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Development of Urban Information Platform for Cross-Domain Urban Design

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Abstract: This research developed an urban information platform to enable holistic urban design across multiple disciplines and regions, addressing Japan's urban challenges. By aggregating a wide range of urban data into a geographic database, the study emphasizes data-driven decision-making in urban planning. The platform supports the visualization and analysis of critical domains like medical and water supply, enhancing decision-making processes. Key contributions include the creation of evaluation indicators and the demonstration of the platform's application in urban design discussions.

Key words: Urban Design, Data Science, Evidenced Based Policy Making, GIS

1. INTRODUCTION

The 2024 earthquake in the Noto region of Ishikawa Prefecture, Japan, dramatically underscored the vulnerabilities inherent in underdeveloped rural areas. The severe damage inflicted on public infrastructure by the earthquake significantly impeded prompt disaster response efforts. This event has starkly illuminated the risks and challenges confronted by local municipalities, which are often characterized by limited resources and declining populations. The depopulation of rural regions, where a sparse population is distributed over extensive areas, including those with inadequate transportation networks, complicates the provision of sustainable public services.

The vulnerability of these rural areas stems significantly from Japan's pronounced population decline, characterized by a low birthrate and an aging demographic [1]. The nation's overall population is on a downward trajectory, with the impact of this decline being acutely felt in rural regions. The aging population has led to a diminishing labor force and escalating social security expenses, thereby exerting increased economic pressure on the country. Moreover, the migration of younger individuals to urban centers has resulted in the depopulation of rural areas and the deterioration of local communities across numerous regions. These demographic shifts are posing new challenges for urban planning and design.

In response to this situation in local cities, the concept of compact city policy is gaining popularity in order to increase urban efficiency by aggregating public infrastructure and facilities necessary for daily life that have become excessively dispersed. For many elderly people, however, leaving their familiar surroundings is a major challenge, hindering the realization of the compact city concept. The recent disaster has forced local communities to consider the option of rebuilding their existing environment or relocating. Particularly in the affected Noto region, where the population is dispersed

across rugged terrain, the expected decline in population will further complicate infrastructure development. Therefore, there is a debate over whether to rebuild and maintain existing infrastructure or to consolidate urban functions and promote residential densification, and how infrastructure should be developed in the future.

We wish to make it clear that the We authors are not endorsing any particular position in this discussion. Nonetheless, this discussion extends beyond the Noto region, indicating that it is a critical issue likely to confront many other regions within Japan. Given the challenges of declining and aging populations, alongside aging infrastructures in Japanese cities, the reorganization and optimization of urban functions are imperative. In this context, this paper aims to examine two perspectives deemed essential for future urban design considerations.

The first perspective emphasizes the interdisciplinary essence of urban design. To efficiently utilize scarce resources amidst a declining population, it is crucial to integrate and restructure urban functions. This necessitates an urban design approach that transcends traditional spatial rearrangement, incorporating a wide range of fields including administration, healthcare, education, and commerce. Urban design must extend its focus beyond isolated sectors to embrace a collaborative framework among multiple urban functionalities. For instance, in deliberations on whether to rebuild or relocate, it is imperative to engage in a holistic discussion that not only addresses immediate human needs through healthcare and commerce but also considers the essential urban infrastructure such as water supply and roads.

2. RESERCH OBJECTIVES

The significance of cross-disciplinary and cross-regional approaches in urban design forms the cornerstone for forthcoming deliberations on urban planning in Japan. This research acknowledges the necessity of reevaluating and enhancing urban functionalities through broad regional collaboration and a multidisciplinary perspective. Yet, initiating discussions from such a perspective presents numerous challenges, primarily due to the extensive data requirements for comprehensive analysis across various urban functions and regions. Moreover, the acquisition of such data, even if feasible, demands advanced technologies for big data visualization and analysis—a task daunting without substantial administrative resources.

The purpose of this study is to identify the need for a cross-disciplinary and cross-regional urban design information platform and to propose a foundation for its establishment in the context of Japan's declining and aging population. This platform will enable the aggregation, visualization, and analysis of data on urban activities across diverse fields, such as urban planning, health and medical welfare, and water supply services, on a nationwide scale in Japan.

In an era marked by population decrease, the reorganization and efficiency enhancement of urban structures are imperative. Achieving these objectives necessitates a deep comprehension of the intricate interplays between various sectors, predicated upon this comprehensive understanding. Thus, this research endeavors to create an information platform that amalgamates urban data and employs a Geographic Information System （GIS） for its visualization. This initiative aims to empower urban designers and policymakers with data-driven insights, fostering more sustainable and efficacious urban planning strategies.

3. PREVIOS RESEARCH

To grasp the contemporary trends and methodologies in leveraging Geographic Information Systems （GIS） and data analytics within cross-disciplinary and cross-regional urban design frameworks, a

literature review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA [2]) guidelines. This review utilized the Scopus and Web of Science databases, focusing on publications from 2015 onwards with the keywords "GIS", "urban design", and "data analysis". These keywords facilitated a targeted search across both databases to collate existing insights into GIS utilization and data analytics application in urban design contexts.

The initial search returned 632 articles from Scopus[3] and 601 from Web of Science[4]. After the removal of duplicates, 995 unique articles were identified. A subsequent screening based on titles and abstracts reduced the pool to 49 papers, which were then examined in full.

Among these, 16 papers proposed frameworks or algorithms for urban analysis but lacked detailed system architecture descriptions. Five studies concentrated on developing interfaces for data analysis or evaluating existing systems, with three specifically addressing cross-disciplinary urban design through the development of particular systems. Dammag, A.Q., et al. are conducting a cross-disciplinary assessment and strategy formulation for urban planning in rural areas using GIS [5]. Viktor Sebesty´en et al. assess urban structure based on a multilayered GIS analysis from a cross-disciplinary perspective, focusing on well-being in cities [6]. Suleyman Sisman et al. aimed to make it possible to select suitable sites for various facilities in smart city development by building a GIS-based suitable site determination model, and created a suitable site determination model for Electric Vehicle spots as a case study[7]. Nonetheless, these contributions did not tackle the demographic challenges of population decline, decreasing birthrates, aging demographics, or deteriorating infrastructure. Furthermore, their focus on data analysis was restricted to specific areas without considering a cross-regional or scalable approach to data analytics. Additionally, there were no suggestions for creating data analysis environments accessible to the broader public.

Given the unique challenges Japanese cities face, such as population decline, falling birthrates, aging populations, and decaying infrastructure, designing urban initiatives that are both cross-disciplinary and cross-regional is crucial. Equally vital is the development of a supportive environment for these initiatives and making such endeavors accessible to the wider society. Thus, we posit that establishing an urban information platform that facilitates cross-disciplinary and cross-regional urban design could significantly contribute to addressing future urban challenges.

4. RESEARCH METHOD

4.1 System Overview

Figure 1 presents the schematic of the system to be developed in this study, comprising three principal layers. Firstly, there is an urban database designed to aggregate data essential for policy formulation at a suitable scale. Secondly, the urban data utilization platform is tasked with analyzing, visualizing, and disseminating the data sourced from the urban database. The third layer encompasses a suite of urban evaluation indices, which will be integrated as applications within the urban data utilization platform.

The urban database will be constructed utilizing GIS technology and programming languages such as Python[8], with its management facilitated by "ArcGIS Online"(AGOL) [9] provided by Esri, Inc. AGOL is recognized for its comprehensive cloud GIS capabilities, offering a portal for the creation, utilization, and management of geographic data, thereby ensuring the efficient operation of such data. AGOL's tools further contribute to the development of the urban data utilization platform. Notably, applications facilitating the analysis and visualization of urban data across various regions are developed using ArcGIS Experience Builder [10]. This tool empowers users to design web application interfaces without coding, thereby streamlining and simplifying application deployment. ArcGIS Hub

[11], another pivotal application, supports the dissemination of open data and the publication of applications on websites created via ArcGIS Hub.

To address cross-disciplinary and cross-regional urban challenges, a comprehensive set of urban evaluation indicators will be derived from the urban database for implementation as applications on the urban data utilization platform, informed by the research findings. These steps will culminate in the development of visualization strategies and applications on the platform. Consequently, urban evaluation indicators spanning multiple domains will be operationalized as applications, facilitating support for cross-disciplinary and cross-regional urban design.

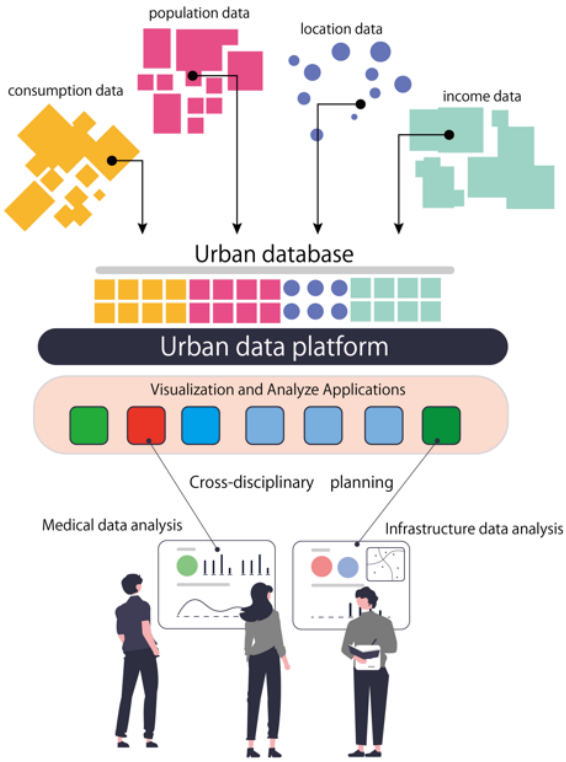

Figure 1. Schematic of the system

4.2 Development of urban database

An urban database was developed to aggregate data and facilitate integration with the urban data utilization platform. The data collection policy extended beyond the existing urban and architectural planning survey systems, incorporating medical and other sectoral data, with a keen focus on data accessibility. The types of data collected, their volume, and primary sources are detailed in Table 1. Data on population and household characteristics are predominantly compiled at the individual and household levels. Human flow data captures the distribution of the population within the city based on residence, time, etc. Industrial data encompass employment patterns and consumer behavior. Land use data detail facility counts and land values by usage type, along with zoning and regulatory information. Accessibility data measure the proximity and travel times to essential services, healthcare, and educational institutions. Medical data include metrics such as hospital bed capacity and physician counts, reflecting the local healthcare infrastructure. Overall, the database comprises over 70 data types, spanning a broad spectrum of urban life. These data are organized by administrative divisions like subregions and municipalities or divided into grid units, enabling their use as geographic information.

Table 1. Items of Urban Database

Category	Number of items	Main Data Source
Population and Household	18	Census 2020 [12]
People Flow Data	2	G spatial information center [13]
Industry Data	18	household consumption survey [14]
Land Use Data	5	Numerical National Land Information [15]
Accessibility	19	Numerical National Land Information
Medical	5	The Ministry of Health, Labour and Welfare [16]

4.3 Development of Urban Data Utilization Platform

The database, once constructed, is organized into layers within AGOL (ArcGIS Online), allowing for the flexible extraction of data items during application development. This setup facilitates geographic visualization, enabling the graphical representation of the data. Moreover, because the data is stored in a geographic format, it can be extracted and visualized at any specific location or within any defined range, offering extensive versatility in analyzing and presenting urban data. This capability is essential for the effective design and implementation of applications aimed at enhancing urban planning and policy-making processes.

5. CASE STUDIES

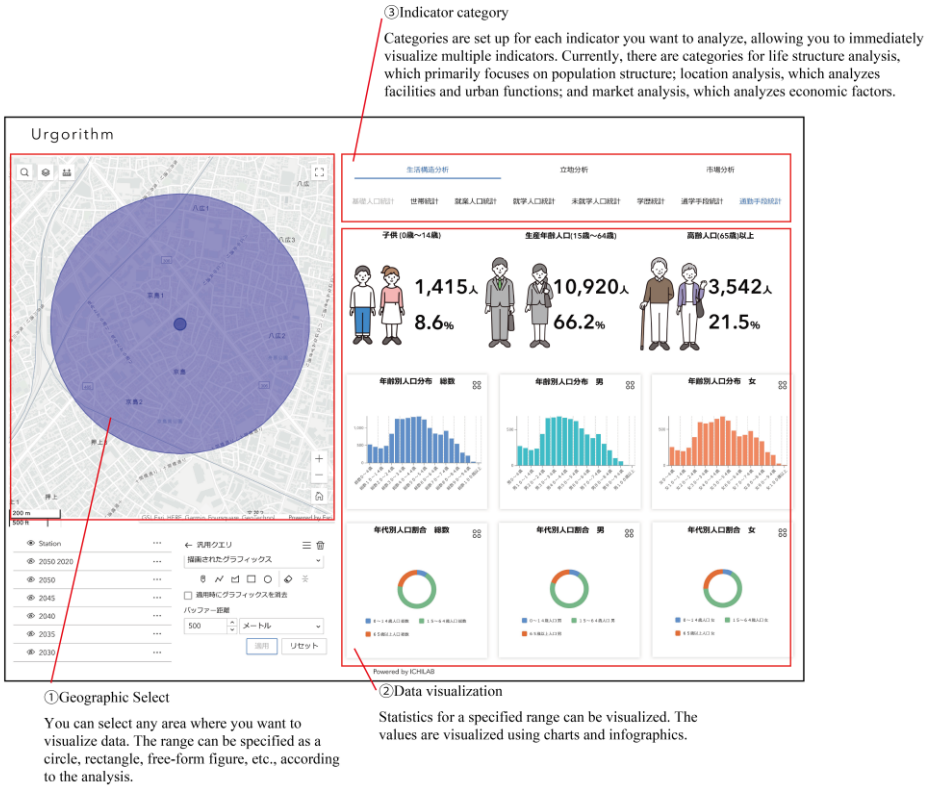

Figure 2. Application user interface

Figure 2 illustrates the basic application user interface (UI) developed within Experience Builder on the urban information platform established in this research. As depicted, the platform enables data analysis from various perspectives, employing geographical visualizations alongside quantitative chart visualizations. Additionally, the query function allows for data analysis at any chosen point. In this

study, indicators within two critical domains—medical administration and water supply administration—were developed. An application was then implemented to facilitate decision-making processes, demonstrating the platform's utility in supporting urban management and planning.

5.1 Medical indicators

The Ministry of Health, Labour and Welfare (MHLW) aims to establish a comprehensive community care system by 2025 to uphold the dignity of the elderly and support their independence, enabling them to live in their familiar environments until life's end. Japan's decreasing birthrate, aging population, and shift towards nuclear family structures have increased the elderly's reliance on social welfare services. This system seeks to offer comprehensive community-based support and services through collaboration across housing, medical care, nursing, daily life support, and preventive measures.

Building such a cross-disciplinary cooperative system necessitates a quantitative assessment of the local comprehensive care system in each area to identify gaps in service provision. From this context, we extracted medical data from the urban database and formulated an index to objectively evaluate and compare the comprehensive care systems across regions.

Utilizing the long-term care insurance business plan as a basis, we defined medical care metrics and established quantitative indices for analysis across 1889 municipalities. The results were standardized into deviation scores for inter-city evaluations and depicted on radar charts to highlight the strengths and weaknesses of each city. We analyzed and assessed seven indicators: emergency medical services, home medical services, family doctors, home-visit nursing care, care for five key diseases, medical care beds, and general hospital beds. As an illustrative case study, we examined three wards in Saitama Prefecture (Figure 3) to evaluate their care systems, facilitating comparisons and identification of similar areas.

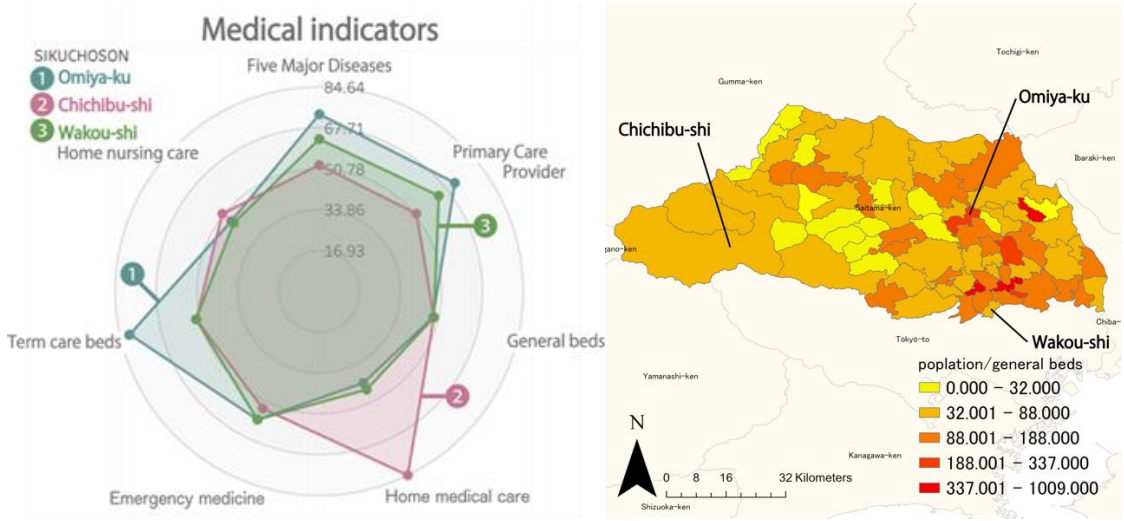

Figure 3. Medical Indicator Results for Three Cities and Population per general beds in Saitama Prefecture

The analysis spotlighted issues like the lack of home-visit care and home medical services, and the uneven distribution of medical resources, informing future policymaking and planning in the medical sector within the comprehensive community care framework. Objective, cross-domain, and regional indicators allowed for the assessment of wide-area collaboration effects, marking a significant contribution towards improving regional comprehensive care systems.

5.2 Waterworks Demand indicators

Waterworks in Japan, managed by municipalities to fulfill public demand from intake to purification, treatment, and tap water supply, face significant challenges due to the country's declining population. This demographic shift has led to reduced water supply revenues amid rising demands for renewal, driven by maintenance costs associated with nuclear family dynamics and urban sprawl. Water usage varies widely across urban areas, serving diverse purposes such as domestic use in households, agricultural use for crop cultivation, and industrial use in manufacturing processes. Despite assessments and construction policy guidance from the Ministry of Land, Infrastructure, Transport and Tourism （MLIT） and the Ministry of Health, Labor and Welfare （MHLW）, local governments struggle to implement effective water supply project policies, necessitating comprehensive strategies.

To address these challenges, we introduced an indicator designed to objectively assess the status of waterworks projects, catering to the specific perspectives of various stakeholders and promoting broad-area collaboration.

This indicator calculates waterworks demand in 1km mesh units, factoring in the aging water supply infrastructure and consumption patterns. Using a city database, we assessed waterworks supply system obsolescence by correlating historical population data with per capita water consumption and analyzed industrial and agricultural water use based on the locations of relevant facilities and areas.

Figure 4 visualizes water demand by overlaying these indicators and objectively evaluating the water infrastructure construction needed to meet that demand. Based on the analysis of water demand by municipality on a large area basis, it is also possible to visualize the uneven distribution of demand within a municipality.This aggregation of data at a granularity that meets the needs of stakeholders facilitates a deeper evidence-based understanding of policy considerations and prioritization of regions, despite the fact that different industry sectors have different perspectives on evaluation.

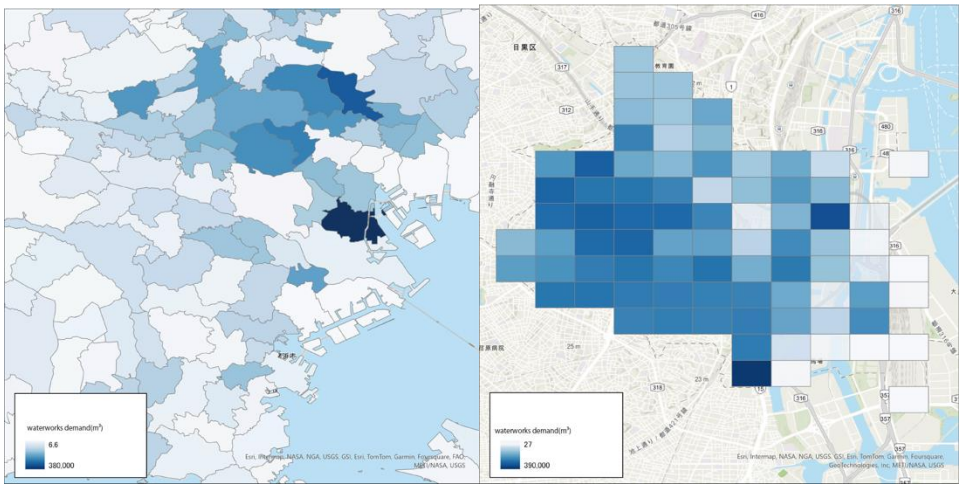

Figure 4. Waterworks Demand Indicator Results at Tokyo area

6. DISCUSSION

In this research, we developed an urban information platform to facilitate cross-disciplinary and cross-regional urban design. Initially, we identified the necessity for such a platform through a comprehensive review of the current state of Japanese cities and relevant studies.

We then amassed a substantial amount of urban-related data from open data sources, consolidating this information into geographic data within the platform. Additionally, we established an urban data utilization platform capable of immediate data visualization and analysis.

To illustrate the platform's utility, we devised evaluation indicators to aid data-driven decision-making, particularly within the domains of medical and water supply administration. These indicators were integrated into the urban information platform, allowing for the simultaneous visualization and assessment of these domains. This enabled informed discussions on urban design that spanned multiple disciplines and regions.

Looking forward, we envision three principal areas for development:

1. Domain Expansion: To enhance the platform's cross-disciplinary capabilities, we aim to incorporate additional domains into the decision-making process, utilizing the urban database we have developed. This also includes refining the precision of the evaluation indicators.
2. Inter-domain Indicator Relationships: A comprehensive urban design approach requires a clear understanding of how different domains interact. Currently, the evaluation indicators operate independently; future work will focus on integrating these indicators to reflect the interconnectedness of urban systems.
3. Quantitative Impact Analysis: It is crucial to assess the tangible impact of the current system on addressing stakeholder concerns. The evaluation indicators, thus far based on theoretical constructs, require validation in practical settings. Consequently, we plan to engage stakeholders in the urban design process, using the system to gather feedback for ongoing refinement.

This study sets the groundwork for a more integrated and actionable approach to urban design, aiming for a future where data-driven insights lead to sustainable and inclusive urban environments.

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