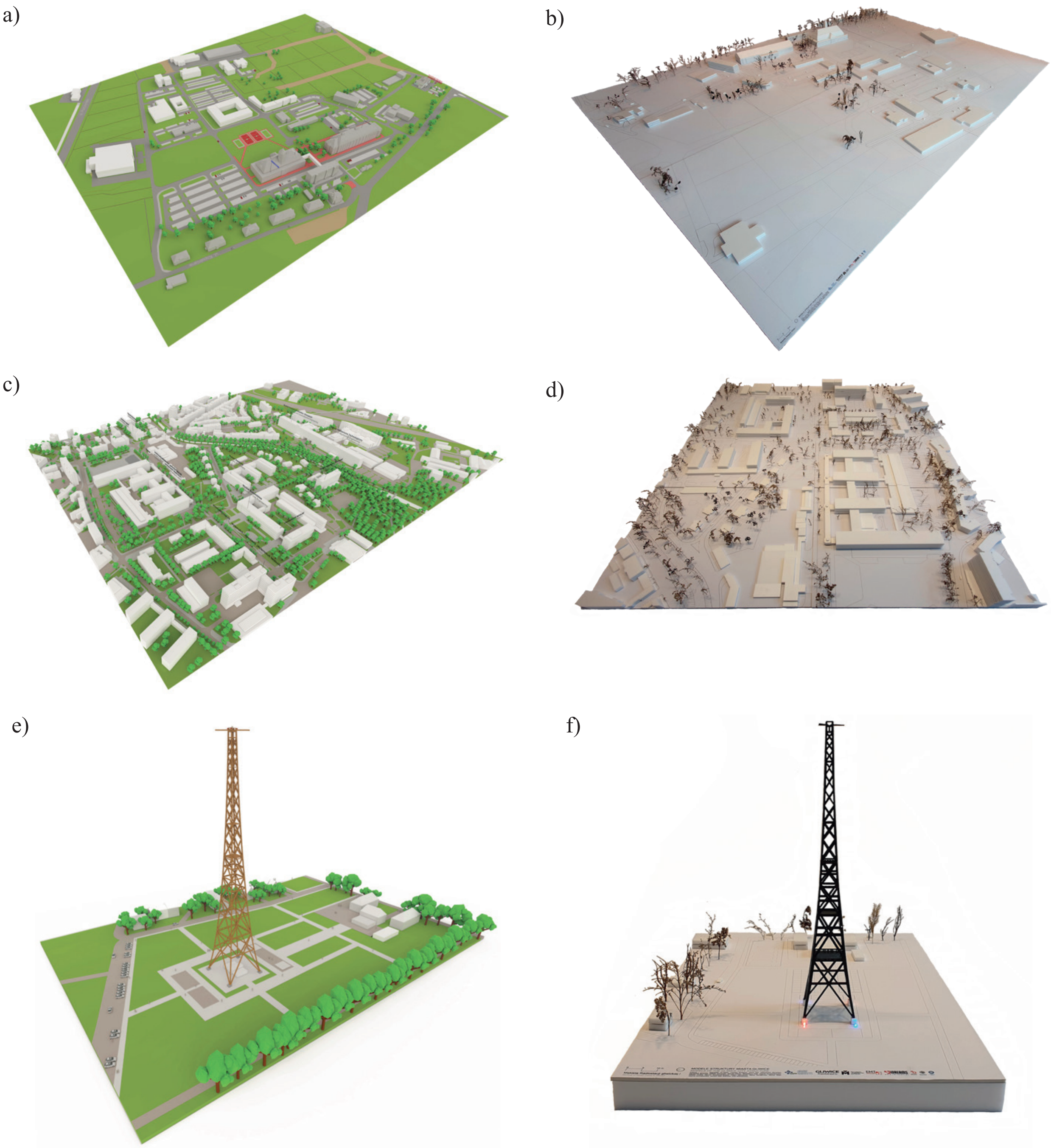


Fig. 11. New Gliwice – 3D model (a), mock-up (b), Akademicka District – 3D model (c), mock-up (d), Gliwice Radio Tower – 3D model (e), mock-up (f)

Source: Modele struktury miasta Gliwice [19], authors: Aleksandra Barańska (a), Adam Michałowy (c), Julia Wiśniewska (a, c, e), Magdalena Fijał (e), group work (b, d, f)

3.5. Models of the structure of the GZM metropolis

In the analysis of the Upper Silesian Metropolis, a kilometer grid model was adopted as the cellular model and the division into districts. This method allowed for a more accurate representation of the data, despite the complexity of the metropolis, which consists of 41 municipalities. The analysis is based on the synthesis of data using GIS software and 3D models, which are available in augmented and virtual reality. A number of analyses were performed, related to, among other things, buildings, communications, demographics or infrastructure of the entire GZM area.

3.5.1. Analysis of the GZM structure according to Kevin Lynch's method

Elements of Kevin Lynch's theory were also used to create an analysis of the Upper Silesian Metropolis (Fig. 12a), so as to show it on a broader scale than the city. Its versatility of application in image analysis and multifaceted operation was highlighted. Its various elements were highlighted in the 3D model (Fig. 12b). Roads are depicted in the model as orange 3D lines and are: Drogowa Trasa Średnicowa, A1, A4 highways, S1 expressway. Nodes are depicted in the model as orange cylinders. For the GZM, these are the A1-A4 and A4-S1 interchanges. Landmarks are depicted in the model as red cylinders. Prominent examples are the Gliwice Radio Station, the "Room" steel mill in Ruda Śląska, KTW in Katowice, the Szombierki Combined Heat and Power Plant in Bytom and Spodek in Katowice. The edges were visualized in the model as blue and yellow three-dimensional lines. The 220 kV and 400 kV overhead electromagnetic voltage lines, as well as the Rawa, Bytomka, Przemsza, Czarna Przemsza, Klodnica, Brynica rivers were depicted in this way. The areas were depicted in the model by color-coding the predominant type in a given square kilometer, from among: low greenery, high greenery, residential areas and industrial areas. A kilometer grid division of the metropolitan area was used to delineate the areas, in order to more accurately depict the data in individual squares of 1 square kilometer, and to more clearly perceive a given section of the GZM.

a) b)

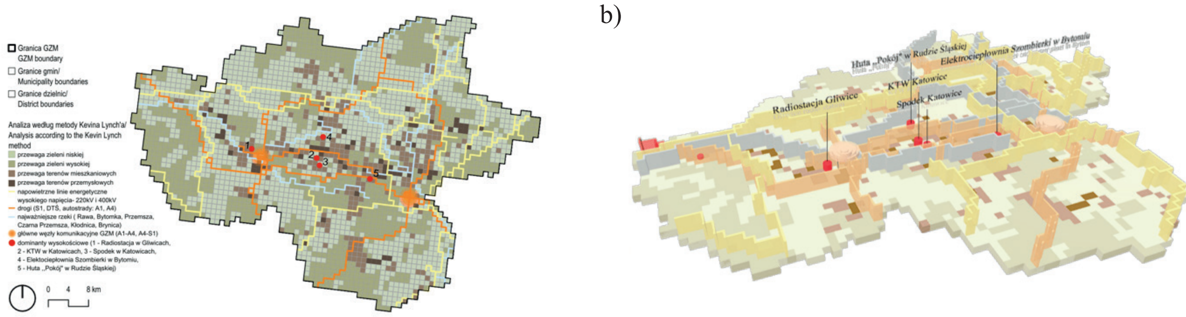


Fig. 12. Analysis of the Upper Silesian-Zagłębie Metropolis according to Kevin Lynch's method – plan (a), 3D model (b)
Source: Modele struktury Metropolii GZM [20], author: Karolina Wąsińska

4. EXPERIMENTS USING ARTIFICIAL INTELLIGENCE

The authors undertook an experiment using the artificial intelligence platform "Midjourney". Images, representing elements of Kevin Lynch's theory, were generated for the city of Gliwice. Attempts to generate images and identify individual image elements are presented below.

Attempts were made to generate two snapshots of images showing a 2D city plan and a 3D model. The following different combinations of keywords were tested, in order to get the effect as close as possible to the effects we know from studies carried out without AI. Trials of different keywords and evaluation of the images generated based on them are presented in the discussion. The best results were obtained based on the keywords: "'The image of the city' by Kevin Lynch, urbanism 2D analysis map of Gliwice, Poland, with highlighted elements of paths, edges, districts, nodes and landmarks" and "'The image of the city' by Kevin Lynch, urbanism 3D analysis model of Gliwice, Poland, with highlighted elements of paths, edges, districts, nodes and landmarks".

Artificial intelligence presented an image of the city of Gliwice, according to Kevin Lynch's theory, on a 2D map (Fig. 13a) and a 3D model (Fig. 13b), by highlighting its various elements. Roads were visualized as white, orange and blue lines. Edges were visualized as separating areas with blue and white zones and highlighting in orange the demarcating development. Areas were depicted as white, gray, black and orange zones. Nodes were depicted as intersections of lines. Landmarks were visualized as orange and white circles where they occur and highlighted on the 3D model as, for example, height or volume dominant.

With reference to the morphology of Gliwice, the church tower shaped like All Saints' Church can be identified in Figure 13b. Another element is the river, which can be identified as the Klodnica River. The scale of similarity can be estimated at 40%.

a)

b)

Fig. 13. Illustrations showing the image of the city of Gliwice using artificial intelligence – plan (a), 3D model (b)
Source: Image generated by the artificial intelligence platform "Midjourney"

4.1. Paths of the city of Gliwice using artificial intelligence

The AI depicted the paths of the city of Gliwice, according to Kevin Lynch's theory, on a 2D map (Fig. 14a) and a 3D model (Fig. 14b), by depicting them as blue, orange and white lines. AI, on the model, does not show all the paths, and their markings are not fully legible.

Figure 14a shows a river that can be recognized as the Klodnica River. The church tower, visible in the foreground of Figure 14b, is similar in form to a garrison church. A noticeable feature is the rectangular square, which resembles a market square in shape. The scale of similarity of Gliwice's morphology can be estimated at 40%.

a)

b)

Fig. 14. Illustrations of the paths of the city of Gliwice using artificial intelligence – plan (a), 3D model (b)
Source: Image generated by the artificial intelligence platform "Midjourney"

4.2. Edges of the city of Gliwice using artificial intelligence

Artificial intelligence depicted the edges of the city of Gliwice, according to Kevin Lynch's theory, on a 2D map (Fig. 15a) and 3D model (Fig. 15b), by depicting them as separated by blue and white zones and highlighting in orange the demarcating buildings. AI has retained Gliwice's characteristic elements in the analysis, such as the river, the DTŚ expressway and the quarter buildings.

With reference to the morphology of Gliwice, in Figure 15b, the expressway – reminiscent of the Drogowa Trasa Średnicowa – and the river – reminiscent of the Klodnica – can be identified in the foreground. Among the buildings, a tower can be seen, which is similar in shape to the Radio Station. The scale of similarity can be estimated at 40%.

a)

b)

Fig. 15. Illustrations of the edges of the city of Gliwice using artificial intelligence – plan (a), 3D model (b)
Source: Image generated by the artificial intelligence platform "Midjourney"

4.3. Areas of the city of Gliwice using artificial intelligence

Artificial intelligence depicted areas of the city of Gliwice, according to Kevin Lynch's theory, on a 2D map (Fig. 16a) and a 3D model (Fig. 16b), by depicting them as color-coded zones. The AI, with its variety of colors, highlights the presence of many types of areas in Gliwice.

Figure 16b highlights the quarter buildings, which are developments characteristic of the structure of Gliwice. The scale of similarity can be put at 15%.

a)

b)

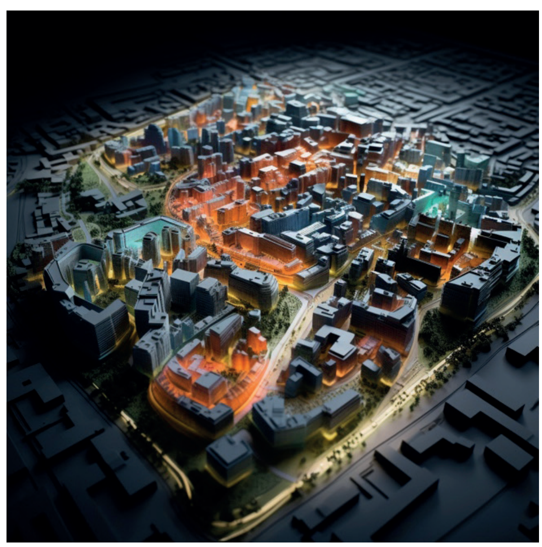


Fig. 16. Illustrations of the areas of the city of Gliwice using artificial intelligence – plan (a), 3D model (b)
Source: Image generated by the artificial intelligence platform "Midjourney"

4.4. Nodes of the city of Gliwice using artificial intelligence

The AI depicted the nodes of the city of Gliwice, according to Kevin Lynch's theory, on a 2D map (Fig. 17a) and 3D model (Fig. 17b), by depicting them as circles where the blue lines intersect. AI, on the model, does not highlight the nodes fully legibly.

In reference to the morphology of Gliwice, elements such as the expressway, which resembles the Drogowa Trasa Średnicowa, and the church, located among the development, which was identified as All Saints' Church, were highlighted in Figure 17b. The scale of similarity can be estimated at 40%.

a)

b)

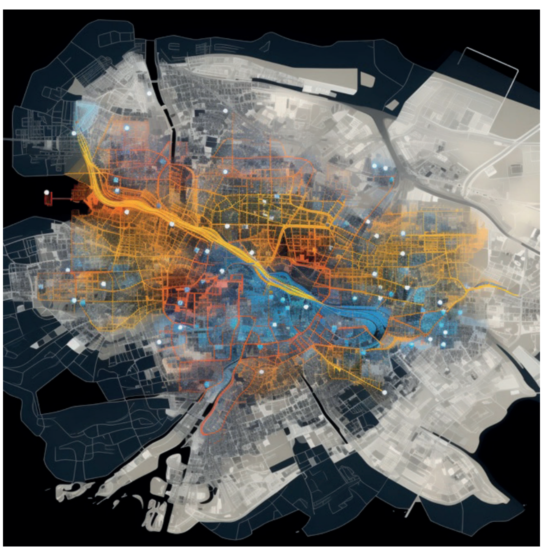
Fig. 17. Illustrations of the nodes of the city of Gliwice using artificial intelligence – plan (a), 3D model (b)
Source: Image generated by the artificial intelligence platform "Midjourney"

4.5. Landmarks of the city of Gliwice using artificial intelligence

Artificial intelligence depicted the landmarks of the city of Gliwice, according to Kevin Lynch's theory, on a 2D map (Fig. 18a) and 3D model (Fig. 18b), by depicting them as circles on a map and color-coded objects. AI, with the help of colors, shows the division into different types of landmarks (e.g., height or volume dominants) and marks the areas of their prevalence in a given area.

In Figure 18b, a church tower is highlighted, which can be identified as St. Bartholomew's Church through its form and shape. The scale of similarity can be estimated at 20%.

a)



b)

Fig. 18. Illustrations of the landmarks of the city of Gliwice using artificial intelligence – plan (a), 3D model (b)
Source: Image generated by the artificial intelligence platform "Midjourney"

5. DISCUSSION

Table 1 shows the different methods used in the representation of city image elements. Included in the comparison is the method pioneered by Kevin Lynch and the other methods the authors analyzed in the case study: mock-ups, 3D models, panoramic photos, augmented reality, virtual reality and AI. All those mentioned are intended to illustrate mapping.

In the course of experimenting with AI, 10 attempts were made to generate images of the city's structure using AI. These attempts are summarized in Table 2 and describe the effects that were obtained. The emphasis of the study was on obtaining clear and readable effects in the images. A three-point scale was adopted to evaluate the generated images as the effects of the keywords used: (–) not present, (+/–) partially present, (+) present.

Table 1. Comparison of different methods used to represent city image elements

CITY	METHOD	DISTRICTS	NODES	PATHS	EDGES	LANDMARKS
Boston, New Jersey, Los Angeles, K. Lynch	drawing	filling with hatch	circle with hatch	black continuous lines	black dashed lines	star, triangle
Bolonia	Mock-up	solid	vertical sticks of different heights	orange threads	black threads	photos of the objects in their locations
Aachen	3D model	orange flat outlines, trace of the city's buildings	green cylinders	light green continuous lines	red thick continuous line	blue solids
Zabrze	3D model, panorama	colorful flat outlines, trace of the city's simplified geometry	blue cylinders	grey continuous lines	red thick continuous line	yellow solid of the building
Gliwice	3D model, panorama, augmented reality	grey flat outlines, trace of the city's simplified geometry	blue cylinders	black thick continuous line	thin blue continuous line	grey cylinders
GZM	3D model, augmented reality	trace of the GZM in terms of a kilometer grid with a color-coded breakdown of the predominant type of terrain in a given quadrant	orange cylinders	orange three-dimensional lines	blue and yellow three-dimensional lines	red cylinders
Gliwice	AI-generated image	color-coded areas	circles where the blue lines intersect	blue, orange and white lines	separate with blue and white zones, highlight in orange delineating development	circles and color-coded highlights

Source: own work

Table 2. Comparison and rating of the effects of using different keywords for image generation using AI

Attempt No.	KEYWORDS	Readability of city image elements in 2D plan	Readability of city image elements in 3D image	Rating of the connection between the generated image and the city
1.	The image of the city Gliwice	–	–	–
2.	'The image of the city' by Kevin Lynch, Gliwice	–	–	–
3.	'The image of the city' by Kevin Lynch, Gliwice, urbanism	–	–	–
4.	'The image of the city' by Kevin Lynch, Gliwice, urbanism analysis	–	–	–
5.	'The image of the city' by Kevin Lynch, urbanism analysis of Gliwice, Poland	–	–	–
6.	'The image of the city' by Kevin Lynch, urbanism analysis map/model of Gliwice, Poland	–	–	+/-
7.	'The image of the city' by Kevin Lynch, urbanism 2D/3D analysis map/model of Gliwice, Poland	+/–	+/–	+/–
8.	'The image of the city' by Kevin Lynch elements, urbanism 2D/3D analysis map/model of Gliwice, Poland	+/–	+/–	+/–
9.	'The image of the city' by Kevin Lynch, urbanism 2D/3D analysis map/model of Gliwice, Poland, elements of paths, edges, districts, nodes and landmarks	+/–	+/–	+
10.	'The image of the city' by Kevin Lynch, urbanism 2D/3D analysis map/model of Gliwice, Poland, with highlighted elements of paths, edges, districts, nodes and landmarks	+	+	+

Source: own work

Trial 1 generated graphics showing the city in abstract and unreal form. Trials 2 and 3 produced results without results, they did not show the urban structure either as a map or as a model, they showed the city as a painted, even fairy-tale, image. In sample 4 and 5, the urban structure began to take shape, but in a very schematic form – with links and points. In sample 6 the images were presented in the form of a plan and model of the city, the structure of the city of Gliwice began to be identified. In sample 7 and 8, maps and models were already presented in more detail, and the results showed individual elements characteristic of the city image, but in a very general form. In sample 9, the individual elements that make up the city image were shown, but they were not quite clear and noticeable. The most authoritative results were obtained in sample 10, where the individual elements of the city were properly highlighted for easier reading and understanding.

Generating an image using AI may not be efficient, due to the operation of the algorithm and building associations based on the data found by AI in the web space. Prompting according to a very detailed key gives better results, because the greater amount of information, presented in the generated image, is not the result of individual data completion by AI. For this reason, a sample of 10 prompts was presented in the results of the study, aimed at obtaining the most authoritative effect.

The above experiments contradict the systemic, data-driven and GIS-based approach to city analysis that Filomena, Judith A. Verstegen, Ed Manley (2019) [29], Dalton and Bafna [30], Bim Jiang [31], among others, attempt to implement.

The trials conducted allow the following conclusions. In most cases, the resulting images are not consistent with the location in terms of scale and city-specific elements. Some of its elements were overscaled, for example, rivers (Fig. 13a, 13b, 14a), dominants (Fig. 13b). The generated city plans should also be considered random: although attempts were made to generate images of Gliwice, which has a medieval origin and the structure of the former outline of the oval shape of the city walls is still legible, most images do not reflect this.

6. CONLUSIONS

The city image mapping experiments described in the article should be considered promising. The use of mock-ups, 3D models, augmented reality and virtual reality should be considered effective in the symbolic and spatial virtualization of city image elements. Panoramic shots or simplified 3D geometries superimposed on city plans that synthesize images should be considered to concretize selected places, corresponding to objects that we can easily identify with selected familiar places. AI-generated images intended to represent elements crystallizing the image of a city, referring to Kevin Lynch's theory, should be considered useless in the study of selected cities due to their lack of consistency with selected places. It should be conjectured that the methodological thinking characteristic of the theory is not obvious to be used by AI, so as to generate precise images, relating to locations at the same time. It can be guessed that system wide mapping of city image elements can be implemented using dedicated algorithms, based on GIS probably using machine learning or using neural networks. The reliability of the results of future studies of this type will mainly depend on data that are increasingly available. Therefore, the future of city image generation may soon change significantly.

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