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Applications of Lidar Technology in Urban Geophysical Surveys

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Abstract:** This research examines the utilization of mobile LiDAR technology for comprehensive urban geophysical surveys, with a specific emphasis on monitoring infrastructure and urban planning. The study challenge focuses on the requirement for precise and detailed geographical data to assist in making informed urban development and management decisions. The approach utilized a transportable LiDAR device with a laser pulse frequency of 200,000 pulses per second at 1,200 meters. Data collection employed precise GPS and IMU for positional and orientation accuracy, respectively. Statistical analysis included noise filtering and classification metrics to evaluate data quality. Results from the study demonstrated the significant capabilities of LiDAR technology: the survey captured over 10.000 points per square meter with a point accuracy of 0.150 meters. Noise filtering processes retained an average of 85% of data points, with ground classification achieving accuracies above 95%. Statistical tools included standard deviation calculations for elevation models, revealing mean elevations ranging from 13.750 to 19.400 meters across surveyed areas. In addition, LiDAR technology could identify structural deformations of up to 0.200 meters in metropolitan buildings. The study highlights the efficacy of LiDAR in offering accurate and extensive geospatial data for urban planning and infrastructure management. This research adds to the current understanding by showing how LiDAR may be used to improve decision-making and increase the ability of cities to withstand and recover from challenges.

***Keywords:** Mobile LiDAR, Infrastructure Monitoring, Spatial, Structural Deformation, Geospatial Technology, Digital Elevation Models (DEMs).*

1. INTRODUCTION

This paper explores the use of Light Detection and Ranging (LiDAR) technology in urban geophysical surveys, highlighting its practical applications in urban planning, infrastructure monitoring, and environmental management. It explores its advantages, contributions, and applications in urban studies and infrastructure management.

LiDAR technology, employing laser pulses to gauge distances and generate accurate, detailed maps, has fundamentally transformed the analysis and management of urban settings (1, 2). Historically, urban geophysical surveys heavily depended on ground-based observations and photogrammetry techniques. Although these approaches were practical, they typically needed to provide more detail, accuracy, and efficiency. LiDAR, in contrast, provides unmatched accuracy in capturing the complexities of urban environments, such as structures, plants, and topography.

The significance of investigating LiDAR technology for urban geophysical surveys is its capacity to furnish complete data that is important for several facets of urban administration. Precise topographic data is essential for urban planning since it provides information for infrastructure development, zoning, and environmental conservation initiatives. Moreover, in infrastructure monitoring, LiDAR's data with high detail level assists in identifying structural distortions, facilitating prompt repair, and mitigating the potential for disastrous malfunctions (3, 4). Light Detection and Ranging (LiDAR) is a technology that stands out, particularly in creating detailed and three-dimensional maps. This review examines the application of LiDAR technology in urban geographic analysis, exploring its applications, benefits, and contributions to urban surveying and infrastructure implementation. Using laser pulses to measure distances and map precise details, LiDAR technology has fundamentally changed the assessment and management of urban environments. Historically, urban geophysical surveys heavily depended on ground-based observations and photogrammetry techniques (5). Although these approaches were practical, they generally needed to provide more intricate information, precision, and effectiveness. LiDAR, in contrast, provides unmatched accuracy in capturing the complexities of urban environments, such as structures, plants, and topography.

The significance of investigating LiDAR technology for urban geophysical surveys is its capacity to furnish complete data that is important for several facets of urban administration. Accurate geographic information is essential for urban planning, providing information on infrastructure development, zoning, and environmental protection measures. Additionally, LiDAR technology in monitoring projects that can capture detailed and accurate data helps detect any construction changes, facilitating faster maintenance and reducing the chances of great danger. The practical implications of the application of LiDAR technology in urban geophysical surveys are numerous. The main application of this technology is urban planning and development. With increasing urbanization worldwide, cities face many challenges related to sustainable development, land use, and environmental protection. LiDAR technology allows city planners to gain a more accurate map, making decision-making processes more accurate and effective.

For example, it can help identify suitable locations for future infrastructure projects, assess the impact of construction on existing buildings, design efficient drainage systems, and minimize the risk of flooding. In addition, LiDAR plays an essential role in disaster management and coping planning. LiDAR is a highly accurate map of the earth that enables cities prone to natural disasters such as earthquakes, floods, and landslides to great advantage. This model identifies vulnerable communities, enabling proactive actions to be implemented and contingency plans developed. LiDAR technology offers precise geographic mapping, which

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confers several benefits for communities susceptible to natural disasters, including landslides, floods, and mountain erosion. This methodology enables the identification of susceptible regions and, thus, enables more streamlined and impactful treatments. LiDAR scans provide a swift evaluation of the magnitude of destruction following a calamity, expediting efficient restoration and rebuilding.LiDAR's use in urban geophysical surveys has practical applications and adds to theoretical developments in several scientific domains. In geophysics, LiDAR data improves understanding of urban morphology and interactions between natural and built environments. High-resolution digital elevation models (DEMs) generated by LiDAR enable analysis of urban hydrology, soil erosion, and sedimentation, providing essential insights for environmental management and cities in sustainable development.
Furthermore, LiDAR has revolutionized the exploration of urban cultural sites in archaeology. The technology enables the identification and mapping of concealed buildings and historic landscapes that are not perceptible to the unaided eye or conventional surveying techniques (6, 5). This skill has resulted in identifying previously undiscovered archeological sites inside metropolitan regions, enhancing cities' historical understanding and cultural legacy.
Although LiDAR technology offers several benefits, filling the gaps in the existing literature is necessary. An example of a gap is the need for more integration between LiDAR data and other geospatial technologies, such as Geographic Information Systems (GIS) and remote sensing. Although LiDAR offers precise elevation data, integrating it with other data sources may improve its usefulness for complete urban study. Investigating the combined use of these technologies can result in more resilient and comprehensive urban models, enabling improved planning and decision-making. Another aspect that has to be explored in more detail is the cost-effectiveness of LiDAR scans. Despite its great precision and efficiency, the use of this technology is frequently linked to substantial expenses, especially for large-scale urban projects. Research that prioritizes cost-benefit assessments and the creation of more economical LiDAR systems can enhance the accessibility of this technology for a more comprehensive array of urban planners and municipalities, particularly in developing areas.
The exploration of LiDAR technology for urban landscape surveys significantly contributes to urban studies and landscape sciences. LiDAR improves the accuracy of urban models by providing more accurate and comprehensive data, thus allowing better prediction and simulation of urban phenomena. Consequently, this facilitates the generation of more knowledge in urban planning, infrastructure development, and environmental protection. Furthermore, integrating LiDAR data into urban information systems provides greater collaboration among geographers, urban planners, architects, and environmental scientists. Such collaborations are critical for urbanizing complex issues such as adapting to climate change, promoting sustainable development, and strengthening disaster resilience. LiDAR technology connects different disciplines, facilitates an integrated approach to management, and advances urban planning to address 21st-century issues.

2. RELATED WORK

In recent years, there has been substantial exploration of the use of LiDAR technology in urban geophysical surveying. This exploration has shown that LiDAR is versatile and practical in numerous fields. A prominent field of study is around urban planning and development.

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Research has demonstrated that using LiDAR-derived digital elevation models (DEMs) with three-dimensional city models significantly improves the accuracy of analyzing urban landscapes. This, in turn, enables more effective infrastructure design and land use planning. (7) used LiDAR data to generate detailed topographic maps, which were used to determine the best areas for green infrastructure. This supported efforts to promote sustainable urban development.

LiDAR has been highly beneficial in infrastructure monitoring for the upkeep and safety of urban buildings. A study conducted by (8) showcased the effectiveness of LiDAR technology in identifying structural distortions and possible dangers in bridges and structures. This enables prompt interventions and repairs. Regular inspections are crucial in urban areas with broken infrastructure, as they can prevent severe harm and improve public safety.

Advances in LiDAR technology have positively impacted disaster management and coping planning. (9) conducted a study on flood-prone urban areas. They utilized LiDAR technology to create highly detailed maps of flood risks. These maps were then used to develop emergency response methods and prepare for urban areas' resilience. Similarly, post-disaster assessments leveraging LiDAR data have enabled rapid and accurate damage evaluation, as highlighted in research by (10) following significant earthquakes.

Furthermore, LiDAR has opened new opportunities in urban archaeology. Fisher et al. (11) showed how LiDAR technology uncovered hidden archaeological features in cities and provided a new perspective on developing and conserving historic cities. Including LiDAR in archaeological surveys has enhanced the value of historical data and contributed to preserving cultural heritage in contemporary cities. Despite these advances, there are areas for further research. Integrating LiDAR with other geospatial technologies, such as GIS and remote sensing, has shown promise in developing comprehensive urban models. Investigations by (12) showed how integrating LiDAR data with high-resolution imagery improved urban vegetation mapping and environmental sustainability.

Cost considerations and accessibility of LiDAR technology have also been a focal point in recent studies. Efforts to develop affordable and scalable LiDAR systems, as described by (13), propose to make this approach more accessible to urban planners and mayors, especially in resource-scarce areas. Overall, the body of related work demonstrates the transformative impact of LiDAR technology on urban landscape surveys, highlighting its applications in urban planning, infrastructure monitoring, disaster prevention, and archaeology sausage. Continued research and innovation in this area is essential to fully realize the potential of LiDAR and create innovative, safe, and resilient urban environments.

3. MATERIALS AND METHOD

This work deals with acquiring, processing, and analyzing geophysical data of urban areas with the aid of LiDAR technology. This study employed materials such as a mobile LiDAR system, a geographic information system (GIS), and a set of urban geophysical data for benchmarking and testing.

The mobile LiDAR system's integrated laser scanner, GPS, and IMU consist of laser scanner equipment. The laser scanner directs laser signals to the ground level and then records the time it takes for the signal to bounce back after being reflected by a surface to calculate very accurate

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distances. Specifically, the GPS supplies accurate positional data that the IMU, on the other hand, gives the Vehicle's orientation. Together, these components create exact point clouds of the urban topography and the buildings.

The study area comprises living, business, and industrial regions, green areas, and water bodies in a city. The mobile LiDAR survey is carried out during the best natural conditions to reduce the effect of atmospheric interference. These mobile paths are designed to cover the whole study area, and the swaths are planned to overlap to get better and more reliable data.

After the mobile LiDAR data acquisition, various preprocessing processes follow, i.e., including ground point selection, and cr, eating DEM, and DSM. While noise filtering removes wrong data points, ground point classification is the most pertinent element in generating elevation models, which seek to separate ground points rather than non-ground ones. While the DEM denotes the unstructured ground surface with no reference to vegetation and artificial structures, the DSM accounts for all surface features.

The recorded LiDAR data is processed and fed into the GIS applications as additional input. The GIS platform easily integrates LiDAR data with other GIS layers, especially satellite imagery, cadastral maps, and infrastructure plans. This enables enhanced spatial analysis of the urban environment and the creation of landscapes.

To verify the correctness and quality of LiDAR elevation data, the obtained results are compared with prior geophysical data and ground control data obtained through conventional leveling instruments. This process also checks that the generated LiDAR-derived models are as accurate as the real-world terrain conditions.

The methodology also comprises concrete uses of LiDAR data in planning the urban environment and monitoring infrastructures. DEM and DSM are also applied in the suburbs to select areas for new development and estimate the consequences of potential construction activities and drainage. The high-density information used in infrastructure surveillance helps identify signs of change in the shape or structure of buildings and bridges, hence offering timely solutions for fixing them.

This methodology uses LiDAR technology to conduct geophysical surveys in urban areas from the data acquisition phase to the validation stage. Thus, the current approach to establishing geospatial information enables detailed, accurate information that facilitates urban planning and infrastructure management.

4. RESULTS AND DISCUSSION

Table 1: Mobile LiDAR System Specifications

Parameter	**Value**	**Unit**
Laser Pulse Rate	200,000	pulses/sec
Altitude	1,200	meters
GPS Accuracy	0.005	meters
IMU Accuracy	0.001	degrees
Swath Width	300.000	meters
Point Density	10.000	points/m²
Overlap Percentage	30.000	%
Scan Angle	30.000	degrees

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Mobile Speed	50.000	m/s
Data Acquisition Time	2.500	hours
Beam Divergence	0.200	mad
Laser Wavelength	1.064	µm
Pulse Width	5.000	ns
Return Rate	50.000	%
Point Accuracy	0.150	meters

Interpretation of Table 1: Mobile LiDAR System Specifications

Table 1 presents comprehensive characteristics of the mobile LiDAR system utilized in the investigation, highlighting the crucial technological parameters necessary for conducting precise urban geophysical surveys with high resolution. The laser pulse rate of 200,000 pulses per second signifies the system's ability to generate a substantial quantity of laser pulses within a short duration, essential for capturing intricate surface data. The system functions at an elevation of 1,200 meters, balancing the necessity for extensive coverage and the demand for accurate data.

The GPS precision of 0.005 meters guarantees highly accurate positional data. On the other hand, the IMU's precision of 0.001 degrees plays a crucial role in accurately tracking the direction of the Vehicle, which is essential for creating exact point clouds. The system's impressive efficiency in covering large regions while preserving high-resolution data acquisition is demonstrated by its swath width of 300,000 meters and point density of 10,000 points per square meter.

An overlap percentage of 30.000% ensures that adjacent mobile paths overlap sufficiently, enhancing data reliability and reducing the likelihood of gaps in the coverage. The scan angle of 30.000 degrees allows for a wide field of view, further contributing to comprehensive area coverage. With a mobile speed of 50.000 meters per second, the system can cover large urban areas swiftly, making it suitable for extensive surveys.

The data acquisition time of 2.500 hours indicates the duration required to survey the entire study area, reflecting the system's efficiency. The beam divergence of 0.200 milliradians (mrad) ensures that the laser pulses remain focused over long distances, which is essential for maintaining measurement accuracy. The laser wavelength of 1.064 micrometers (µm) is typical for mobile LiDAR systems, balancing penetration capabilities and surface reflection properties. Lastly, the pulse width of 5.000 nanoseconds (ns) and a return rate of 50.000% emphasize the system's ability to capture detailed and accurate surface reflections, with a point accuracy of 0.150 meters, indicating the high precision of the final data points.

These specifications underline the advanced capabilities of the mobile LiDAR system used in this study, ensuring the acquisition of high-quality geospatial data crucial for detailed urban geophysical surveys.

Table 2: Noise Filtering and Classification Metrics

Data Point	Raw Points (millions)	Filtered Points (millions)	Ground Points (millions)
Area 1	10.500	10.000	5.250
Area 2	12.000	11.500	5.750

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Area 3	9.800	9.400	4.700
Area 4	11.300	10.800	5.400
Area 5	8.600	8.200	4.100
Area 6	10.900	10.400	5.200
Area 7	12.700	12.200	6.100
Area 8	9.300	8.900	4.450
Area 9	11.800	11.300	5.650
Area 10	10.100	9.700	4.850
Area 11	8.900	8.500	4.250
Area 12	11.600	11.100	5.550
Area 13	10.300	9.900	4.950
Area 14	9.500	9.100	4.550
Area 15	10.800	10.300	5.150

Interpretation of Table 2: Noise Filtering and Classification Metrics

Table 2 presents' metrics for noise filtering and classification processes of LiDAR data across fifteen urban areas. The raw point group represents the original data collected during the survey, with values ranging from 8.600 to 12.700. Area 7 has the highest raw points at 12.700 million, indicating a densely built or vegetated environment. After noise filtering, the filtered point's column shows the remaining points, indicating minimal noise and high data quality. The ground point's column indicates the number of points classified as ground, which is essential for generating accurate digital elevation models (DEMs). Area 7 has the highest ground points at 6.100 million, indicating a reliable basis for elevation modeling. The table highlights the efficiency of noise filtering and classification processes in retaining high-quality data for urban geophysical analysis, with the substantial number of ground points ensuring accurate DEMs for urban planning, infrastructure monitoring, and other geospatial applications.

Table 3: Digital Elevation Model (DEM) Statistics

Area	Min Elevation (m)	Max Elevation (m)	Mean Elevation (m)	Standard Deviation (m)
Area 1	5.500	25.300	15.450	6.250
Area 2	6.200	30.100	18.150	7.450
Area 3	4.800	22.700	13.750	5.650
Area 4	7.100	28.600	17.850	6.900
Area 5	5.900	26.400	16.150	6.500
Area 6	6.300	29.200	17.750	7.050
Area 7	4.500	24.800	14.650	5.950
Area 8	7.200	31.600	19.400	8.050
Area 9	5.800	27.900	16.850	6.700
Area 10	6.000	28.100	17.050	6.800
Area 11	4.900	23.600	14.250	5.850
Area 12	6.700	30.900	18.800	7.600

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Area 13	5.600	26.800	16.200	6.450
Area 14	6.100	27.500	16.800	6.700
Area 15	5.300	25.700	15.500	6.150

Interpretation of Table 3: Digital Elevation Model (DEM) Statistics
Table 3 shows the numerical results from digital elevation models (DEMs) constructed using LiDAR data for fifteen cities. These results provide insights into the elevation of each site, which helps understand landforms and topography. The table contains four statistical values for each location: minimum elevation, maximum elevation, average elevation, and relative elevation. Minimum elevation: This metric indicates the minimum elevation within each area. Values range from 4,500 m in Area 7 to 7,200 m in Area 8, indicating more significant variability at lower elevations in urban areas. Maximum elevation: The maximum elevation represents the highest point within each area. Values range from 24,800 m in Section 7 to 31,600 m in Area 8, reflecting differences in elevation due to geological features, such as slopes or elevated structures. Average Elevation: The average elevation gives the average elevation for the whole area.

Values range from 13,750 m for Area 3 to 19,400 m for Area 8, representing the overall elevation of each city neighborhood. Very steep areas may be hilly or areas with tall buildings—standard Deviation: Elevation standard measures the variation or spread of elevation values within each area. Large standard deviation values, such as 8,050 m in eight sites, indicate high elevation variability, which may be due to various land uses or geological constructions. Table 3 shows the characteristics of the LiDAR-derived DEMs in urban characterization. These assessments are critical for urban planning, flood risk assessment, and infrastructure design, providing planners and engineers with a wealth of aerial data critical for decision-making and development. The observed spatial variation indicates that accurate elevation modeling is essential for correctly understanding and managing urban landscapes.

Table 4: Digital Surface Model (DSM) Statistics

Area	Min Elevation (m)	Max Elevation (m)	Mean Elevation (m)	Standard Deviation (m)
Area 1	10.500	50.300	30.450	12.250
Area 2	12.200	55.100	35.150	13.450
Area 3	8.800	47.700	28.750	11.650
Area 4	13.100	53.600	33.850	12.900
Area 5	11.900	49.400	31.150	12.500
Area 6	12.300	54.200	32.750	13.050
Area 7	9.500	48.800	29.650	11.950
Area 8	13.200	56.600	36.400	14.050
Area 9	11.800	51.900	31.850	12.700
Area 10	12.000	52.100	32.050	12.800
Area 11	9.900	44.600	27.250	11.850
Area 12	12.700	55.900	34.800	13.600
Area 13	11.600	49.800	31.200	12.450
Area 14	12.100	51.500	32.800	12.700

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Area 15	10.300	47.700	29.500	11.650

Interpretation of Table 4: Digital Surface Model (DSM) Statistics

Table 4 presents the statistical parameters from Digital Surface Models (DSMs) generated with LiDAR data in fifteen cities. These metrics provide insights into surface elevation characteristics, including artificial buildings and vegetation, essential for urban systems and environmental management. The metrics include minimum, maximum, median, and absolute elevation. Minimum Height represents the lowest point above the land surface, while the highest Height represents the highest point, including skyscrapers and towers. The mean elevation gives the average surface elevation at each location, reflecting the overall elevation of the urban landscape. Standard Deviation measures the variation or dispersion of elevation values at each location. LiDAR-derived DSMs provide detailed land surface elevation information for urban planning, infrastructure planning, and environmental management. The observed spatial variability highlights the diverse characteristics of the urban environment and emphasizes the importance of accurate land surface modeling in urban development and sustainable infrastructure.

Table 5: Structural Deformation Detection Metrics

Structure	Initial Height (m)	Detected Height (m)	Deformation (m)
Building 1	45.300	45.150	0.150
Building 2	50.700	50.500	0.200
Bridge 1	35.800	35.600	0.200
Building 3	40.500	40.350	0.150
Bridge 2	28.300	28.100	0.200
Building 4	38.700	38.500	0.200
Building 5	47.800	47.600	0.200
Bridge 3	30.300	30.150	0.150
Building 6	42.700	42.500	0.200
Building 7	36.800	36.650	0.150
Bridge 4	33.300	33.150	0.150
Building 8	44.700	44.500	0.200
Building 9	39.800	39.650	0.150
Bridge 5	32.300	32.100	0.200
Building 10	41.700	41.500	0.200

Interpretation of Table 5: Structural Deformation Detection Metrics

Table 5 presents metrics for detecting structural deformations using LiDAR technology across ten urban structures. These metrics provide insights into the accuracy and effectiveness of LiDAR in monitoring and assessing changes in structural integrity over time. The metrics include Initial Height, indicating the initial height measurement before Deformation; detected Height, indicating the measured Height during the LiDAR survey; and Deformation, indicating the extent of Deformation observed in each structure. These metrics are essential for prompt maintenance and safety assessments of bridges, buildings, and other projects. The precise measurements LiDAR provides enable engineers and planners to quickly identify potential

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issues, facilitating timely interventions to mitigate risks and ensure the durability and safety of urban buildings.
The application of LiDAR technology in urban geophysical surveys represents a significant improvement in the acquisition and analysis of spatial data, as indicated by all the findings in Tables 1 to 5. The following tables demonstrate the revolutionary impact of LiDAR in capturing detailed and precise geographic information that is important for urban planning, infrastructure monitoring, and disaster management. Tables 1 and 2 show the technical capabilities of the mobile LiDAR system and the effectiveness of the noise filtering and classification procedures. The system's high frequency and accurate GPS and IMU data allow for more accurate and precise data capture in urban areas. A robust noise filtering system, evidenced by the widespread storage of filters and geographic locations, ensures data quality and reliability. This is critical to ensuring high-quality digital elevations (DEM) and creating digital surface models (DSM). Tables 3 and 4 provide key statistical results derived from the DEMs and DSMs, which provide insights into urban form and surface characteristics. The variation in minimum, maximum, median, and average elevation values at different locations reflects the complexity of urban systems. These considerations are essential for urban planning strategies, such as flood risk assessment, infrastructure design, and environmental management, where accurate elevation data inform decision-making processes. Table 5 shows that LiDAR can more accurately detect structural deformations in urban areas. The measured changes in system height demonstrate the role of LiDAR in monitoring the health of infrastructure over time, allowing for early analysis of changes that may affect safety and productivity. Such capabilities are critical for efficient maintenance strategies and ensuring urban infrastructure's resilience and durability. Overall, the findings in these figures indicate that LiDAR technology plays a transformative role in the success of urban landscape surveys. LiDAR technology offers detailed data on urban topography, infrastructure, and ecological systems, aiding in informed decision-making and promoting resilience. Future advancements will drive innovation in urban planning, disaster preparedness, and infrastructure management.

5. CONCLUSION AND RECOMMENDATIONS

Therefore, incorporating LiDAR technology in urban geophysical surveys is a revolution in the collection, analysis, and usage of spatial data in urban development and physical infrastructure. The findings from Tables 1 to 5 summarize that LiDAR has greatly revolutionized acquiring accurate and sensitive quality data for designing various urbanized areas.
The high-density DEMs and DSMs obtained in Tables 3 and 4 show that LiDAR plays an important role in elevation data in urban planning projects such as flood hazard mapping, land management, and construction plans. Thus, safety factors resulting from the accuracy of the LiDAR-derived elevation models and their ability to detect geometric distortions (Table 5) facilitate risk management and the early identification of issues with city structures.
Suggestions for how LiDAR may be developed and applied in the future include enhancing the data processing procedures to filter out noise and enhance classification results, as listed in Table 2. Also, combining LiDAR data with other sources of geospatial data, such as satellite imagery and/or ground surveys, provides more comprehensive solutions for modeling and monitoring urban environments.

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Moreover, increasing the application of LiDAR to the real-time identification of urban processes, including road traffic, pedestrian movement, and climatic fluctuations, may extend the city's capability of withstanding shocks and stresses and promote sustainability. The effective use of LiDAR and the application of the new solutions require the partnership of scientists, urban planners, and government agencies.

Thus, LiDAR technology has once again changed the course of urban geophysical surveys due to its ability to offer extensive information about the urban territory. By utilizing the potential for data to support decision-making and preventive action related to a city's infrastructure, cities can contribute to progress in sustainable development of the inhabitants' quality of life.

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