AESOP 2025 CONGRESS

Istanbul, 7-11 July

AESOP

YTU YILDIZ TEKNIK ÜNIVERSITESI

FRACTAL CITIES

with GIS & Spatial Statistics

ADVANCED QUANTIFICATION OF URBAN COMPLEXITY & ADAPTIVE CAPACITY: SUB-FRACTAL ANALYSIS AND SPATIAL STATISTICS IN IZMIR

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EVOLUTION of PLANNING THEORIES

CRITIQIES OF COMPREHENSIVE PLANNING

Lack of flexibility

CP can be inflexible and unable to adapt to changing circumstances.

Inefficiency

CP can be time-consuming, resource-intensive, and slow in decision-making.

Overreliance on expert knowledge

CP may prioritize expert opinions over community input.

Limited public engagement

CP often fails to effectively involve the public in decision-making processes.

Fragmentation and complexity

CP can be complex, leading to fragmented implementation and accountability issues.

Unrealistic assumptions

CP sometimes relies on assumptions that may not hold true.

Lack of flexibility for incremental change

CP may overlook small-scale changes and grassroots initiatives.

Lindblom (1959)-Etzioni (1967)-Davidoff (1965)-Sager (2022)-Krumholz and Forester (1990)-Friedmann (1993)-Jacobs (1961)-Harvey and Castells-Healey (1996)-Innes (1983)

THE ERA OF COMMUNICATIVE ACTION IN PLANNING

by Jurgen Habermas (1984)

Positive

Enhanced understanding: Deepens understanding of complex dynamics and relations in planning.

Empowerment and inclusivity: Recognizes power relations and diverse perspectives, promoting inclusivity.

Collaboration and consensus-building: Fosters collaboration, negotiation, and consensus among stakeholders.

Participatory democracy: Engages citizens in decision-making, enhancing democratic principles.

Negative

Challenges in addressing diverse interests: Balancing conflicting interests can be challenging.

Potential for disagreement and conflict: Open dialogue may lead to disagreements and conflicts.

Time and resource-intensive: Requires significant time, effort, and resources.

Lack of clear decision-making mechanisms: Emphasis on collaboration can result in indecisiveness.

CONTEMPORARY APPROACHES IN URBAN PLANNING

These approaches reflect a shift towards participatory and inclusive practices, considering the complexities of planning and the need for effective communication and engagement.

Communicative Planning Theory

Emphasizes inclusive dialogue and collaborative decision-making among stakeholders to create shared understanding and challenge top-down approaches.

Strategic Planning

Anticipates changes and engages in open dialogue, collaboration, and consensus building to address power relations and shape the future.

New Urbanism

Focuses on sustainable, mixed-use neighborhoods with pedestrian-friendly streets and accessible public spaces to foster community interaction.

Collaborative Planning

Promotes diverse stakeholder involvement, authentic dialogue, and shared knowledge to enhance adaptability, resilience, and collective learning.

CITIES with COMPLEXITY THEORIES

THE COMPLEXITY

complicated: Intricate and interconnected, involving multiple interrelated factors or components, relationships are more predictable and linear.

complex: Involving intricacy or difficulty, but can be understood or unraveled through analysis or systematic methods, relationships are unpredictable and non-linear.

non-linearity: refers to relationships between variables that deviate from a straight line, resulting in unpredictable or varying changes in one variable in response to changes in another.

Key Characteristics of Complex Systems

Multitude of interactions.	Non-equilibrium state: Dynamic functioning.
Emergence from component interaction.	Numerous flexible components.
Adaptive asymmetrical structures.	**Non-linear input functions.**
Diverse timescale behaviors.	State determined by inputs/outputs.
Rapid adaptation, slower change.	Dynamic interaction fluctuations.
Multiple system depictions.	Open systems

by Paul Cilliers (2005)

The Downfall of Deterministic Models

Simplification of complexity

Static and single-time period analysis

Neglect of **non-linear** relationships

Simplistic economic assumptions

Inability to capture feedback loops and effects

Lack of adaptability and resilience

Incomplete representation of social and cultural factors

THE COMPLEX-CITIES

butterfly effect by E. Lorenz | heisenberg's uncertainty | analogy of heraclitus

and

other theories from natural sciences and philosophy

caused

PARADIGM SHIFT IN URBAN THEORIES

Key Characteristics of Complex-Cities

Non-linearity: Unexpected system responses.

Emergence: Synergistic properties emerge.

Self-organization: Spontaneous order creation.

Adaptivity: Responsive to change.

Uncertainty: Inherent unpredictability.

Interconnectedness: Complex network interactions.

Constant Change: Dynamic and evolving.

THE MODELS on COMPLEX-CITIES

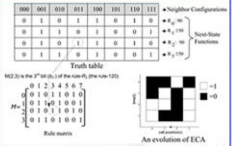
AGENT-BASED MODELS (ABMs)

simulate the behavior and interactions of individual agents within a system, revealing how their actions shape overall dynamics.

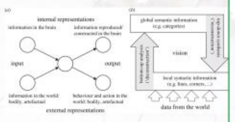
DISSIPATIVE MODELS	SYNERGETIC MODELS	CELLULAR AUTOMATA MODELS	FACS & IRN MODELS

FACS and IRN are city simulation models that combine cellular automata with individual free agents. FACS models the movement and behavior of these agents, while IRN represents their interconnected components. These models explore self-organization at both individual and global levels, studying the reciprocal influence between individual actions and the organization of the city.

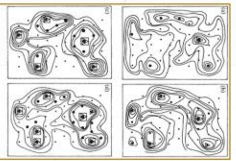
Cellular automata models simulate cells in a matrix with local rules and neighbor interactions. They generate complex global patterns and behaviors. These models are used to explore self-organization in various fields. Cells' behavior influences the overall system dynamics.



Synergetic models, based on Hermann Haken's theory of self-organization known as synergetics, focus on the collaborative behavior and interconnections among components, subsystems, and individuals within a system, drawing inspiration from various disciplines to explain complex phenomena.



Dissipative models integrate Lösch and Christaller's central place theory, depicting urban systems as self-organizing structures that evolve non-equilibrium conditions, utilizing dispersion, connections, and fluctuations to shape spatial order.

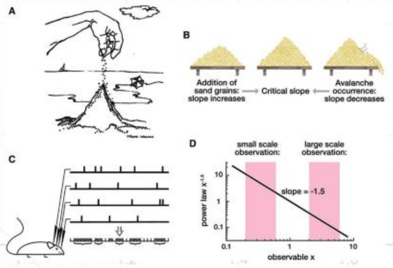


PATTERN-BASED MODELS (PBMs)

identify recurring patterns in a system's elements or components, uncovering underlying principles and processes that generate or influence those patterns.

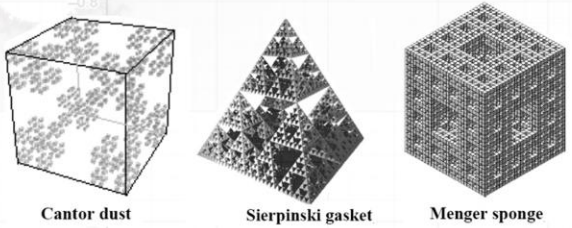
SANDPILE MODELS

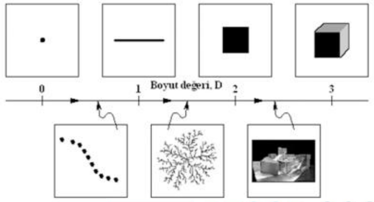
Sandpile models demonstrate self-organized criticality, where adding sand creates avalanches until a stable state is reached. The size distribution of avalanches remains consistent, revealing the dynamics of self-organization. These models shed light on complex dynamics in natural and artificial systems.



FRACTAL MODELS

Fractal models in urban studies utilize self-similarity and fractal dimensions to depict complex urban structures and processes. These models capture the intricate growth and change of cities on different scales, applying principles of self-organization and chaos theory. Fractals represent repeating patterns and order parameters that govern self-organized urban systems. **They offer insights into the non-equilibrium nature of urban environments, departing from traditional equilibrium-based theories.**





URBAN PLANNING & COMPLEX-CITIES SUMMARY

PLANNING ● COMPLEXITY

END OF 19th CENTURTY

COMPLEXITY in natural sciences

transition to scientific discipline

1950s

RATIONAL COMPREHENSIVE PLANNING

- unrealistic assumptions
- lack of stakeholder involvement
- inflexibility
- overemphasis on technical expertise
- limited scope

COMPLEXITY in computational sciences

1970s

PLANNING DILEMMA (Portugali,2012)

- conflicting objectives
- uncertainty and unpredictability
- multiple stakeholders
- ethical considerations
- limited resources

DEVELOPMENT of SYSTEM APPROACH opposite to bottom-up thinking

CRITISM OF TECHNICAL APPROACH PRODUCING PHYSICAL SOLUTUONS TO URBAN PROBLEMS

1980s

COMMUNICATIVE ACTION in planning

- collaborative decision-making
- open and transparent communication
- inclusivity and diversity
- reflexivity and learning
- context sensitivity
- pragmatism

COMPLEXITY THINKING

EARLY 21st CENTURY

EFFECTS OF COMPLEXITY in planning

EMERGENCE MANDELBROT BATTY CILLIERS NON-LINEARITY SELF-ORGANIZATION SCALE-FREE NETWORKS FEEDBACK LOOPS ADAPTATION CHAOS BIFURCATION JACOBS ALEXANDER HETEROGENITY COMPUTATIONALLY INTENSIVE FRACTALS CO-EVOLUTION MULTIPLE-SCALES

- A SHIFT AWAY FROM PREDICT AND CONTROL PLANNING
- RECOGNITION OF THE IMPORTANCE OF FEEDBACK AND LEARNING
- INCREASED EMPHASIS ON COLLABORATION AND PARTICIPATION
- RECOGNITION OF THE IMPORTANCE OF CONTEXT AND HISTORY

NON-CONVENTIONAL MATHS for analysing URBAN SYSTEMS

FRACTAL DIMENSION

$$D = \log N / \log S$$

N: the number of parts or subdivisions that a fractal produces from each segment

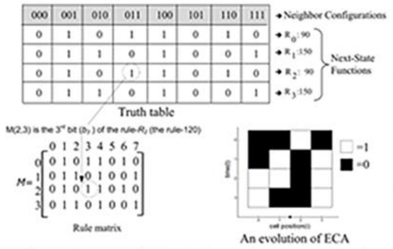
S: the size ratio of each new part compared to the original segment.

$$D = \log(N) / \log(1 / \varepsilon)$$

N: the number of boxes of size ε needed to cover the object or set

ε : represents the size of each box

CELLULAR AUTOMATA



COMPLEX-CITIES APPROACHES for MODELLING

AGENT-BASED MODELS | PATTERN-BASED MODELS

- DISSIPATIVE CITIES
- SYNERGETIC CITIES
- CELLULAR AUTOMATA CITIES
- FACS & IRN CITIES
- SANDPILE CITIES
- FRACTAL CITIES with GIS & Spatial Statistics

(Portugali,2012)

DEFINITION & SUBJECTS of FRACTAL ANALYSIS

WHAT IS FRACTAL?

A fractal is a mathematical concept that describes a complex geometric shape or pattern that exhibits self-similarity at different scales. In other words, a fractal displays similar patterns or structures when magnified or zoomed in. Fractals can have intricate, detailed features and are often characterized by their fractional or non-integer dimension. They are used to model and understand various phenomena in fields such as mathematics, physics, computer science, and even in the study of natural and **urban systems.**

HOW LONG IS THE COAST OF BRITAIN?

The coastline paradox states that the measured length of a coastline increases as the measuring scale becomes finer. This is because coastlines exhibit intricate, self-similar patterns at different scales. As we zoom in and capture more details, the measured length increases, challenging the notion of a definitive coastline length. It highlights the fractal nature of coastlines and the limitations of precise measurement using traditional methods.

Unit = 200 km, Length = 2400 km (approx.)

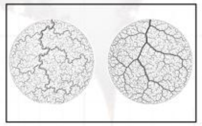
Unit = 100 km, Length = 2800 km (approx.)

Unit = 50 km, Length = 3400 km (approx.)

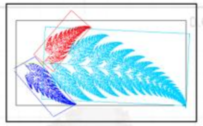
THE SUBJECTS

STRUCTURE TYPES / CHARACTERISTICS OF THE OBJECTS

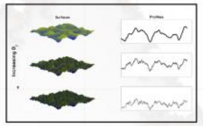
MULTI-SCALE FRACTAL	SELF-AFFINE FRACTAL	PATTERN EMMBEDDED FRACTAL (in 3D)	TIME SERIES with FRACTAL	MULTI-FRACTAL	LACUNARITY



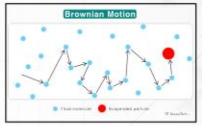
Multi-scale fractals are patterns that maintain their overall shape while revealing more detail as the level of observation changes. They are used in various fields to analyze complex structures at different scales, providing a deeper understanding of the system's behaviors and relationships.



Self-affine fractals display self-similarity with different scaling factors in various directions. They analyze complex natural phenomena and aid in urban planning decisions. By understanding interconnections within the built environment, they inform transportation infrastructure and land use regulations.

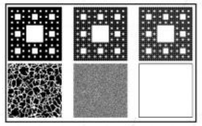


Pattern-embedded fractal structures in 3D refer to fractals that contain smaller, similar patterns within the larger pattern. These subpatterns are nested or repeated, creating a fractal with multiple levels of self-similarity. They are used to study surface roughness, social phenomena, and the relationships between elements in the built environment.



Fractal time series are data patterns that exhibit self-similarity at different scales. They can be found in natural phenomena like weather and stock prices. Analyzing these time series using fractal analysis techniques provides insights into their statistical properties and helps in forecasting future patterns.

Multifractal structures exhibit self-similarity at multiple scales and have varying fractal dimensions. They are found in natural and man-made systems, offering complexity and irregularity. Multifractal analysis quantifies their nature and helps understand system dynamics.

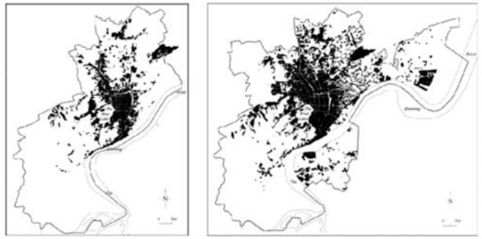


Lacunarity is a measure of spatial heterogeneity or gaps within a fractal pattern. It quantifies the distribution and clustering of elements in the pattern. In urban planning, lacunarity helps analyze land use patterns and transportation networks to understand their structure and make informed decisions.

FRACTAL APPLICATIONS & DATA TYPES

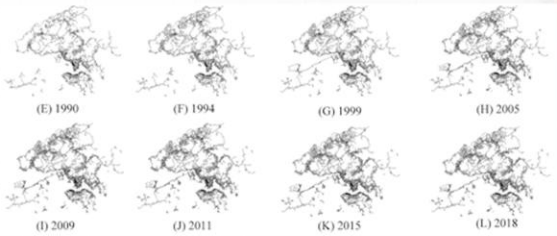
DATA TYPES → FRACTAL GEOMETRY APPLICATIONS IN URBAN PLANNING

MACROFORM STAIN



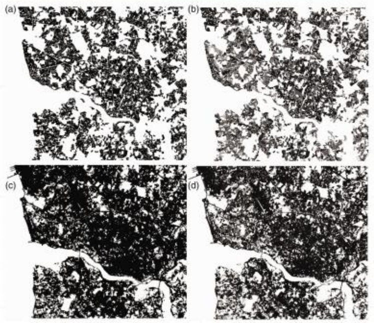
This method focuses on analyzing the overall shape and structure of a city. It examines the growth, expansion, and factors influencing urban development. It helps predict future urban growth and assess the compactness of cities.

URBAN ROAD NETWORK



This approach involves analyzing the changes in cities over time by studying their road systems. It provides insights into the development direction, areas of growth, and overall changes in the city's infrastructure.

BUILT ENVIRONMENT OF THE CITY



Fractal analysis can be performed on the built environment, including buildings, and green areas. The lacunarity method is commonly used, which involves defining a region of interest, identifying voids or empty spaces, calculating **lacunarity** to quantify variability, and analyzing the results to understand the spatial arrangement of building elements.

URBAN MORPHOLOGY

Explaining urban development and self-similarity.

Defining urban form and scaling cities with fractal parameters.

Analyzing urban growth and characterizing structures.

Calculating fractal dimensions for spatial structure and distribution.

Understanding the hierarchical nature of cities.

AN OVERVIEW OF THE RESEARCHES BASED ON THE APPLICATIONS OF FRACTALS

FIELD OF STUDY	RESEARCH SUB-FIELDS	RESEARCHERS	NUM.
urban formation	the morphology of urban lan use	(Batty & Longley, 1988; Feng & Chen, 2010; Purevtseren et al., 2018)	3
	urban growth and form	(Batty et al., 1989; Batty, 1991; Batty & Longley, 1994; Y. Chen et al., 2017; Man & Chen, 2020)	4
	urban morphology	(Batty et al., 1993; Y. Chen, 2020; Y.-G. Chen, 2018; Frankhauser, 1998a)	4
	urban pattern	(Frankhauser, 1998a, 2004, 2008; Jevrić et al., 2014b; Tannier et al., 2012)	5
sprawl management	urban border	(Jevric & Romanovich, 2016)	1
	urban agglomeration	(Frankhauser, 1998b)	1
	urban sprawl	(Terzi & Kaya, 2008b, 2011)	2
	urbanized area	(Y. Chen, 2015; Shen, 2002)	2
street network	urban road network analysis	(Benguigui, 1995; Dasari & Gupta, 2020; Kim et al., 2003b; Lu & Tang, 2004; Mo et al., 2015; Mohajeri et al., 2012; Rodin & Rodina, 2000; Sreelekha et al., 2017b; Sun et al., 2012; Wang et al., 2017; Zhang et al., 2021; Zhang & Li, 2012)	10
	multifractal characterization of road network	(Long & Chen, 2021; Murcio et al., 2015; Pavón-Domínguez et al., 2017, 2018)	4

URBAN GEOGRAPHY

Fractal geometry aids in understanding the complexity and irregularity of urban space.

It reveals self-similarity and diverse layouts in urban areas.

Fractal dimensions quantify the spatial structure of cities.

Fractal geometry assists in controlling urban sprawl and optimizing urban patterns.

It helps in planning green spaces and improving city design.

Multifractal analysis is used to study road networks and identify spatial issues.

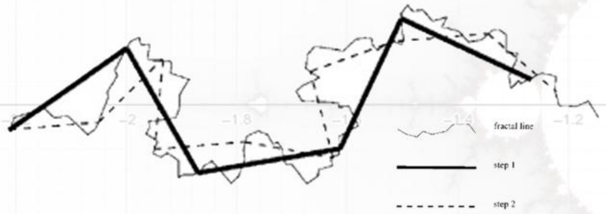
It helps optimize road layouts and address gaps in urban transportation.

ANALYSIS of FRACTALS in ROAD and CITY SYSTEMS

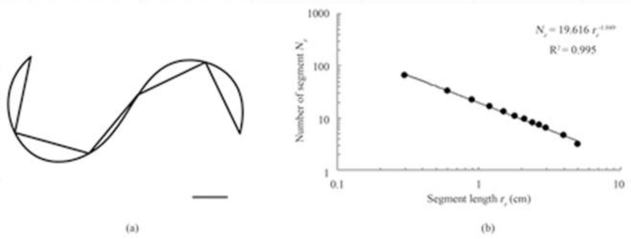
THE TECHNIQUES USED FOR THE ANALYSIS

LINE-WALKING TECHNIQUE

This technique involves defining a base line and measuring its length while maintaining the geometric form of a line feature. Different approaches exist depending on the starting point of the baseline.

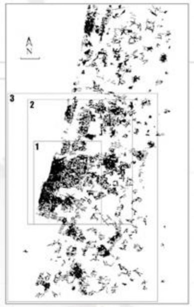


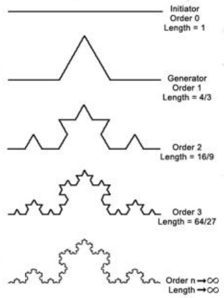
To calculate the length of the line, several straight segments (radii) of a circle arc are drawn with a pair of map dividers. The shorter the radius, the more accurate the measure.



LENGTH-AREA RELATIONSHIP TECHNIQUE

This technique focuses on establishing the relationship between the lengths of line features and the regions they cover or serve. However, this technique assumes a single center point for the distribution zone of the road network, which may have limitations.





- A map of the urban area is divided into study regions or zones.
- The length of line features (e.g., roads) within each study region is measured.
- The areas or regions covered by these line features are determined.
- The relationship between the lengths of line features and the corresponding areas is analyzed.

BOX-COUNTING TECHNIQUE

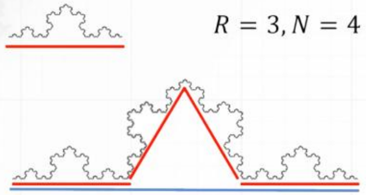
This approach involves covering the research area with a square grid of homogeneous cells. The size of the cell and the number of cells containing the line feature are used to calculate a regression function, allowing the estimation of fractal characteristics. The box-counting method requires the detection and adjustment of cell sizes.

D = log(N) / log(R)

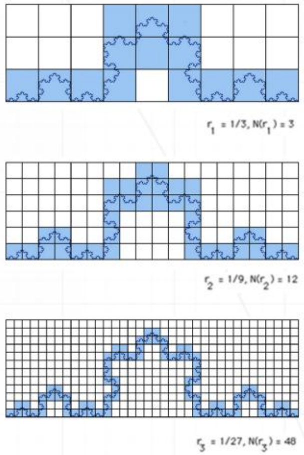
D = log(N) / log(1 / ε)

N: the number of boxes of size ε needed to cover the object or set

ε : represents the size of each box



$$D = \frac{\log(N)}{\log(R)} = \frac{\log(4)}{\log(3)} = \frac{.60206}{.47712} = 1.262$$



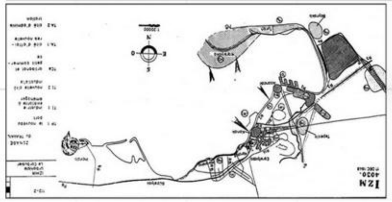
PLANNING in THE IZMIR CITY

EARLY PLANS OF THE IZMIR CITY

Rene and Raymond Danger's and Henri Prost's Plan, 1925

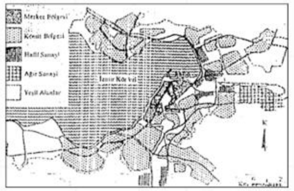
Turkey's inaugural urban planning project in 1925 involved creating a master plan for İzmir to address the city's rapid growth, enlisting international experts who brought modernist planning ideas and techniques.

Le Corbusier's Plan, 1949



The second planning attempt in İzmir occurred in two stages: pre-World War II involved approach and planner search, while post-war period concluded with plan submission to the Municipality.

Albert Bodmer's Plan, 1960



Due to evolving trends and expectations, the 1955 plan, originally designed for low density and a small scale, necessitated numerous requests for changes, leading to the development of a new revision plan by the municipal leadership within a year of its adoption.

PLANNING PROCESS FOR EACH PLAN

Political & Social Structure of the country

Spatial Structure of the city

Plan Proposal & Decisions

Theoretical Background of Plan

Imlementation

MASTER PLANS OF THE IZMIR CITY

Kemal Ahmet Aru, Gündüz Özdeş and Emin Canpolat Plan, 1955

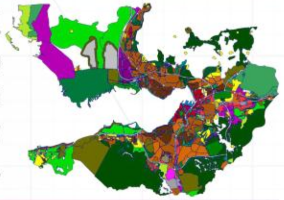
After Le Corbusier's second proposal, the authorities in İzmir pursued alternative approaches to initiate the third planning endeavor, which took place during a significant period in Turkey's urbanization trajectory and within a distinctive sociopolitical and socioeconomic context.

İzmir Metropolitan Planning Office's Plan, 1973-1978

İzmir's rapid urbanization in the 1950s and 1960s necessitated a comprehensive fifth planning effort that considered the city's growth objectives, its merging with surrounding areas, and the changing economic and political context.

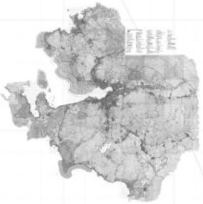
İzmir Metropolitan Municipality Plan, 1989

The 1973 plan in İzmir was revised in 1978, but the actual urban development diverged from the plan due to government changes and unauthorized projects. The sixth planning initiative in İzmir responded to this and new planning legislation.



İzmir Metropolitan Municipality's Environmental Plan, 2012

The Izmir Metropolitan Entire Environmental Plan aims to tackle challenges arising from uncontrolled urbanization and fragmented planning, promoting balanced industrialization and sustainable development while safeguarding ecological and cultural values until 2030.



DATA PREPERATION

PLAN BORDERS & RAW NETWORK DATA

This study focuses the impact of master plan decisions on urban complexity, emphasizing the shift from traditional border-based city concepts to a network-based understanding, and highlights the need to evaluate planning decisions within the boundaries of each plan period.

The Izmir Metropolitan Area examination relies on standardized maps from the General Directorate of Maps, covering four time periods:

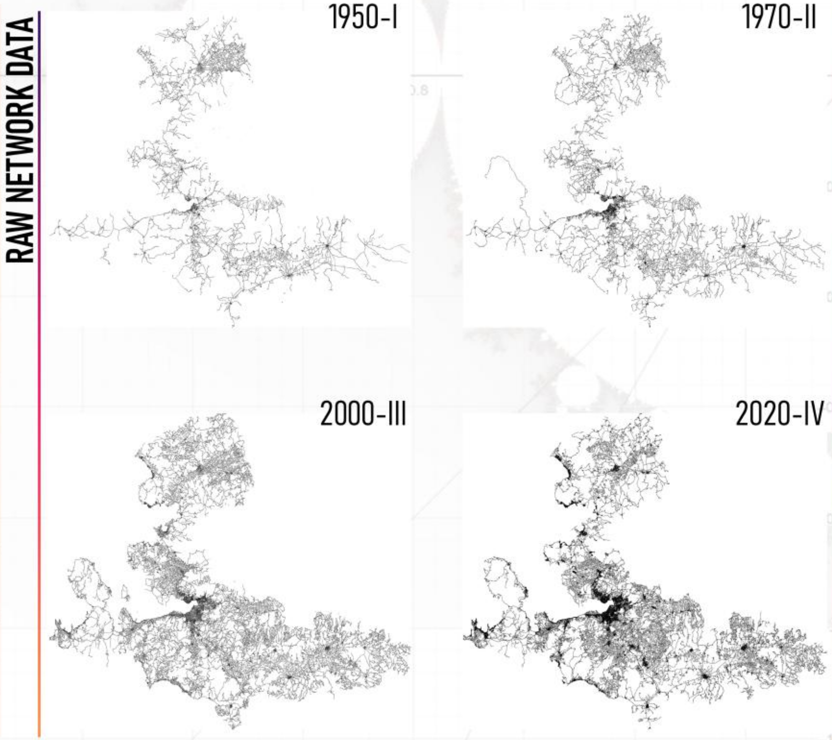
First Period: 1958-1964

Second Period: 1974-1980

Third Period: 1996-2000

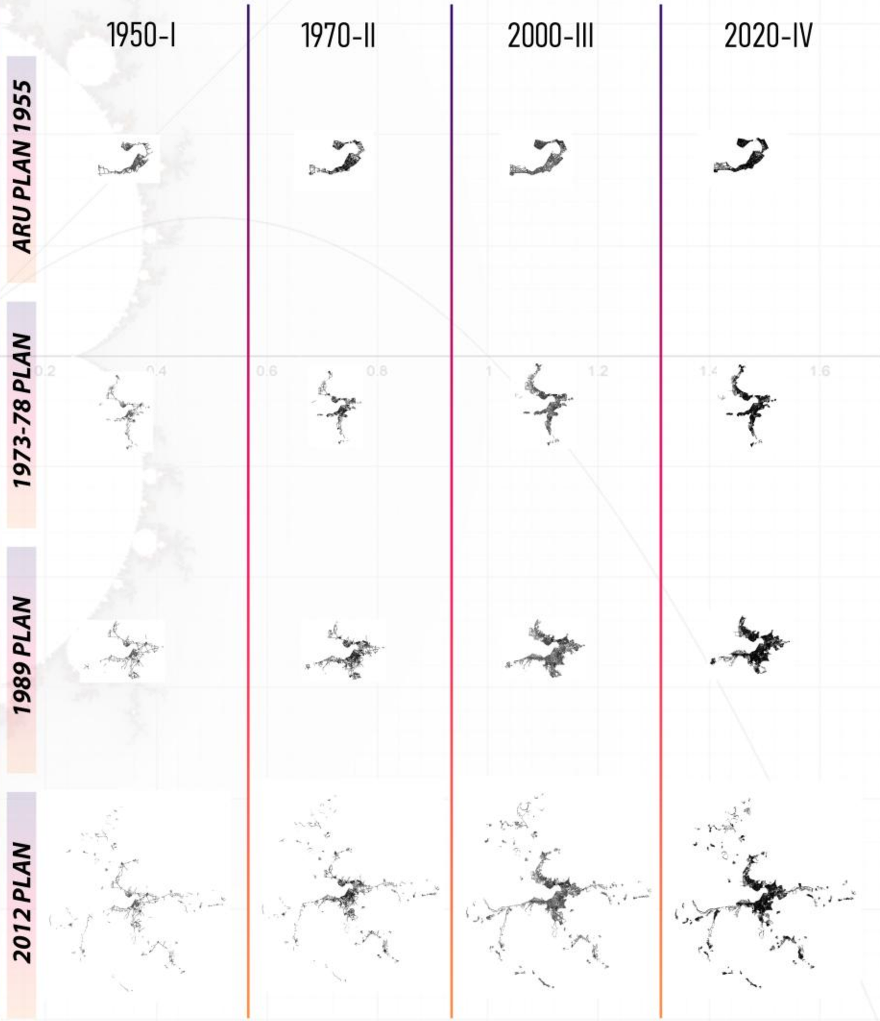
Fourth Period: 2012-2020

These maps provide detailed information on terrain, vegetation, infrastructure, and road hierarchy. They are analyzed using software tools like Photoshop and Fractalyse to assess the correlation between the map and uni-fractal analysis. The road network maps are periodically prepared for analysis, ensuring consistency and reliable results.



THE DATASET FOR THE ANALYSIS

CUT NETWORK MAPS



The METHODS with FRACTAL MATHEMATICS

FRACTAL ANALYSIS (HOW IT IS DONE)

BOX-COUNTING ANALYSIS

Divide the Network: The road network is divided into a series of boxes of different sizes. These boxes can be square or rectangular in shape.

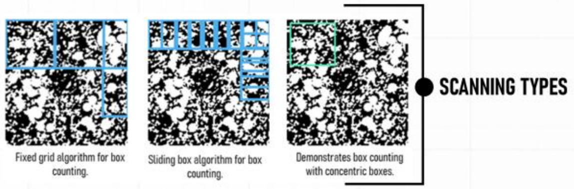
Count Boxes: Count the number of boxes that contain a part of the road network for each size of the box. This is done by determining if a box intersects with any road segment or intersection.

Calculate Fractal Dimension: Calculate the fractal dimension using the formula **$D = \log(N) / \log(1/L)$**, where D is the fractal dimension, N is the number of boxes that contain a part of the network, and L is the size of the boxes.

Plot the Data: Plot the logarithm of the number of boxes N against the logarithm of the inverse of the size of the boxes 1/L on a graph.

Fit a Regression Line: Fit a linear regression line to the data points on the graph. The slope of the regression line represents the fractal dimension.

Interpret Results: The calculated fractal dimension provides insights into the complexity and organization of the road network. A higher fractal dimension indicates a more complex and branching network, while a lower fractal dimension suggests a less complex and more linear network.



Additionally, the box-counting analysis was applied to **16 maps** divided according to the plan boundaries mentioned in the previous sections. The goal was to observe the overall change in fractal values over four time periods based on each plan boundary and assess the consistency of these values. The **Fraclac** plugin of the **Image_J** program was utilized to conduct the Fractal examination.

the LOCAL CONNECTED FRACTAL DIMENSION (the DLC) ANALYSIS

A method used to quantify the complexity of spatial patterns in network data images or geographical information systems.

Image Extraction: Extract the desired area of interest from satellite images or aerial photographs using remote sensing techniques.

Preprocessing: Preprocess the extracted image to enhance its quality and remove any noise or unwanted elements.

Define Target Pixel: Select a target pixel within the image for analysis.

Radius Selection: Choose a radius (r) for analysis, which determines the scale at which the LCFD will be calculated.

Pixel Connectivity: Determine the number of pixels connected to the target pixel within the chosen radius. This is done by assessing the spatial relationships between pixels.

Calculate LCFD: Use the formula **$LCFD = \log(Nr) / \log(r)$**, where Nr is the number of connected pixels and r is the radius of analysis. The LCFD value represents the degree of self-similarity and complexity of the spatial patterns at the chosen scale.

Repeat for Different Scales: Repeat steps 3-6 for various radius sizes to analyze the fractal dimension at multiple scales.

Determine Representative Scale: Identify the scale with the highest LCFD value, which represents the most characteristic fractal dimension of the object.

Interpret Results: Analyze the LCFD values to gain insights into the complexity, connectivity, and spatial patterns of the object. This information can be used to understand urban form, classify land uses, analyze urban sprawl, and extract building footprints, among other applications.

Efficiency Improvement: The process of calculating LCFD can be made more efficient by using fractal dimension tools that determine the highest R^2 value, indicating a robust correlation between observed and predicted values. **LCFD and Box-Counting methods are run by free box method taking R-Squared value as 0.99.**

SUB-FRACTAL ANALYSIS

Define the Study Area: Select the specific area for analysis, focusing on the urban road network.

Utilize Software/Tools: Use specialized software or tools, such as the Fraclac plugin of Image_J, for analysis.

Extract Road Network Data: Obtain the necessary data representing the road network.

Perform Sub-Fractal Analysis: Analyze sub-regions of the road network using text or color representations.

Determine Box Size: Choose an appropriate box size to divide the road network for analysis.

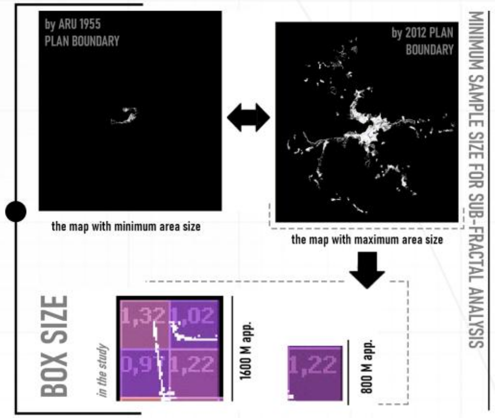
Count Boxes (Ns) with Road Network Elements: Calculate the number of boxes containing road network components.

Plot log S (box size) against log Ns (box count) on a graph: Visualize the relationship between box size and the number of boxes.

Interpret Fractal Dimension: Gain insights into road network complexity based on the obtained fractal dimension.

Consider Limitations: Account for limitations like determining the minimum sample size based on pixel ratio to ensure consistency.

The box sizes for Sub-Fractal analysis are determined as %1 pixel size ratio.



The METHODS with SPATIAL STATISTICS

CREATING NEW DATA SET

(HOW IT IS DONE)

SUB-FRACTAL ANALYSIS

Define the Study Area: Select the specific area for analysis, focusing on the urban road network.

Utilize Software/Tools: Use specialized software or tools, such as the Fraclac plugin of Image_J, for analysis.

Extract Road Network Data: Obtain the necessary data representing the road network.

Perform Sub-Fractal Analysis: Analyze sub-regions of the road network using text or color representations.

Determine Box Size: Choose an appropriate box size to divide the road network for analysis.

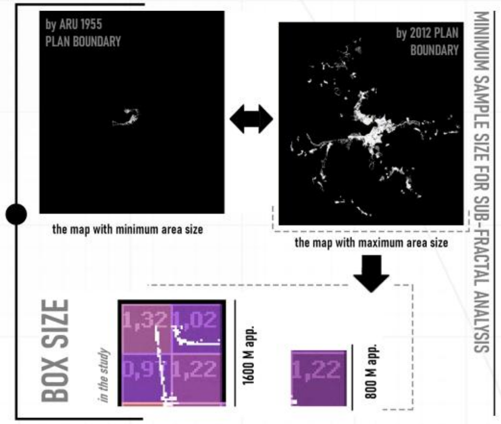
Count Boxes (Ns) with Road Network Elements: Calculate the number of boxes containing road network components.

Plot log S (box size) against log Ns (box count) on a graph: Visualize the relationship between box size and the number of boxes.

Interpret Fractal Dimension: Gain insights into road network complexity based on the obtained fractal dimension.

Consider Limitations: Account for limitations like determining the minimum sample size based on pixel ratio to ensure consistency.

The box sizes for Sub-Fractal analysis are determined as %1 pixel size ratio.



DIFFERENCE ANALYSIS

Create an Excel File: Prepare an Excel file to name the boxes and record their respective fractal values for both the initial and post-plan conditions.

Calculate Difference in Fractal Values: Subtract the box fractal dimension values of the initial condition from the box fractal dimension values of the post-plan state.

Obtain Positive and Negative Values: The calculated difference values can be positive or negative, representing the direction of the change in complexity.

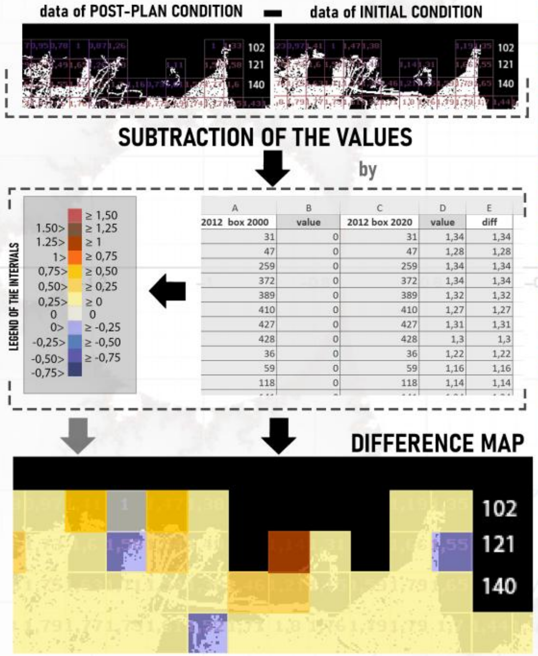
Establish a Number Range System: Define meaningful intervals for the difference values. In this study, the interval is set at 0.25 based on the accumulated range of difference values.

Use Color Codes to Create a New Map: Prepare a new map using color codes at 0.25 intervals. Cool colors indicate negative values, while warm colors represent positive values. The color gradation reflects the amount of change in complexity.

Analyze the Map: The new map shows the direction and magnitude of complexity change, highlighting the ranges of change in the city.

Evaluate Planning Decisions: Compare the master plans with satellite images or land use maps to understand the reasons for complexity level changes and the extent of those changes.

Identify Areas of Significant Change: The difference analysis helps identify areas that have experienced the largest or smallest changes due to planning decisions.



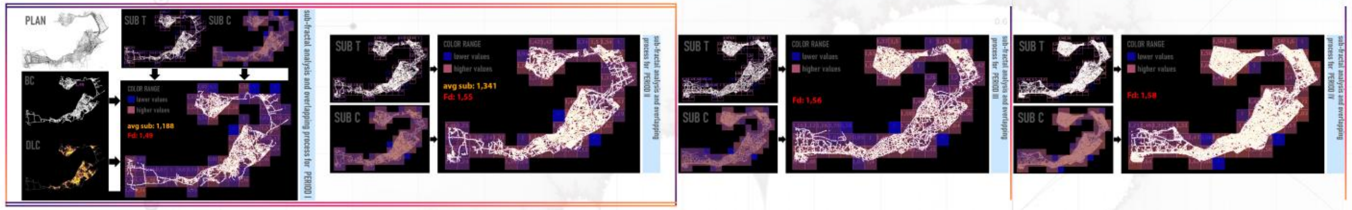
A	B	C	D	E
2012 box 2000	value	2012 box 2020	value	diff
31	0	31	1,34	1,34
47	0	47	1,28	1,28
259	0	259	1,34	1,34
372	0	372	1,34	1,34
389	0	389	1,32	1,32
410	0	410	1,27	1,27
427	0	427	1,31	1,31
428	0	428	1,3	1,3
36	0	36	1,22	1,22
59	0	59	1,16	1,16
118	0	118	1,14	1,14

Assess Planning Decision Impact: The outcome of the difference analysis and spatial autocorrelation analysis provides a comprehensive understanding of the impact of planning decisions on the city's complexity.

The difference analysis helps evaluate the effects of planning decisions on the complexity of the city, highlighting areas of significant change and providing insights for urban planning and decision-making.

SUB-FRACTAL ANALYSIS & PERIODIC OVELAPPING PROCESS

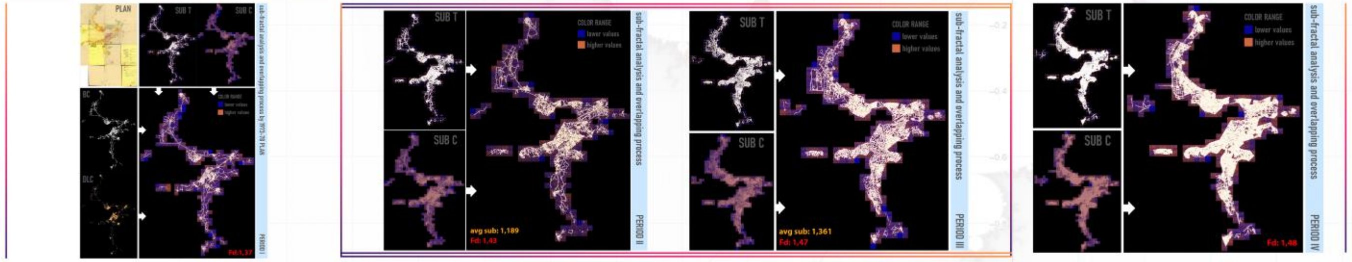
KEMAL AHMET ARU, GÜNDÜZ ÖZDEŞ AND EMİN CANPOLAT PLAN, 1955



KEMAL ARU PLAN, 1955 (BETWEEN PERIOD I AND PERIOD II)

The Kemal Aru Plan experienced a significant increase in complexity and development between period I and period II, as indicated by the rise in **sub-fractal dimension from 1.188 to 1.341.** The study highlights the importance of sub-fractal analysis in understanding urban evolution and improving urban planning. It reveals the spatial and functional relationships within the city and informs strategies for effective urban management. The growth observed can be attributed to a **combination of top-down planning decisions and bottom-up processes, such as micro-decisions by inhabitants and segregation.**

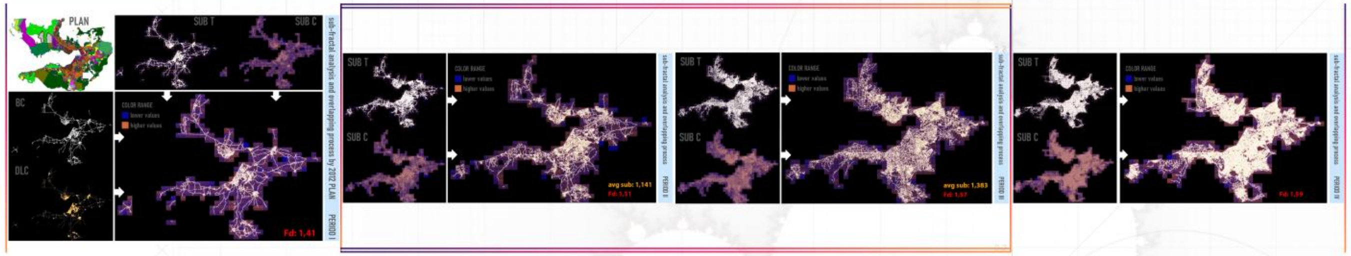
IZMİR METROPOLITAN PLANNING OFFICE'S PLAN, 1973-1978



THE IMM 1973-78 PLAN (BETWEEN PERIOD II AND PERIOD II)

The IMM 1973-78 Plan showed substantial development between period II and period III, with **the sub-fractal dimension increasing from 1.189 to 1.361.** This indicates significant growth and complexity in the urban area. Sub-fractal analysis is valuable in urban planning, allowing for the identification of patterns and structures. The increase in sub-fractal dimension suggests urban expansion due to factors like population growth, land use changes, or new planning policies.

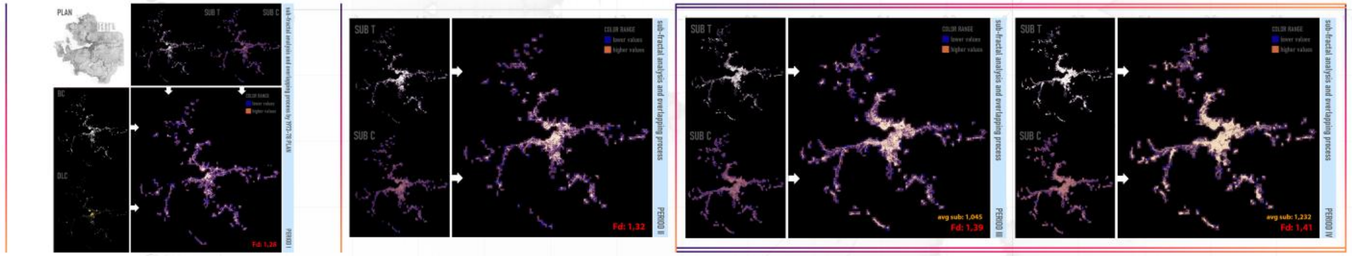
IZMİR METROPOLITAN MUNICIPALITY PLAN, 1989



THE IMM 1989 PLAN (BETWEEN PERIOD II AND PERIOD II)

The IMM 1989 Plan showed significant changes between period II and period III. **The sub-fractal dimension analysis revealed an increase in the average value from 1.141 to 1.383,** indicating a shift towards a more complex urban pattern. **The box-counting values also increased from 1.51 to 1.57,** signifying greater overall complexity and diversity. Integrating these analyses allows for a comprehensive understanding of the urban system and enables the development of effective strategies for sustainability and livability.

IZMİR METROPOLITAN MUNICIPALITY'S ENVIRONMENTAL PLAN, 2012

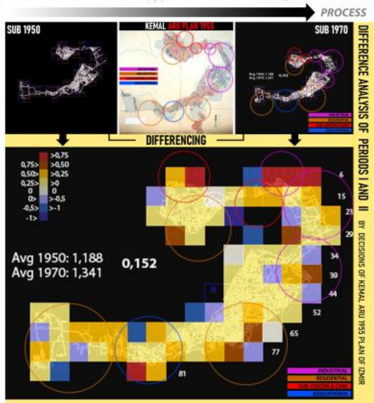


THE IMM 2012 PLAN (BETWEEN PERIOD III AND PERIOD IV)

The IMM 2012 Plan yielded significant changes between period III and period IV. **The sub-fractal dimension analysis showed an average increase from 1.045 to 1.232, indicating a shift towards a more complex urban pattern. Box-counting values increased slightly from 1.39 to 1.41,** highlighting overall growth in complexity. Combining these analyses provides a comprehensive understanding of the urban system, **considering both micro and macro-level factors. Turbulence in complexity theory explains the dynamic behavior and emergence of new patterns.**

The DIFFERENCE ANALYSIS and RESULT TABLES – 1955, 1973-78, 1989

KEMAL AHMET ARU, 1955



SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR KEMAL ARU PLAN 1955

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)	DEVELOPMENT direction
INDUSTRIAL	C > 0,75	%12,79 positive	0,25 > a > 0	PERIPHERIAL
RESIDENTIAL	0,50 > C > 0,25			
SUB-CENTRAL& COMMERCIAL	0,75 > C > 0,50			
EDUCATION & HEALTH	0,50 > C > 0,25			

PERIODS I-II

Adaptive Capacity Range: Identifying Changes

Adaptive capacity refers to a system's ability to adjust to disturbances.

Sub-fractal analysis helps understand the adaptive capacity range.

Izmir has an adaptive capacity range of 0.25 < a < 0.

Effects of Major Landuse Decisions

Industrial areas had a significant impact on complexity (C > 0.75).

Commercial/sub-central, residential, and wide-use educational/health areas had a moderate impact (0.75 > C > 0.25).

Total Change of the City System

The city system's complexity level changed by approximately 12.89%.

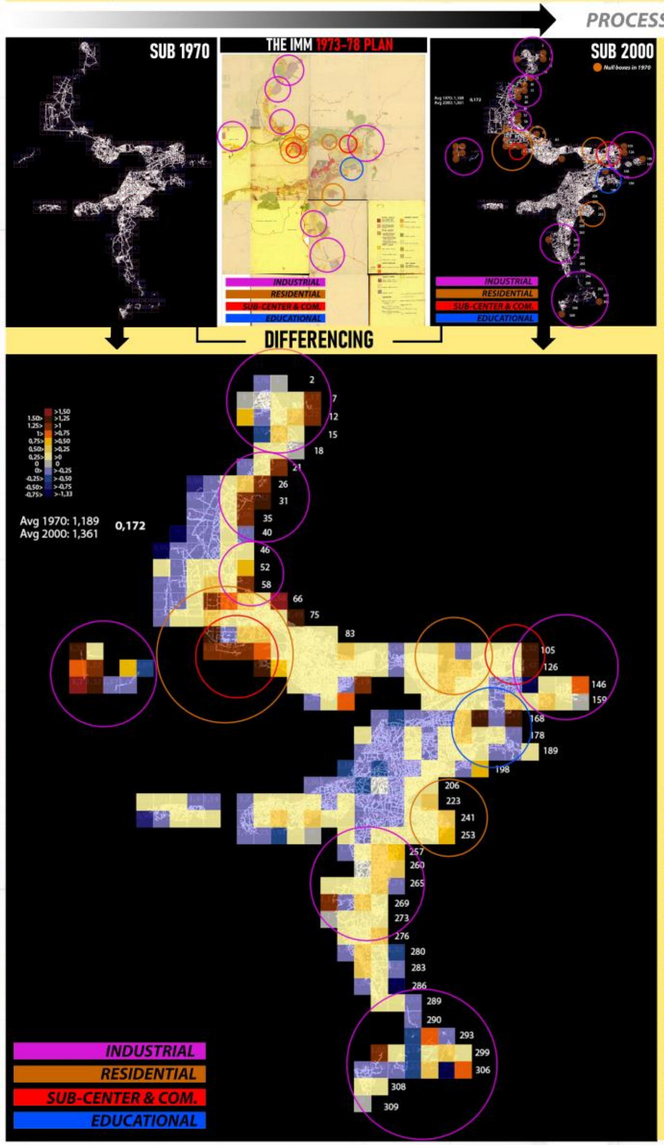
The sub-fractal analysis revealed differences in box values between 1950 and 1970.

Development Direction

Peripheral areas experienced significant changes.

New development areas were mainly located in the city's periphery.

IZMİR METROPOLITAN PLANNING OFFICE'S PLAN, 1973-1978



DIFFERENCE ANALYSIS OF PERIODS II AND III BY DECISIONS OF THE IMM 1973-78 PLAN

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 1973-78 PLAN

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)	DEVELOPMENT direction
INDUSTRIAL	C > 1	%14,46 positive	0,25 > a > 0	THE AXIS OF NORTH-SOUTH
RESIDENTIAL	0,75 > C > 0,25			
SUB-CENTRAL& COMMERCIAL	1,50 > C > 1			
EDUCATION & HEALTH	1,25 > C > 0,75			

PERIODS II-III

Adaptive Capacity Range

127 out of 309 boxes fell within the adaptive capacity range.

The IMM 1973-78 Plan positively impacted Izmir's complexity level.

Effects of Major Landuse Decisions

Industrial area decisions had the highest impact on complexity.

Commercial/sub-central, residential, and wide-use educational/health areas had moderate impacts.

Total Change of the City System

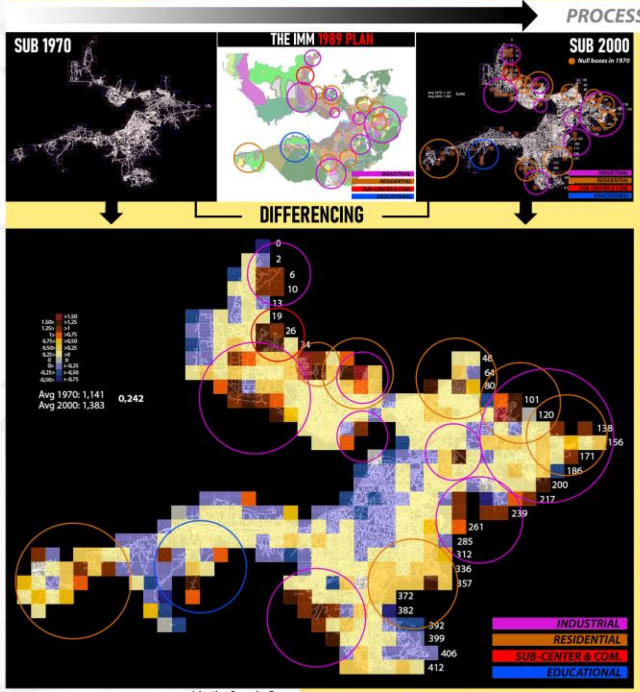
The complexity level of the city system changed by approximately 14.46%.

Development Direction

The IMM 1973-78 Plan influenced the city's structure, mainly in the north-south axis.

New development areas were observed in this axis, indicating corridor development.

IZMİR METROPOLITAN MUNICIPALITY PLAN, 1989



DIFFERENCE ANALYSIS OF PERIODS II AND III BY DECISIONS OF THE IMM 1989 PLAN

Adaptive Capacity Range

166 out of 413 boxes fell within the adaptive capacity range.

Effects of Major Landuse Decisions

Industrial area decisions had the highest impact on complexity.

Commercial/sub-central, residential, and wide-use educational/health areas had moderate impacts.

Total Change of the City System

The complexity level of the city system increased by approximately 21.19%.

Development Direction

The east-west axis showed a high fractal value, indicating corridor development.

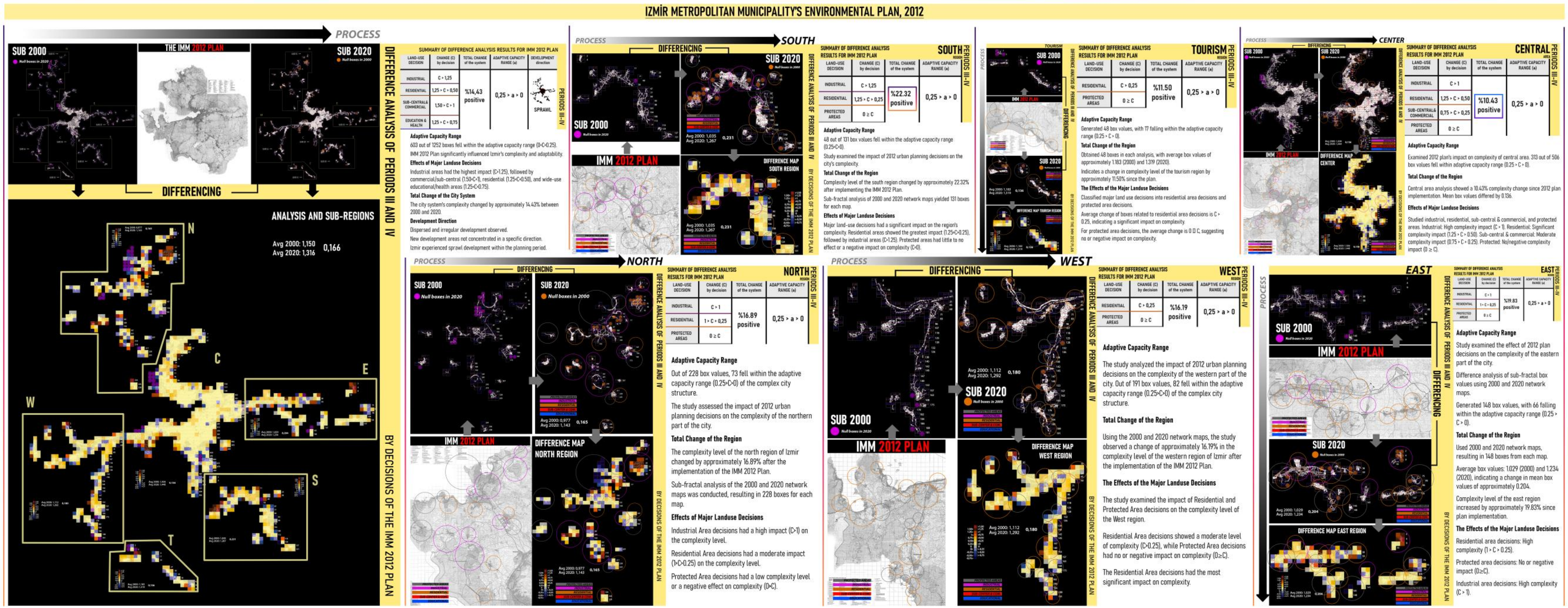
New development areas were mainly foreseen in the east-west direction.

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 1989 PLAN

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)	DEVELOPMENT direction
INDUSTRIAL	C > 1	%21,19 positive	0,25 > a > 0	THE AXIS OF WEST-EAST
RESIDENTIAL	1 > C > 0,50			
SUB-CENTRAL& COMMERCIAL	1,50 > C > 1			
EDUCATION & HEALTH	1,25 > C > 0,75			

PERIODS II-III

The DIFFERENCE ANALYSIS and RESULT TABLES – 2012 with sub-regions



IZMİR METROPOLITAN MUNICIPALITY'S ENVIRONMENTAL PLAN, 2012

PROCESS

SUB 2000 — Null boxes in 2020 | THE IMM 2012 PLAN | SUB 2020 — Null boxes in 2000

DIFFERENCING

ANALYSIS AND SUB-REGIONS

Avg 2000: 1,150
Avg 2020: 1,316
0,166

N C E W S T

DIFFERENCE ANALYSIS OF PERIODS III AND IV — BY DECISIONS OF THE IMM 2012 PLAN

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)	DEVELOPMENT direction
INDUSTRIAL	C > 1,25	%14,43 positive	0,25 > a > 0	SPRAWL
RESIDENTIAL	1,25 > C > 0,50			
SUB-CENTRAL& COMMERCIAL	1,50 > C > 1			
EDUCATION & HEALTH	1,25 > C > 0,75			

Adaptive Capacity Range

603 out of 1252 boxes fell within the adaptive capacity range (0<C<0.25).

IMM 2012 Plan significantly influenced Izmir's complexity and adaptability.

Effects of Major Landuse Decisions

Industrial areas had the highest impact (C>1.25), followed by commercial/sub-central (1.50<C<1), residential (1.25<C<0.50), and wide-use educational/health areas (1.25<C<0.75).

Total Change of the City System

The city system's complexity changed by approximately 14.43% between 2000 and 2020.

Development Direction

Dispersed and irregular development observed.

New development areas not concentrated in a specific direction.

Izmir experienced sprawl development within the planning period.

SOUTH

PROCESS — DIFFERENCING — SUB 2000 — SUB 2020 — IMM 2012 PLAN — DIFFERENCE MAP SOUTH REGION

Avg 2000: 1,035
Avg 2020: 1,267
0,231

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN — SOUTH REGION (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)
INDUSTRIAL	C > 1,25	%22.32 positive	0,25 > a > 0
RESIDENTIAL	1,25 > C > 0,25		
PROTECTED AREAS	0 ≥ C		

Adaptive Capacity Range

48 out of 131 box values fell within the adaptive capacity range (0.25>C>0).

Study examined the impact of 2012 urban planning decisions on the city's complexity.

Total Change of the Region

Complexity level of the south region changed by approximately 22.32% after implementing the IMM 2012 Plan.

Sub-fractal analysis of 2000 and 2020 network maps yielded 131 boxes for each map.

Effects of Major Landuse Decisions

Major land-use decisions had a significant impact on the region's complexity. Residential areas showed the greatest impact (1.25>C>0.25), followed by industrial areas (C>1.25). Protected areas had little to no effect or a negative impact on complexity (C<0).

TOURISM

SUB 2000 — IMM 2012 PLAN — SUB 2020 — DIFFERENCE MAP TOURISM REGION

Avg 2000: 1,183
Avg 2020: 1,319
0,136

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN — TOURISM REGION (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)
RESIDENTIAL	C > 0,25	%11.50 positive	0,25 > a > 0
PROTECTED AREAS	0 ≥ C		

Adaptive Capacity Range

Generated 48 box values, with 17 falling within the adaptive capacity range (0.25 > C > 0).

Total Change of the Region

Obtained 48 boxes in each analysis, with average box values of approximately 1.183 (2000) and 1.319 (2020).

Indicates a change in complexity level of the tourism region by approximately 11.50% since the plan.

The Effects of the Major Landuse Decisions

Classified major land use decisions into residential area decisions and protected area decisions.

Average change of boxes related to residential area decisions is C > 0.25, indicating a significant impact on complexity.

For protected area decisions, the average change is 0 ☐ C, suggesting no or negative impact on complexity.

CENTER

SUB 2000 — SUB 2020 — IMM 2012 PLAN — DIFFERENCE MAP CENTER

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN — CENTRAL AREA (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)
INDUSTRIAL	C > 1	%10.43 positive	0,25 > a > 0
RESIDENTIAL	1,25 > C > 0,50		
SUB-CENTRAL& COMMERCIAL	0,75 > C > 0,25		
PROTECTED AREAS	0 ≥ C		

Adaptive Capacity Range

Examined 2012 plan's impact on complexity of central area. 313 out of 506 box values fell within adaptive capacity range (0.25 > C > 0).

Total Change of the Region

Central area analysis showed a 10.43% complexity change since 2012 plan implementation. Mean box values differed by 0.136.

Effects of Major Landuse Decisions

Studied industrial, residential, sub-central & commercial, and protected areas. Industrial: High complexity impact (C > 1). Residential: Significant complexity impact (1.25 > C > 0.50). Sub-central & commercial: Moderate complexity impact (0.75 > C > 0.25). Protected: No/negative complexity impact (0 ≥ C).

NORTH

PROCESS — DIFFERENCING — SUB 2000 (Null boxes in 2020) — SUB 2020 (Null boxes in 2000) — IMM 2012 PLAN — DIFFERENCE MAP NORTH REGION

Avg 2000: 0,977
Avg 2020: 1,143
0,165

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN — NORTH REGION (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)
INDUSTRIAL	C > 1	%16.89 positive	0,25 > a > 0
RESIDENTIAL	1 > C > 0,25		
PROTECTED AREAS	0 ≥ C		

Adaptive Capacity Range

Out of 228 box values, 73 fell within the adaptive capacity range (0.25>C>0) of the complex city structure.

The study assessed the impact of 2012 urban planning decisions on the complexity of the northern part of the city.

Total Change of the Region

The complexity level of the north region of Izmir changed by approximately 16.89% after the implementation of the IMM 2012 Plan.

Sub-fractal analysis of the 2000 and 2020 network maps was conducted, resulting in 228 boxes for each map.

Effects of Major Landuse Decisions

Industrial Area decisions had a high impact (C>1) on the complexity level.

Residential Area decisions had a moderate impact (1>C>0.25) on the complexity level.

Protected Area decisions had a low complexity level or a negative effect on complexity (0>C).

WEST

PROCESS — DIFFERENCING — SUB 2000 (Null boxes in 2020) — SUB 2020 (Null boxes in 2000) — IMM 2012 PLAN — DIFFERENCE MAP WEST REGION

Avg 2000: 1,112
Avg 2020: 1,292
0,180

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN — WEST REGION (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)
RESIDENTIAL	C > 0,25	%16.19 positive	0,25 > a > 0
PROTECTED AREAS	0 ≥ C		

Adaptive Capacity Range

The study analyzed the impact of 2012 urban planning decisions on the complexity of the western part of the city. Out of 191 box values, 82 fell within the adaptive capacity range (0.25>C>0) of the complex city structure.

Total Change of the Region

Using the 2000 and 2020 network maps, the study observed a change of approximately 16.19% in the complexity level of the western region of Izmir after the implementation of the IMM 2012 Plan.

The Effects of the Major Landuse Decisions

The study examined the impact of Residential and Protected Area decisions on the complexity level of the West region.

Residential Area decisions showed a moderate level of complexity (C>0.25), while Protected Area decisions had no or negative impact on complexity (0≥C).

The Residential Area decisions had the most significant impact on complexity.

EAST

PROCESS — DIFFERENCING — SUB 2000 — IMM 2012 PLAN — SUB 2020 — DIFFERENCE MAP EAST REGION

Avg 2000: 1,029
Avg 2020: 1,234
0,204

SUMMARY OF DIFFERENCE ANALYSIS RESULTS FOR IMM 2012 PLAN — EAST REGION (PERIODS III-IV)

LAND-USE DECISION	CHANGE (C) by decision	TOTAL CHANGE of the system	ADAPTIVE CAPACITY RANGE (a)
INDUSTRIAL	C > 1	%19.83 positive	0,25 > a > 0
RESIDENTIAL	1 > C > 0,25		
PROTECTED AREAS	0 ≥ C		

Adaptive Capacity Range

Study examined the effect of 2012 plan decisions on the complexity of the eastern part of the city.

Difference analysis of sub-fractal box values using 2000 and 2020 network maps.

Generated 148 box values, with 66 falling within the adaptive capacity range (0.25 > C > 0).

Total Change of the Region

Used 2000 and 2020 network maps, resulting in 148 boxes from each map.

Average box values: 1.029 (2000) and 1.234 (2020), indicating a change in mean box values of approximately 0.204.

Complexity level of the east region increased by approximately 19.83% since plan implementation.

The Effects of the Major Landuse Decisions

Residential area decisions: High complexity (1 > C > 0.25).

Protected area decisions: No or negative impact (0≥C).

Industrial area decisions: High complexity (C > 1).

MAXWELL-BOLTZMANN STATISTICS

Definition

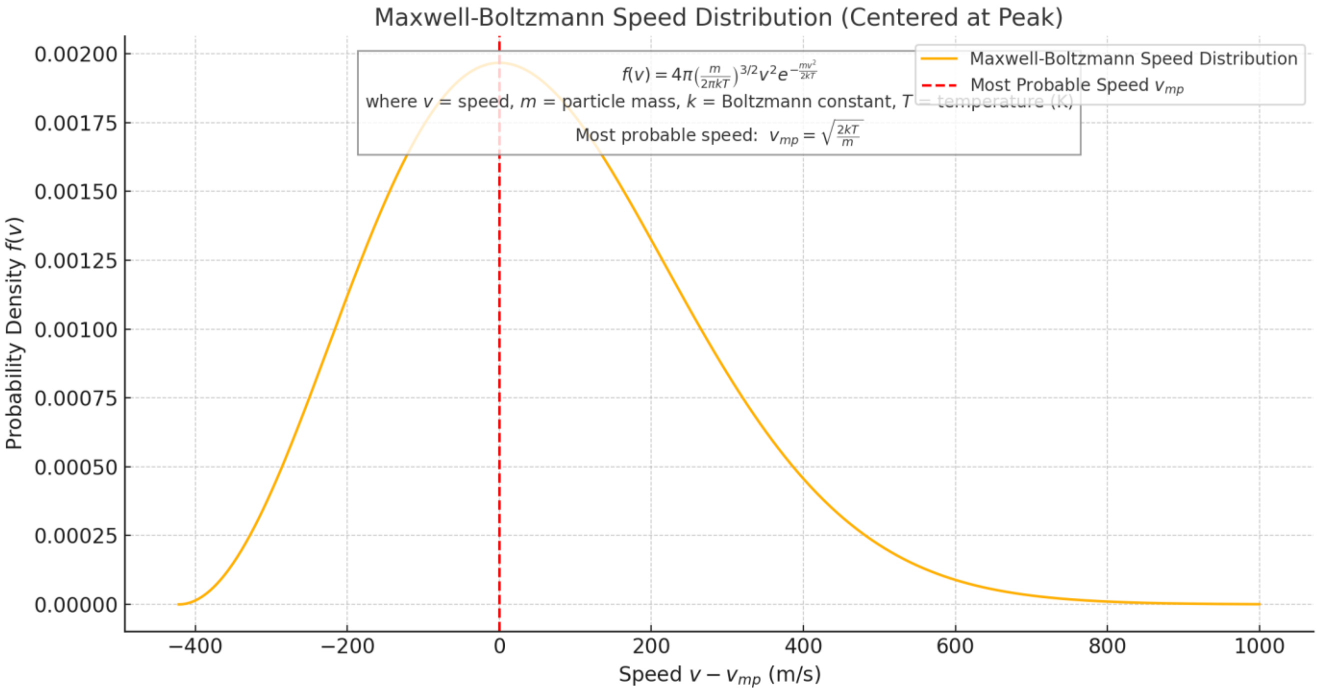
The Maxwell-Boltzmann distribution describes the probability distribution of speeds (or energies) of particles in an ideal gas. **This distribution directly results from the principle that natural systems tend toward minimum energy and maximum entropy, meaning they most likely occupy the most disordered (high-entropy) and lowest-energy states** (Atkins & de Paula, 2010; Callen, 1985).

THEN;

$$f(v) = 4\pi \left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-\frac{mv^2}{2kT}}$$

- $f(v)$: Probability density for speed v
- m: Mass of a single particle
- k: Boltzmann constant
- T: Absolute temperature (Kelvin)
- v: Particle speed

The distribution peaks at the **most probable speed** $v_{mp} = \sqrt{2kT/m}$, where the greatest number of particles are found.



The Maxwell-Boltzmann distribution describes the probability density f(v) for finding a particle with speed v in an ideal gas at temperature T. The functi
- The v² term (from 3D geometry) gives higher weight to h
- The exponential term ensures that very high speeds become ı
- The distribution's peak (v = 0 on this graph) corresponds to the most probable sp ound.
This distribution is fundamental in statistical mechanics, reflecting both en

•Atkins, P., & de Paula, J. (2010). *Physical Chemistry* (9th ed.). Oxford University Press.
•Callen, H. B. (1985). *Thermodynamics and an Introduction to Thermostatistics* (2nd ed.). Wiley.

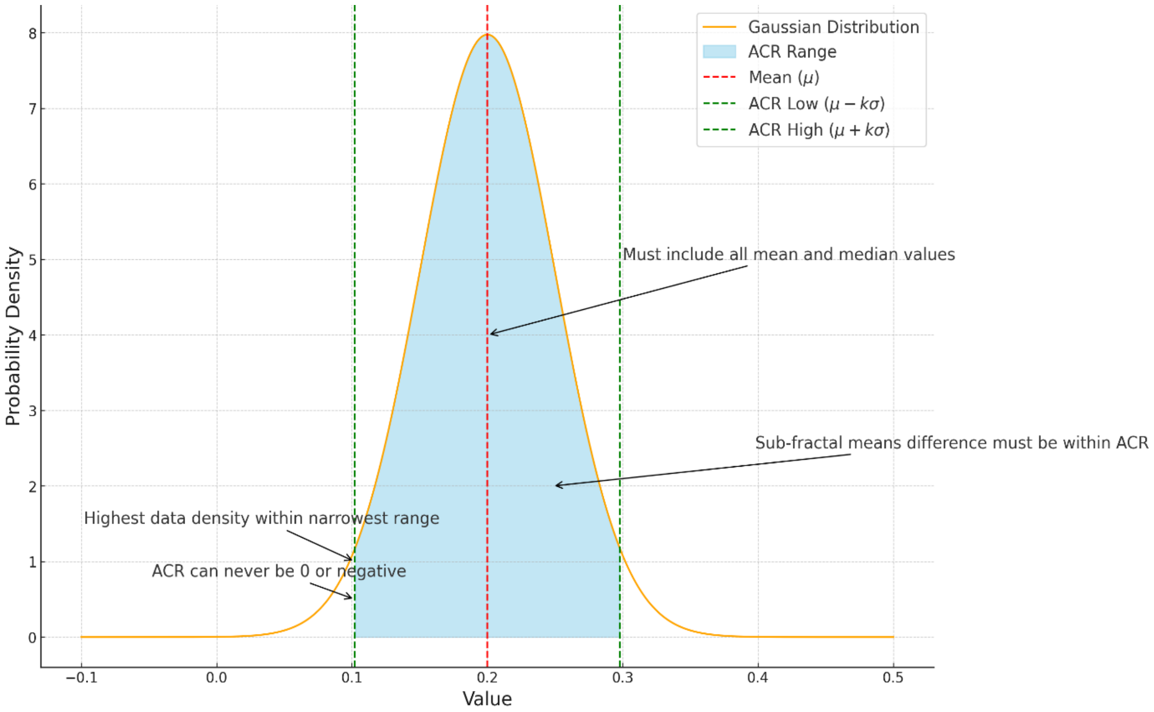
IF CITIES ARE;

… are considered as **complex natural systems,** a similar mathematical approach can be applied to urban analysis—**treating cities as systems that evolve towards states of minimum energy and maximum entropy.** Thus, **the adaptive capacity range** of urban environments can be quantified using statistical mechanics principles analogous to those used **for natural systems** (Batty, 2005; Portugali, 2011).

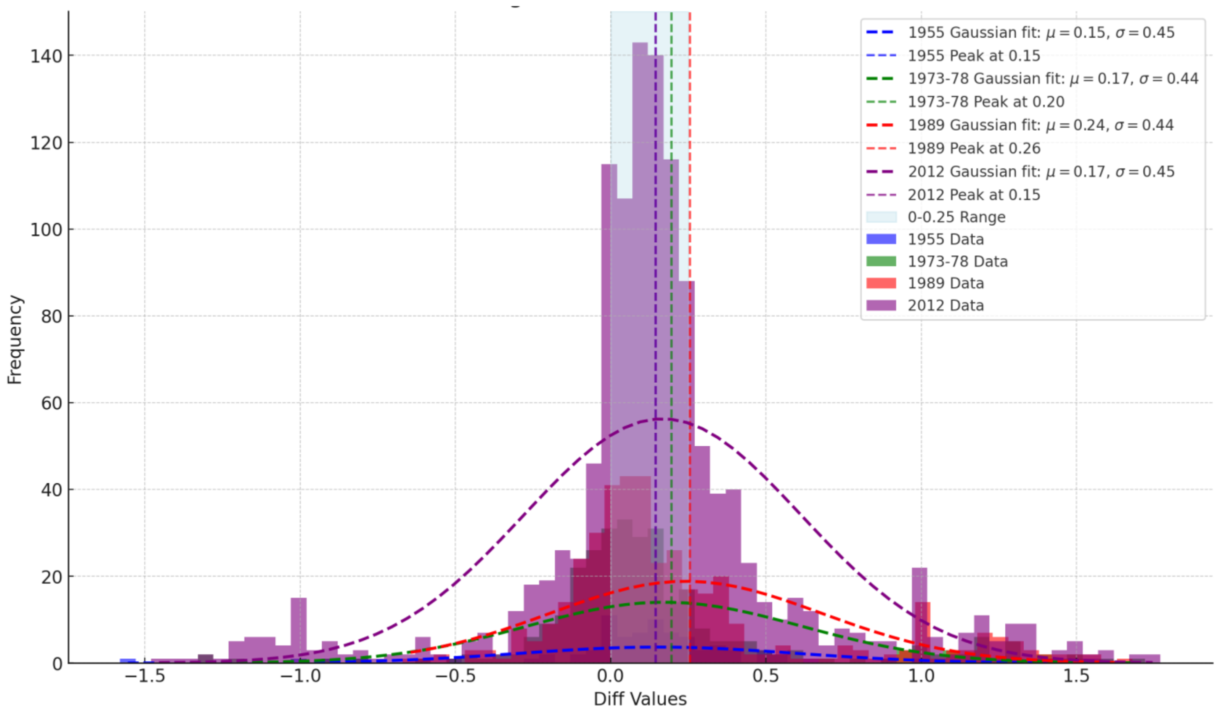
THEN WE CAN DEFINE ADAPTIVE CAPACITY RANGE WITH SIMILAR RULES

1	The ACR must always take a positive value to accurately indicate the presence of adaptability.	$ACR = [\mu - k\sigma, \mu + k\sigma]$ where $\mu - k\sigma > 0$
2	To capture urban resilience, the ACR calculation must systematically incorporate both the mean and median at each stage of analysis.	$ACR(t_i) = [\mu(t_i) - k\sigma(t_i), \mu(t_i) + k\sigma(t_i)]$ where $\mu(t_i) - k\sigma(t_i) > 0$
3	The deviation between sub-fractal means at any two measurement points must not exceed the ACR, ensuring adaptability remains within defined bounds.	$2A \geq \lvert \mu(t_i) - \mu(t_j) \rvert$
4	The ACR is defined as the narrowest interval that contains the highest data density while me-eting all statistical constraints, making it a reliable index of urban system resilience.	$P(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ for the **area** by integrating $\int_{\mu-k\sigma}^{\mu+k\sigma} f(x)d(x)$

THEORETICAL DEFINITION of ACR



0,25 > the adaptive capacity > 0 is PRACTICAL RESULT FOR THE IZMIR CITY SYSTEM



TECHNICAL FINDINGS by FRACTAL ANALYSIS

LAND USE DECISION
that change the level of complexity the most

INDUSTRIAL > Sub-CENT. – COMMERCE > EDUCATION & HEALTH > RESIDENTIAL

PROTECTED AREAS

NO EFFECT or AFFECT negatively

ADAPTIVE CAPACITY RANGE for ALL-SYSTEMS by periods

0,25 > a > 0 (determined by the most common range in the system.)

THE PLAN THAT CAUSED THE MOST CHANGES

%12,79	%14,46	%21,19	%14,43
ARU PLAN 1955 >	1973-1978 PLAN >	1989 PLAN >	2012 PLAN

NORTH %16,89
SOUTH %22,32
WEST %16,19
EAST %19,83
TOURISM %11,50
CENTRAL A. %10,43

THE MOST EMERGENT PLANNING ERAS

AFTER 1989 PLAN & 1973-1978 PLAN

DEVELOPMENT DIRECTIONS

ARU PLAN	1973-78 PLAN	1989 PLAN	2012 PLAN
PERIPHERIAL	NORTH & SOUTH	WEST & EAST	SPRAWL

END OF PRESENTATION

Thank you!

AESOP 2025 CONGRESS