A New Approach to Urban Planning Based on Daily Life Rhythms Using Human Mobility Data

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***Abstract*— Modern urban planning has treated space as the main variable and time as a secondary element. This study reviews the development of time concepts in urban planning from the viewpoint of how measurement technologies have changed. It also reinterprets Lefebvre's rhythmanalysis in the context of recent technological advancements. By organizing existing research along two axes, spatiotemporal granularity and description mode, this study shows that the area of setting target states and designing interventions based on micro-scale quantitative data from dense sensing remains undeveloped. This study proposes Rhythmopolis as a theoretical framework to address this gap. Rhythmopolis would change urban planning from a forward problem of predicting activity from space to an inverse problem of tuning space from target rhythms. To solve this inverse problem, this study introduces the Music Information Retrieval framework and presents a method for structuring rhythm quality, which was previously dismissed as error, into multi-dimensional vectors. In the history of urban concepts, Metropolis addressed the organic development of single cities, and Megalopolis addressed regional networks connected by infrastructure. Rhythmopolis is positioned as a third concept that aims at distributed urban management at the district level through temporal structure optimization.**

Keywords- rhythmanalysis; time geography; human mobility data; inverse problem; music information retrieval.

I. INTRODUCTION

Modern urban planning has treated space as the main variable and time as a secondary element. Traditional planning methods, such as zoning assume that arranging urban functions in physical space will organize people's activities in a reasonable way. In current cities, however, people with various lifestyles interact in complex ways, and there is a gap between static spatial plans and the dynamic rhythms of daily life.

The French philosopher Lefebvre [1] defined arrhythmia as a state where social disorder occurs due to conflicts between rhythms. According to Lefebvre, cities are originally dynamic places where various organic rhythms interact and produce space. Space-centric urban planning, however, blocks this dynamism and causes structural arrhythmia. In this study, urban rhythm is defined as the spatiotemporal overlapping of human activities in urban space, representing the dynamic pulse of the city generated in each area. While traditional planning focused on static arrangement, urban rhythm captures the dynamic interaction between people and space.

In recent years, Lefebvre's theoretical framework has been reconsidered in the context of urban informatics with the spread of Global Positioning System (GPS) and smartphones. Using human mobility big data, it has become possible to visualize rhythms, which were previously qualitative concepts, as quantitative patterns [2][3]. In these quantitative studies, however, the challenge of connecting diagnosis of the current state to prescription for the future remains. Existing research has succeeded in visualizing and classifying rhythm patterns, but methods for tuning spatial interventions to resolve arrhythmia have not been established.

This study aims to propose Rhythmopolis as a theoretical framework for quantitatively evaluating the spatiotemporal structure of cities based on human mobility data and developing it into concrete planning theory. The main feature of this framework is reconstructing the urban planning process from a space-centric forward problem to an inverse problem that tunes spatial forms and policies based on target rhythms.

In the history of urban concepts, this study is positioned as follows. In the early 20th century, Geddes [4] conceptualized post-industrial revolution urban concentration as Metropolis and discussed the organic relationship between cities and regions. Later, Gottmann [5] analyzed the connected urbanization of the northeastern United States and named the regional urban area where multiple metropolitan areas are connected by transportation and communication infrastructure as Megalopolis. The Megalopolis concept assumed that regional infrastructure connections bring economic efficiency. In the 21st century, however, this infrastructure-dependent urban model has shown problems, such as increasing maintenance costs, vulnerability to disasters, and environmental burden [6]. In contrast, Rhythmopolis proposed in this study introduces time as a variable and provides a framework for autonomous management at smaller district levels. This is positioned as a form of distributed approach to the challenge of how to sustainably operate existing stock in mature cities.

This study is organized as follows. Section II reviews the development of time concepts in urban planning from the viewpoint of how measurement technologies have changed. Section III examines how urban rhythms have different characteristics depending on mobility infrastructure and cultural practices and identifies factors that determine rhythms. Section IV proposes Rhythmopolis as a theoretical framework for quantitatively evaluating urban rhythms and developing them into planning theory, based on the discussions in Sections II and III. Section V presents the contributions and future challenges of this study.

II. THE DEVELOPMENT OF TIME CONCEPTS IN URBAN PLANNING

This section reviews how time concepts have been treated in urban planning and related fields from the viewpoint of how measurement technologies have changed.

Literature was collected from databases, such as Web of Science, Scopus, and Google Scholar using keywords including rhythmanalysis, time geography, and human mobility, focusing on papers in urban planning, transportation engineering, and geography. It should be noted that rhythmanalysis and related temporal approaches face recognized limitations in the existing literature, including challenges in applying frameworks across diverse urban contexts, difficulties in precisely operationalizing temporal variables, and the blurred boundaries between spatial and temporal dimensions of rhythm.

This study sets four time periods based on the development stages of measurement technologies for understanding human movement and activity in cities. Table 1 shows each period, the main measurement technologies and data sources available, and the scope of analysis they enabled.

TABLE I. PERIODS AND MEASUREMENT TECHNOLOGIES

Period	*Time Frame*	*Main Data Sources*	*Analysis Focus*	*Representative Work*
Period 1: Aggregate	-1960s	Census, registration	Static population	CIAM, Athens Charter (1933)
Period 2: Flow Structure	1960s-1990s	Person trip surveys, traffic counts	OD flows, time allocation	Time geography [7], four-step model
Period 3: Individual Tracking	1990s-2010s	GIS, GPS, digital cameras	Individual space-time paths	Geocomputation [8][9][10]
Period 4: Dense Sensing	2010s-	Smartphone GPS, Wi-Fi probes, beacons, LiDAR, camera analytics	Crowd behavior, semantic analysis	Urban computing [11]

A. Period 1: Aggregate Data (Before 1960s)

In pre-industrial society, time was embedded in natural cycles and the nature of labor. As Thompson [12] pointed out, after the industrial revolution, time concepts shifted from task-oriented time to clock time. Data on population and movement available in this period depended on censuses. In Western countries, modern census systems were established from the late 18th to early 20th centuries (US: 1790, UK: 1801, France: 1801). These data captured where people lived at specific points in time, with time resolution limited to years and spatial resolution limited to administrative units. It was technically difficult to capture the temporal structure of people's daily movements and activities.

These measurement technology constraints determined the scope of theory. In functionalist urban planning by the Congrès Internationaux d'Architecture Moderne (CIAM) in the early 20th century, time was positioned as a secondary element subordinate to space [13]. The 1933 Athens Charter classified urban functions into four categories of housing, work, recreation, and transportation, and proposed separating these spatially through zoning. This method focused on dividing and fixing urban space by function [14] and did not consider temporal changes in activities. As Virilio [15] critically analyzed in his dromology, maximizing movement speed was considered the indicator of progress, and time was recognized as a cost to overcome. Lynch [16] early pointed out time and memory perception in cities, but this was not positioned in the mainstream of planning technology that prioritized efficiency. As a result, spatiotemporal distortions, such as commuting congestion and suburban sprawl from job housing separation became structurally fixed. In response to this situation, Jacobs [17] criticized that zoning type planning blocks urban vitality and discussed the importance of mixed uses and diverse streets.

B. Period 2: Flow Structure (1960s-1990s)

From the 1960s, with urban expansion and motorization progress, the need to understand dynamic flows increased. Person trip surveys were developed and institutionalized to meet this need. In the United States, large-scale transportation surveys starting with the Chicago Area Transportation Study were conducted from the late 1950s, and transportation demand forecasting methods based on Origin-Destination (OD) data were established. Person trip surveys recorded all trips of sample household members on the survey day, improving time resolution to hours and spatial resolution to zones.

In 1963, the Buchanan Report published in the UK presented how urban structure should respond to increasing automobile traffic [18]. The report viewed cities as a structure of rooms and corridors and proposed hierarchically separating environmental areas and the primary road network. This urban skeleton concept implicitly assumed temporal relationships between traffic flows and land use but did not treat rhythm itself as a planning variable.

An important theoretical contribution of this period was time geography proposed by Hägerstrand [7]. Hägerstrand built a theoretical framework that treats time as a scarce resource equal to space. Time geography visualized individual movement as trajectories in space-time and enabled quantitative description of constraints. At the national scale, Gottmann pointed out that cities are defined not by buildings but by movements of people, goods, and information, and described commuting flows as tidal waves. Space syntax by Hillier and Hanson [19] showed that spatial layout determines movement patterns, but these theories did not sufficiently address variation by time of day.

Time geography tends to discard the qualitative aspects of creativity and difference by focusing on structure and regularity. Time geography asks how individuals move efficiently while avoiding constraints and does not consider the quality of time [20].

C. *Period 3: Individual Tracking (1990s-2010s)*

From the 1990s, with the spread of personal computers, Geographic Information Systems (GIS) became widely used. With the spread of Integrated Circuit (IC) transit cards and cell phones, it became technically possible to track individual movement continuously with high accuracy.

Miller [8] proposed methods for representing and analyzing space-time prisms in 3D within GIS environments, and Kwan [9][10] visualized differences in space-time accessibility by gender and socioeconomic attributes. In transportation engineering, activity-based models that treat travel as derived demand from activities developed [21]. While the four-step model treats trips independently, activity-based models simulate entire daily activity schedules of individuals, enabling more realistic transportation demand forecasting.

During this period, activity surveys based on observing pedestrian behavior also developed with the spread of digital cameras. Whyte [22] conducted systematic behavioral observation in public spaces in New York and quantitatively recorded patterns of people staying and moving in plazas and streets. This method is pioneering work that empirically analyzes relationships between physical characteristics of space and user behavior. Gehl [23] conducted long-term observation of pedestrian behavior in Copenhagen and other European cities and presented activity categories of necessary activities, optional activities, and social activities. Gehl's method evaluates public space quality by pedestrian stay time and activity diversity and was later systematized as Public Space Public Life Surveys. These surveys succeeded in describing behavioral patterns at specific locations in detail but did not develop into frameworks for understanding city wide rhythms in an integrated way.

Meanwhile, from the 1980s, critical examination of homogenized time also progressed. The concept of duration proposed by Bergson refers to time that changes qualitatively within consciousness, contrasted with clock time, and became the theoretical source of this criticism. Lefebvre extended Bergson's philosophical concept to the social dimension of urban space under capitalism and proposed rhythmanalysis [24]. Lefebvre critically analyzed the situation where cyclical rhythms from nature and the body are suppressed by linear rhythms demanded by capitalism. However, as Lefebvre himself stated that rhythm can be measured but cannot be reduced to quantitative, methods for using the qualitative concept of rhythm as indicators applicable to planning practice were not established. Rosa [25] argued in social acceleration theory that time scarcity in modern society is the root cause of arrhythmia.

D. *Period 4: Dense Sensing (2010s-Present)*

From the 2010s, with the spread of smartphones and various sensing technologies, it became possible to measure urban flows with high accuracy. Main measurement technologies include smartphone GPS (time resolution of seconds, spatial accuracy of meters), Wi-Fi probes and beacons (tracking flows including indoors), Light Detection and Ranging (LiDAR) (3D measurement at centimeter level), and camera analytics (person detection, tracking, and attribute estimation using deep learning). González et al. [2] analyzed location data from 100,000 mobile phone users and showed the predictability of human movement patterns.

In the field of urban computing systematized by Zheng [11], research is progressing on integrating various data sources to understand and predict the dynamic state of cities. Song et al. [26] proposed a system that treats human mobility data as time series images and classifies city states, such as sleeping, working, and rush hour through unsupervised learning. Sparks et al. [27] derived temporal signatures of cities using Point of Interest (POI) operating hour data and quantitatively compared rhythm differences across cultures.

Most of this research focuses on pattern classification, anomaly detection, and monitoring the current state. While these studies have succeeded in identifying urban states, discussion of how urban planning should intervene in these rhythms is not sufficient.

From the planning side, chrono-urbanism [28] proposed in Europe in recent years and the 15-Minute City by Moreno [29] have attracted attention. These present visions, such as daily life being completed within a 15-minute walk and adapting cities to human rhythms and show directions for urban planning. The significance of this approach is that it can show planning directions based on clear value judgments. However, sufficient discussion has not been made to deepen plans quantitatively and in detail at the district level.

Based on the above discussion, the treatment of time concepts in urban planning can be organized along two axes of spatiotemporal granularity and description mode, as shown in Figure 1.

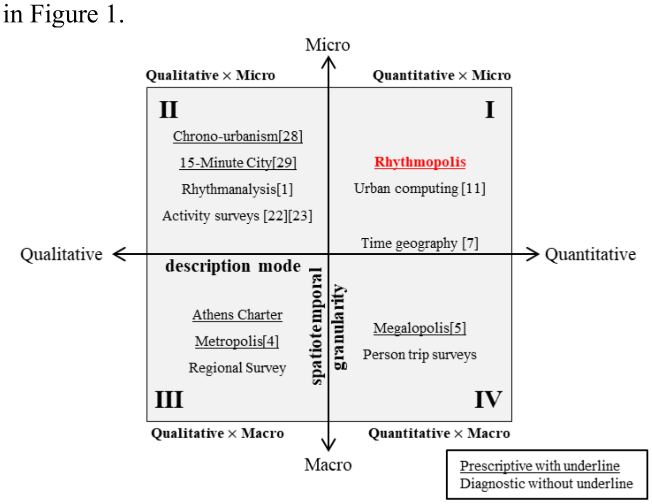

Figure 1. Treatment of Time Concepts in Urban Planning.

Geddes' Metropolis and CIAM's Athens Charter are positioned in Quadrant III as qualitative prescription at the macro scale. Gottmann's Megalopolis and the four-step model are positioned in Quadrant IV as macro scale and quantitative approaches based on statistical data. At the micro-scale, Lefebvre's rhythmanalysis is positioned in Quadrant II as qualitative diagnosis, while chrono-urbanism and the 15-Minute City aim to return to human scale. Time geography, which deals with individual space-time paths, is positioned to bridge quadrants in that it deals with social structure through micro-scale quantitative description. Recent urban computing has enabled ultra-high-resolution description through GPS and other technologies, but its focus is monitoring the current state, and it remains in the diagnosis area of Quadrant I, which is quantitative and micro-scale. Rhythmopolis proposed in this study is a theoretical framework for converting high density data into concrete interventions in this Quadrant I and develops the prescription area at a quantitative and micro-scale. These technological advances have laid the foundation for discussing qualitative differences in urban rhythms. However, urban rhythms are not a uniform phenomenon; each city is expected to have its own distinctive rhythms shaped by infrastructure and culture. The following section reviews research based on such data to clarify the regional characteristics of urban rhythms.

III. Regional Characteristics of Urban Rhythms

This section examines how urban rhythms are determined by mobility infrastructure and cultural practices. Newman and Kenworthy [30] classified major world cities from the viewpoint of transportation infrastructure and urban density into rail-dependent, automobile-dependent, and mixed types. This section theoretically examines characteristics that each mobility infrastructure gives to urban rhythms, referring to this classification.

A. Discrete Rhythms in Rail-Dependent Cities

In cities with developed rail networks, urban rhythms tend to synchronize with train schedules. Rail mode share in central Tokyo is about 50.3%, and similar trends are confirmed in Paris, Hong Kong, and other cities [31]. Rail is a system that transports large numbers of people at scheduled times, and the higher the rail dependency, the more discrete the wave pattern of human flows is expected to be.

Batty [32] called this characteristic temporal bundling and pointed out that periodic density changes occur when many individuals' movements are bundled at specific times. As a characteristic of rail systems, delays propagate throughout the network. Tan et al. [33] demonstrated through simulations of London's rail network that without recovery measures, secondary delays would increase by 151.33% compared to when countermeasures were implemented.

In rail cities, Transit Oriented Development (TOD) centered on stations progresses, concentrating commercial and business functions around stations. Calthorpe [34] systematized the TOD concept and argued that high-density, mixed-use development centered on public transit nodes reduces automobile dependency and achieves sustainable urban forms. In such cities, station boarding and alighting rhythms are considered to synchronize directly with activity rhythms in surrounding areas.

B. Continuous Rhythms in Car-Dependent Cities

In North American cities, such as Los Angeles and Houston, and Middle Eastern cities, such as Dubai and Riyadh, automobile mode share is high. Automobile commuting mode share in the Los Angeles metropolitan area is about 88%, and public transit use is 6%. In these cities, departure times are largely left to individual discretion [35].

Mokhtarian and Chen [36] showed that commuting time distribution in automobile-dependent cities approximates a normal distribution and demonstrated that peak sharpening as in rail cities is less likely to occur. Characteristics of automobile cities include prolonged congestion and flattened peaks. According to Daganzo [37], when road networks reach saturation, temporal demand spreads and peak periods extend.

Parking infrastructure is also involved in the formation of such continuous rhythms, not just road infrastructure. Shoup [38] showed that cruising for parking can account for about 30% of downtown traffic and pointed out the influence of parking policy on urban rhythms. Parking location, capacity, and pricing structures are factors that indirectly determine urban rhythms through spreading arrival times at destinations and adjusting stay durations.

C. Modal Interaction in Mixed Cities

Many large cities have mixed structures where multiple transport modes coexist. New York, Chicago, Berlin, and Seoul fall into this category. Banister [39] proposed modal shift from automobile dependency to public transit, walking, and cycling as a sustainable urban transport paradigm. In cities in transition, however, multiple rhythms interfere in layered ways.

In mixed cities, pulse-like rail rhythms and continuous automobile rhythms intersect spatially and temporally, forming complex polyrhythms. Mobility as a Service (MaaS), which has spreading in recent years, is a platform that promotes integrated use of multiple modes and may bring flexibility to urban rhythms [40].

D. Cultural Modulation of Rhythms

Cultural and social practices specific to cities and regions are also elements that determine urban rhythms. Zerubavel [41] presented the concept of social construction of time and argued that time divisions, such as working hours, rest periods, and holidays are culturally determined.

In Spain, southern Italy, Greece, and other places where siesta culture is established, distinct rhythms are formed from about 1pm to 4pm. In southern European countries like Spain, lunch breaks last around 50 minutes, with over half of workers eating with family. In contrast, other European countries average less than 30 minutes, and some nations rarely eat with family at all [42]. In Islamic regions, Friday is important as a day of worship, and many countries have Friday and Saturday as holidays. According to Wang et al. [43], traffic volume on highways during China's major holidays has been found to reach up to 1.88 times that of adjacent weekdays.

The influence of seasonal changes on urban rhythms is closely related to cultural interpretation. Kato [44] pointed out time consciousness based on four season cycles as a characteristic of Japanese culture and discussed relationships where natural cycles and social activities mutually determine each other. More generally, in monsoon climate cities, wet and dry season rhythms, and in high latitude regions, midnight sun and polar night rhythms are considered to influence urban activity patterns.

E. Factors Determining Urban Rhythms

Based on the above discussion, main factors determining urban rhythms can be organized as follows. First, infrastructure factors include rail network development, road capacity, and public transit service frequency and hours. Second, spatial structure factors include urban density, job housing relationships, and commercial facility location patterns. Third, institutional factors include working hour regulations, store hour regulations, and school start times. Fourth, cultural factors include mealtime practices, work values, and religious time norms. Fifth, climate factors include temperature, daylight hours, and seasonal changes. Rhythm characteristics specific to each city are formed by the combined action of these factors.

However, in the 21st century where sustainability is demanded, spatial resources have reached their limits of expansion. The approach of adapting life to space can no longer be sustained. Instead, a shift to an approach that adapts space to target life rhythms is now required. How can we reverse the causal relationship between space and rhythm that has been taken for granted in traditional planning? The following section proposes Rhythmopolis as a theoretical framework to address this question.

IV. Theoretical Framework: Rhythmopolis

This section integrates the discussions in previous sections and proposes Rhythmopolis as a theoretical framework for quantitatively evaluating urban rhythms and developing them into planning theory.

A. The Concept of Rhythmopolis and the Inverse Problem Approach

Rhythmopolis is a theoretical framework that views cities not as collections of static spaces but as collections of dynamic temporal structures and reconstructs the direction of causality in planning. Figure 2 illustrates this conceptual evolution by comparing three urban paradigms. In the early 20th century, Metropolis conceptualized by Geddes aimed at organic development of single cities through spatial expansion. Later, Megalopolis introduced by Gottmann extended this to inter-city connection through regional infrastructure. These 20th century concepts were models that maintained and developed urban functions through spatial expansion, driven by population growth and economic development. In contrast, Rhythmopolis proposed in this study aims at autonomous growth at the district level through optimization of temporal structure in mature cities where physical spatial expansion has reached saturation. Section II clarified the relationship between technological development and time concepts in urban planning, and Section III organized factors that shape rhythms based on existing research in each city. The theoretical framework proposed in this section attempts to tune existing urban stock along the time axis. This represents a paradigm shift from spatial expansion to temporal intensification.

The core of this framework is transforming urban planning from setting space and observing results (forward problem) to

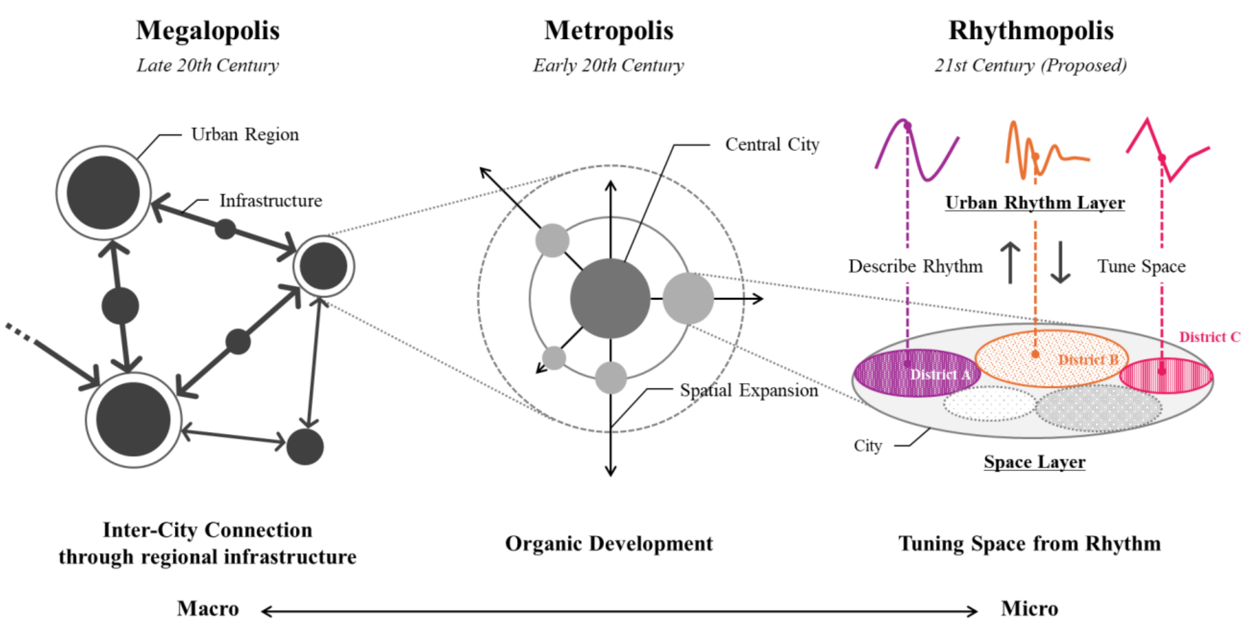

Figure 2. Conceptual Comparison of Metropolis, Megalopolis, and Rhythmopolis.

tuning space based on target rhythms (inverse problem). Traditional urban planning was a forward problem approach that tried to control activity R (Rhythm) by determining space S (Space). This can be expressed mathematically as:

$$R = f(S) + \varepsilon \quad (1)$$

Here f is a mapping representing physical constraints that space places on activity, and ε is an unpredictable error term. In traditional zoning methods, while the state of space input S could be understood, it was difficult to understand how the resulting rhythm R interferes. Arrhythmia criticized by Lefebvre can be interpreted as a state where the error term ε increases due to the rigidity of space S, causing urban life rhythms to malfunction.

Rhythmopolis reconstructs this as an inverse problem that sets target rhythm R_{target} and searches for spatial configurations S that minimize error from the actual output:

$$S^* = \arg\min_S \mathcal{L}(f(S), R_{\text{target}}) + \lambda \cdot R(S) \quad (2)$$

Here $\mathcal{L}$ is a loss function (degree of rhythm deviation), R is a regularization term (feasibility of spatial configuration), and λ is a regularization parameter.

B. *Structuring the Error Term: Introducing Signal Processing*

The biggest barrier to solving this inverse problem is the multi-dimensional nature of activity rhythm R and the error term ε that has been treated as unpredictable noise. In urban analysis so far, attempts have been made to extract periodicity of urban activities using Fourier transforms [45][46]. Fourier transform is a method for decomposing time series signals into frequency components and has succeeded in extracting basic periodicities, such as daily (24 hour) and weekly (168 hour) cycles.

However, Fourier transform assumes stationarity, making it difficult to capture nonstationary changes, such as cultural and seasonal modulation seen in Section III. Rhythm quality pointed out by Lefebvre refers to dynamism where multiple rhythms interfere while producing urban space, but such qualitative aspects are discarded in conventional methods.

Therefore, this study introduces the theoretical framework of Music Information Retrieval (MIR) [47][48]. MIR is an interdisciplinary research field that has developed since the late 1990s, aiming to automatically extract and analyze meaningful information from music signals. The feature of MIR is that it converts physical signals into perceptually meaningful higher-order features, such as timbre, tempo, and harmony.

The reason MIR is considered applicable to urban rhythm analysis is the structural similarity between the two. Just as multiple instruments in music play different rhythms while forming overall harmony, in cities different rhythms, such as rail, automobiles, pedestrians, and commercial activities interfere in layers while forming the overall temporal structure of the city. In recent years, the descriptive capability of MIR has been applied to fields other than music analysis, including machine anomaly detection [49], heart sound classification in medicine [50], and ecosystem monitoring in bioacoustics [51], expanding its application range as a general signal processing framework for diagnosing the state of complex systems.

By treating urban human mobility data as signals and applying the MIR framework, rhythm R can be described for the first time as a multi-dimensional vector:

$$R(t, x) = [timbre(t, x), tempo(t, x), harmony(t, x)]^{\top} \quad (3)$$

Here t is time and x is location. Table 2 shows conceptual correspondences between music attributes and urban rhythms.

TABLE II. CORRESPONDENCE BETWEEN MUSIC ATTRIBUTES AND URBAN RHYTHM

Music Attribute	*Urban Rhythm Correspondence*	*Structural Components*
Timbre	Micro-structure and dynamic texture of stay behavior	Statistical shape of stay duration distribution and dynamic fluidity (turnover and flux)
Tempo	Periodic fluctuations in aggregate population	Intensity and phase of daily and weekly periodic cycles in aggregate population
Harmony	Layering and composition of diverse activity types	Quantity and composition of everyone's type of life rhythm

By defining such multi-dimensional features, qualitative concepts discussed in Section III, such as discrete rhythms of rail cities, continuous rhythms of automobile cities, and cultural modulation can be operated as quantitative and comparable variables. By structuring rhythm quality that was discarded as error term ε, the foundation for setting objective functions for the inverse problem is established.

C. *Expanding Control Variables and Planning Implications*

By vectorizing rhythm R through the MIR framework, variables that could not be operated in space-centric models become defined as new control variables.

For temporal interventions, flextime policies and staggered commutes and school times are effective for rhythm periodicity. Pedestrian space design and signal control tuning contribute to tempo adjustment, and demand spreading policies, dynamic pricing, and distributed operating hours are considered for compressing dynamic range.

For spatial interventions, spatial and temporal arrangement of mixed uses is important to increase polyrhythm harmony. Specifically, this includes multipurpose facility use through time sharing, placement of flexible public spaces, and promotion of mixed land use around nodes.

For institutional interventions, promotion of flextime policies, telework support, and distributed school start times apply. These policies are expected to reduce the sharpness of city-wide rhythms by expanding individual discretion over activity start times. By combining these temporal, spatial, and institutional measures, it becomes possible to tune urban rhythms toward target states.

Rhythmopolis does not reject existing zoning. It is an approach that dynamically optimizes space S as a solution to achieve target rhythm R_{target}, rather than treating it as a fixed premise. Normative approaches, such as the 15-Minute City can also be positioned within the Rhythmopolis framework. The goal of daily life being completed within a 15-minute walk can be interpreted as one example of target rhythm R_{target} defined from an accessibility viewpoint, and Rhythmopolis provides a framework for generalizing and treating this quantitatively.

D. Future Prospects and Challenges

Implementation of the Rhythmopolis theoretical framework requires addressing the following technical and social challenges. First, development of methods for identifying the mapping f. The mapping from space S to rhythm R is nonlinear and high dimensional, but recent advances in technologies, such as deep learning can be effective means for approximating and estimating these complex dependencies. Modeling the mapping f based on observation data is key to evolving this framework from descriptive to predictive.

Second, building consensus formation processes for target rhythm R_{target}. Defining desirable rhythms involves not only technical optimization but also social value judgments. Rhythmopolis has the potential to function as an evidence-based platform supporting consensus formation among various stakeholders by using rhythm as a quantitative common language.

Third, preparing verification environments for intervention effects. For spatial interventions that are difficult to experiment with in actual cities, approaches that estimate causal effects through simulation in environments, such as digital twins are considered effective.

This paper focused on the conceptual definition of Rhythmopolis. Specific feature extraction using MIR and verification of relationships with urban space using actual data are outside the scope of this study, but these are important challenges to address for connecting the proposed theoretical framework to urban planning practice.

V. CONCLUSION

This study organized the theoretical history of how time concepts have been treated in urban planning from the viewpoint of how measurement technologies have changed and attempted to reinterpret Lefebvre's rhythmanalysis in the context of current urban informatics. Based on this, this study proposed Rhythmopolis as a theoretical framework that enables quantitative analysis of urban rhythms based on human mobility data and development into planning theory.

This study makes three primary contributions. First, by organizing the development of time concepts in urban planning along two axes of spatiotemporal granularity and description mode, this study showed that the area of setting targets and tuning interventions based on micro-scale quantitative data from dense sensing remains undeveloped. Second, this study proposed Rhythmopolis as a theoretical framework to address this gap. In the history of urban concepts, Metropolis aimed at organic development of single cities, and Megalopolis aimed at inter-city connection through regional infrastructure. Rhythmopolis is positioned as a third concept aiming at autonomous district level operation through temporal structure optimization. Third, this study presented a viewpoint for transforming the logic of planning from the forward problem of predicting activity from space to the inverse problem of tuning space from target activities. To solve this inverse problem, the theoretical framework of MIR was introduced as a means for structuring rhythm quality that was discarded as error.

In future research, the first stage will be collecting human mobility data from multiple cities, extracting rhythm features, and evaluating the accuracy of inter-city comparison and arrhythmia detection. The next stage will be estimating causal relationships between spatial interventions and rhythm changes and developing inverse problem solution methods.

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