Towards Extended Digital Building Passports for Urban Sustainability: Developing a GIS-Based Dashboard Using Multi-Source Data — A Case Study from Türkiye

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Key words: Building passport, Energy performance of buildings, Land administration, Sustainable cities.

SUMMARY

The built environment plays a crucial role in achieving energy efficiency and advancing sustainable development, where structured, interoperable, and accessible building information has become indispensable. In line with the European Union's Energy Performance of Buildings Directive (EPBD) and the emerging framework of Digital Building Passports (DBPs), there is an increasing emphasis on integrating building-level energy performance data with broader land administration related data including building and apartment unit characteristics, socio-economic characteristics, public administration and public law restriction zones, earthquake risk zones and distance to social, educational, transportation areas. DBPs offer a promising source of data for tracking the lifecycle of buildings, encompassing attributes such as energy use, material composition, and renovation history. However, their potential can only be realized when supported by advanced spatial data infrastructures that enable integration, visualization, analysis, dissemination, and decision-making. This paper presents the design and implementation of a GIS-based dashboard for extended DBPs, which consolidates heterogeneous data sources including cadastral records, energy performance certificates, socio-economic indicators, and spatial accessibility metrics. The developed dashboard dynamically represents building- and unit-level characteristics (e.g., age, geometry, use type), energy performance data, administrative and cadastral attributes, demographic data, and accessibility to key urban services. By enabling comprehensive visualization and analysis, the dashboard may contribute to a practical tool for policymakers, urban planners, energy authorities, and land administration agencies. It may also support the assessment of energy efficiency strategies and the advancement of sustainable urban development, thereby aligning with climate resilience and digital transformation objectives at both local and national levels.

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1. INTRODUCTION

The built environment is fundamentally significant in terms of energy efficiency and sustainable development. The necessity for structured, interoperable, and accessible building information, particularly concerning energy performance, has become increasingly pronounced. This necessity has been acknowledged by numerous international and regional entities, including the European Union (EU). The EU's Energy Performance of Buildings Directive (EPBD), initially introduced in December 2002 and most recently revised in May 2024, articulates that "*Member States shall describe their national calculation methodology on the basis of Annex A to the key European standards on the energy performance of buildings*" (Official Journal of the European Union, 2024). The directive defines the energy performance of buildings as the "*calculated or metered amount of energy needed to meet the energy demand associated with a typical use of the building, which includes energy used for heating, cooling, ventilation, domestic hot water, and lighting*" (Official Journal of the European Union, 2024). According to the directive, Energy Performance Certificate (EPC) is mandatory for newly constructed buildings or building units (Official Journal of the European Union, 2024). As delineated in the directive, the components of an EPC generally consist of: (a) the energy performance class, ranging from A to G, (b) the calculated annual primary and final energy use and consumption, (c) operational greenhouse gas emissions, (d) recommendations for enhancements in energy efficiency, (e) the validity of the calculations and a maximum deviation for the energy performance, (f) a validity check of the input data of the building (e.g., floor area, year of construction, renovation status, construction type, energy source type), among others. Moreover, the EPBD has underscored the importance of establishing "*a national database for the energy performance of buildings*" populated with empirical data "*to be gathered from all relevant sources related to energy performance certificates*" (Official Journal of the European Union, 2024).

In addition to EPCs, the significance of digital building passports (DBPs) has been recently highlighted. DBPs facilitate the tracking of information associated with buildings, materials, systems, energy use, renovations, and other relevant data, thereby improving decision-making processes through enhanced data quality, tracking, and storage (IEA, 2020). According to Chandran et al. (2024) argue that integrating building passports into land administration systems can enhance interoperability between information systems. Building passports encompass owner information and cadastral links, 3D location, material and component intelligence, certifications, life cycle assessments, pricing, and economic value. Furthermore, data from DBPs can be integrated with wider land administration datasets through advanced spatial data infrastructures to support the decision-making processes of land administration organisations and municipalities. These datasets include characteristics of buildings and apartment units, socio-economic profiles, zones defined by public administration, legal restrictions, earthquake hazard areas and proximity to social, educational and transport facilities. In this context, a GIS dashboard can be considered a good solution, as it can facilitate integration, visualisation, analysis and sharing, and enhance decision-making and coordination among stakeholders from different organisations. According to Coetzee et al. (2020), municipalities can use such a dashboard to support data integration and decision-making.

The objective of this study is the design, development, and implementation of a GIS-based dashboard to represent extended DBPs data and data from other land administration sources such as building and condominium unit characteristics, socio-economic characteristics, public administration and public law restriction zones, earthquake risk zones and distance to social, educational, transportation areas. Such a dashboard may function as a prototype for integrating building-level information into the national land administration infrastructure, providing a promising method to manage and monitor the lifecycle characteristics of buildings while facilitating informed decision-making at both local and national levels. The methodology encompasses the collection of heterogeneous datasets (e.g., vector and textual) derived from cadastral systems, EPC records and GIS analyses. These data are transferred into a GIS geodatabase, harmonized, analysed, and spatially matched with individual buildings and condominium units. The developed dashboard enables the dynamic visualization of essential characteristics, including building and condominium unit-level attributes (e.g., building age, 2D/3D geometry, use type), energy performance data (e.g., building energy class), administrative data (e.g., address, neighbourhood, district), cadastral data (e.g., parcel), and population registry data (e.g., age groups of residents). Additionally, it integrates neighbourhood-level socio-economic indicators, such as education level, income, marital status, and development index. The prototype is further enriched with spatial accessibility metrics, encompassing distances to critical public and private services, such as transportation hubs (e.g., railways, bus stops), educational facilities (e.g., university, high school, primary school), healthcare facilities (e.g., hospital, pharmacy), shopping centres, green spaces (e.g., parks, forests), cultural and entertainment venues (e.g., cinema, theatre, museum, amusement park), religious facilities, and areas subject to public law restrictions (e.g., military zones, protected areas).

The remainder of the paper is organised as follows: Section 2 provides an overview of energy management and digital land and building information systems in Türkiye. Section 3 details the methodology and steps for developing a GIS dashboard for DBPs, together with the data sources. Section 4 concludes the paper.

2. ENERGY AND LAND ADMINISTRATON DATA MANAGEMENT IN TÜRKİYE

This section first presents the most recent information on legislation and structures related to building energy data management, and then on land information data management systems. The information provided in this section is used as a basis for developing a GIS-based dashboard for presenting energy data alongside other data sources.

2.1 **Building energy management in Türkiye**

In Türkiye, mandatory energy certification of buildings was introduced nearly twenty years ago as part of efforts to improve energy efficiency. The legal foundation was laid in 2007 with the enactment of Energy Efficiency Law No. 5627, which established EPC and set out its minimum content. This includes details such as the building's energy demand, insulation quality, performance of heating and cooling systems, and overall energy consumption class (Energy Efficiency Law, 2007). In 2008, the Regulation on Energy Performance in Buildings was issued to implement the provisions of the law. The regulation, aligned with the European Union's Energy Performance of Buildings Directive (EPBD), seeks to ensure the efficient and sustainable use of energy resources and prevent unnecessary energy consumption. At a minimum, the certificate provides calculated data on the building's energy requirements, energy class, insulation characteristics, and the efficiency of heating and cooling systems. EPCs may also contain:

- building information (national identifier, number of floors, floor heights),
- information about the issuing organization and responsible personnel,
- gross and net floor areas,
- the intended use of the building (e.g., residential, governmental),
- annual energy consumption for heating, cooling, air conditioning, ventilation, and hot water (kWh/year),
- annual primary energy use for each energy type (kWh/year),
- classification of primary energy use per floor area according to an A–G reference scale,
- annual greenhouse gas emissions per floor area (kg CO_2/m^2-year),
- classification of annual GHG emissions based on the A–G scale,
- share of renewable energy (Regulation on Energy Performance in Buildings, 2008).

The regulation became operational on 1 January 2011, from which date newly constructed buildings were required to achieve at least Class C in energy consumption and CO_2 emissions to obtain an EPC. Since then, no occupancy permit has been issued to buildings lacking an EPC. Existing buildings that already had occupancy permits before this date were also obliged to acquire a certificate. Furthermore, starting from 1 January 2020, an EPC became mandatory for all buildings involved in sales or rental transactions, with some exemptions such as industrial, agricultural, religious, protected, or temporary buildings, as well as those located outside urban areas with a total construction area under 1,000 m² (Regulation on Energy Performance in Buildings, 2008). It is critical to emphasize that the EPC must cover the entire building rather than individual units.

These calculations are carried out using the Building Energy Performance Calculation Software (BEP-TR), which applies both to new and existing structures and is accessible through the Ministry of Environment, Urbanization, and Climate Change. EPCs may only be issued by energy efficiency consultancy firms licensed under Law No. 5627, and these companies must employ staff who have successfully completed accredited training on EPC regulations. Finally, each EPC remains valid for a period of ten years from the date of issuance (BEP-TR, 2025).

2.2 Land administration systems and data in Türkiye

Türkiye has a long history of cadastral mapping, and today, over 99% of the national cadastre has been completed. For decades, cadastral records were primarily managed in 2D, which limited their ability to accurately represent complex property structures, such as multi-storey buildings, condominium ownership and underground constructions. In response to this, the General Directorate of Land Registry and Cadastre (GDLRC) launched the 3D City Models and 3D Cadastral Bases project in 2020 (GDLRC, 2024). The project aims to establish the GDLRC 3D City Models Management Information System, which integrates the production, verification, hosting, integration, and sharing of 3D geospatial data. A key objective is the integration of 3D building models with cadastral records to provide ownership-related information in a 3D environment. This approach will support real estate valuation, urban planning, and energy efficiency analysis by linking geometric building models with legal and administrative information (GDLRC, 2024a). CityGML, one of the most widely adopted international standards for 3D city models, has been selected as the underlying data format. Standards tailored for Türkiye were defined by GDLRC, covering object classes such as building, roof, storey, condominium unit, and shared spaces, all structured in compliance with CityGML specifications (GDLRC, 2024b). The project combines two production pathways: (i) photogrammetric methods, producing orthophotos, DEMs, and textured building models; and (ii) digitization of 2D architectural projects, used to create vector-based 3D models enriched with architectural plan attributes. These models are then cross-validated and improved by integrating photogrammetric and architectural sources (Aydinoglu et al., 2025). Importantly, such enriched 3D datasets provide a robust foundation for analysing building energy performance, including energy demand by storey, façade orientation, and potential for solar energy use.

The need for a National Spatial Data Infrastructure (NSDI) in Türkiye emerged in the early 2000s, when the "Preliminary Study Report for the Establishment of the National Geographic Information System" was published under the e-Transformation Turkey Project (GD-GIS, 2020a). Subsequent policy frameworks, including the Presidential Decree on Geographical Information Systems (2019), formalized the governance structure of Türkiye National Spatial Data Infrastructure (TUCBS). Its purpose is to standardize, integrate, share, and secure geographic data nationwide, providing the foundation for coordinated spatial data use across sectors. TUCBS consists of 32 geographic data themes and 52 sub-themes, designed to ensure interoperability between institutions and consistency with the EU's INSPIRE Directive (GD-GIS, 2019; GD-GIS, 2020b). Among these, the building theme is particularly relevant to energy efficiency. The building data model includes attributes such as total construction area, number of above- and below-ground floors, and conditioned floor area. Furthermore, it integrates a dedicated data type for Building Energy Characteristics (binaEnerjiOzellikleri), capturing information on energy consumption classes (A–G), greenhouse gas emissions (A–G), renewable energy usage rates, and technical features of heating, cooling, ventilation, and lighting systems. This alignment between land administration data and energy performance attributes positions TUCBS as a strategic enabler for tracking energy efficiency in the built environment.

The Address Registration System was originally established to manage the residential and address information in Türkiye within a centralized digital framework. Its spatially enabled extension, the Spatial Address Registration System (Mekânsal Adres Kayıt Sistemi-MAKS), integrates textual address data with geographic coordinates, providing a consistent geocoded address infrastructure (NVI, 2024). MAKS eliminates inconsistencies and redundancies in address data, ensuring that public services—such as education, health, and taxation—are planned and implemented efficiently. By linking building-level addresses with cadastral parcels and national population registers, MAKS plays a pivotal role in urban management and service delivery. In the context of energy, MAKS facilitates the spatial linkage of EPCs to specific addresses and parcels, enabling reliable monitoring of energy efficiency across different regions and building types.

The Land Registry and Cadastre Information System (Tapu ve Kadastro Bilgi Sistemi -TAKBİS) is Türkiye's core digital platform for property rights management. Initiated in 2002 as a pilot project and rolled out nationwide by 2012, TAKBIS integrates all 973 land registry offices in Türkiye, as well as one overseas office in Berlin, into a centralized digital environment (GDRLC, 2024c). TAKBIS enables the electronic management of land registry data, including ownership records, mortgages, and transfers. It also provides integration with GIS platforms, allowing spatial visualization of registry data. Through its e-Government portal integration, TAKBIS has improved transparency and efficiency in property transactions. From an energy perspective, TAKBIS is relevant because it establishes a reliable link between property ownership and building records, which is crucial when assigning responsibilities for energy performance compliance. By ensuring that property-related data is accurate, accessible, and interoperable, TAKBIS indirectly supports energy policy implementation and monitoring (GDRLC, 2024c).

Complementing TAKBIS, the Spatial Property System (Mekânsal Gayrimenkul Sistemi – MEGSIS) provides a web-based platform for integrating cadastral data with land registry information and sharing it with stakeholders through open geospatial services. Developed by GDRLC, MEGSIS consolidates cadastral data from local offices, harmonizes them into a central system, and delivers services via international mapping standards such as WMS (GDRLC, 2024d). MEGSIS services are available both to institutions (municipalities, banks, planning authorities) and to citizens through the e-Government portal, offering map-based access to cadastral information. In addition, MEGSİS provides orthophoto services and supports interoperability with external GIS applications. The availability of standardized cadastral datasets through MEGSIS is essential for integrating cadastral information with 3D building models, energy certification data, and urban planning systems, thereby contributing to data-driven decision-making in energy-efficient urban development (GDRLC, 2024d).

3. DEVELOPING A GIS-BASED DASHBOARD FOR BUILDING PASSPORTS

3.1 Study area and dataset

The study area is located in the easternmost part of the Anatolian side of the Istanbul Metropolitan Area in Türkiye (**Figure 1**). The district of Tuzla, with an area of approximately 138 km², encompasses 17 neighbourhoods (GDM, 2025). It also includes industrial areas, a military area, and a protected area. According to the official urban-rural population statistics published by Turkish Statistical Institute (TurkStat) in 2022, 11 neighbourhoods are categorized as high-density, 5 neighbourhoods as medium-density, and 1 neighbourhood as low-density settlement areas (TurkStat, 2022). According to official population statistics published in 2024, the district has a total population of 301.400, with the majority of this population living in the southern and central parts of the district. (TurkStat, 2024). According to the Socio-Economic Development Index of Districts report published in 2022 by the General Directorate of Development Agencies, which assesses the development levels of districts in Turkey using six development categories, Tuzla district is classified within the first (highest) development category (General Directorate of Development Agencies, 2022).

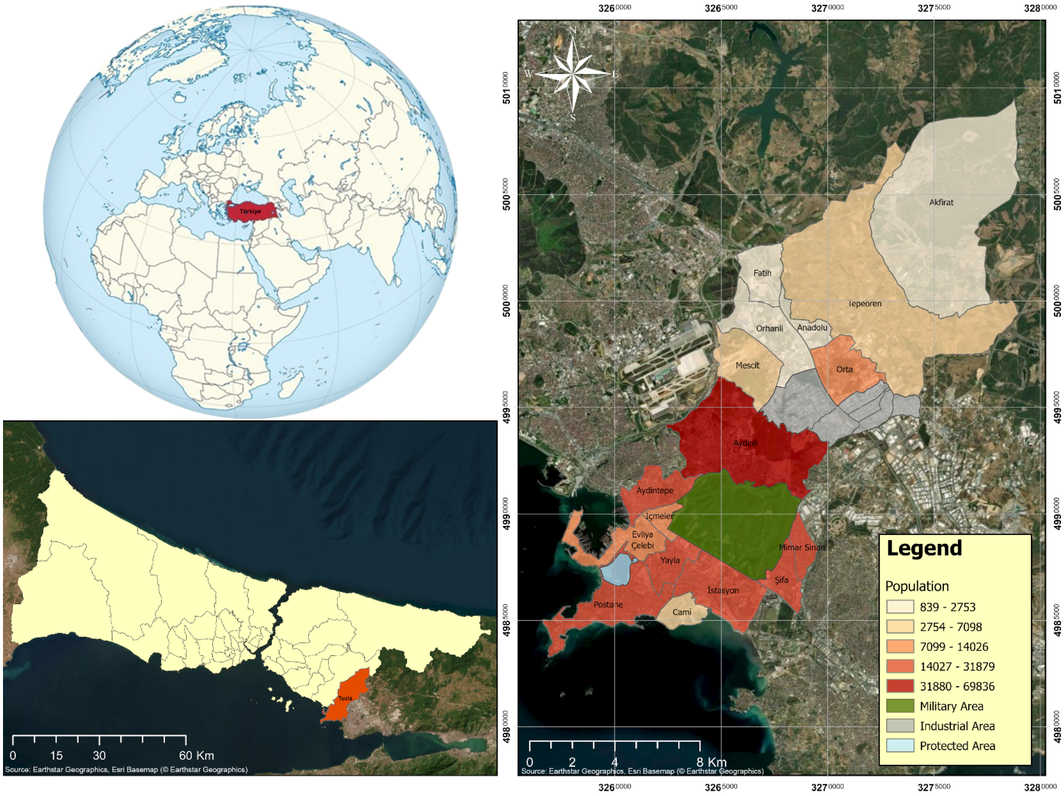

Figure 1. Location map of the study area

To develop a GIS-based dashboard for digital building passports, spatial and non-spatial datasets related to buildings from many sources are required. Within the scope of this study, road network data for the study area were obtained from the OpenStreetMap (OSM) data portal (OSM, 2025); urban points of interest (PoI) were gathered from the Istanbul Metropolitan Municipality's open data portal (IMM, 2025); neighbourhood-level population data were sourced from the TurkStat data portal (TurkStat, 2025); and socio-economic data at the neighbourhood level (such as income levels, education levels, and consumption behaviours), building energy certificates, 3D building and condominium unit models were obtained from the databases of the TÜBİTAK Project No. 122R021, funded by the Scientific and Technological Research Council of Türkiye (TUBITAK) (Aydinoglu, 2025).

3.2 Spatial data analysis and data preparation

The spatial and non-spatial data preparation process is crucial for creating digital building passports. This process ensures that data from various sources is transformed into a coherent, integrated, and analysable structure, thus laying the foundation for reliable and sustainable decision-support mechanisms. This process includes an integrated data preparation methodology as in **Figure 2**, which includes the stages of collecting, organizing, transforming and analysing spatial data related to buildings. Also, this process is a fundamental step for creating reliable, holistic and comparable building data. In the first step, spatial data related to buildings is obtained from different sources and in different formats (e.g., gml, shp, json, etc.). This data collection process is critical for preparing the heterogeneous spatial data for subsequent processing. In the second step, the obtained spatial and attribute data are edited to ensure data integrity and quality control. This improves the data for digital building passports.

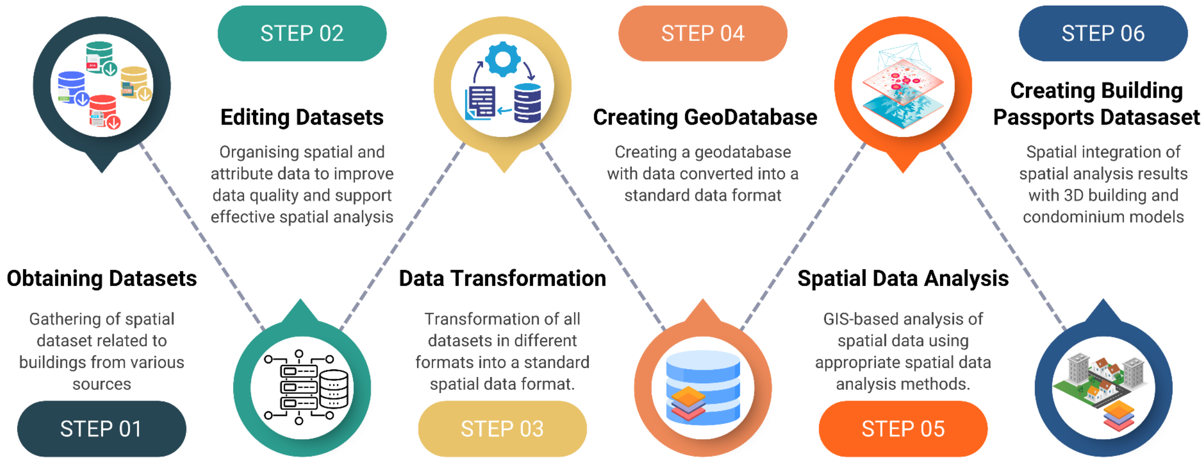

Figure 2. The process of preparing datasets for digital building passports

In the third step, datasets available in different formats are converted into a standardized spatial data structure, thereby ensuring interoperability among data from various sources. For example, the acquired 3D building models are in gml format, road network data are in shp format, and urban points of interest are in csv format. All datasets were converted into the shp format using the relevant transformation software. In the fourth step, the transformed data are imported to a geodatabase and organized within a specific schema. This structure enables secure storage of the data and facilitates effective use in advanced spatial analyses. In the fifth step, GIS-based spatial analysis methods are applied to the data in the database created in the previous step to generate various indicators related to buildings and their surroundings. This stage is a critical process that enriches the content of building passports and forms the basis for spatial decision support mechanisms. As demonstrated in the spatial analysis example (proximity analysis) in **Figure 3**, data within the database are evaluated using appropriate analysis techniques, and the results are then incorporated back into the database. In the final step, all spatial analysis outputs are spatially joined with the 3D building and condominium unit models. In this way, an integrated data infrastructure based on both spatial and attribute information is established, enabling building passports to attain a comprehensive, reliable, and multi-dimensional structure. The methodology developed in this process provides a robust foundation that can be utilized in various domains, including building management, property valuation, energy efficiency, disaster management, and sustainable urban planning.

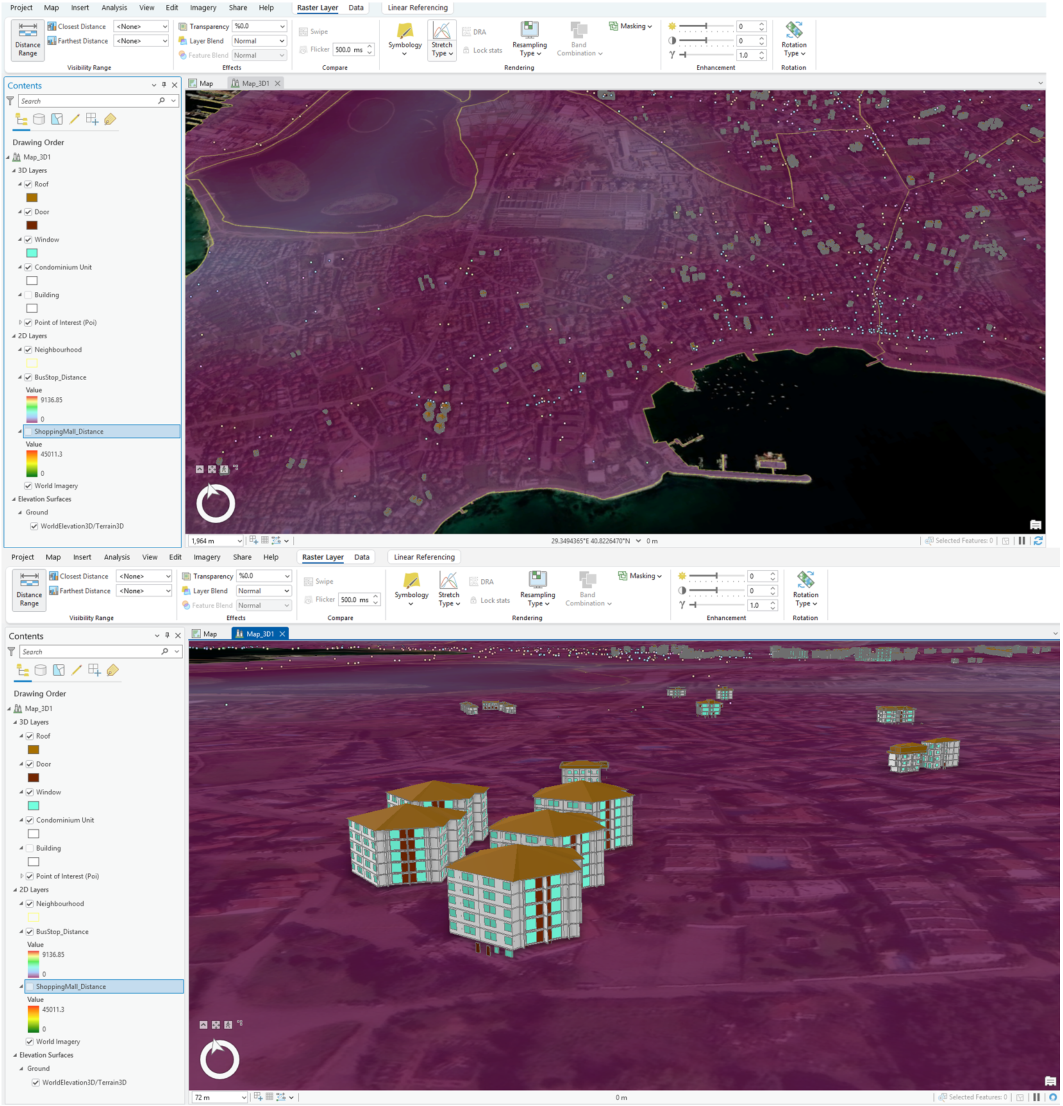

Figure 3. An example of spatial data analysis for building passports and the spatial integration of analysis results

3.3 Implementation of building passport dashboard

A web-based dashboard was developed to visualize and manage all data prepared for digital building passports. In the creation of the web dashboard, the ArcGIS Experience Builder application development tool was used, as shown in the developer interface in **Figure 4** (ESRI, 2025). ArcGIS Experience Builder, developed by ESRI, is considered a highly configurable solution for creating compelling web applications without the need for coding knowledge. In addition to offering rich templates for the web application development process, it enables the creation of detailed web applications for diverse target audiences by integrating web maps, applications, pages, interconnected components, and both 2D and 3D spatial data through a flexible drag-and-drop approach. The developed web applications can be easily configured for various screen resolutions (such as web, mobile, and tablet), and the publication process of the application can be carried out effortlessly. Moreover, with the built-in application components (widgets) available in Experience Builder, users can view maps, perform filtering operations, generate charts, or create detailed data lists. It is also possible to enable interactions between components, allowing one component to respond to actions taken in another—for instance, when a selection is made from a list, the map can automatically zoom to the corresponding location. Within the scope of this study, the data containing all relevant information were uploaded to the ArcGIS Online system for use on web platforms over map basemaps. While 2D data were directly uploaded to the ArcGIS Online system as hosted feature layers, a local scene was created for the 3D models, and the data were published as a Web Scene. In order to dynamically present various attributes related to real estate—such as socio-economic indicators, building, and unit characteristics, as well as accessibility to urban functions—based on 3D models within the application, a grid structure (Grid Row and Grid Column) was implemented, incorporating 16 Fixed Panels. The dashboard's default resolution was set to 1920x1080.Then, the attributes corresponding to each category were added to the respective panels. e 2D/3D data uploaded to the system were used to prepare the map basemap (scene) within the Scene Viewer environment, which was then integrated into the dashboard. With the addition of the map basemap, the data and the information contained in the created panels were each linked. To enable real-time updating of dashboard information based on the 3D model selected by the users, a trigger mechanism was established between the map basemap and the panels (**Figure 4**). Thus, the design and development process of the digital building passport dashboard for urban sustainability has been completed, as illustrated in Figure 5.

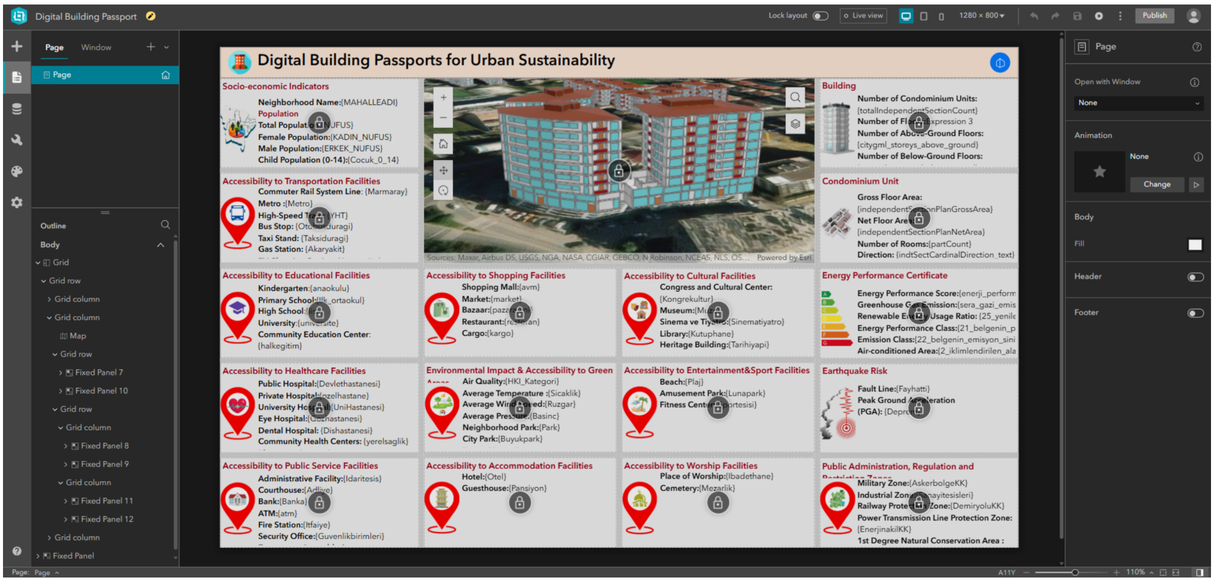

Figure 4. Design and development of a building passport dashboard using ArcGIS Experience Builder

Through the developed digital building passport dashboard, it is possible to access, in real time and dynamically, comprehensive information related to any property, including its 3D model, as well as neighbourhood-level socio-economic indicators such as population, income level, education level, marital status and household expenditure behaviours. Additionally, information is available for categories including building characteristics, condominium unit characteristics, building energy performance certificate, accessibility to transportation facilities, educational facilities, healthcare facilities, shopping facilities, cultural facilities, public service facilities, accommodation facilities, industrial facilities, worship facilities, entertainment & sports facilities, environmental impact and access to green areas, earthquake risk, and public administration regulation and restriction zones. In addition to this information, it is also possible to access data such as 3D models of floors, balconies, doors, windows, and roofs integrated into the dashboard; 2D cadastral parcels on which the properties are located; urban points of interest within the classified area by category; and classified road network data (Figure 5).

Figure 5. GIS-based dashboard for building passports

4. CONCLUSION

In this study, a GIS-based dashboard for extended Digital Building Passports (DBPs) was created to unify data from cadastral systems, energy performance certificates, socio-economic indicators, and spatial accessibility measures.
Türkiye's land administration ecosystem has undergone a profound transformation over the past two decades, evolving from a predominantly 2D cadastre into a digital and increasingly 3D environment. Key initiatives, including 3D cadastre projects, TUCBS, MAKS, TAKBIS, and MEGSIS, have collectively established a robust and interoperable infrastructure for managing land and building information. Recent advancements, particularly the inclusion of energy-related attributes in the TUCBS building data theme, demonstrate a growing alignment between land administration and national energy efficiency and sustainability policies. The integration of cadastral, registry, and address systems with 3D city models and building energy characteristics provides a foundation for advanced applications in smart cities and energy-efficient building management.
The extended GIS-based DBP dashboard demonstrates strong potential for supporting integrated urban governance. By consolidating heterogeneous datasets—including cadastral records, energy performance certificates, socio-economic indicators, and accessibility measures—the system enables comprehensive spatial and semantic analyses. Its applications extend across urban planning, disaster risk management, and social equity, while also serving property owners, investors, and public institutions through transparent and reliable digital infrastructure.
By linking building- and unit-level attributes with energy and demographic data, the dashboard provides policymakers and planners with a robust decision-support tool for evaluating energy efficiency, prioritizing renovations, and advancing sustainability strategies. Its alignment with Türkiye's strategic frameworks—such as the Strategic Plan (2024–2028), the Energy Efficiency 2030 Strategy, and the II. National Energy Efficiency Action Plan (2024–2030)—underscores its policy relevance and timeliness. Ultimately, the DBP dashboard contributes to sustainable urban development, climate resilience, and the digital transformation of the built environment.

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BIOGRAPHICAL NOTES

Suleyman Sisman (M.Sc.) currently works at the Department of Geomatics Engineering, Gebze Technical University, Turkey. He, as a geomatics engineer, completed his M.Sc. study on modelling mass real estate valuation by GIS-based machine learning techniques. He continues his PhD study about machine learning techniques, spatial data analysis, spatial data infrastructure, smart cities, sustainable land management, and Geographic Information Systems (GIS).

Abdullah Kara (Ph.D.) holds a Ph.D. degree (2021) from Yıldız Technical University (YTU) with a thesis on the extension of Land Administration Domain Model (LADM) with valuation information, which is used as a basis for the development of LADM Part 4 - Valuation information. He worked as a post-doctoral researcher (2021-2024) at the GIS Technology Section, Delft University of Technology. He has worked as an assistant professor at Gebze Technical University starting from 2024. He has been actively involved in FIG working groups

Arif Cagdas Aydinoglu (Ph.D.) graduated from Department of Geomatics Engineering of Karadeniz Technical University (KTU) in 1999. During his PhD "Developing Geo-data Exchange Model for Turkey" completed in 2009, he worked about developing base geo-data models in UGent-Belgium for 1 year and in TUDelft-the Netherlands for 9 months. After appointed to Istanbul Technical University (ITU) as an assistant professor in 2009, he completed projects about determining policies and geo-data specifications for Turkey National GIS (TUCBS). He completed his post-doc research in the EC Joint Research Center (JRC)- Italy in 2015 and worked as lead training expert and data expert in European Union IPA project that focused on INSPIRE capacity building in Turkey. He works as a professor in Gebze Technical University (GTU) since 2017. After following administrative duties, he is Head of Department of Geomatics Engineering and Director of Transportation Technologies Institute.

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