Identifier-driven sharing and application mechanism based on primitive topographic features: An example of buildings

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Keywords: spatial unit, identifier, cross-domain information

SUMMARY

The national-level dissemination of geospatial resources necessitates the effective integration of data across multiple domains. A notable challenge arises from the fact that numerous datasets specific to certain domains contain only indirect spatial references, thereby limiting their direct applicability in spatial contexts. Traditionally, topographic maps have been regarded as essential national data, distinguished by their clearly defined themes, specifications, and quality. Topographic features can serve as valuable geospatial references for cross-domain data, thereby enabling effective integration with information acquired from various stakeholders. This study seeks to broaden the applications of national base maps by investigating how building features with diverse specifications can function as a foundation for the geospatial referencing of cross-domain data. By associating building features with multiple domain identifiers, such as building numbers and street addresses, various themes of building-related data that lack spatial context can be geospatially referenced. This methodology not only revitalizes the potential applications of building features but also facilitates their integration and interaction with other domain data based on location, thus allowing for effective incorporation into geospatial applications. As a critical component of topographic maps, building data is characterized by spatial units with clear semantics according to the selected Level of Detail (LOD). Each semantic spatial unit of a building possesses specific identifiers, and each type of identifier adheres to its own design and maintenance protocols, necessitating a separate examination of the linking operations. Through an analysis of various identifier systems of buildings in Taiwan, this study demonstrates that establishing unambiguous cross-domain linking relationships requires the spatial units of building features, the temporal versions of identifiers, and the domain data to meet the criteria of both uniqueness and temporal consistency. This requirement transcends the traditional approach of merely linking disparate data based solely on common identifiers. From the perspective of national spatial data infrastructure, this underscores the necessity for a more comprehensive temporal version management system for the topographic feature database, driven by the characteristics of the identifiers. Furthermore, it emphasizes the importance of incorporating temporal considerations into domain data to achieve accurate integration with topographic features, thereby facilitating optimal utilization of cross-domain information.

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1. RESEARCH BACKGROUND

As human living environments become increasingly complex, the precise delineation of spatial units has become ever more critical. Whether in administrative management conducted by government agencies or applications in the private sector such as logistics, real estate management, and more, the clear identification and labeling of various spatial phenomena are essential. This necessity has made identifier systems an indispensable reference. By assigning unique codes, identifier systems can correspond to specific areas or entities, ensuring that each dataset or feature can be accurately located and identified, thereby enhancing data validity and accuracy. However, over time, spatial units may undergo changes, such as administrative boundary adjustments, road expansions, or building demolitions. Consequently, identifier systems must possess not only uniqueness and durability but also the ability to track temporal versions. This means that an identifier system should be capable of recording changes in each spatial unit throughout its lifecycle and providing both the latest data updates and historical records as needed.

Geographic Information Systems (GIS) are technologies capable of efficiently processing and analyzing vast amounts of geospatial data and are widely used in urban planning, environmental protection, transportation management, and public safety. The advantage of GIS lies in its ability to depict various dimensions of phenomena, such as land use, population distribution, and traffic flow, thus involving data sharing and collaboration among numerous governmental and private organizations. When managing spatial data from multiple sources, GIS often has to face the challenges of cross-domain integration caused by inconsistencies in identifier systems. Therefore, GIS must address how to integrate these disparate identifier systems and ensure data accuracy and consistency in cross-domain applications.

With the rapid development of the internet and technology, the term "Digital Twin (DT)" has gained increasing attention and application. The rise of digital twin technology further emphasizes the need for cross-domain data integration and linkage. Digital twin systems aim to simulate various real-world phenomena, ranging from urban infrastructure to natural environments, through precise virtual models. To achieve this, digital twins require extensive spatial data from diverse sources, and such data must possess both temporal and spatial associations to accurately reflect changes in the real world. Thus, establishing an identifier system with temporal version management that can connect spatial data from different sources across domains will be crucial for the development of digital twin technology.

2. FUNDAMENTAL CHARACTERISTICS OF IDENTIFIERS

2.1 ANALYSIS OF THE BASIC CHARACTERISTICS OF IDENTIFIERS

Based on the current advancements in Geographic Information Systems (GIS), data is no longer confined to operations on a single user's device but can flow and interconnect through the internet, enabling interoperability to develop cross-domain applications. Among these advancements, the use of unique identifiers has emerged as a critical issue. Data from various domains, regardless of its source or storage location, should be represented by a unique identifier within its reference system. This allows for establishing relationships between two or more pieces of data during cross-domain integration.

Unique identifiers (UIDs) are symbols or data used to uniquely identify specific features. In many systems, UIDs serve to distinguish between different features, ensuring that each feature is unique within the system, thereby avoiding confusion or duplication. UIDs are widely applied in fields such as database design, networks and technology, product identification, personal identification, and spatial identification. Their implementation often adheres to specific reference systems and unified principles to construct identifier compositions. These identifiers also possess certain essential characteristics.

In his research, Gremeaux (2011) referenced the INSPIRE (Infrastructure for Spatial Information in the European Community) project, a geographic information infrastructure initiative in Europe, to be responsible for coordinating and standardizing spatial data among EU member states. The unique identifier defined by INSPIRE (inspireID) includes the following four specific requirements:

- Uniqueness: Each spatial object within a domain must possess a distinct identifier, ensuring that no two objects share the same identifier. This requirement is critical for the precise differentiation and localization of spatial objects, thereby enhancing the accuracy of data management and system operations.

- Persistence: The identifier of a spatial object must remain constant throughout its lifecycle. Even if the object's attributes or geometry undergo modifications, its identifier should not change. This consistency is vital for the continuous tracking and identification of the object, thereby maintaining data reliability and facilitating accurate historical records.

- Traceability: A Spatial Data Infrastructure (SDI) necessitates mechanisms for locating and identifying spatial objects through unique identifiers. This capability allows users to easily access data services and identify data sources, thereby enhancing data availability and interoperability, which in turn supports efficient data retrieval and informed decision-making.

- Feasibility: The identification system should be capable of mapping existing national identifiers to new international standards, such as INSPIRE, to ensure data compatibility and consistency. This design enhances the accuracy and efficiency of cross-border data exchanges without necessitating substantial modifications to existing systems, thereby promoting international collaboration and data sharing.

In addition to elucidating the overarching concept of an identifier system, this study emphasizes the application of spatial identifiers. A Geographic Identifier (GeoID) is a coding system specifically designed to uniquely identify geographic locations. These identifiers are prevalent in GIS, databases, and various applications, providing unique identification with spatial relevance. This functionality is crucial for the tracking, management, and analysis of data pertaining to specific geographic areas, thereby enabling precise geolocation capabilities. Beyond the fundamental characteristics previously mentioned, GeoID also incorporates the following features:

- Standardization: Geographic identifiers typically follow certain standards or specifications, such as ISO 19115 and other international standards. Standardized identifiers facilitate data integration and analysis, thereby enhancing accuracy, reliability, and interoperability across various sources.

- Hierarchical Structure: Geographic identifiers are designed hierarchically, reflecting relationships from countries down to streets. This structure aids in the identification of specific areas, and data visualization, and simplifies management and analysis.

- Scalability: Systems are constructed with scalability in mind to accommodate the addition of new geographic areas or codes. Modular architectures and scalable databases allow for seamless updates without disrupting system functionality.

- Cross-Platform Compatibility: Geographic identifiers are compatible across different GIS platforms, which enhances data sharing and interoperability. This compatibility reduces errors and inconsistencies, thereby improving data quality for applications such as urban planning and resource management.

- Temporal Considerations: Geographic areas and their corresponding identifiers are subject to change. Timely updates and versioning are essential to maintain data accuracy, particularly in response to changes such as boundary adjustments or area reclassifications.

2.2 IDENTIFICATION REFERENCE SYSTEM

In principle, geographic identifiers (geo-identifiers) should be systematically encoded to establish a comprehensive and consistent coding structure for the description of various phenomena. Such a systematic design facilitates the accurate identification and representation of specific spatial regions or points, thereby enhancing geographic information management and location services. By methodically integrating geo-identifiers related to the same subject, a framework known as the “Geographic Identifier Framework” (GID Framework) can be developed. This framework allows users to assign geo-identifiers that correspond to their data, thereby streamlining the retrieval of datasets that align with specific spatial descriptions from backend databases. This process not only aids in effectively linking attribute data with spatial data but also improves data accuracy and enhances the potential for spatial analysis. As a result, users can achieve increased efficiency and precision in subsequent data queries and analyses (Hong & Lin, 2006).

When creating a geo-identifier reference system, it is typically designed to undergo a process of "standardization" to prevent inconsistencies among the data generated by the system. However, many existing systems demonstrate varied interpretations of standardization, which necessitates data conversion during cross-domain applications. Additionally, temporal factors can influence system performance; in the absence of update mechanisms or adequate scalability, erroneous data may arise, adversely affecting applications. To solve these problems, several measures are recommended: the implementation of a unified update mechanism, the design of scalable systems, the maintenance of historical version records, the provision of comprehensive query interfaces, and the execution of user training and feedback collection to enhance data accuracy and system reliability.

In conclusion, the effective management of geo-identifiers is contingent upon the establishment of maintenance mechanisms, version records, and organizational frameworks. A well-structured system can significantly enhance data accuracy and facilitate precise analysis. Conversely, without effective maintenance, data inaccuracies may accumulate, compromising operational integrity. Therefore, maintenance mechanisms and version records must be integrated into the system design to ensure its long-term stability and functionality.

3. INVENTORY AND ANALYSIS OF THE IDENTIFIER SYSTEM FOR BUILDINGS AND LAND IN TAIWAN

3.1 BUILDING IDENTIFIER – ADDRESS AND BUILDING NUMBER

3.1.1 ADDRESS

The address is composed of a combination of Chinese characters and numerical identifiers, systematically structured by household registration offices into hierarchical categories, including City, Township/District, Village, Neighborhood, Street/Road, Lane, Alley, Sub-Alley, and Number. The assignment of address data is managed by the Household Registration Division of the Civil Affairs Bureau of county and city governments, as well as township, town, city, and district household registration offices. This responsibility falls under local self-government affairs. Household registration units manage and maintain address data through the household registration information system based on actual conditions and provide historical address inquiries.

The current methods of address assignment and plate installation across various counties and cities are largely similar. In addition to the existing address data, it is also necessary to record the results of operations such as the initial assignment of address, reassignments, additions, and reorganizations. (Ministry of the Interior Information Center, 2009). Following the completion of a building, the builder or owner is required to apply for an initial address at the household registration office, accompanied by the necessary permits.

Changes to addresses may occur because of building mergers, subdivisions, or urban planning initiatives. Additional numbers are designated with extensions (e.g., "No. 1-1"). In instances where multiple houses are consolidated, any unused numbers are preserved for potential future allocation. The household registration office is responsible for reorganizing them if inconsistencies with actual conditions in doorplate numbering arise due to road construction, renaming, or disordered numbering. Furthermore, residents may petition for renumbering in cases where the building's entrance is altered, numbers are duplicated, or the numbers are considered inauspicious (for instance, those ending in "4"). Address is rendered void when a building is demolished.

3.1.2 BUILDING NUMBER

The initial registration of building ownership also referred to as preservation registration, involves the formal registration of newly constructed or legally established buildings with the appropriate authority to secure ownership rights (Gu, 2022). Upon completion of the registration process, a unique five-digit building number is assigned, and a building registration book is created. General buildings are sequentially assigned numbers based on their lot or sub-lot designations, whereas special buildings share a common five-digit parent number, with individual structures receiving a three-digit suffix (e.g., 00427-013). Special buildings are defined as those located on the same site, under unified ownership, and utilized for identical purposes, which may include public facilities, local government structures, educational institutions, industrial sites, warehouses, religious edifices, and historically or aesthetically significant buildings.

Following the "Cadastral Survey Regulations" in Taiwan, building surveys are categorized into two distinct types: the initial building survey and the building resurvey. Circumstances necessitating a building resurvey encompass "expansion or renovation," "partial destruction, subdivision, or consolidation," as well as "complete destruction or alterations in the land parcel number, address, or other conditions requiring inspection." The condition of the building post-resurvey may differ from its status at the time of initial registration.

For buildings that have been subdivided, one of the structures will retain the original building number, while the remaining buildings will be assigned sequential numbers that follow the last building number associated with the land parcel. Newly allocated building numbers must be documented in the building number management book or entered into computerized management systems. In instances of building consolidation, only the earliest building number from the consolidated entities will be preserved, while all other building numbers must be removed and are prohibited from being reused.

3.2 LAND IDENTIFIER – ADMINISTRATIVE REGION CODES

The data about administrative boundaries enables a precise delineation of the spatial extent of each administrative region. This information serves as a foundational element for the representation of base maps within geographic information systems (GIS) and is integral to the generation of statistical data and thematic maps. Furthermore, administrative boundary data functions as a vital reference for data interchange among various units, thereby facilitating the sharing and collaboration of diverse datasets across different departments. This collaboration enhances the efficiency of governmental resource allocation and strengthens the empirical foundation for policymaking. Such data are essential for effective planning, management, and decision-making processes (Department of Land Administration, 2010). In Taiwan, administrative region codes, which are overseen by the Department of Household Registration, serve as unique identifiers for each administrative division, encompassing village and neighborhood codes. The coding system is structured hierarchically using numerical codes and is segmented into four parts: provinces and municipalities (2 digits); counties and cities (3 digits); county-level cities, towns, townships, and districts (2 digits) with an additional digit for household registration purposes; and villages and neighborhoods (3 digits), resulting in a total code length of 11 digits. For instance, the complete code for Bai'e Village in Jiaoxi Township, Yilan County, Taiwan Province is "10002050012," while the code for Shaochuantou Neighborhood in Gushan District, Kaohsiung City, is "64000020037," with "000" appended to the names of municipalities to ensure uniformity in code length.

3.3 IDENTIFIER REFERENCE SYSTEM AND ITS MAINTENANCE MECHANISM

The analysis of identifier systems reveals that building numbers are integral to the cadastral framework, while address and administrative region codes are administered by the Department of Household Registration. These identifiers function within their designated reference systems and comply with established standardization protocols. In addition, each identification code system also maintains its version history, allowing users to track and review historical data to understand its evolution and updates.

This organized coding framework enhances the accuracy and consistency of data, facilitating integration and exchange among various administrative units, which in turn improves overall management efficiency and transparency. When comparing the update mechanisms of the three identification systems, it is observed that administrative region codes typically remain static once established, except for a singular comprehensive update necessitated by shifts in governmental responsibilities. Conversely, building numbers may change due to property division or merger and are recorded through building surveys and registration to maintain their historical versions. Any redundant identification codes generated after a property merger will be directly deleted and not retained for use, ensuring that duplicate identification codes do not appear along the overall timeline.

In addition to updates due to changes in property ownership, addresses differ from building numbers in that when a property merger results in multiple addresses, the extra addresses are changed to reserved numbers for future use by newly constructed buildings. This could lead to duplicate identifiers, so an additional reorganization mechanism is implemented to resolve the issue of duplicate and disordered addresses that may arise in certain areas due to long-term changes.

4. INVENTORY AND ANALYSIS OF THE IDENTIFIER SYSTEM FOR BUILDINGS AND LAND IN TAIWAN

4.1 THE MAINTENANCE MECHANISM OF THE NATIONAL IDENTIFIER REFERENCE SYSTEM IN TAIWAN

Cross-domain spatial data can be interconnected through the use of identifiers, thereby facilitating the integration and linkage of disparate datasets. For instance, when two datasets from distinct organizations utilize the same address, these spatial datasets can be associated via a common geographic identifier, allowing for their incorporation into a spatial unit system. Such interconnections not only establish relationships among the datasets but also enable a range of correlation analyses and applications. By examining multiple data sources linked to the same address, researchers can attain a more nuanced understanding of population distribution, resource allocation, and socio-economic conditions within the area. This integration method not only enhances the value of the data but also provides a solid foundation for collaboration across multiple fields.

Therefore, the spatial unit system can be regarded as a fundamental component for cross-domain data connectivity within a digital twin system. This system not only facilitates data sharing and integration across different fields but also provides the necessary spatial reference framework for building accurate digital twin models.

4.2 CHALLENGES OF MULTI-IDENTIFIER SYSTEMS IN CROSS-DOMAIN APPLICATIONS

During the process of cross-domain data integration, challenges arise due to the different standardized identification code systems and varying methods of recording time versions used by each domain. These factors bring a series of challenges to data integration, including inconsistencies in data formats, confusion in time versions, and the risk of data loss during the integration process. To address these issues, the following will provide a detailed explanation of potential specific situations and explore feasible solutions. The aim is to offer more effective support and reference for cross-domain data integration.

4.2.1 THE IDENTIFIERS ACROSS DIFFERENT DOMAINS ARE INCONSISTENT

In different systems or domains, the same feature may be identified using different identifiers. Taking spatial units of single households as an example, in the cadastral domain, the identifier is typically the building number, while in the household registration system, the identifier is the address. Due to differences in the assignment methods, there is generally no systematic correspondence between building numbers and addresses. This discrepancy can lead to difficulties in accurately identifying the same spatial object during cross-system data tracking, thereby increasing the complexity of data integration.

To address this issue, relevant authorities should establish a correspondence table for spatial units of different households, clearly defining the relationships between the identifiers. This ensures data accuracy and consistency in cross-domain integration processes, enhancing data management efficiency. In addition to in-person applications, the Department of Household

Registration offers an online cadastral information service system, which allows users to query corresponding building numbers based on addresses (Figure 1).

Figure 1, The online cadastral information service system (Department of Land Administration)

4.2.2 THE FORMAT OF STRING-BASED GEOLOCATION IDENTIFIERS IS INCONSISTENT, AND THE CONVERSION SYSTEM IS INCOMPLETE

In Taiwan, address assignments are made by the local government, so the standards may vary. Additionally, due to differences in recording methods among various organizations, there may be inconsistencies caused by mixed use of numerical digits, Chinese characters, and full-width, or half-width characters. Furthermore, it is common for individuals to omit certain fields when writing addresses, leading to discrepancies in address records across different organizations.

To address this issue, a conversion system is employed to standardize geographic identifiers. Currently, Taiwan Geospatial One Stop(TGOS) provides publicly available APIs. Users can apply for an API key to perform batch address conversions(Figure 2). However, TGOS has certain limitations. Since the network map services integrated into the TGOS platform are published by various responsible authorities, the platform adopts a centralized management and decentralized processing approach. As a result, when standardizing address conversions, the platform may not fully account for the timeliness of the data, leading to limitations in fuzzy matching.

In addition, the address conversion system provided by TGOS cannot recognize address records beyond the "number," such as floor descriptions. Therefore, to improve the reliability of geographic identifiers in string format, Taiwan not only needs to develop a more robust standardized conversion system but also incorporate temporal considerations. This would prevent situations where addresses cannot be matched due to the lack of time-based adjustments in the conversion process.

Figure 2, TGOS Geocoding Service (Ministry of the Interior)

4.2.3 TEMPORAL INCONSISTENCY

In the context of cross-domain associations, managing multi-identifier systems is complex due to issues related to update timing and versioning across different systems. Each system independently updates data based on its specific needs, leading to discrepancies in timing. Without synchronization mechanisms or version control, it becomes challenging to maintain data associations, adversely affecting accuracy and consistency. For example, building number and

address systems may use different identifiers to represent the same object. However, due to differences in update timing, data content may vary. In cases such as building subdivisions, changes to corresponding spatial extents may not be adequately recorded, potentially resulting in errors or outdated data.

Additionally, delays in updating geographic identifiers can exacerbate issues. For instance, an address might remain in mapping data even after a building is demolished, highlighting the importance of temporal version tracking. To address these issues, implementing temporal version recording and synchronization mechanisms is recommended. Designing cross-system data synchronization strategies, annotating data with timestamps, and establishing standardized update protocols can help reduce the risk of inconsistencies. However, the cost of version management and its impact on system performance must also be considered, as multi-version records require additional resources and optimization. This study recommends that data providers explicitly record update times. Furthermore, the government could establish a centralized version control platform to coordinate data updates across systems, minimizing conflicts and comparison workloads, and thereby improving integration efficiency and accuracy.

4.2.4 THE INTEGRITY AND PRESERVATION OF HISTORICAL DATA

In a multi-system environment, incomplete historical data retention can disrupt data traceability and continuity, particularly during comprehensive reviews or historical analyses. Some systems may only retain the latest or partial versions, leading to data gaps that hinder understanding of trends and cause errors in cross-domain data linkage.
This study proposes a centralized historical data repository to address these issues. The repository should include time-version management to ensure accurate recording and tracking of all data versions, enabling effective data evolution management and reliable retrieval for future analyses.

5. THE BENEFITS OF INTEGRATING SPATIAL UNITS WITH IDENTIFIER

Through the incorporation of spatial units that possess distinct identifiers, we establish identifiable characteristics. For instance, household units are associated with domain identifiers, while village perimeters are connected to administrative region codes, resulting in a comprehensive data framework. This study will evaluate the practical significance and advantages of this framework, as well as suggest possible applications and avenues for future development.

5.1 ESTABLISHING BASIC DATA — THE RELATIONSHIP BETWEEN SPATIAL UNITS AND IDENTIFIER

First, it is necessary to establish the basic data for spatial units, integrating individual household units with building numbers and addresses. Both can serve as unique identifiers, but their difference lies in the direction in which they are applied to link data across different domains. When a building number is used as an identifier, it is typically applied in cadastral-related data domains, such as basic building information or property registration records. On the other hand, using an address as the unique identifier encompasses a broader range of data fields and application scenarios(Figure 3).

By combining village or neighborhood identifiers with administrative region codes, a spatial unit defined by administrative boundaries and codes can be created. This approach effectively integrates geographic divisions with data management, facilitating further identification and application(Figure 4).

Figure 3, The building number and address of the household units

Figure 4, Administrative region codes of the administrative region

5.2 PRESENT THE STATE OF A SPECIFIC TIME USING A UNIQUE IDENTIFIER

Based on the established spatial unit database, domain data can be effectively linked through common identifiers. For example, as illustrated in Figure 5, the primary use data from building registrations is integrated into the spatial representation of household units, with different colors used to distinguish various building purposes. This approach visually demonstrates the spatial distribution of building uses. From the figure, it is evident that different types of building uses may coexist within the same area, such as parking spaces, mixed-use buildings combining residential and commercial purposes, and buildings primarily designated for residential use.

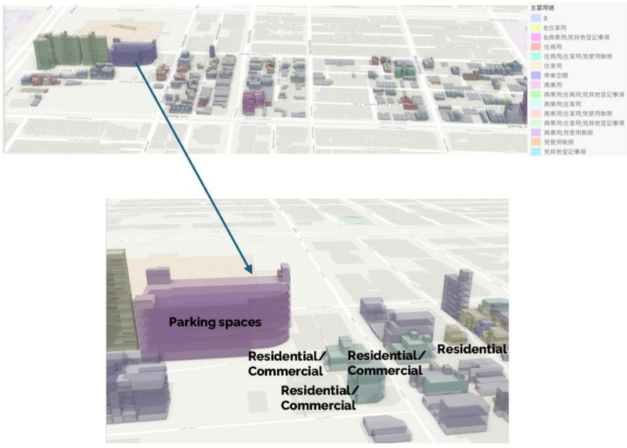

Figure 5, The spatial distribution of building uses

Through the application of common identifiers, domain data can be effectively linked to reveal changes and dynamic characteristics across different temporal and spatial contexts. For example, as shown in Figure 6, population data was combined with administrative codes and mapped to village-level spatial units. This study focuses on household changes across four years, with changes visualized using colors: yellow for increases and gray for decreases. Notably, the red-circled area, Jianjun Village (code 64000080068), showed a declining household trend before 2019, followed by growth from 2019 to 2021, suggesting significant socio-economic changes during this period. Temporal population data enables deeper insights into urban development trends and dynamics.

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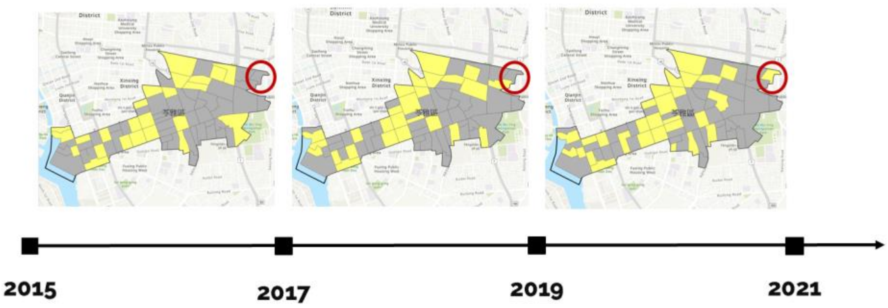

Figure 6, The change in the number of households from 2015 to 2021

5.3 THE BENEFITS BROUGHT BY CROSS-DOMAIN ASSOCIATIONS TO SPATIAL ENABLING

By associating the spatial units of households within a building with company registration data and business registration data from open datasets based on their addresses, the spatial distribution of enterprises in the area, as shown in Figure 7, can be derived. Furthermore, through the integration of visibility analysis, the results, as illustrated in Figure 8, can be obtained. When observing from the west-side window on the 5th floor of the Lingya District Administrative Center, with a horizontal field of view of 90 degrees and a vertical field of view set to 45 degrees, the visible area within 200 meters is depicted. The yellow portions indicate the visible area, while the black portions represent areas obstructed from view.

By associating spatial units with their respective commercial uses through the linkage mechanism, further analysis of the field of view can be conducted. This not only facilitates considerations for developers and real estate companies in designing projects and evaluating property advantages but also offers a visualized representation. Through this approach, the commercial purposes of each spatial unit can be analyzed in detail, providing practical value in urban planning and real estate development.

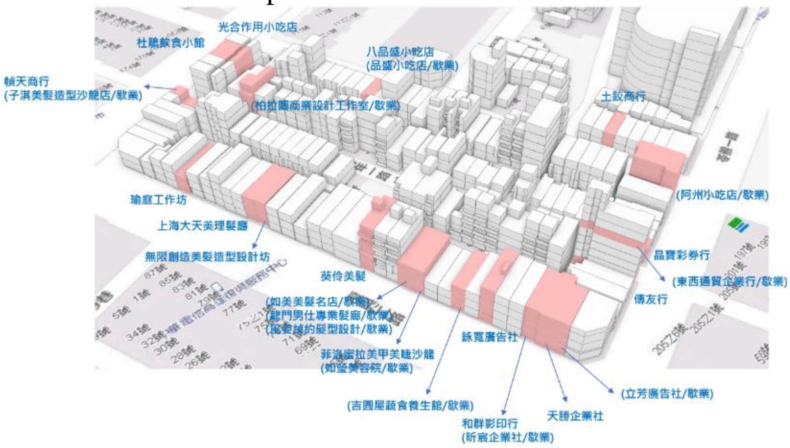

Figure 7, The spatial distribution of enterprises

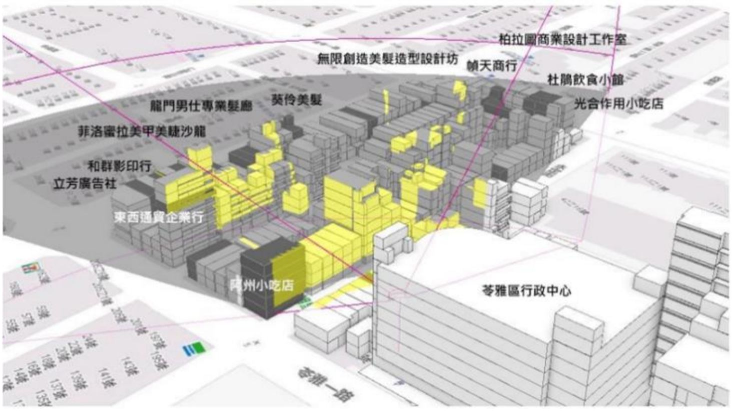

Figure 8 The integration of enterprises' distribution and visibility analysis

6. CONCLUSION

Identifiers play a critical role in cross-domain data integration. They not only ensure accurate correspondence of data from different sources but also maintain data consistency and accuracy in cross-system applications. Whether in government administration or private sector applications, a unique and stable identifier system effectively facilitates data integration. However, as spatial units change over time, the temporal aspect of identifier systems becomes increasingly significant. It is essential to implement version management for identifiers and synchronize the update frequencies and timelines across different systems to mitigate the risk of data inconsistencies.

In the field of digital twins, a stable common reference unit and an identifier system with time-versioned records are key elements in linking the virtual and physical worlds. Such mechanisms not only ensure the accuracy of virtual models but also provide a consistent spatial reference, facilitating the integration and application of cross-domain data. This enables precise digital simulations and supports informed decision-making.

Future research is expected to incorporate more diverse cross-disciplinary data and link these data to the foundational spatial units of three-dimensional buildings through identifier systems, thereby achieving the goal of 3D spatial enabling. This process will not only enhance our understanding and application of 3D spaces but also lay the foundation for diversified applications. With such integration, we can explore broader application scenarios encompassing urban planning, architectural design, resource management, and more, ultimately driving the development of smart cities. It is hoped that these efforts will promote collaboration across different fields, further enhancing the efficiency and value of data utilization.

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