SYNERGY OF AR AND GIS DATASETS TO IMPROVE SPATIAL REASONING AND NAVIGATION INTELLIGENCE

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ABSTRACT

Augmented Reality (AR) has become a pivotal technology for advancing spatial cognition and navigation, enabling the seamless integration of digital information into real-world environments. When used with Geographic Information Systems (GIS), AR provides a powerful framework for context-aware visualization and interaction with geospatial data. This paper explores intelligent navigation systems that integrate AR interfaces with GIS databases, supported by artificial intelligence algorithms for adaptive decision-making. The proposed approach emphasizes methodological rigor by integrating spatial data processing, dynamic route optimization, and interactive overlays of geoinformation through smart AR glasses. Such integration reduces cognitive load, enhances situational awareness, and facilitates efficient orientation in complex spatial contexts. Potential applications include urban mobility, cultural heritage interpretation, tourism, and emergency response, where real-time geospatial guidance is critical. The synergy of AR, GIS, and AI technologies significantly improves navigation accuracy and user experience compared to conventional systems. By situating AR within the broader geospatial analytical framework, this study contributes to the development of next-generation intelligent navigation tools and highlights the role of integrated geoinformation technologies in shaping smart environments and spatial decision support systems.

Keywords: Augmented Reality (AR), Geographic Information Systems (GIS), Artificial Intelligence (AI)

INTRODUCTION

Advances in geospatial technologies have changed human concepts of perceiving, interpreting, and interacting with space. GIS has long formed the backbone of spatial analysis, providing structured datasets that allow accurate modelling, visualization, and decision-making [1] [2]. Meanwhile, AR has emerged as a potent medium to enhance human spatial cognition by superimposing digital information on real-world environments [3] [4].

Convergence of the AR and GIS datasets is a significant stride towards improvement of spatial reasoning and navigation intelligence. While bringing the analytical depth of GIS, AR adds the immersive capability, which allows users to experience geoinformation more intuitively and interactively. This synergy strengthens cognitive mapping and situational awareness and points to new pathways for applications in urban mobility, crisis management, tourism, and smart city development.

By embedding spatial data into everyday environments, AR-GIS integration transforms geoinformation science from a specialist tool into a medium accessible to wider audiences. Particularly for the Balkan region, with its diverse landscapes and complex urban topography, AR-GIS integration contributes to academic and practical value in new opportunities for enhancing spatial literacy, optimizing navigation systems, and supporting decision-making procedures on everything from everyday mobility to emergency response.

This paper explores the theoretical foundations, methodological approaches, and practical applications of AR-GIS synergy, aiming to demonstrate how such integration can advance spatial reasoning and foster intelligent navigation solutions for contemporary geoinformation science. In doing so, it seeks to bridge the gap between abstract geospatial analysis and lived urban experience, offering insights relevant both to global smart city initiatives and to regional challenges.

GIS DATASETS AS THE FOUNDATION OF SPATIAL INTELLIGENCE

GIS datasets form the foundation of spatial intelligence by enabling capturing, structuring, analysis, and visualization of geospatial data, transforming raw location information into meaningful spatial insights for decision-making. GIS integrates diverse data types to reveal spatial patterns and relationships that support planning, resource management, and analytical reasoning across disciplines, extending GIS beyond simple cartography into a holistic spatial intelligence framework [1] [5].

Points of interest (POIs) represent the most direct connection between spatial data and everyday human activity. They may include landmarks, museums, stadiums, cultural sites, and exhibition venues. Within GIS datasets, POIs are described through structured information such as precise geographic coordinates, descriptive attributes (including type, opening hours, accessibility, and popularity), and connectivity data that show transport links, pedestrian routes, and proximity to other attractions [6] [7]. By organizing POIs in this way, GIS enables planners and developers to design applications that support visitor navigation, optimize travel routes, and draw attention to lesser-known locations [7].

Augmented reality adds a new experiential layer to GIS datasets by transforming spatial information into interactive content. Research on the integration of GIS and AR shows that spatial datasets provide the geometric and semantic foundation required to anchor digital content accurately in real-world environments [3]. When AR is integrated with POI data, users can explore tourism destinations through historical reconstructions and multimedia guides layered onto real-world views [8]. In sports environments, AR enhances the spectator experience by providing live statistics, seat navigation, and interactive fan zones within stadiums. Similarly, exhibitions can be reimagined through AR by enriching displays with 3D models, multilingual explanations, and engaging forms of digital storytelling [8].

The combination of GIS datasets and AR creates a dynamic form of spatial intelligence that evolves through user interaction. In tourism, GIS supports smart platforms that recommend attractions based on visitor preferences, crowd levels, or thematic routes, while AR delivers immersive and personalized guidance [9]. In sports venues, GIS assists in crowd management, safety planning, and fan engagement, with AR offering real-time overlays of match information and navigation support [10]. Exhibition organizers rely on GIS to map indoor spaces, monitor visitor movement, and optimize booth placement, while AR transforms static exhibits into interactive and educational experiences [11].
Overall, GIS datasets form the foundation of spatial intelligence by turning raw location data into meaningful insights and engaging digital experiences. When combined with augmented reality, they redefine how people interact with tourism destinations, sports facilities, and exhibitions. This integration not only increases user engagement but also establishes new standards for cultural, recreational, and educational experiences in the digital age [1] [12].

AR TECHNOLOGIES IN SPATIAL REASONING

AR technologies have become central to the evolution of spatial reasoning. By projecting geoinformation into real-world environments, AR reduces the abstraction traditionally associated with maps and GIS interfaces. Users no longer interpret symbols on a flat surface alone; instead, they interact with spatial data in situ, experiencing it as part of their immediate surroundings [13] [14]. This shift is more than technical - it represents a cognitive transformation in how spatial relationships are understood and applied.
Spatial reasoning depends on the human ability to form cognitive maps - mental models of spatial relationships that guide orientation and movement. AR strengthens this process by embedding geospatial cues directly into the user's field of vision. A short walk through a city, for example, can be enhanced with AR overlays that highlight landmarks, suggest thematic routes, or provide real-time orientation support. The immediacy of these cues reduces cognitive load and improves accuracy in navigation decisions [15].
In professional contexts, such as logistics or urban planning, this capability translates into more efficient workflows. Planners can visualize proposed infrastructure directly on site, while logistics managers can optimize routes with live AR guidance. These examples illustrate how AR transforms cognitive mapping from a mental exercise into an embodied experience.
AR's contribution to situational awareness is equally significant. In emergency response, responders equipped with AR can see hazard zones, evacuation routes, or sensor data overlaid on the environment. This immediate visualization supports rapid decision-making when time is critical [16] [17]. Smart city applications extend this principle further. Traffic flows, crowd densities, and infrastructure conditions can be visualized in real time, allowing city managers to anticipate problems before they escalate. Here, AR does not replace GIS analysis but amplifies it, turning complex datasets into actionable insights visible at a glance.
Spatial literacy - the ability to understand and apply spatial concepts is often difficult to teach because it requires abstract reasoning. AR reduces this barrier by making geoinformation interactive. Students can explore terrain models, climate data, or urban layouts through AR applications that project these datasets into their immediate environment. This experiential learning fosters deeper comprehension and retention of spatial concepts [18]. A short case example: in geography classes across Europe,

AR-based fieldwork has been used to overlay historical maps onto current landscapes, helping students grasp both spatial change and continuity [19]. Such applications demonstrate AR's pedagogical potential.
Tourism and cultural heritage provide fertile ground for AR's role in spatial reasoning. Visitors navigating complex urban landscapes or heritage sites benefit from AR overlays that combine navigation with contextual storytelling [20] [21]. A thematic route through Belgrade's fortress, for instance, could be enriched with AR projections of historical events, guiding visitors while simultaneously deepening their cultural understanding. This dual function: navigation plus interpretation illustrates how AR extends spatial reasoning into cultural and experiential domains.
Finally, AR technologies point toward new paradigms in intelligent navigation and smart city development. By merging GIS datasets with immersive visualization, urban mobility systems can deliver personalized, context-aware guidance that adapts to real-time conditions. Citizens might receive dynamic rerouting instructions based on traffic congestion or environmental hazards, while planners could use AR to visualize infrastructure projects within their actual surroundings. This trajectory suggests that AR is not merely an accessory to GIS but a transformative technology that redefines how spatial reasoning is practiced in both everyday life and professional domains.

SYNERGY OF AR AND GIS DATASETS

The integration of AR and GIS (Figure 1) represents a powerful synergy that is reshaping how spatial data is perceived, analysed, and applied. GIS provides the analytical backbone, offering structured, multi-scale datasets that capture the complexity of physical and built environments. AR delivers immersive visualisation, placing this information directly into the user's context. Together, they transform abstract geospatial data into actionable, intuitive experiences that support decision-making across diverse domains [22] [23]
For example, it is already used in underground maintenance, water and sewer systems, urban planning, indoor environments, and increasingly in tourism. Each of these applications depends on specific types of data. Underground utilities require detailed georeferenced maps of pipelines, cables, and subsurface structures [24]. Water, sewer, oil, and gas networks rely on condition monitoring data, flow measurements, and routing information with meter level accuracy [25]. Urban planning and cadastre demand 3D city models, parcel boundaries, zoning maps, and infrastructure datasets that can be visualized at street level. Indoor environments need positioning data from Bluetooth Low Energy (BLE) beacons, Ultra Wideband (UWB) sensors, or Pedestrian Dead Reckoning (PDR) algorithms, combined with facility management records and asset inventories.

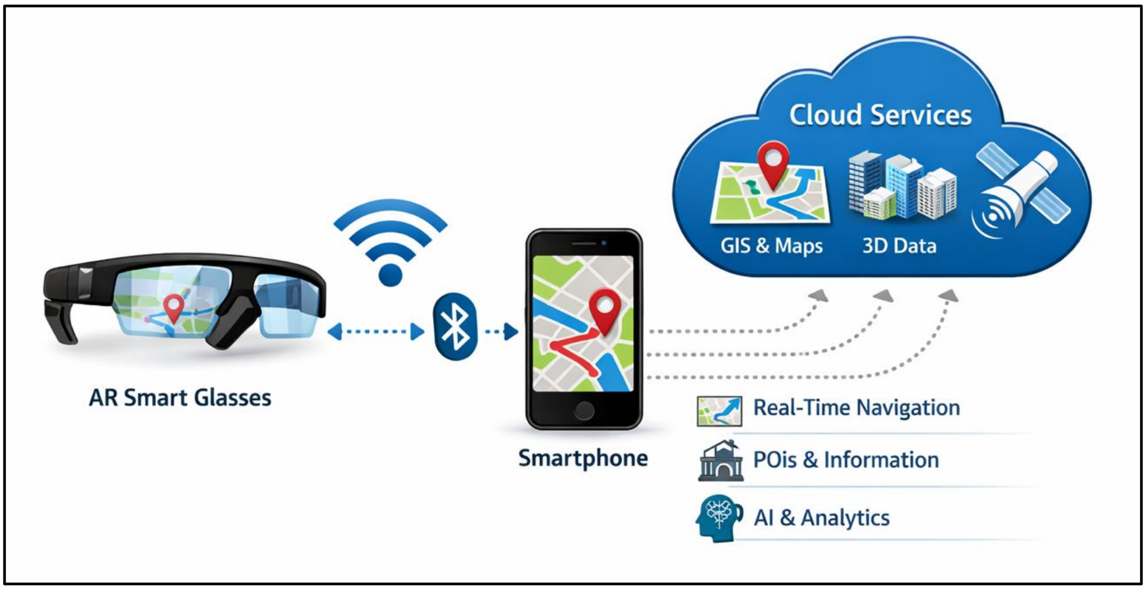

Figure 1. Example of AR and GIS integration, source: authors

Beyond these technical domains, AR-GIS is also finding a role in public engagement and tourism. By overlaying cultural heritage information, landscape changes, or thematic routes onto real environments, AR makes complex geoinformation accessible to visitors. When combined with AR glasses, this potential expands further: visitors could see parcel data, historical maps, or curated city models projected seamlessly into their surroundings. The datasets most relevant for such applications include 3D city models, cadastral maps, cultural heritage archives, and real-time mobility data, which together create immersive and informative experiences [26] [5]. This sets the stage for a deeper exploration of how AR glasses can transform tourism in urban environments.

NAVIGATION INTELLIGENCE IN URBAN SCENARIOS

Navigation in complex urban environments requires more than simple wayfinding; it demands contextual intelligence that adapts to the user's location, interests, and situational needs. This ability is provided by the combination of AR and GIS, which turns navigation into an engaging, educational, and customised experience. AR glasses, equipped with dedicated applications and real-time data streams, represent the next step in urban navigation intelligence.

In practice, AR glasses function as wearable navigation platforms. They have sensors for orientation and positioning, a transparent display built into the lenses, and an application that links to GIS datasets and urban information systems. Visual cues, such as contextual icons indicating points of interest, highlighted landmarks, or arrows guiding the path, are projected directly into the user's field of vision by the display. This method, in contrast to conventional smartphone maps, removes the need for users to look down at a screen, enabling them to stay completely focused on their environment.

Consider a visitor navigating the Belgrade Fortress, a site that combines historical significance with modern urban life. The AR glasses activate the navigation app and overlay a path through the fortress grounds as the visitor starts to walk. The glasses display visual cues at each turn, such as a highlighted outline of the fortress walls or a glowing arrow pointing to the next gate. The glasses include brief historical notes about the building of the Roman castrum, the mediaeval fortifications, and the Ottoman and Austrian influences that influenced the location. The visitor can learn about history without interfering with the flow of movement thanks to these notes, which show up as subtle text or audio cues. The glasses could display reconstructions of previous conflicts at strategic points or architectural phases, blending cultural heritage with spatial orientation. AI algorithms process the visitor's preferences and movement patterns in real time, ensuring that the guidance adapts dynamically to their pace and interests. AI also filters and prioritizes the most relevant datasets whether historical notes, nearby cafés, or cultural events so that the user receives context-aware information without distraction.

Navigation intelligence extends beyond history. As the visitor approaches the central promenade, the glasses highlight nearby cafés and restaurants, drawing on urban GIS datasets of food and beverage locations. Recommendations are personalized: a symbol for the best local coffee, a marker for traditional Serbian cuisine, or a prompt for vegetarian and vegan options. Even crowd density could be indicated by real-time data, indicating less crowded dining areas or quieter routes.

The system integrates multiple datasets such as cultural heritage archives for historical overlays, tourism and hospitality databases for food, coffee, and leisure recommendations, mobility and transport feeds for guiding visitors to bus stops or parking areas and environmental monitoring data (air quality, noise levels) for optimizing comfort. By combining these layers, AR glasses transform navigation into a holistic urban experience, where movement is seamlessly linked with knowledge, culture, and leisure.

The most important feature of navigation intelligence is adaptability. If the visitor deviates from the suggested path, the glasses instantly recalculate the route, projecting new cues without interruption. If the user expresses interest in a particular topic the app adjusts its overlays, prioritizing relevant information. This personalization ensures that navigation is not only efficient but also meaningful.

If we assume that the city of Belgrade (Table 1) has 1.4 million tourists annually and adoption rate for a similar system using AR and GIS of 7% this translates to approximate 1350 tourists on a peak day citywide, and around 470 peak-day AR-GIS tourists at a single "top hotspot" like the Belgrade fortress. This assumes 35% share concentrated at a top attraction like the fortress [27].

Table 1. Baseline Parameters and Assumptions for AR–GIS Tourist Demand Estimates in Belgrade

Parameter	Value	Units	Notes
Annual tourists	1,400,000	people/year	Belgrade total tourists (assumption)
Adoption rate (low)	5.00%	%	Conservative lower bound
Adoption rate (mid)	6.00%	%	Midpoint scenario
Adoption rate (high)	7.00%	%	Conservative upper bound
Average trip length	2.50	days	Assumption (e.g., city-break duration)
Peak factor	2.00	x	Multiplier to approximate peak-day vs average-day demand
Hotspot share	35.00%	%	Share of AR tourists concentrated at a top attraction (e.g., Fortress)
Interactions per tourist-day	30	events/day	AR actions (POI views, routing recalculations, translations, etc.)

Source: [27]

This example illustrates how AR-GIS synergy can redefine navigation in urban scenarios. It moves beyond simple wayfinding to create immersive journeys, where every step is enriched with context. For tourists, this means deeper engagement with cultural heritage.

For residents, it offers practical guidance in daily mobility, from locating services to avoiding congestion. For city managers, it provides a platform to communicate urban change directly to citizens.

CONCLUSION

Advances in geospatial technologies have fundamentally changed how people understand and interact with space. One of the most significant developments in this field is the integration of AR and GIS. By combining the analytical strength of GIS with the immersive and visual nature of AR, this integration introduces new ways of thinking about space, navigation, and decision-making. Spatial data is no longer limited to abstract maps or databases; instead, it becomes intuitive, interactive, and directly connected to the user's real-world surroundings, improving spatial awareness and cognitive understanding.

Across many application areas, the potential of AR-GIS integration is already evident. In underground utilities and infrastructure management, AR can project subsurface networks directly into the user's field of view, improving safety and reducing errors during maintenance work. In water, sewer, oil, and gas systems, this technology supports condition monitoring and route planning with meter-level accuracy, helping organizations save both time and resources. Urban planning and cadastral management benefit from mobile AR combined with 3D city models, allowing planners, professionals, and citizens to visualize parcel boundaries, zoning regulations, and proposed changes directly at street level. Beyond technical and professional use, AR-GIS also plays an important role in public engagement, making cultural heritage, landscape evolution, and emergency training more accessible to non-experts through realistic and interactive visualizations.

An example of this concept can be seen in the case of navigation intelligence at Kalemegdan Fortress in Belgrade. Using AR glasses, visitors can explore the area through overlaid routes, historical information, and contextual recommendations for food, coffee, or leisure activities. This approach transforms simple navigation into a richer urban and cultural experience. Supporting such applications requires diverse datasets, including historical archives, 3D city models, cadastral data, mobility information, and environmental monitoring, highlighting the complexity and breadth of data behind intelligent urban navigation systems.

Despite these promising developments, several challenges remain. Accurate tracking and georeferencing at the scale of entire cities, efficient rendering of large and complex 3D models on mobile devices, and seamless interoperability between AR platforms and GIS backends are still active research topics. Overcoming these limitations is crucial for moving AR-GIS solutions from experimental pilots to widely adopted, real-world systems.

In conclusion, the integration of AR and GIS represents more than a technical upgrade, it marks a shift in how geospatial data is produced, communicated, and experienced. By uniting analytical precision with immersive visualization, AR-GIS opens new opportunities in urban mobility, tourism, crisis management, and smart city development. As research continues to refine technical challenges and broaden application areas, AR-GIS integration is set to become a pillar of modern geospatial science, reshaping how people engage with space in the digital age.

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REFERENCES

[1] K. Jr. Pavelka and M. Landa, "Using Virtual and Augmented Reality with GIS Data," ISPRS International Journal of Geo-Information, vol. 13, no. 7, p. 241, 2024.

[2] Z. Li et al., "GIScience in the era of Artificial Intelligence: a research agenda towards Autonomous GIS," Annals of GIS, vol. 31, no. 4, pp. 501-536, 2025.

[3] J. Safari Bazargani, M. Zafari, A. Sadeghi-Niaraki, and S.-M. & Choi, "A Survey of GIS and AR Integration: Applications," Sustainability, vol. 14, no. 16, p. 10134, 2022.

[4] J. Keil, A. Korte, A. Ratmer, D. Edler, and F. & Dickmann, "Augmented Reality (AR) and Spatial Cognition: Effects of Holographic Grids on Distance Estimation and Location Memory in a 3D Indoor Scenario," PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science, vol. 88, pp. 165-172, 2020.

[5] T.L. Huang and J.H. & Hong, "Combination of Augmented Reality and 3D Geographic Information: A User perspective towards Feature-Based Augmented Reality," AGILE GIScience Ser., vol. 5, p. 29, 2024.

[6] A. Psyllidis et al., "Points of Interest (POI): a commentary on the state of the art, challenges, and prospects for the future," Computational Urban Science, vol. 2, 2022.

[7] M. Šoltésová, B.l Štrba, Ľ. Iannaccone, and C. & Sidor, "Application of GIS Technologies in Tourism Planning and Sustainable Development: A Case Study of Gelnica," ISPRS International Journal of Geo-Information, vol. 14, no. 3, p. 120, 2025.

[8] R. G. Boboc, E. Băutu, F. Gîrbacia, N. Popovici, and D.-M. & Popovici, "Augmented Reality in Cultural Heritage: An Overview of the Last Decade of Applications," Applied Sciences, p. 9859, 2022.

[9] I. Cibilić, V. Posloncec-Petric, and K. & Tominic, "Implementing Augmented reality in Tourism," in Proceedings of the ICA, vol. 4, 2021, pp. 1-5.

[10] Y. S. Yadav and D. & Sandeep, "Smart stadiums: Enhancing fan experience through technological innovations in sports venues," International Journal of Sports, Health and Physical Education, vol. 6, no. 1, pp. 50-52, 2024.

[11] J. Wider Li, W. Y. Ochiai, and M. A. & Fauzi, "A bibliometric analysis of immersive technology in museum exhibitions: Exploring user experience," Frontiers in Virtual Reality, vol. 4, 2023.

[12] B. Wang, "The application of interactive design technology in digital intelligent exhibition display," Computer Aided Design and Applications, vol. 21, no. S28, pp. 296-308, 2024.

[13] M. Billinghurst, A. Clark, and G. Lee, "A Survey of Augmented Reality," Foundations and Trends in Human-Computer Interaction, vol. 8, no. 2-3, pp. 73-272, 2015.

[14] J. Zhang, X. Xia, R. Liu, and N. & Li, "Enhancing human indoor cognitive map development and wayfinding performance with immersive augmented reality-based navigation systems," Adv. Eng. Informatics, vol. 50, 2021.

[15] J. Hatvani et al., "Enhancing human spatial awareness through augmented reality technologies," Biomedical Engineering Letters, vol. 15, pp. 995-1002, 2025.

[16] B. Smit, R. Voûte, and E. & Verbree, "CREATING 3D INDOOR FIRST RESPONDER SITUATION AWARENESS IN REAL-TIME THROUGH A HEAD-MOUNTED AR

DEVICE," ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2021.

[17] Z. Stefanidi, G. Margetis, S. Ntoa, and G. & Papagiannakis, "Real-Time Adaptation of Context-Aware Intelligent User Interfaces, for Enhanced Situational Awareness," IEEE Access, vol. 10, 2022.

[18] C. Carrera and L. & Asensio, "Augmented reality as a digital teaching environment to develop spatial thinking.," Cartography and Geographic Information Science, vol. 44, pp. 259-270, 2017.

[19] R. Schmidt and B. & Stumpe, "Systematic review of mobile augmented reality applications in geography education," Review of Education, 2025.

[20] N. Chung, H. Lee, J. Kim, and C. & Koo, "The Role of Augmented Reality for Experience-Influenced Environments: The Case of Cultural Heritage Tourism in Korea," Journal of Travel Research, vol. 57, pp. 627-643, 2018.

[21] E. Litvak and T. & Kuflik, "Enhancing cultural heritage outdoor experience with augmented-reality smart glasses," Personal and Ubiquitous Computing, vol. 24, pp. 873-886, 2020.

[22] T. Kersten and D. & Edler, "Special Issue “Methods and Applications of Virtual and Augmented Reality in Geo-Information Sciences”.," PFG – Journal of Photogrammetry, Remote Sensing and Geoinformation Science, vol. 88, pp. 119-120, 2020.

[23] P. Ghadirian and I. & Bishop, "Integration of augmented reality and GIS: A new approach to realistic landscape visualisation," Landscape and Urban Planning, vol. 86, pp. 226-232, 2008.

[24] A. Fenais, S. Ariaratnam, S. Ayer, and N. & Smilovsky, "Integrating Geographic Information Systems and Augmented Reality for Mapping Underground Utilities," Infrastructures, 2019.

[25] L. Nguyen, D. Bui, and R. & Seidu, "Utilization of Augmented Reality Technique for Sewer Condition Visualization," Water, 2023.

[26] S. Yalcin, B. Erkek, and E. & Ayyıldız, "Integrating Photogrammetric 3D City Models and CityGML Data into Augmented Reality for Enhanced Urban Planning and Cadastre Management.," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2025.

[27] Sekretarijat za upravu – Sektor za statistiku / Secreteriat for administration - Sector for statistics, "Godišnjak statističkih podataka grada Beograda 2024 / Statistical yearbook of Belgrade 2024," 2024. [Online]. https://beostat.beograd.gov.rs/images/Zis/Files/Godisnjak/G_2024.pdf