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ORIGINAL ARTICLE

Application of mobile mapping technology in automating inventory and legal compliance checks for advertising signs and devices

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Abstract

The increasing number of advertisements in public spaces, combined with ineffective control mechanisms, leads to growing visual pollution in urban areas. The aim of this study was to develop and evaluate a semi-automated workflow for the inventory and legal compliance assessment of advertising signs and devices using mobile mapping data and geographic information system (GIS) tools. The analysis of legal regulations reveals that their complexity significantly hampers the processes of recording, monitoring, and conducting administrative proceedings. To address these challenges, a methodology based on data collected using a mobile mapping system was developed. This system includes Light Detection and Ranging (LiDAR) scanners, a 360-degree camera, and a Global Navigation Satellite Systems (GNSS)/ Inertial Measurement Unit (IMU) positioning unit, enabling rapid and accurate spatial data collection. The proposed solution covers the entire process – from field data acquisition, through processing, legal and spatial analysis, to support for administrative procedures. Research results confirm the high effectiveness of the proposed approach, demonstrating a clear advantage of mobile laser scanning (MLS) technology over traditional inventory methods in terms of accuracy and operational efficiency. Dedicated software tools were also developed, extending the functionality of the open-source QGIS software. The Street3D application enables comprehensive recording, verification, and analysis of advertising devices in compliance with current regulations. This methodology can significantly support municipal authorities in shaping an orderly, functional, and aesthetically pleasing public space.

Keywords: outdoor advertising, spatial order, spatial analyses, 360-degree photo documentation, laser scanning, landscape resolution

1 Introduction

The rules for the implementation of signs and advertising devices in Poland derive from generally applicable regulations, i.e., the Construction Law Act (Act, 1994), as well as local laws, i.e., resolutions adopted at the municipal level, known as "landscape resolutions."

The preparation of a landscape resolution by the municipality is not formally preceded by the obligation to conduct an inventory and analysis of existing advertisements, small architectural objects, and fences in public spaces. However, such actions are recommended as they provide essential data for developing effective regulations. An example of a municipality that conducted such an inventory is Rumia, where 4,387 outdoor advertising carriers were inventoried, which allowed a better understanding of the scale of the problem and the development of appropriate regulations at the municipal level, i.e., the aforementioned "landscape resolution" (Naszemiasto.pl, 2021).

In Poland, over many years, the problem of illegal and arbitrary placement of signs and advertising devices on properties has grown, causing significant disorder in public spaces.

The Supreme Audit Office (NIK) report revealed that on streets controlled by NIK in selected cities, as many as 58% of advertisements were placed illegally in the road lane (i.e., without the required permit) or in violation of the conditions of administrative decisions. The most significant irregularities were noted in Zakopane (97%) and Wrocław (84%), while the lowest percentage of illegal advertisements was found in Gdańsk (17%) (NIK, 2017).

Currently, the process of inspecting the legality of advertising

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placement, including those placed in road lanes, is most often performed manually, and advanced geographic information system (GIS) tools are not used for its operation and optimization. Due to both staffing and technical difficulties in building supervision authorities, road managers, and municipalities (lack of effective tools to support verification or control), a significant percentage of advertisements are placed on properties illegally.

The high share of illegal advertisements in many cities primarily indicates the ineffectiveness of traditional inspection methods used, among others, by road managers. This problem points to the urgent need to apply modern solutions, such as mobile mapping systems and GIS tools, which can significantly improve the inventory and enforcement processes.

A variety of approaches have been used for monitoring outdoor advertising in urban space, including manual field inspections, close-range and immersive photogrammetry, traditional geodetic measurements, conventional photographic documentation, oblique imagery from Unmanned Aerial Vehicles (UAV) or manned platforms, airborne Light Detection and Ranging (LiDAR), and computer-vision-based detection methods. These approaches differ substantially in geometric accuracy, inventory completeness, operational efficiency, street-level visibility, and evidential value for administrative proceedings. In practice, many of them are suitable only for selected tasks, such as documenting individual objects, detecting large billboards, or analysing visual impact. Still, they do not provide a comprehensive workflow for large-scale street-level inventory combined with legal compliance assessment. This creates a clear need for an integrated solution that links precise mobile data acquisition, spatial analysis, and administrative verification within a single operational framework. The study focuses on developing and evaluating a semi-automated methodology for the inventory and legal compliance assessment of advertising signs and devices using mobile mapping systems and GIS tools. The proposed approach enables the transfer of a substantial part of fieldwork to the office and allows focus on analytical tasks. The developed system acquires three-dimensional data, including point clouds and 360-degree photoregistration, and uses them to create a 3D advertising database. By integrating these data with cadastral information and administrative records on building permits and construction notifications, the system supports more efficient verification and management of advertising devices.

Recent international literature treats visual pollution not only as an aesthetic problem, but also as a measurable urban-environment phenomenon that can be assessed through GIS, image-based analysis, and perception-oriented methods (Adam et al., 2022; Gao et al., 2024). In parallel, research on mobile mapping, spatial decision support, and digital-twin-oriented urban monitoring emphasizes the importance of interoperability, repeatable workflows, and institutional usability of geospatial systems for municipal applications (Elhashash et al., 2022; Wen and Li, 2022; Scolamiero et al., 2025).

Against this background, the research gap addressed in this study concerns the limited availability of integrated, compliance-oriented workflows dedicated to outdoor advertising, i.e., workflows that combine street-level acquisition, attribute-rich 3D inventory, GIS-based analysis, and support for legal verification within one operational environment. Accordingly, the scientific contribution of this paper is methodological and applied: it proposes and evaluates such a workflow and demonstrates how dedicated GIS software can support legally grounded advertisement management in municipal practice.

2 The legal principles for the placement of signs and advertising devices

The Construction Law (Act, 1994) in Article 28 establishes the principle that construction works can only commence based on a building permit decision, subject to Articles 29–31.

Article 29, paragraph 3, point 3c states that a building permit decision is not required, but a notification referred to in Article 30 is required for construction works involving the installation of signs and advertising devices, except for illuminated and backlit advertisements located outside built-up areas as defined by road traffic regulations.

Article 3, point 3 of the Construction Law Act (Act, 1994) defines the term "structure" as any construction object that is not a building or a small architectural object, and includes in this category, among others, free-standing signs and advertising devices permanently attached to the ground.

Therefore, when placing an advertising sign, one must always consider the statutory obligation to notify architecture and construction department of the relevant county office or city office with county rights. In the case of a free-standing structure permanently attached to the ground, a building permit must be obtained (it is not just the installation of an advertisement, but the construction of a structure permanently attached to the ground).

The requirement to obtain a building permit also applies to the installation of illuminated and backlit advertisements located outside built-up areas as defined by road traffic regulations.

Article 4, point 23 of the Public Roads Act (Act, 1985), specifies that an advertisement is a sign or advertising device placed in the field of view of a road user, as defined in Article 2, points 16b and 16c of the Act of March 27, 2003, on Spatial Planning and Development (Act, 2003), as well as any other visual information carrier, along with its structural elements and attachments, that is not a road sign referred to in regulations issued under Article 7 of the Act of the Road Traffic Law (Act, 1997), a sign set up by the municipality informing about objects located by the road, including public utility objects, a sign informing about the form of monument protection, or an information board about the name of the form of nature protection as defined in Article 115 of the Act on Nature Protection (Act, 2004).

Additionally, it is necessary to cite the definitions referred to in the Public Roads Act, which are contained in the Spatial Planning and Development Act (Act, 2003). According to Article 2, point 16b of the Act, an advertising sign is a material object intended or used for the display of advertisements along with its structural elements and attachments, with a flat surface used for the display of advertisements, in particular, advertising banners, advertisements affixed to building windows, and advertisements placed on scaffolding, fences, or construction site equipment, excluding small everyday objects used according to their intended purpose.

Meanwhile, according to Article 2, point 16c of the Spatial Planning and Development Act (Act, 2003), an advertising device is a material object intended or used for the display of advertisements along with its structural elements and attachments, other than an advertising sign, excluding small everyday objects used according to their intended purpose.

According to Article 37a of the Spatial Planning and Development Act (Act, 2003), with regard to advertisements, it provides the optional possibility for the Municipal Council to adopt a resolution establishing the rules and conditions for the placement of small architectural objects, advertising signs and devices, and fences, their dimensions, quality standards, and types of building materials that can be used. The Supreme Administrative Court commented on this optionality in its ruling of November 5, 2024, case number II OSK 3/24, stating that Article 37a of the aforementioned act "provides the possibility" for the municipal council, but does not mandate the adoption of such a resolution. This resolution, known as the landscape resolution, is a local law act.

Such a resolution may specify the rules and conditions for the placement of advertising signs and devices, including their dimensions and the number of signs that may be placed on a given property by the entity conducting business there.

In this resolution, the municipal council may also establish an absolute ban on the placement of fences and advertising signs and devices, excluding signs.

Article 37d provides for the imposition of penalties on the entity that placed an advertising sign or device in violation of the provisions of the ”landscape resolution.” Such an entity is subject to a financial penalty. If it is not possible to determine such an entity, the penalty is imposed on the owner, perpetual user, or independent possessor of the property or construction object on which the advertising sign or device was placed.

Also significant in this matter is the Judgment of the Constitutional Tribunal of December 12, 2023, case number P 20/19, which relates to Article 37a, paragraph 9 of the Act on Spatial Planning and Development (Act, 2003), to the extent that it requires the resolution referred to in Article 37a, paragraph 1 of the aforementioned act to specify the conditions and deadline for adapting existing advertising signs and devices, erected based on a building permit, to the prohibitions specified in this resolution, without providing statutory grounds and procedures for seeking compensation by entities obliged to remove them. The Constitutional Tribunal states that this provision is inconsistent with Article 21 in conjunction with Article 2 of the Constitution of the Republic of Poland. This judgment confirms that legally erected objects of this type cannot be subject to ”landscape resolutions” and cannot be ordered to be dismantled or modified.

In summary, an investor who intends to carry out works involving the placement of an advertising sign or device will be subject to general regulations, i.e., the Construction Law Act, and in special cases will be forced to consider the rules resulting from local law acts, i.e., the so-called landscape resolutions. Additionally, all such devices erected before the entry into force of a given landscape resolution, in accordance with the Constitutional Tribunal’s resolution P 20/19, will not be subject to any adaptation to the rules established in such a resolution – it only applies to newly erected objects. The Supreme Administrative Court has already commented on this matter (after the Constitutional Tribunal issued the aforementioned resolution) in its judgment of December 19, 2024, case number II OSK 631/23, stating: “*in light of the established unconstitutionality of Article 37a, paragraph 9 of the Spatial Planning and Development Act, it must be agreed that the introduction in the landscape resolution of regulations requiring the adaptation of legally erected advertising signs or devices, based on a building permit before the date of its entry into force, without any compensatory mechanism (protective regulations), is illegal.*”

The Council of Europe report cited here is used only as an illustrative background source rather than as a comprehensive comparative legal review. The countries discussed below were selected because they exemplify different institutional settings of outdoor advertising control described in that report, including regional, municipal, and nationally framed approaches.

For example in Belgium as stated by Strebler in Council of Europe Strebler (2017), “*referring to Brussels-Capital Regional Government (Decree, 2006), the regional rules applicable to the Brussels Region are geared to the harmonious integration of advertising into the urban landscape (structures visible from the ”outdoor” public area) while avoiding any visual nuisance, prohibiting support structures that are dangerous for road safety, guaranteeing the liveability of dwellings and regulating new forms of advertising (wraps and vinyl sheeting). Advertising and corporate signage are, in principle, subject to prior planning permission, unless they benefit from the exemption granted for temporary or small-sized structures.*”

“*In Germany, in the absence of federal legislation, outdoor advertising falls essentially within the remit of the Building Code for which the individual Länder define the implementation procedures. Installations require (municipal) planning permission and are subject to local taxation. They must fit in with the urban landscape of town centres; in residential areas, only house-building businesses may carry advertising (with an exception made for special events). Advertising is prohibited in natural or sparsely populated areas*” (Strebler, 2017).

Similarly, in Italy (see Strebler, 2017), municipalities establish requirements for advertising placement, and, similarly to Germany and Belgium, permits are required to install advertising. As in Poland, in Italy, restrictions on advertising placement are also imposed by the Highway Code.

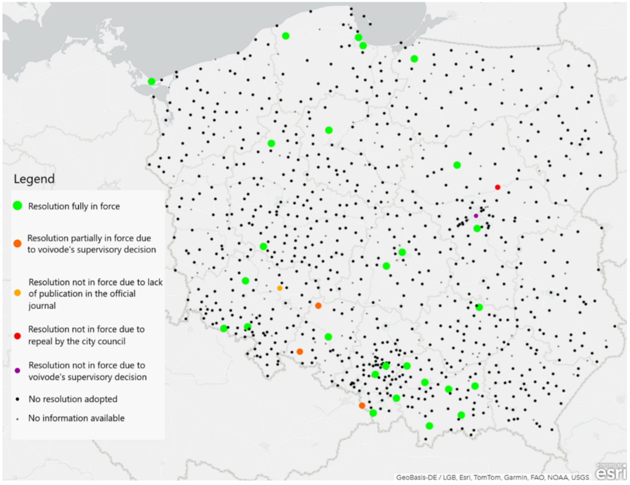

Figure 1: The implementation status of landscape resolutions in Poland (source: https://web.archive.org/web/20251012233155/https://sprzatamyreklamy.org/uchwaly-krajobrazowe-w-polsce/)

Similarly, in France (see Strebler, 2017) “*It is prohibited in principle outside urban districts and in ”environmentally sensitive” areas and must comply with various requirements (density, surface area, site, etc.); only certain forms of advertising (light projection, building wraps) require prior permission; in other cases the authorities are merely notified beforehand of plans to install other types of structure. The municipal or inter-municipal authorities may pass by-laws governing advertising with a view to limiting the options open under national regulations. Safety concerns may also constitute grounds for restricting the possibilities of roadside advertising.*”

These examples should therefore be treated as illustrative rather than exhaustive, and they are used here only to provide a broader European context for the Polish case.

2.1 Current state of implementing Landscape Resolutions in Poland

According to NIK (2017), the actual state of managing advertisements in urban spaces led to alarming conclusions. Cities largely failed to use the available legal tools to improve spatial order effectively. According to data from the Ministry of Culture and National Heritage, as of December 31, 2024, landscape resolutions were adopted in 79 municipalities in Poland, including six provincial cities: Łódź, Kraków, Opole, Gdańsk, Kielce, and Poznań. In 2024, they were also adopted in Jastrzębie-Zdrój, Łomianki, Muszyna, Zduńska Wola, Ustrzyki Dolne, and Radzymin, bringing the total to six new resolutions. The following map (Figure 1) illustrates which cities and municipalities have decided to regulate the placement of advertising boards and devices through landscape resolutions, which serve as a tool for organizing public space in terms of advertising exposure.

The latest research by the NIK (2023) indicates several key issues related to advertising in urban public spaces:

- Ineffectiveness of law enforcement – landscape resolutions are implemented unreliably or not adopted (e.g., in Wrocław);
- Illegal advertisements – a high percentage of illegal advertisements, especially in road lanes;
- Inventory of advertisements as a key process – a thoroughly conducted inventory enables determining the number, types, and locations of advertisements, which forms the basis for

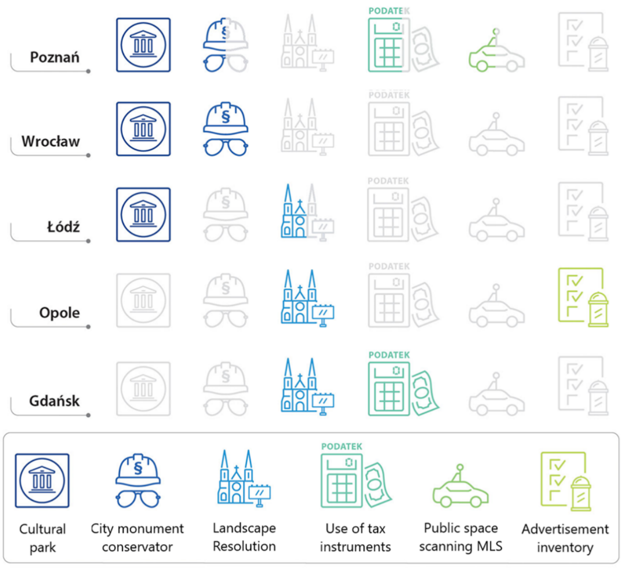

Figure 2: Tools used by the audited municipalities in the process of managing advertising in public spaces from 2020 to 2023. Coloured icons indicate tools reported as used in a given city, whereas grey icons indicate tools not reported in the NIK summary (NIK, 2024).

Figure 3: Measurement system based on a 360-degree camera and Real-Time Kinematic (RTK) GNSS/Inertial Navigation Systems (INS) by Mosaic

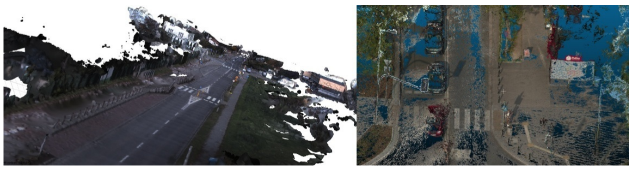

Figure 4: 3D mesh generated from 360-degree camera photos

designing effective legal and organizational solutions;
- Financial losses – improper determination and enforcement of fees result in loss of revenue;
- Systematic control of advertisement legality – the need to ensure regular control over advertisements in urban spaces, especially on municipal properties and State Treasury lands managed by municipalities.

The tools used by cities, including mobile cartographic systems and GIS tools, indicate their potential in improving the management of urban advertisements. These technologies enable quick, reliable, and precise inventory and data analysis, which can bring many benefits, such as (NIK, 2024):
- effective monitoring of the implementation of landscape resolutions;
- access to reliable management information that can be used in administrative and enforcement procedures;
- tightening the system of collecting fees for occupying road lanes, including introducing penalties for illegal occupation. This would increase city revenues, especially if a landscape resolution containing fee regulations is implemented. This resolution may also provide for penalties for placing advertisements that do not comply with the applicable regulations;
- creating transparent and intuitive maps supporting the raising of social awareness regarding urban aesthetics.

Cities should strive to optimize the process of managing advertisements by implementing modern technologies that enable electronic documentation of the state of advertising surfaces and visualization of advertisements in the context of their surroundings. The high share of illegal advertisements in many cities primarily indicates the ineffectiveness of traditional control methods used by road managers. This problem indicates an urgent need to apply modern solutions, such as mobile mapping systems and GIS tools, which can significantly improve the process of inventory and enforcement of regulations. Figure 2 presents data from NIK (2024), illustrating the scale of illegal and non-compliant advertisements, further emphasizing the need for changes in the approach to managing the urban landscape.

An optimal solution is the use of GIS software, which enables the integration of spatial data from various sources, such as the locations of advertising media and administrative decisions. Registers from the Chief Inspectorate of Building Control (GUNB) and the National Official Business Register (REGON) can also be beneficial, as they are crucial in analyses of compliance with landscape resolutions. The REGON database allows the identification of business entities, enabling precise determination of which advertising media are signs and which constitute other forms of advertising. Additionally, systems and portals from which fees related to the use of advertising space may come are also important.

This enables advanced spatial analyses and effective data management. Another important aspect is the visualization of information, which allows the adjustment of the aesthetics of advertisements to the surrounding urban space.

2.2 Current state of research and discussion on the use of mobile mapping in the inventory of advertising boards and devices

Kwiatek (2015) demonstrated that data registration using photographs and their subsequent analysis of information contained on advertising media can be effectively carried out using close-range photogrammetry. Close-range photogrammetry allows measurements based on photographs, while immersive photogrammetry relies on measurements from panoramic video. Thanks to technology that allows recording 10–15 panoramas per second while driving a car equipped with an immersive camera, Inertial Measurement Unit (IMU), and Global Positionig System (GPS), it is possible to precisely perform any measurement by indicating four points on a given advertising medium (Figure 3).

The authors believe, however, that this method has its limitations, such as imperfect representation of 3D space through the generation of a 3D mesh, which can negatively affect measurement accuracy and prevent precise measurement of advertisements placed in shop windows due to the lack of generated planes for such locations. Figure 4 presents an example of such a 3D mesh, showing the way space is represented and the related limitations in the context of advertising surface analysis.

Moreover, according to the authors, the method of 3D mesh reconstruction from photographs has its drawbacks, as moving objects, such as passing cars, can be recorded, temporarily obscuring advertising surfaces. This can result in data loss and errors when reconstructing objects located behind these obstacles. Unlike the described technology based on 3D space reconstruction from spherical photos, this problem does not occur in systems using laser scanners. Thanks to the high density of the beam and proper scanner mounting, it is possible to precisely map advertising surfaces and effectively eliminate moving objects from the final product. The photogrammetric method has a reconstruction flaw that practically prevents obtaining data for the "thickness" attribute of the advertisement, and this parameter is often included and described in landscape resolutions. It is difficult or often impossible to dimension other objects necessary to assess the compliance of the advertisement, such as architectural elements or distances from building number plates.

Chmielewski (2021) presents an advanced methodology for assessing the visual impact of large advertisements on the urban landscape. It describes an approach based on visibility range and spatial volume analysis, using tools such as 3D isovist. It is a spatial analysis tool that allows the determination of which parts of the surroundings are visible from a specific point in three-dimensional space. In the context of outdoor advertisements, it enables the assessment of how much a given advertisement dominates the field of view of a pedestrian or observer, which is particularly useful in evaluating its impact on the urban landscape. Complementing this method is voxel modelling, which involves dividing space into small volume units (voxels), allowing analysis of the obstruction of landscape elements. The use of these tools allows precise analysis of the visibility and impact of advertising objects on urban space, considering their effect on building elements, such as the facades of historic buildings.

The method presented by Chmielewski (2021) is based on advanced visibility analysis using Grasshopper software in the parametric modelling environment Rhinoceros. The key elements of this analysis are:

- Ray-casting – an algorithm that assesses the visibility of building surfaces from various viewpoints.
- Visualization of results – results are presented in the form of colour gradients indicating the degree of visibility of individual objects (e.g., building facades).
- Voxelization – modelling space in the form of three-dimensional grids (voxels), including elements such as vegetation or terrain obstacles.
- Voxel data – enabling the representation of complex elements, such as vegetation.

Regarding the method presented in the article, the authors note its limitation to large advertisements: The method focuses on large billboards, which limits its usefulness in analysing smaller media (e.g., signs, city lights). The data acquisition and analysis process described is more time-consuming compared to modern mobile laser scanning (MLS) techniques, which offer faster results. Photogrammetric spatial models (airborne laser scanning, ALS) are characterized by lower precision compared to MLS, limiting the ability to analyse small architectural elements in detail.

In addition to the approaches discussed above, other technologies used in practice for advertisement inventory also differ significantly in terms of measurement reliability, completeness of inventory, operational efficiency, and evidential value. Laser rangefinders, despite their high measurement precision, have limitations in collecting contextual information that is more easily obtained through photographs, such as the type of advertisement, its installation, or its relation to the surroundings. Data acquisition is relatively time-consuming, which is problematic for large urban areas with high advertisement density. While effective in point field control, in full inventory, where rapid data collection is required, this technology is too time-consuming. Theodolites and tachymeters, like laser rangefinders, enable very precise measurements and also enable detailed dimensioning of all geometric features of advertisements. This allows obtaining complete information about their surface, installation method, and location in space. Importantly, the data obtained in this way is highly reliable and can serve as indisputable evidence in administrative proceedings. Despite these advantages, this method requires manually measuring each location, which significantly extends inventory time and limits efficiency on a large scale. Traditional photography can serve as an auxiliary tool in documenting and verifying selected advertisements in relation to already existing records. It is especially useful as evidence in the case of point control or interventions reported by residents. It allows documenting the presence of an advertisement but does not provide complete measurement data or spatial information, limiting its application in comprehensive inventory.

Oblique photos taken from drones or manned aircraft are increasingly used in urban space analysis. They allow quick acquisition of a large amount of image data from a wide perspective, making them useful especially for inventorying large urban areas. However, this method has significant limitations. It does not allow the identification of all advertisements – especially smaller media, obscured by trees, buildings, or other obstacles. This limits its usefulness in comprehensive urban inventories.

Additionally, the geometric representation obtained from oblique photos is often insufficient for precisely determining the dimensions and locations of advertisements. This is confirmed in Ptak et al. (2023), where the YOLOv7 algorithm was applied for automatic detection and segmentation of billboards, including large road signs, based on photos from UAVs. The method achieved a detection effectiveness of 61% (mAP0.5 = 0.61) and a segmentation effectiveness of 60% (mAP0.5 = 0.60). These results pertain only to large advertising formats, such as freestanding billboards, which were the most recognizable category in the model. Despite high indicators, the system does not identify all objects with full effectiveness, meaning that even in the case of well-visible and trained advertisements, detection errors may occur. For smaller media or partially obscured objects (e.g., by trees or urban infrastructure elements), effectiveness significantly decreases. Therefore, this method is mainly used for detecting large billboards and does not allow a complete inventory of the entire spectrum of advertisements present in public space (Figure 5).

Importantly, detection effectiveness significantly decreases for smaller advertising formats or media partially obscured (e.g., by trees or architectural elements). Therefore, this method is primarily effective for large advertising boards like billboards and does not guarantee a complete inventory of all media present in urban space. Aerial scanning using LiDAR technology is a precise method of acquiring spatial data, but in the context of advertising inventory, it encounters several significant limitations. Firstly, the LiDAR scanning process does not cover all areas where advertisements may be located, especially in spaces with limited access, such as road lanes. Due to legal regulations, drone flights over roads or built-up areas may be restricted, making it difficult to cover entire urban areas accurately. As a result, despite its geometric accuracy, aerial LiDAR is not sufficient on its own for a complete, street-level, compliance-oriented inventory of advertising devices.

In summary, the reviewed approaches differ substantially in measurement reliability, inventory completeness, operational efficiency, and suitability for compliance-oriented urban analyses. Methods based solely on photographs, oblique imagery, or airborne data are often insufficient for the detailed assessment of street-level advertisements, particularly where geometric precision, contextual interpretation, and evidential value are required. These limitations indicate the need for an integrated street-level data acquisition and processing workflow better suited to the inventory and legal compliance assessment of advertising devices.

Figure 5: Visualization of detection results using the YOLOv7 algorithm (source: Ptak et al., 2023)

3 Methodology of the proposed MMS-based workflow

The methodology applied in this study consisted of five main stages: (1) acquisition of street-level spatial data using a mobile mapping system equipped with LiDAR, GNSS/IMU, and 360-degree cameras; (2) trajectory processing and generation of georeferenced point clouds and panoramic imagery; (3) detection of advertising objects followed by operator verification and geometric correction; (4) integration of the collected data with cadastral and administrative records in a GIS database; and (5) spatial, legal, and compliance analyses supporting reporting and administrative procedures. This workflow enabled the transformation of raw field data into a structured 3D database of advertisements and supported the semi-automated assessment of their compliance with applicable regulations.

This research was designed as a geospatial systems case study focused on the development and assessment of an integrated workflow rather than on a examined benchmark of individual sensors or detection algorithms. The input data consisted of street-level point clouds, panoramic imagery, GNSS/IMU trajectory data, cadastral and address layers, and administrative records related to building permits, notifications, and road-lane occupation. The outputs were a 3D advertisement database and GIS layers enabling location, geometry, and compliance-related attribute analysis.

In this study, a Mobile Mapping System (MMS) was employed to enable precise spatial data collection and comprehensive 3D mapping of the environment (Figure 6). The system is designed to support detailed inventory and analysis of outdoor advertising boards and devices, providing accurate information on their location, dimensions, and characteristics. The MMS integrates multiple sensors, including HD cameras, 360-degree panoramic cameras, LiDAR scanners, GNSS receivers, and IMU, allowing simultaneous acquisition of high-resolution spatial and visual data. This combination of components ensures accurate positioning of scanned points, automated processing of large-scale datasets, and adaptability to diverse terrain conditions. The flexibility of the system allows modifications to camera types and LiDAR generations, making it suitable for both urban and non-urban environments, while providing full control over data collection, synchronization, and subsequent processing.

Knowing the relationships between system elements, the position of scanned points in a specified coordinate system can be calculated. For accurate point position calculation, two positioning systems, namely GNSS and IMU, are used. The IMU measures the distance travelled between each GNSS measurement to ensure continuous positioning (Jansson and Horemuz, 2013). The IMU records the orientation, speed, and gravitational force of a moving object using accelerometers and gyroscopes.

Spatial data are acquired using measurement vehicles, differing in specifications depending on the type of terrain – urban or non-urban. The main advantage of developing a proprietary solution instead of purchasing ready-made systems and platforms is full control over component selection in terms of precision and cost, as well as the ability to adapt the system to specific needs flexibly. An important element was the ability to equip the system with various cameras, including 360-degree panoramic cameras, which allowed high-quality spatial data acquisition. The system's flexibility allowed it to be adapted and modified according to changing requirements and ensured full control over the data collection process, its synchronization, and further processing. The mobile mapping system used for measurements consists of the following subsystems:

- GNSS and IMU (average horizontal accuracy 3-5 cm, average vertical accuracy 5-10 cm);
- Frame cameras (recording the image in front of the vehicle) – analysis of cracks in the road surface, used in road surface condition analysis;
- LadyBug5 camera (records 360-degree images – 35 MP panorama);
- Laser scanning (point cloud) performed using a measurement set consisting of two integrated, simultaneously operating LiDAR devices.

In the proposed workflow, advertisement objects are first detected automatically in image data using an AI-based detection model. The preliminary detections are subsequently verified and geometrically corrected by an operator based on 360-degree imagery and point cloud data. This operator-assisted stage is necessary both to improve positional and geometric accuracy and to supplement the database with attributes that require human interpretation. In particular, selected non-standard or qualitative attributes, such as the technical or visual condition of the advertisement (e.g., good or poor condition), are assigned manually, as they were not included in the automatic detection model.

To improve reproducibility, the workflow can be described through three operational components: (i) acquisition and georeferencing of spatial data, (ii) operator-assisted verification and attribute completion, and (iii) GIS-based legal and spatial analysis. In the present study, validation had an operational character and was based on georeferencing quality, consistency of the result-

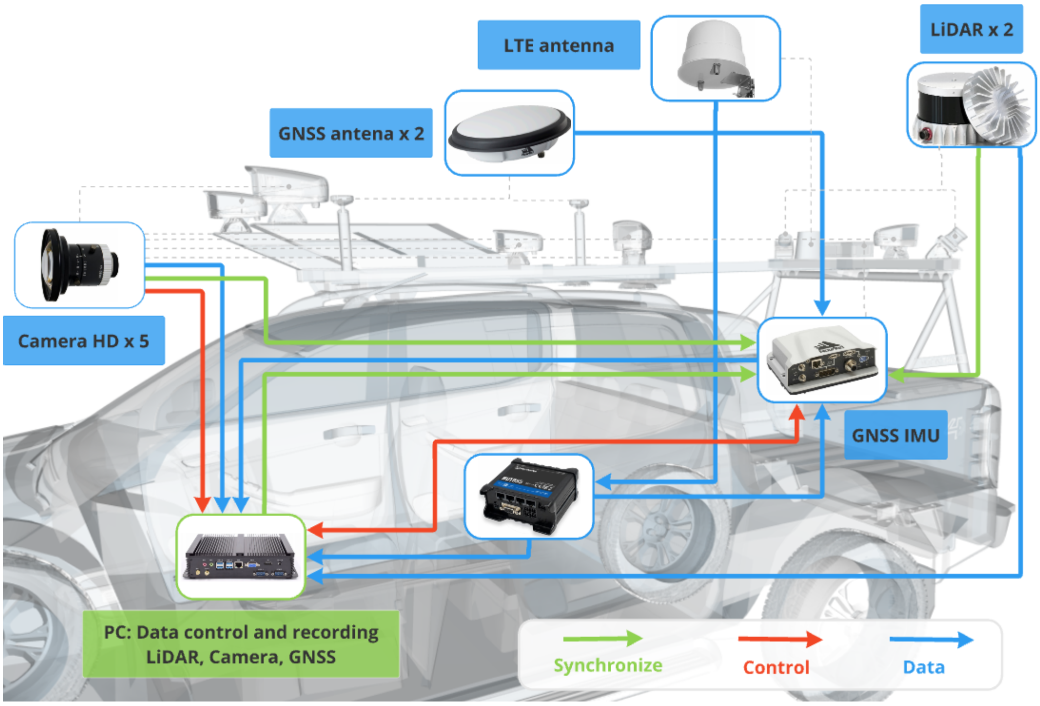

Figure 6: Conceptual drawing describing a mobile mapping system and the relationships between different components and system units

ing 3D inventory, and the system's ability to support compliance checks required in municipal practice. In the Pruszcz Gdański case study, photoregistration and 3D laser scanning were carried out in April 2022 along 102 km of streets, resulting in the identification of 5709 outdoor advertising devices with a combined surface area of 21,951.93 m^2. The measurement setup provided a survey range of 90 m and included a NovAtel GNSS/IMU unit (RTK positioning accuracy 1 cm; azimuth accuracy 0.1°), two integrated Ouster OS1-64 LiDAR sensors (accuracy ±1.5 cm; 64 channels; 2.6 million points per second), and a Ladybug5+ panoramic camera (8192 × 4096 px; effective resolution approx. 33.6 MP; nominal manufacturer resolution 35 MP). After post-processing, the LiDAR point density in built-up areas at 40 km/h ranged from 2250 to 2540 points/m^2 for ground surfaces, 1570 to 2100 points/m^2 for wall surfaces, and 1360 to 1480 points/m^2 for overhead surfaces; on country roads at 80 km/h, the respective ranges decreased to 1120–1260, 790–1050, and 660–740 points/m^2.

The measurement vehicles shown in the photo (Figure 7) have different hardware configurations, tailored to various applications, such as scanning in urban areas and non-urban areas. Various modifications concerning cameras and LiDAR generations allow adjusting the configuration to specific requirements and the type of terrain being scanned. Thanks to the flexibility of these solutions, it is possible to conduct precise measurements in different terrain conditions.

To justify the selection of the proposed workflow, a comparative assessment of selected technologies used in outdoor advertising inventory was carried out. The comparison focused on criteria relevant to municipal practice and legal compliance verification, including measurement reliability, completeness of inventory, street-level visibility, ability to assess hard-to-reach advertisements, operational efficiency, evidential value, and reusability of the acquired data. The assessment presented in Table 1 represents the authors' synthesis based on literature review, practical experience gained during work with datasets acquired using different technologies, and the functional requirements of advertisement inventory and compliance assessment.

As shown in Table 1, the proposed MLS-based workflow provides the most favourable combination of measurement reliability,

Figure 7: MLS used for data collection in the study, operated in cooperation with Smart Factor

inventory completeness, street-level visibility, evidential value, and operational efficiency for compliance-oriented urban applications. These characteristics formed the basis for the development of the proprietary MMS-based solution described in this study.

Table 1 should therefore be interpreted as a structured evaluation framework rather than a laboratory benchmark. The criteria were selected because they directly reflect the functional requirements of advertisement inventory in municipal administration, where measurement accuracy must be combined with evidential value, inventory completeness, and operational efficiency.

Based on these advantages, a proprietary MMS-based solution was developed to support the systematic inventory of public space, including the recording of advertisement locations and parameters. The acquired data are further processed in a GIS environment, enabling regular updates of the advertising database and supporting the monitoring of spatial changes, compliance assessment, and administrative decision-making.

Table 1: Comparative assessment of selected technologies for outdoor advertising inventory, including the proposed MLS-based workflow

Criterion	Proposed MLS*	Rangefinder	Theodolite	Photos	Oblique imagery	Aerial LiDAR
Accurate and reliable measurement	yes	yes	yes	no	no	yes
Ability to measure all advertisements	yes	no	no	no	no	no
Full street visibility	yes	no	no	no	no	yes
Measurement of hard-to-reach ads	yes	no	no	no	no	yes
Large-area inventory in a short time	yes	no	no	no	yes	yes
No need for fieldwork by municipal staff	yes	no	no	no	no	yes
Data integrity (unquestionable evidence)	yes	no	yes	no	no	yes
Complete ad information (area, type, mount, etc.)	yes	no	yes	no	no	no
Comprehensive technological support	yes	no	no	no	no	no
Reusability of data in other urban processes	yes	no	no	no	yes	yes

* "Proposed MLS" refers to the proposed MLS-based workflow developed in this study.

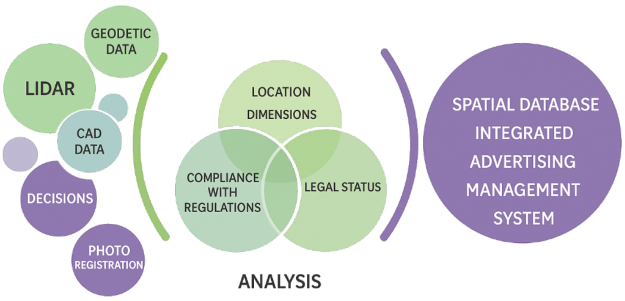

Figure 8: Research process model (source: Zharkovskyi, 2019)

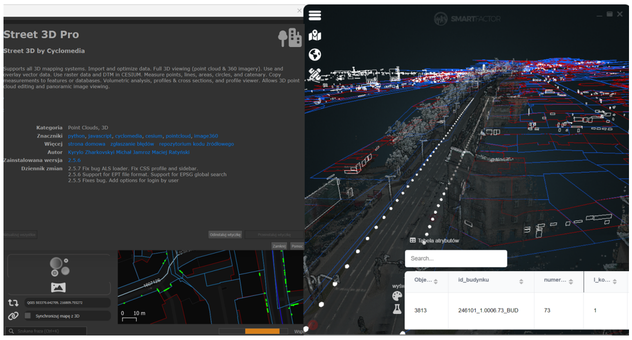

Figure 9: Street 3D program interface integrated with QGIS

4 Results – Inventory and analysis of outdoor advertising

As part of the preparatory research conducted in 2019, the author and co-author of this article faced technical challenges related to efficient data processing and analysis. The post-processing stage, which included integrating data from various sources and further processing it, including assigning appropriate attributes and conducting advanced spatial analyses, proved particularly challenging. These problems stemmed, among other things, from the need to adapt analytical methods to the complex structure of information about advertising media and ensure measurement accuracy.

The research process model, presented in Figure 8 in a simplified version, illustrates how data should be transformed into a spatial GIS database for managing advertisements. The database is based on PostgreSQL with PostGIS extensions (postgis_sfcgal).

In practice, the complexity of the process and the number of tools used at various stages meant that there was no single comprehensive solution. The following list of tools reflects the main stages of the research process, including applications and technologies necessary for efficient data processing and analysis in the context of managing advertising space in Nysa. GIS software used:

- Bentley MicroStation with TerraSolid extensions (TerraScan and TerraMath);
- Inertial Explorer – trajectory processing from GNSS based on ASG-EUPOS reference stations, enabling high-precision spatial data through satellite signal correction;
- Esri ArcGIS Desktop (including ArcScene for 3D data visualization);
- FME Desktop (Feature Manipulation Engine by Safe Software) for data transformation and integration;
- QGIS (Quantum GIS) as a spatial analysis tool.

The lack of ready-made (built-in) functionalities in the used programs forced the author to develop appropriate solutions. None of the available commercial solutions allowed the complete execution of the process, especially in terms of working with 3D data, such as point clouds and 360 photo registrations. Therefore, the author decided to create a comprehensive GIS solution based on open-source libraries to minimize costs and implementation time. The program was intended to be both intuitive and easy to use. After conducting an analysis, the author integrated several libraries, including Potree as a QGIS plugin, to handle 3D data (Figure 9).

Street 3D is a universal 3D GIS software that enables working with any spatial data from mobile, stationary, or airborne laser scanning (MLS, TLS, and ALS). The program is designed with versatility and efficiency in mind, allowing the integration, analysis, and visualization of 3D data from various sources. One of its main applications is the inventory and analysis of small architectural objects and advertisements in urban spaces (Figure 10).

The application utilizes a database tailored for working with 3D data, enabling their storage as complete spatial models. This allows users to conduct advanced spatial analyses, such as verifying advertisement locations or accurately modelling elements of urban infrastructure.

Technological environment and the role of individual components:

Potree – The library is used for efficient visualization of point clouds. It has been integrated to display and interact with MLS and ALS data smoothly, allowing visualization of large datasets in the browser without loss of performance. Loading scan data from the GUGiK API and synchronizing point clouds from mobile and airborne scanning;

Three.js – Used for rendering 3D graphics, it provides a realistic

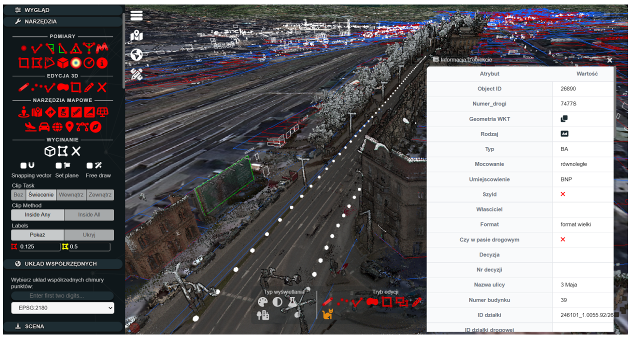

Figure 10: Street 3D program interface and 3D data

representation of objects in space, including vector data and 3D models. Creating visualizations of 3D data, such as small architectural objects and advertisements;

Cesium.js – The library supports advanced visualization of 3D maps and spatial data in a global context. Rendering the entire world and performing analyses such as object visibility (Viewshed Analysis);

Grid.js – Used for presenting data in tabular form, it provides an intuitive way to manage object attributes. Displaying lists of advertising objects and their detailed attributes;

jsTree – Handles data hierarchy, allowing intuitive management of data layers in the project. Organizing the structure of 3D data, such as the classification of point clouds;

OpenLayers – Visualization of 2D maps, synchronization of GIS views with 3D data. Displaying traditional GIS maps as backgrounds for spatial data;

MapTiler – Used for integrating the digital terrain model (DTM) on a global scale. Generating detailed base maps in 3D view with high precision, especially in urban areas;

Node.js and AWS SDK for JS – Backend support and integration with cloud services. They ensure smooth communication between the application and spatial data servers. Delivering cloud data (e.g., Amazon S3) and processing it in real-time;

Proj4.js – Handling spatial coordinate transformations. Working with various coordinate systems to ensure geographic consistency;

Python – Supports spatial analyses and backend integrations;

Electron.js – Used to create the desktop application.

5 Discussion – Challenges and limitations

Verification of compliance with landscape resolutions is challenging due to their complexity and the variability of provisions across different cities. These regulations are often detailed and encompass various requirements for advertising media, including dimensions, placement, illumination, and legal approvals. Landscape resolutions may define different types of advertising media (billboards, signs, lightboxes, banners) and specify the attributes they must meet. Table 2 presents a basic set of advertisement attributes commonly required to assess compliance with landscape resolutions in Polish cities. Each row in the table represents an attribute necessary for evaluation. The attributes presented in Table 2 were derived primarily from an analysis of selected Polish municipal landscape resolutions (Resolution, 2018, 2020), while publicly available implementation summaries were used as supplementary contextual sources. Optional attributes correspond to additional legal requirements, such as building permits, occupancy decisions, or compliance with road lane regulations. Geospatial attributes (coordinates, parcel IDs, and street names) enable precise spatial analysis and support the automation of compliance verification. In the analysed implementation scenario, the model assumed approximately 3,000 registered advertising media, with surface areas ranging from small formats (below 2 m^2) to large billboards (above 24 m^2). It was further assumed that around 5% of advertisements remained illegal and that such unauthorized installations persisted for more than 30 days, thereby contributing to the projected income from fines. Based on these case-specific assumptions and operational data obtained from the implemented system, the estimated revenues generated from enforcement actions related to approximately 3,000 advertisements were projected to range between EUR 920,000 and EUR 1.38 million. These figures should be treated as illustrative, case-based estimates rather than a universal revenue model for all municipalities. Although the use of advanced tools such as Street 3D integrated with QGIS represents a significant step toward automation and improved spatial accuracy, it also requires careful planning of data acquisition, processing, and integration. Nevertheless, the estimation was grounded in real data obtained from the implemented system, providing a useful basis for assessing the technical and economic efficiency of the proposed approach.

The integration and processing of such detailed spatial and attribute data introduce additional technical and organizational challenges. These include the need for consistent data standards, high-quality 3D models, and effective system interoperability, all of which are essential to ensure reliable automation and efficient implementation of landscape resolution monitoring. Proportions of advertising relative to the building: Regulations may specify what percentage of the building's surface, storefront, or floor can be occupied by advertisements, as well as regulate their distances from doors, advertising zones, or building numbers. The location of advertisements relative to public space is an important aspect of compliance assessment. In particular, their distances from elements of public infrastructure, such as bus stops, intersections, and other urban features, should be verified. Spatial-data-based automation significantly facilitates this process, especially in the context of complex and locally differentiated regulations. Three-dimensional building models enriched with precise spatial data allow accurate analysis of advertising surfaces in relation to façades, floors, storefronts, and other architectural elements. They also support the calculation of the maximum proportion of building surface that may be occupied by advertisements, taking into account all existing media. Effective compliance assessment also requires the identification and vectorization of key architectural elements, such as doors, windows, and address plaques. If LoD3 building models are available, they can be integrated into the database in the CityGML structure, further enhancing the accuracy of the analysis. Integration with the NMT GUGiK API: Connection with the Digital Terrain Model (DTM) and other databases allows precise determination of the height of advertisements above the ground, which is crucial for ensuring compliance with regulations regarding the height of advertising media installation. This enables automatic calculation of parameters such as height above ground level, allowing strict adherence to legal norms. Figure 11 shows the visualization of inventoried advertisements along with their attributes, which are automatically counted. Among these attributes are geometric parameters such as surface area, perimeter, total surface area, the number of advertising surfaces, and the width and height of the media. These automatic calculations allow precise tracking of advertisement sizes and their compliance with space requirements.

Additionally, integration with the Cadastral Parcel Location Service (ULDK) allows parcel searches, returning information about the cadastral parcel number on which the advertisement is located. The parcel location service allows precise assignment of advertising media to the appropriate land parcels. Connection with the State Border Register (PRG) enables address mapping, which supports the location of media in space, ensuring compliance with the current legal status, especially regarding street and town names.

From a broader urban-management perspective, the proposed solution can be interpreted as a domain-specific geospatial

Table 2: Basic set of advertisement attributes

Advertisement Characteristics	Advertisement Location	Optional Attributes
Type of advertising medium	X coordinate of the advertisement centroid	Was a building permit issued for the advertisement?
Mounting type (perpendicular, parallel, permanently attached to the ground, temporarily attached to the ground)	Y coordinate of the advertisement centroid	Has a building notification been submitted for the advertisement?
Placement (on building wall outside the ground floor area, on building wall in the ground floor area, on fence, in window, on doors)	Z coordinate of the advertisement centroid	Was a decision issued for occupying the road lane for the advertisement?
Is the advertisement a sign?	Street name	Compliance with the landscape resolution assessment (multiple attributes)
Is the advertisement illuminated?	Building number	Information from fee declarations (multiple attributes)
Advertisement width [m]	Road parcel identifier	Information from issued decisions (multiple attributes)
Advertisement length [m]	Parcel identifier where the advertisement is located	Distance from historical buildings
Advertisement perimeter [m]	Is the advertisement located in the road lane?	Geoportal link
Number of advertisement surfaces	N/A	N/A
Total advertisement area [m^2]	N/A	N/A
Height of the lower edge of the advertisement from the ground [m]	N/A	N/A

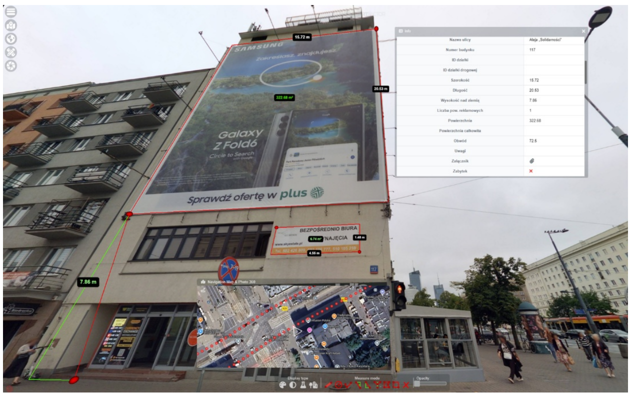

Figure 11: View of 360-degree photo documentation along with advertisement attributes

decision-support system and as a partial digital-twin component for outdoor advertising management. Its role extends beyond inventory because the same data infrastructure can support inspection planning, fee control, interdepartmental communication, and future integration with other urban datasets.

At the same time, implementation in other municipalities may be constrained by limited access to high-quality MLS data, data-maintenance costs, differences in local legal definitions, staff training requirements, and the need to integrate cadastral, address, and administrative registers maintained by different institutions.

Address and infrastructure mapping: Automatically assigning advertisements to specific buildings and their address numbers, and verifying their location relative to landmarks, protective zones, or other public infrastructure (e.g., hydrants, traffic lights) allows a comprehensive assessment of compliance. Checking whether the advertisement meets the requirements for minimum distances from key elements of the space, such as historic buildings, intersections, or protective zones. Thanks to advanced automation with over twenty functions, it is possible to:

- Conduct faster and more accurate verification of advertisements;
- Minimize human errors in the compliance assessment process;
- Standardize verification procedures, regardless of the specifics of local regulations;
- Efficiently manage public space through the ongoing updating of data on existing advertising media;
- Integrate these technologies with administrative processes, enabling cities to control urban space and better enforce landscape regulations more effectively.

One of the key issues related to the implementation of landscape resolutions is the lack of knowledge about the state of public space, including the actual number, type, and distribution of advertisements in the city. The lack of initial inventory and analysis of urban space results in resolutions that are not adapted to the actual state of public space. This, in turn, leads to difficulties in enforcing regulations, as their implementation faces social resistance or a lack of tools for effective monitoring and control of advertisements. In the long term, this situation perpetuates spatial chaos, reduces the effectiveness of local government actions, and negatively impacts the aesthetics of cities. Without reliable data, it is difficult to determine and set fees and penalties that are adequate to the scale and impact of advertising media in a given location. Cities risk proposing rates that are too low, which will reduce budget revenues, or too high, which may discourage investors and advertisers. Figure 12 shows the inventory of advertisements in the form of a cartodiagram, which displays the distribution of advertisements by type and surface area. Additionally, 100-meter segments in the road reference system represent areas with a concentration of advertising media. The pie chart dynamically presents the percentage breakdown of advertisements by media type, allowing a quick comparison of the spatial structure of advertisements in the analysed area.

Another limitation of the present study is that the evalua-

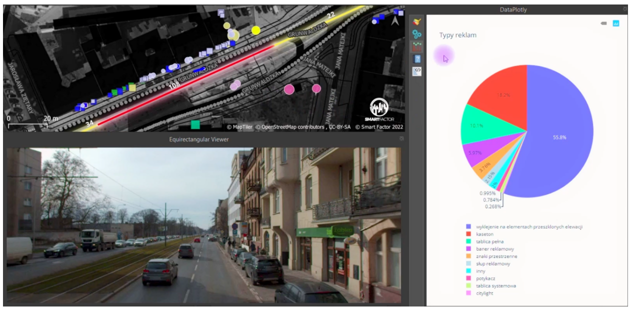

Figure 12: View of the QGIS and Street 3D interface. Inventory of advertisements in urban spaces.

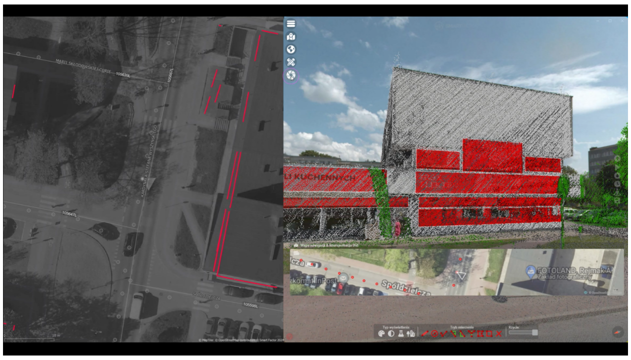

Figure 13: View of the QGIS and Street 3D interface with advertisement inventory data

tion is primarily functional and implementation-oriented. The manuscript demonstrates the suitability of the workflow for compliance-related tasks. Still, future work should include broader quantitative validation, e.g., comparative time measurements, repeatability tests, and accuracy assessment of selected geometric and thematic attributes across multiple case studies.

The program also enables effective inventory and management of small architectural objects, road infrastructure elements, and comprehensive measurement of green areas (Figures 13–16).

Thanks to the integration of the Potree point cloud loader library with the Three.js library, a tool has been developed that enables precise measurements of advanced parameters of spatial objects, including trees. The use of range control with a bounding box (bbox) in XYZ space allows the distinction of cloud points and the dynamic acquisition of information on parameters such as the circumference of the tree crown, its height, and volume (Figure 14).

Figure 15 shows the inventory of objects such as fences, which may be subject to regulations resulting from landscape resolutions. In the context of these elements, it is important to consider parameters such as material type, transparency, and metrics like height. This information allows the analysis of the impact of fences on public space, both in terms of safety and architectural barriers. Analysing these parameters is essential for assessing the impact of fences on the aesthetics and functionality of urban space, enabling the appropriate adaptation of advertising media to landscape protection requirements, as well as ensuring proper access to public space, while respecting urban planning and architectural principles.

Figure 14: View of the Street 3D interface. Measurement of tree height, volume, crown circumference, and trunk circumference.

Figure 15: View of the Street 3D interface. Inventory of fences.

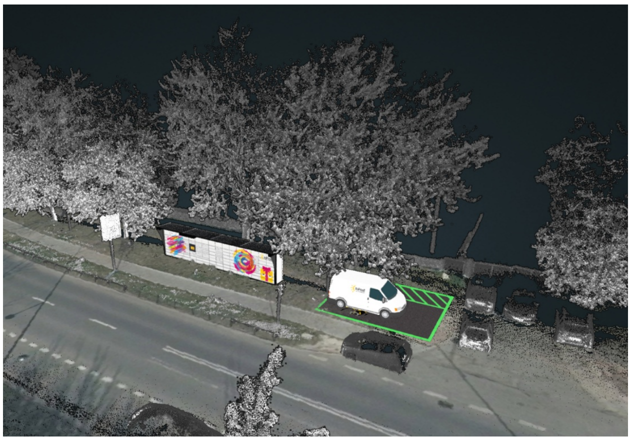

Figure 16: View of the Street 3D interface. Small architecture. 3D objects – designed.

The Street 3D program offers land development modelling functionality by integrating three-dimensional models of objects in formats such as OBJ, glTF, and IFC. The ability to introduce elements of small architecture, such as benches, trash bins, or lighting, allows the analysis of their impact on the functionality and aesthetics of public space. Visualization in a 3D environment supports planning processes, enabling the assessment of spatial relationships between existing buildings and planned objects. This approach promotes optimal land development, taking into account functional, aesthetic, and social aspects (Figure 16).

6 Conclusions

Current problems with managing outdoor advertising in cities stem from insufficient and fragmented legal regulations and difficulties in effectively enforcing landscape resolutions. The Street 3D tool, in synergy with QGIS, offers a comprehensive solution that meets key requirements for inventory, management, and spatial data analysis related to outdoor advertising. The system effectively supports administrative processes, enabling, among other things:

- Electronic documentation of advertisements: detailed inventory of media in urban space;
- Spatial analyses: verification of compliance with landscape resolution regulations and legal provisions, e.g., the Public Roads Act;
- Process automation: generating reports, analysing 3D data, and easy spatial visualization;
- Cloud integration: smooth storage and processing of large MLS, TLS, and ALS data sets;
- Effective monitoring of urban space in the context of implementing landscape resolutions. Precise measurements and spatial analyses, minimizing errors and increasing accuracy;
- Saving time and resources, which translates into more efficient management and increased city budget revenues.

The integration of Street 3D with QGIS provides municipalities with an effective tool for managing advertisements in urban space. The system supports the implementation of landscape resolutions, streamlines administrative procedures, and enables more precise and efficient public space management. Its versatility also allows it to be adapted to changing operational requirements and different terrain conditions.

Methodologically, the study contributes an integrated, compliance-oriented workflow that bridges street-level mobile mapping, GIS analysis, and administrative verification, thereby positioning advertisement control within the broader domain of geospatial decision support for urban management.

Nevertheless, the system has certain limitations. One of the main challenges concerns the integration of data obtained from less advanced control methods, such as conventional photographic documentation. Such photographs, including images submitted by citizens through mobile applications, may be used to verify whether a given advertisement is still present in the field by comparing them with the database of registered advertising media. To overcome this limitation, further system development is planned, including the implementation of automatic advertising-media detection using machine learning (ML) and artificial intelligence (AI). This would improve the automation of the verification process, enhance the efficiency of urban space monitoring, and further strengthen the management of outdoor advertising.

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Author Contributions

Conceptualization, K.Z., M.K. and P.K.; methodology, K.Z.; software, K.Z.; validation, P.K.; formal analysis, M.K. and P.K.; writing—original draft preparation, K.Z and M.K.; writing—review and editing, M.K. and P.K.; visualization, K.Z.; supervision, P.K.. All authors have read and agreed to the published version of the manuscript.

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