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HOMOGENEITY URBAN CELLULAR AUTOMATA MODEL – FROM REGENERATIVE TO SUSTAINABLE CITIES

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SUMMARY

Careful control of the structural makeup of urban places is necessary to maintain their distinctive character while advancing sustainability. A successful approach to this problem is striking a balance between homogeneity and variability in order to provide an urban landscape that is both coherent and dynamic. In the past, homogeneity—which is defined by uniformity and is frequently connected to well-organized and visually appealing spaces—has been valued in urban planning. However, an excessive amount of homogeneity in urban areas and architectural styles could undermine a city's cohesiveness while restricting artistic freedom. Nonetheless, it has been shown that preserving a fundamental diversity of forms and functions can strengthen a city's resilience to changes. Fabric ratios of voids and volumes have been assessed using Cellular Automata investigations at different magnifications in places including Barcelona, Rome, and Hillah, revealing patterns of both independence and synchronization. These data-driven analyses make it easier to develop customized updates that target markets that lack distinctiveness. Others, meantime, flourish on fostered multiplicity, where creativity and social connections liberally support one another. Desired levels of homogeneity can be achieved through various interventions, such as zoning laws that support compact urban forms, green space efforts, and strategic development projects. By incorporating sustainability principles into urban design, these measures seek to create balanced environments that meet the needs of local residents while preserving the authentic character of urban areas.

Key words: *open spaces, built-up areas, autonomous cells (ca), human scale, urban fabric, homogeneity, heterogeneity, sustainability, sustainable constructions.*

INTRODUCTION

Promoting and Understanding the Urban Fabric: Achieving sustainable urban development requires harmony. A fundamental element of urban planning that impacts livability, aesthetic cohesion, and environmental sustainability is the harmony of the urban fabric, defined as the harmonious interaction between built and open spaces [6]. Designing spaces that are effective and reflective of the unique needs and identities of their inhabitants is central to effective city planning. Promoting and Understanding the Urban Fabric: Achieving sustainable urban development requires harmony. A fundamental element of urban planning that impacts livability, aesthetic cohesion, and environmental sustainability is the harmony of the urban fabric, defined as the harmonious interaction between built and open spaces [8].

Designing spaces that are effective and reflective of the unique needs and identities of their inhabitants is central to effective city planning. Because harmony is seen as a means of imposing order and beauty, it is a concept historically encouraged in urban planning. However, current trends toward greater inequality, driven by architectural diversity, mixed land uses, and a surplus of urban functions, are increasing the complexity of the urban fabric [32][19]. These changes can lead to fragmented urban environments, contradicting traditional notions of sustainability and cohesion. Urban diversity goes beyond mere physical variation to being a crucial factor in maintaining a city's changing identity in the face of functional and geographical changes. [1].

Studies on the balance between homogeneity and diversity are an evolving field. Urban uniformity and fragmentation are influenced by scale and spatial configurations, as illustrated by recent research using temporal automata (SEA) to simulate and evaluate urban patterns [23]. For example, studies by Batty et al. (2005) demonstrate how SEA approaches can predict the impact of different planning scenarios on urban homogeneity and model urban growth patterns [3]. These aspects provide actionable insights into how urban environments can be managed to maintain their specific characteristics and functionality. Understanding the dimensions and dependence of measuring urban heterogeneity requires considering how heterogeneity in urban design affects social interaction, environmental sustainability, and economic growth [2][22]. The complex interactions between different urban elements and their implications for sustainable development can be captured through SEA, as presented by recent advances in urban modeling visualization, such as those addressed by White and Anglin (1997) [24][11].

In order to provide a thorough examination of urban heterogeneity, this paper will first review its significance, objectives, and distinguishing characteristics [4]. Following an introduction to the working principles of cellular automata (CA), examples of their implementation are presented in the urban fabrics of Barcelona, Rome, and Hilla. The findings regarding contemporary heterogeneity and heterogeneity patterns are presented in the following analysis, and their implications for promoting sustainable urban development are discussed [5].

Sustainable Urban fabric

The process of arranging diverse natural and constructed elements for different activities in cities and towns in a logical manner in order to produce ecologically sensitive, financially viable, and socially inclusive spaces for communities is known as sustainable urban design and planning [14].

The term "urban fabric" encompasses the myriad physical and spatial components that collectively compose the urban environment. From towering skyscrapers to narrow cobblestone streets, from sprawling parks to intricate transportation networks, these elements come together to create the distinctive aesthetic and functional character of a city [18]. Urban fabric is more than just a collection of structures; it's the very essence of urban life.

Reduced environmental impact and management are essential. Cities are more robust to issues like resource scarcity, population increase, and climate change when they are developed with a thorough grasp of their structure [7]. Planners and architects may create walk able neighborhoods by taking into account how urban components are interconnected. This reduces the need for cars, which in turn reduces traffic and air pollution.

Moreover, incorporating green spaces and sustainable infrastructure enhances residents' well-being and helps mitigate the urban heat island effect. Ultimately, respecting and comprehending the urban fabric allows us to create cities that are not only functional and visually appealing but also capable of enduring over time Preserving historical structures within the urban fabric anchors a city's identity amidst rapid development and fosters a sense of continuity. becomes crucial in building vibrant and sustainable cities [26][12] as in the figure(1) .

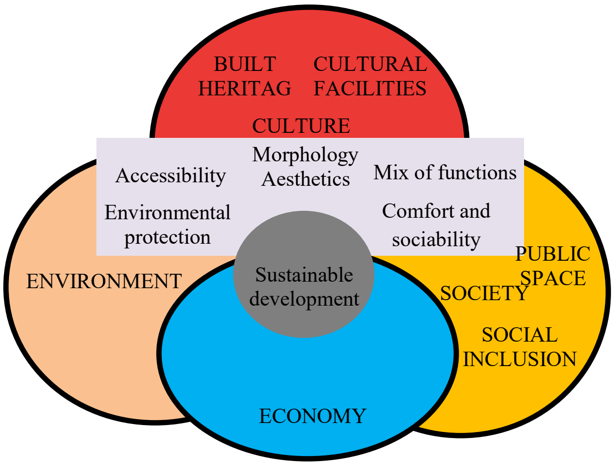


Figure 1. Scope of the research [26].

Homogeneity and Heterogeneity Sustained

Sustainability encompasses the concept of homogeneity, which refers to the balance and uniformity of composition throughout a system or mixture [25]. This equality extends beyond physical elements to include social structures and various aspects of society. In our pursuit of sustainability, we aim to ensure that resources, opportunities, and benefits are distributed equitably.

fostering harmony and resilience across various dimensions of our interconnected world [26] as in the figure.(2)

In the realm of sustainability, heterogeneity refers to a characteristic or state where various elements within a system possess distinct and diverse attributes. This lack of uniformity can arise due to factors such as challenges in achieving randomness or reliance on absolute measures rather than nuanced approaches [9].

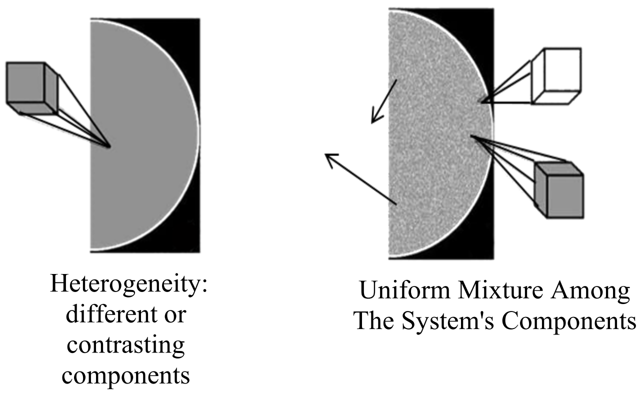


Figure 2. Homogeneous and Heterogeneous Models

Balancing Homogeneity and Heterogeneity in the Sustainable Urban

Sustainability defines homogeneity in terms of the regularity of the urban fabric and the degree of shape symmetry[27]. It lessens the unit parts' independence. Reaching communicative coherence and continuity, as well as homogeneity, is a way to gauge how random the urban fabric is. The degree to which the system deviates from total harmony and the idea of oneness and independence is known as heterogeneity sustainability. It has an inverse relationship with the scale change [9].

In statistics, uniformity When characterizing the characteristics of a dataset, or multiple datasets, sustainability and its opposite, heterogeneity, come into play. They have to do with whether the frequently used presumption that the statistical characteristics of any one component of a larger dataset are identical to those of any other component is correct. When data from multiple research are combined in a meta-analysis, homogeneity quantifies the variations or parallels among the various studies Figure 3.

In summary, some basic sorts of non-homogeneity have been addressed, the idea of homogeneity is utilized for various types of statistical analysis to search for additional features that may need to be considered as variable within a dataset. [28].

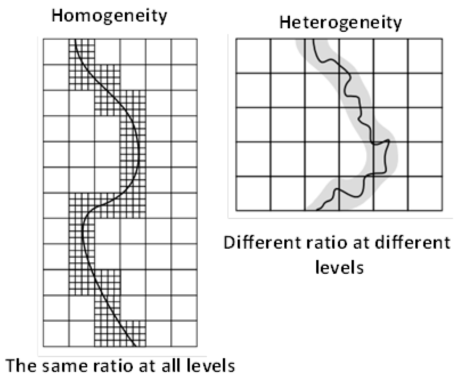
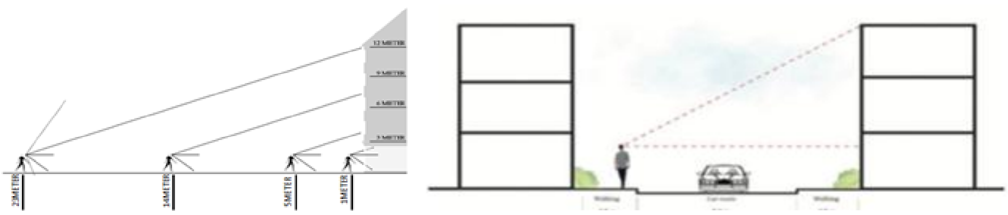


Figure 3. Distinction Between Heterogeneity and Homogeneity

For urban design to be sustainable, human size must be maintained... When cities prioritize designs that address human needs and behaviors, they inherently foster sustainable living [28][20]. By optimizing physical and psychological elements for human use, urban spaces become more conducive to sustainable practices [16]. This human-centered approach fosters harmony between people and their environments, resulting in a more sustainable urban fabric. As Joan Clos emphasized, neglecting the human scale not only leads to ugliness in cities but also undermines their long-term viability and resilience [13] as in the figure(4) .



[FYI, 1 meter = 3.2 feet; thus 5 m. = 16 ft., 14 m. = 46 ft., 23 m. = 75 ft, etc.]

Figure 4. Description of Human scale

The concept of urban fabric represents the physical layout of towns and cities, comparable to the diverse patterns found in textiles. It encompasses both built-up areas, characterized by roofed structures like buildings, and open areas, which include publicly accessible spaces designed for human activity and enjoyment. While the built-up area focuses on structures [29] as in the figure (5).

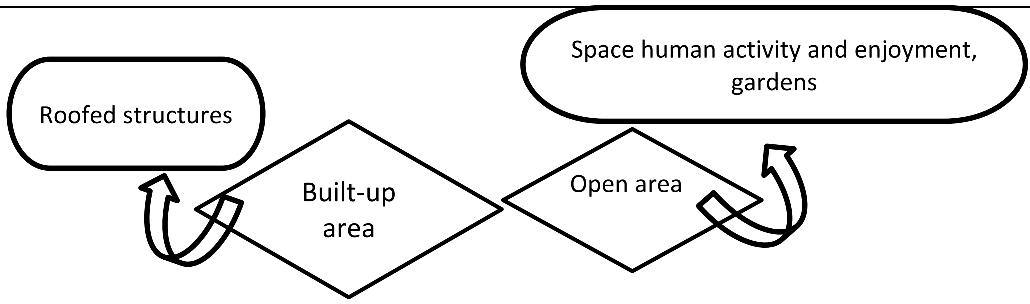


Figure 5. Defined built-up area /open area

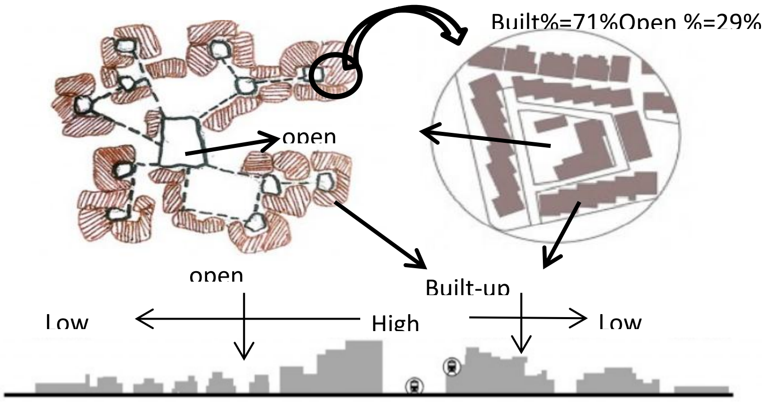


Figure 6. Explain built-up area /open area

Open areas, termed as Urban Open Spaces (UOS), encompass a range of communal spaces like community gardens, green corridors, civic plazas, pedestrian streets, and markets [15][10]. Prioritizing sustainability involves considering the balance and integration of both built and open spaces within the urban fabric, ensuring they contribute positively to environmental, social, and economic well-being [30] as in the figure (6)

Cellular Automata (CA)

mathematical and computational framework that represents an array of cells, each with a future state determined by its current state and the states of neighboring cells. This iterative process, guided by predefined rules, facilitates the transition from simplicity to complexity over time. Time plays a crucial role, as each cell's state evolves based on its neighborhood's temporal progression [30]. In the context of sustainability, CA provides a valuable tool for analyzing dynamic systems and their sustainability implications. Conway's Game of Life, a well-known application of CA, simplifies the rules for determining cell states within an 8-cell neighborhood. By leveraging CA, we can better understand and address sustainability challenges by simulating and predicting the interactions between various environmental, social, and economic factors in urban environments of the following rules [17] as in the figure:(7)

- A cell dies if there are four or more living cells around it or one living cell around it.

- A cell is born (transforms from a state of death tolife) if there are three living cells around it

- A cell remains alive if there are two or three living cells around it.One similar example is the pixel system.

And by applying it, will be able to extract (barcode) for cities. Stakeholders and environmental conditions [31]. By leveraging CA, we can develop innovative strategies, such as city barcoding, to analyze and address sustainability challenges in urban environments as in the Figure (8).

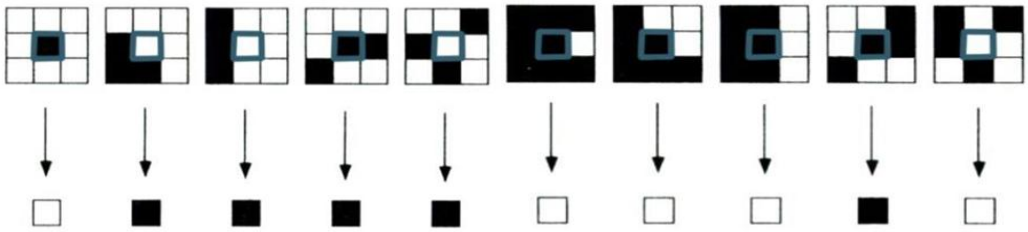


Figure 7. A cell develops according to its surroundings when applying a single repetition of the rules of the game of life.

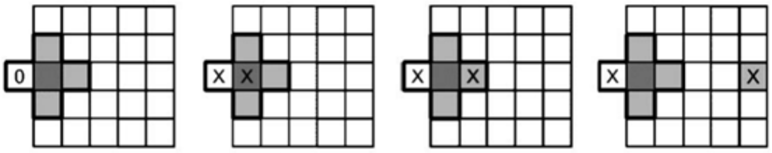


Figure 8. The state of the cell when its circumference is outside the grid.

- In my research, black cells represent the built-up area, and the white color represents open areas as in the figure(9) .

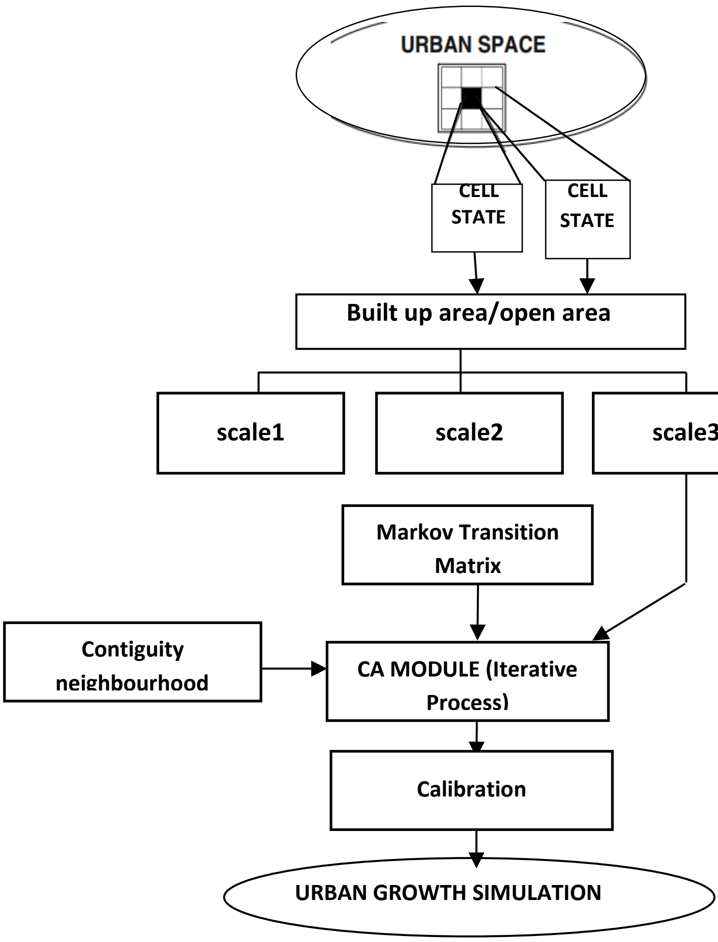


Figure 9. Schematic diagram for CA model.

METHODOLOGY

The research methodology focuses on analyzing urban fabric to identify opportunities for sustainable interventions. By examining three urban samples—Barcelona, Rome, and Hilla—the study assesses both homogeneity and heterogeneity within each context. Previous research established Rome and Barcelona as homogeneous in urban and social aspects, which serves as a benchmark for this study [21].

This research refines the focus to include sustainability, evaluating the environmental, economic, and social dimensions of urban coherence. The aim is to provide a comprehensive understanding of how and where sustainable interventions can be effectively applied to promote development across diverse urban environments.

In the first step: three aerial photographs were taken for each sample with an area of (589,824).

Picture Resolution (1920*1080 (1080 HD))

And the distance of the aerial shot from the ground is 200 m in each sample. a street with a width of 12 m was identified.

In the second step: A grid of 768 m by 768 m was created, and a scale for three phases of scale modification was created in:

The first scale: The grid consists of 4096 cells (64 cells * 64 cells), and each cell has dimensions of 12 m * 12 m according to the human scale (because each sample of the study contains a street with a width of 12 m).

The side length of the cell = 12m.

The second scale: is a grid with dimensions of 768 m * 768 m, but in a smaller scale than the previous one, where the grid consists of 256 cells (16 cells * 16 cells) and each cell has dimensions of 48 m * 48 m.

The side length of the cell = 48m.

The third scale: A grid was made with dimensions of 768 m * 768 m, but in a smaller scale than the previous one, where the network consists of 16 cells (4 cells * 4 cells) and each cell has dimensions 192 m * 192 m.

The side length of the cell = 192m.

It was started in reverse from the smallest scale to the largest because the work was done according to the human scale.

In the third step: the grid was placed on the aerial photographs of the samples (three different scales).In the fourth step, an approximate determination of the built and open spaces was made.

In the fourth step: the cells were changed according to the work of the Cellular automata (CA) rules mentioned in Figure 8 and where the black cell represents the built-up areas and the white color the open areas. Where the built-up area cell becomes if there are four cells of one or more built-up areas around it or one open space cell around it.

The cell is born (transformed from a built state to open) if there are three cells with open space around them

An open space cell remains if there are two or three open space cells around it.

A similar example is the pixel system.

In the fifth step: extract the number of built-up area cells and the number of open space cells. To get the ratio between the numbers of built-up area cells/total number of cells, the ratio of the number of open space cells/total number of cells and the ratio of the number of built-up area cells/number of open space cells.

Then the results are discussed to prove the hypotheses and determine whether the urban fabric is homogeneous or heterogeneous. It was observed that there is a barcode for each urban fabric at a specific scale.

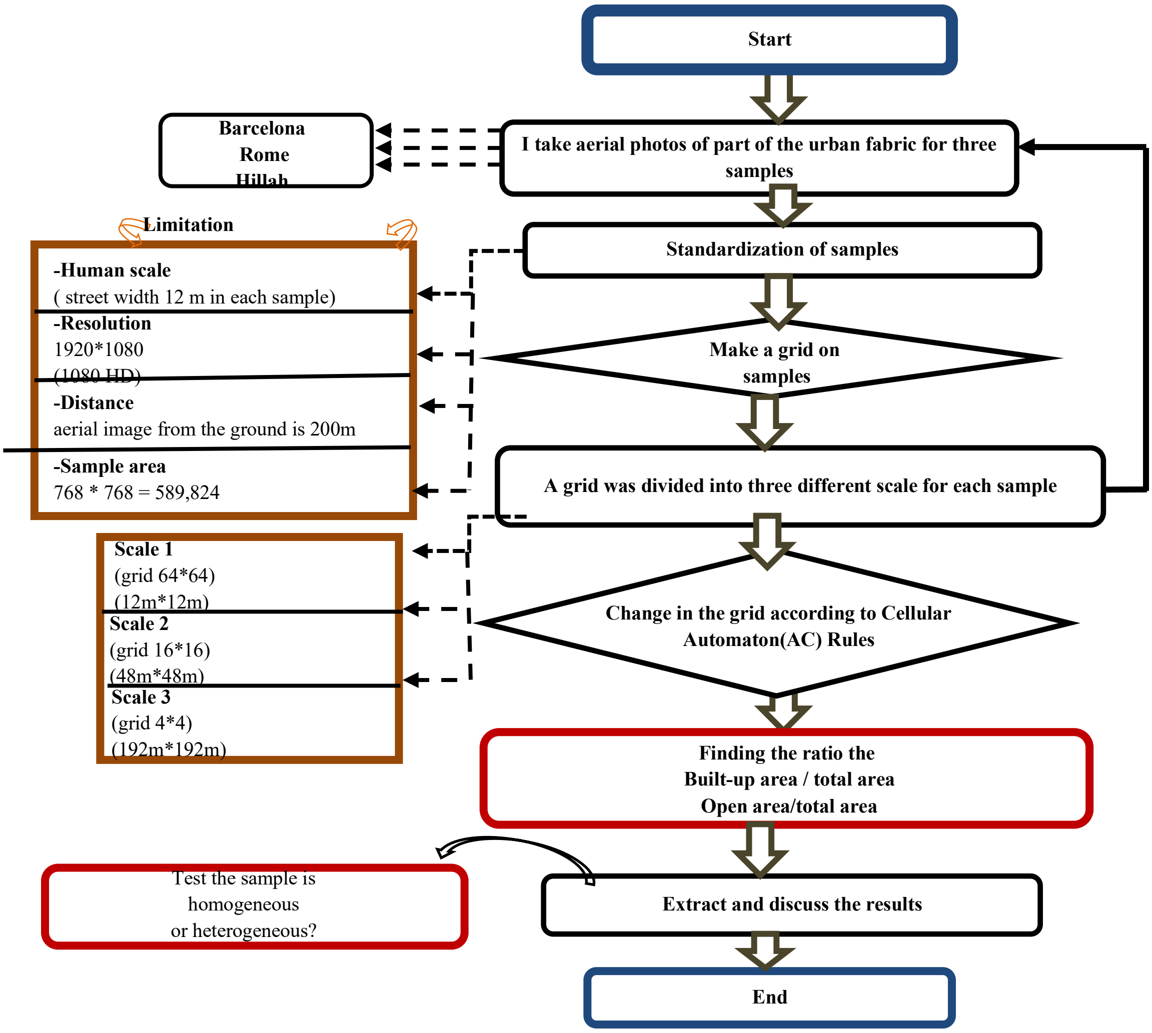


Figure 10. Methodology Structure

First Sample (Barcelona)

In Barcelona, the Old Town, mostly identified like the historical center, originates from the gothic period. It presents a continuous and highly dense urban system. The fabric is very compact and the boundaries are well defined and form .

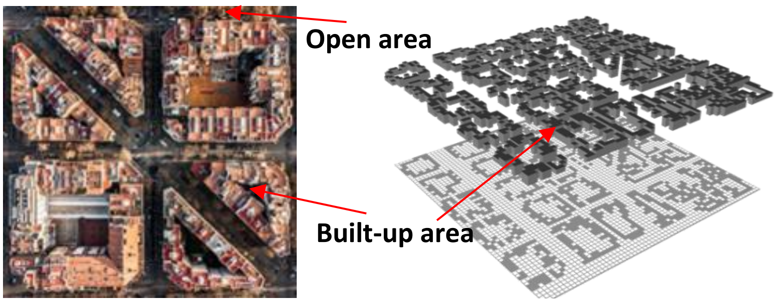


Figure 11. Barcelona's urban fabric

First step, aerial photographs. 4096 cells(64 cells * 64 cells) The grid consists of 256cells (16 cells * 16cells), The grid consists of 16cells (4 cells * 4 cells), Second Step A Grid Was Make Third step, the grid was put on the aerial photographs of the samples and approximate determination of the built and open spaces Fourth step cellular automata carules Fifth step of built-up area cells and the number of open space cell extract the number show in Fig.12.

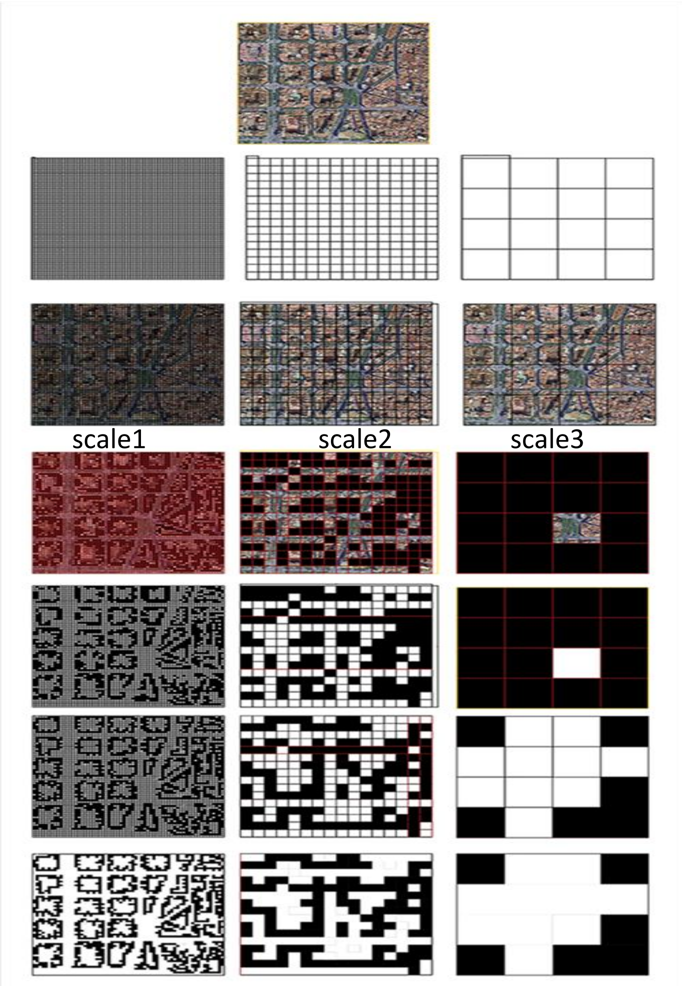


Figure 12. Barcelona urban fabric

Secoand Sample (Rome)

Saint Peter's Church Square, Vatican City, Rome. It should be noted that its urban fabric is homogeneous as if it were one unit, despite the heterogeneity of some parts if we look at them as individual parts, but we also note that they have acquired the character of homogeneity with the passage of time

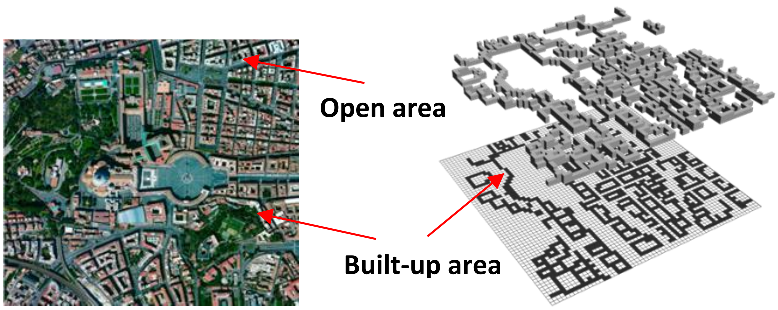


Figure 13. Roma urban fabric

First step , aerial photographs The grid consists of 4096 cells (64 cells * 64 cells), The grid consists of 256cells (16 cells * 16cells), The grid consists of 16cells (4 cells * 4 cells), Second Step A Grid Was Make Third step, the grid was put on the aerial photographs of the samples and approximate determination of the built and open spaces Fourth step: cellular Automata(ca)rules Fifth step:extract the number of built-up area cells and the number of open space cells show in Fig.14.

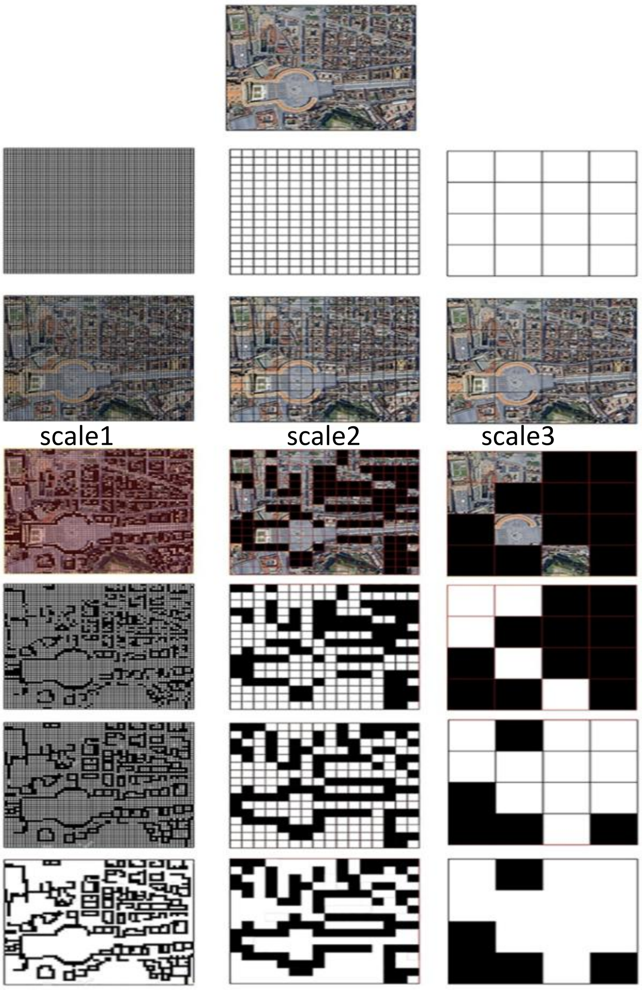


Figure 14. Roma urban fabric

Third Sample (Hillah)

Hillah ,is a city in central Iraq on the Hillah branch of the Euphrates River, 100 km (62 mi) south of Baghdad. It is the capital of Babylon Province and is located adjacent to the ancient city of Babylon. It is situated in a predominantly agricultural .

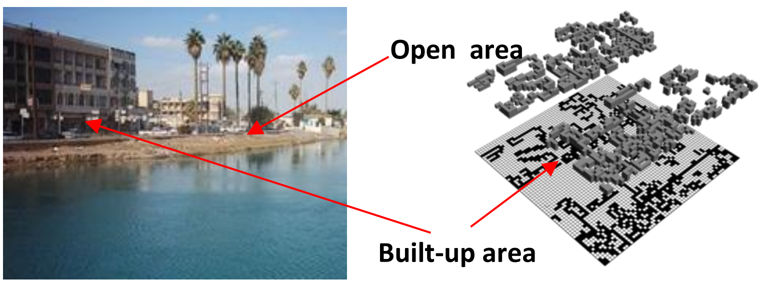


Figure 15. Hillah urban fabric

First step , aerial photographs the grid consists of 4096 cells (64 cells * 64 cells), the grid consists of 256cells (16 cells * 16cells), the grid consists of 16cells (4 cells * 4 cells), second step a grid was make third step, the grid was put on the aerial photographs of the samples and approximate determination of the built and open spaces fourth step: cellular automata(ca)rules fifth step:extract the number of built-up area cells and the number of open space cells show in fig.16.

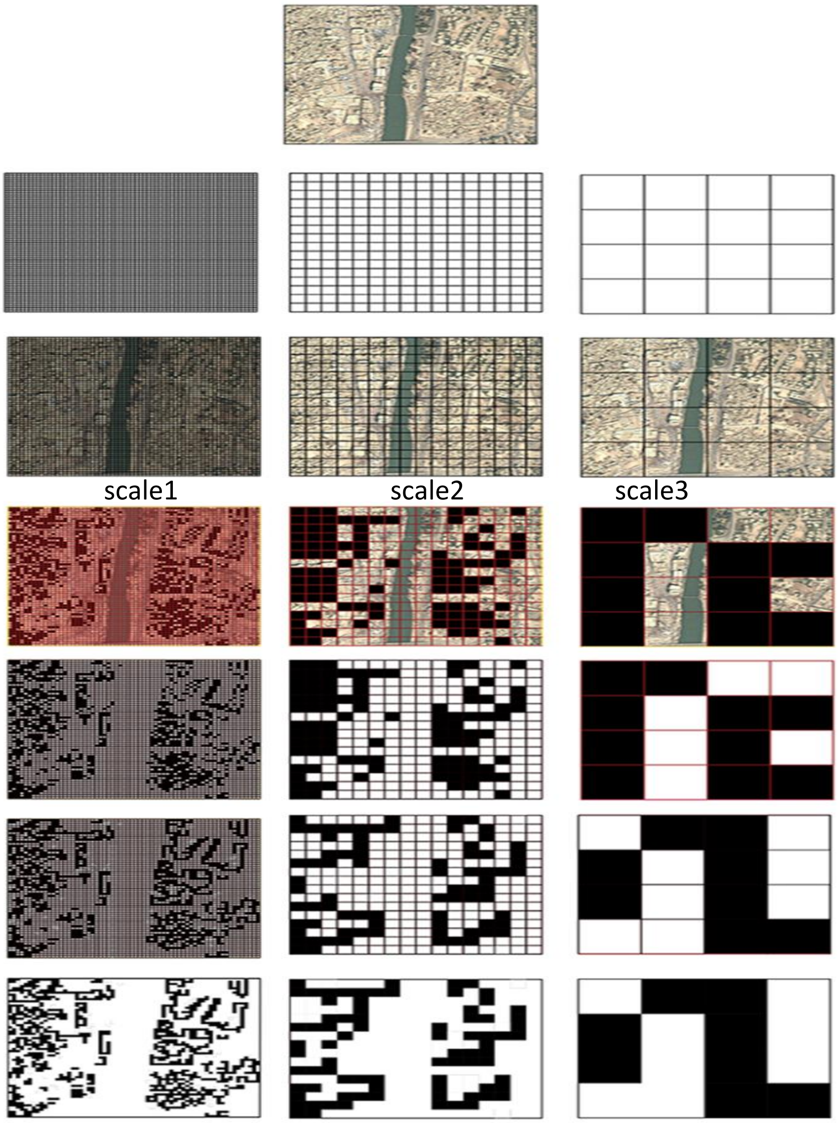


Figure 16. Hillah urban fabric

RESULTS AND DISCUSSION

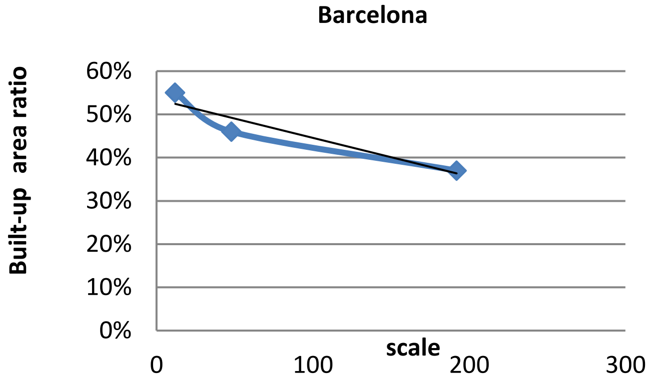
The hypothesis was confirmed by observing clear relationships between scale changes and cell ratios. Specifically:

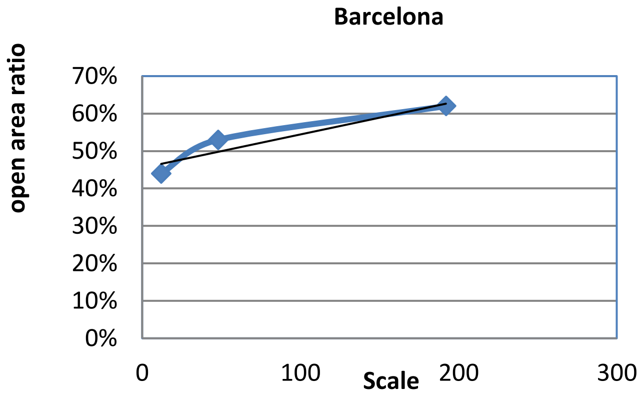
An inverse relationship was found between scale change and the ratio of built-up area cells to the total number of cells, with a 9% change as shown in Graph (1) and Table (1). Conversely, a direct relationship was noted between scale change and the ratio of open area cells to the total number of cells, also showing a 9% change, as depicted in Graph (1) and Table (1).

Table 1. Ratio of built-up areas and open areas for Barcelona's urban fabric

Scale(X)	Number Of Cells (Built-Up Area)	All Cells	(Built-Up Area/Number Of All Cells)*100%(Y)	
12	2257	4096	(2257/4096)*100%	55%
48	120	256	(120/256)*100%	46%
192	6	16	(6/16)*100%	37%

Scale (X)	Number of Cells (Open Area)	All Cells	(Open Area/Number of All Cells)*100%(Y)	
12	1839	4096	(1839/4096)*100%	44%
48	136	256	(136/256)*100%	53%
192	10	16	(10/16) *100%	62%





Graph 1. Ratio of built-up areas and open areas

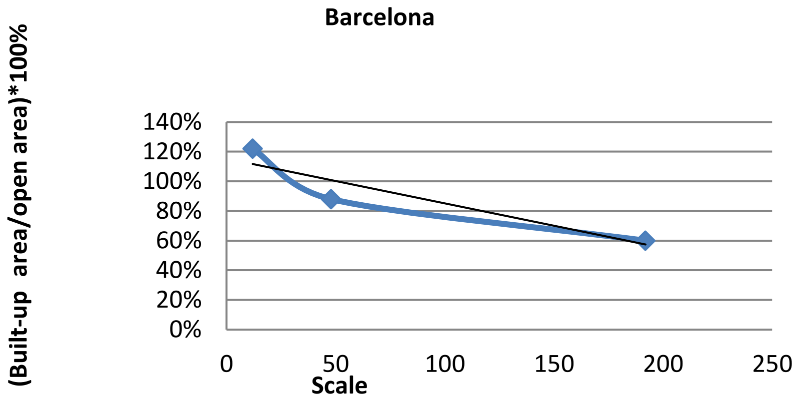
The inverse relationship between the ratio and the change of scale, the results of this sample have similarities with the results of the second sample (Rome).

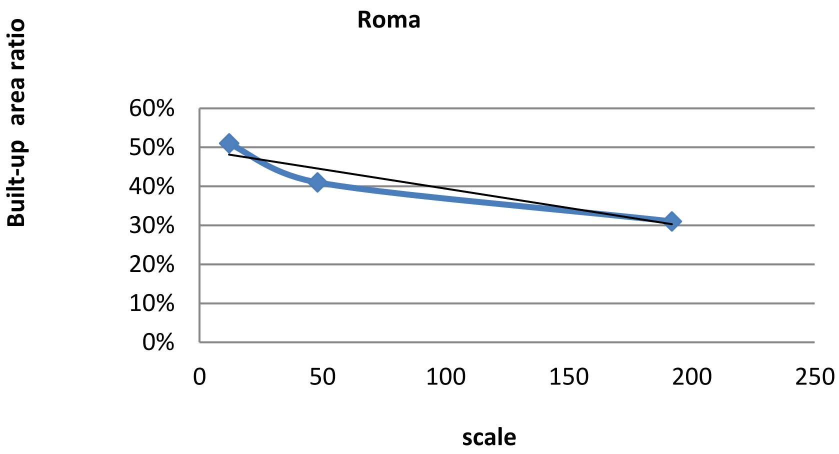
The hypothesis was proven, as there is an inverse relationship between the change of scale versus the ratio of the number of built –up area cells to the total number of cells We note that there is a order in which the scale changes against the change of ratio =10% as in Graph (2) and Table (2)

Table 2. Ratio of Built-Up Areas /Open Areas and built-up areas to Roma

scale	Number of Cells (Built-up area)	Number of Cells (open area)	(Built-up area/open area)*100%	
12	2257	1839	(2257/1839)*100%	122 %
48	120	136	(120/136)* 100%	88%
192	6	10	(6/10)*100 %	60%

Scale (x)	number of cells (Built-up area)	number of all cells	(Built-up area/number of all cells)*100% (y)	
12	2092	4096	(2092/4096) *100%	51%
48	106	256	(106/256)* 100%	41%
192	5	16	(5/16)*100 %	31%





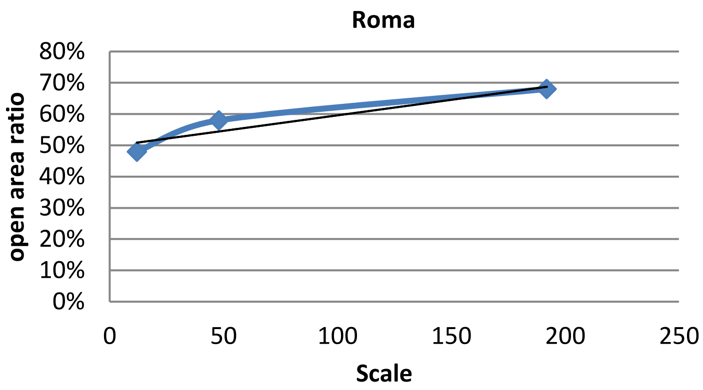
Graph 2. ratio of built-up areas /open areas to Barcelona's and built-up areas to Roma urban fabric

Table 3. Ratio of built-up areas to Roma urban fabric and built-up areas /open areas of Barcelona

Scale (x)	number of cells (Built-up area)	number of all cells	(Built-up area/number of all cells)*100% (y)	
12	2092	4096	(2092/4096)* 100%	51%
48	106	256	(106/256)* 100%	41%
192	5	16	(5/16)*100%	31%

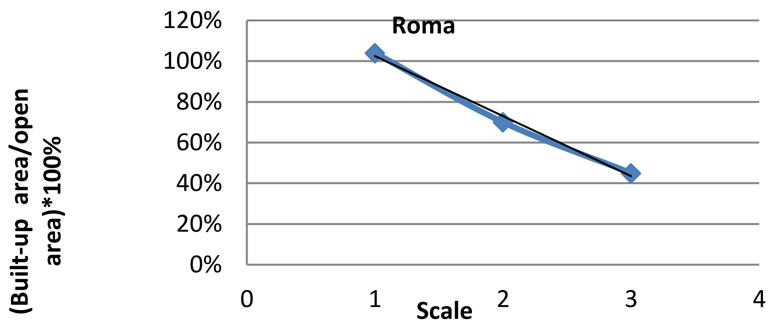
Scale (x)	Number of cells (Built-up area)	Number of cells (open area)	(Built-up area/open area)*100%(y)	
12	2092	2004	(2092/2004)* 100%	104%
48	106	150	(106/150)* 100%	70%
192	5	11	(5/11)*100%	45%

The hypothesis was proven, as there is a direct relationship between the change of the scale versus the ratio of the number of open area cells to the total number of cells We notice that there is a system in changing the scale versus changing the ratio = 10% as in the Graph (3,4)



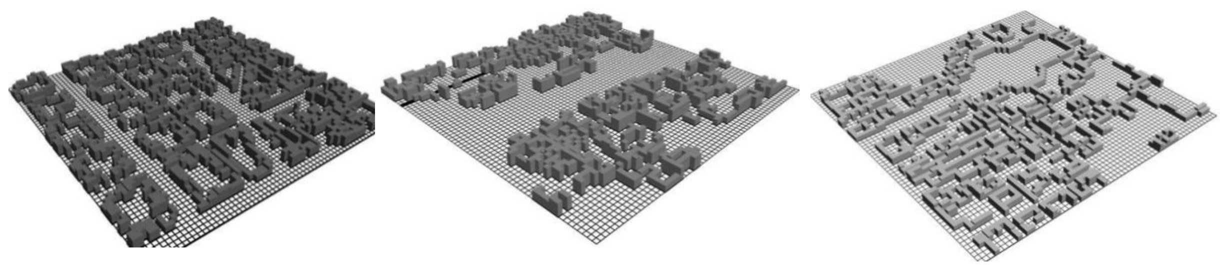
Graph 3. Ratio of open areas

The inverse relationship between the ratio and the change of scale, the results of this sample have similarities with the results of the second sample (Barcelona)



Graph 4. Ratio of built-up areas /open areas

By observing the results in **Barcelona**, was found order through the ratio between the number of cells, the built-up areas, against three stages of scale change, and the constant is **9%** as in the figure(17) .



A **B** **C**

Figure 17. urban fabric of (A) Barcelona, (B) Roma, (C) Hillah is homogeneous

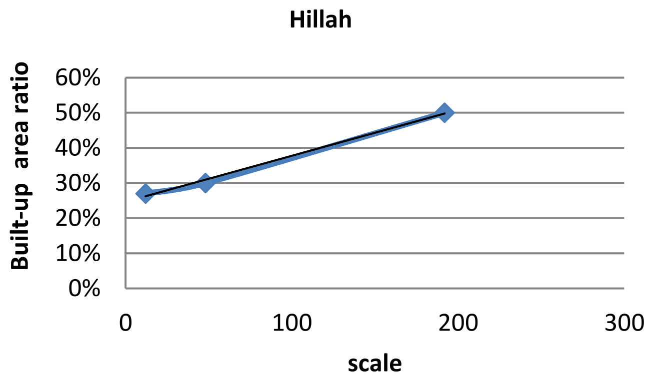
Rome's results show an ordered ratio between cell numbers and built areas across three scale changes, with a constant of 10%, as shown in Figure 17 and Table 4. In contrast, the city of Hilla lacks a specific pattern, indicating heterogeneity.

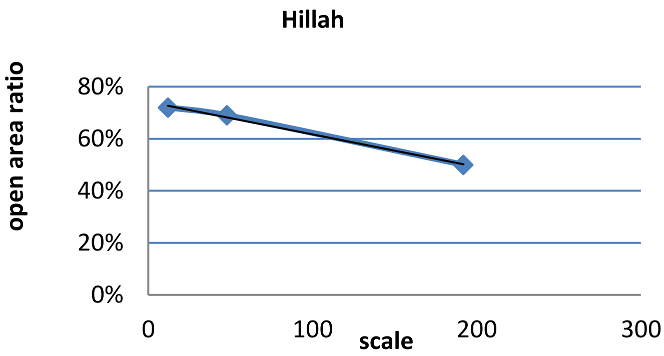
A similarity is observed between the equations for Barcelona ($y = -0.0009x + 0.535$, $R^2 = 0.8929$) and Rome ($y = -0.001x + 0.4933$, $R^2 = 0.8929$). Both equations have the same R^2 value, indicating an inverse relationship between the number of cells and built-up areas across three scale changes, as depicted in Figure (17) and Graph (5).

Table 4. Ratio of built-up and open areas

Scale(x)	number of cells (Built-up area)	all cells	(Built-up area/number of all cells)*100%(y)	
12	1113	4096	(1113/4096)*100 %	27 %
48	78	256	(78/256)*100%	30 %
192	8	16	(8/16)*100%	50 %

Scale(x)	number of cells (open area)	all cells	(open area/number of all cells)*100%(y)	
12	2983	4096	(2983/4096)*100 %	72 %
48	178	256	(178/256)*100%	69 %
192	8	16	(8/16)*100%	50 %





Graph 5. Ratio of built-up areas for Hillah urban fabric

The equations for Barcelona ($y = 0.0009x + 0.455$) and Rome ($y = 0.001x + 0.4967$) show a similar relationship, with the same R^2 value of 0.8929. This indicates a direct correlation between open cell spaces and scale changes in both cities. This similarity highlights the homogeneity of urban fabric in Rome and Barcelona, while the urban fabric in Al-Hilla is heterogeneous and random by comparison.

CONCLUSIONS

- The objective of this study was to enhance urban sustainability by promoting homogeneous urban development. In cases where urban fabric lacks homogeneity, interventions at locations and scales that align with human proportions were identified and validated across three diverse urban contexts: Barcelona, Rome, and Hilla.

- Cellular automation emerged as a valuable tool for evaluating coherence within urban spaces and fabric, aiding in the assessment of sustainability measures.
- The hypothesis regarding the impact of scale variation on homogeneity was confirmed. Notably, there exists an inverse relationship between scale variation and the proportions of built-up areas versus open spaces within urban environments.
- Specifically, in Barcelona, a system was identified where a 9% change in scale corresponded with the ratio of built-up areas to the total area. Similarly, in Rome, a 10% change in scale was found to correlate with the built-up area ratio.
- However, the city of Hilla exhibited randomness and lacked a discernible system when compared to the other samples. Despite this, through the application of cellular automation rules, Barcelona and Rome were identified as exhibiting homogeneous patterns, whereas Hilla's solution remained heterogeneous.

Recommendations

1. Human-Scale Assessment: Assess proposed changes against human-scale standards to ensure they meet established benchmarks. Identify and address any deviations.
2. Intervention Placement: Target specific areas within the urban fabric for intervention to efficiently allocate resources and improve homogeneity.
3. Ratio Determination: Determine the right balance of intervention relative to the urban context to achieve homogeneity while maintaining the existing fabric.
4. Adaptive Strategies: Implement flexible strategies that can adapt to changing urban conditions over time.
5. Community Engagement: Involve local communities and stakeholders in the intervention process to align with their needs and aspirations.
6. Monitoring and Evaluation: Set up mechanisms for ongoing assessment of interventions to ensure they meet sustainability goals and adjust as necessary.

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