Exploring Fractal Dimensions in Shenzhen's Urban Villages: Natural Pattern for Stress Reduction in High-Density Environments

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Abstract
Rapid urbanization presents challenges for designing future cities that enhance residents' quality of life and well-being. Literature has shown that dense environments can potentially contribute to heightened stress levels. Urban stress reduction is a critical concern in contemporary urban studies, involving multiple disciplines to understand how density environments positively impact well-being. Research shows that people tend to seek out natural environments, and aesthetic responses to natural settings positively impact psychological stress and emotional states. Moreover, literature has explored the beneficial impact of fractal dimensions, typically found in natural environments, on cognitive processes and stress reduction. Previous research often used images of natural scenes to calculate fractal dimensions and explore nature's restorative effects. However, there is a lack of deeper exploration of fractal dimensions within dense urban settings. This study sets its foundation in Shenzhen, one of the world's youngest cities, and more specifically in its urban villages, selected here for their unique character and high-density characteristics. This research aims at providing an exploratory analysis of the fractal character of those villages. High-resolution images and eye-level viewpoints are here systematically analysed to provide a different perspective on urban high-density environments through the lenses of spatial geometrical properties and visual complexity. A Python-based box-counting method for determining the fractal dimensions of photographic images is used. The results illustrate that the fractal dimension of urban village street patterns ranges from 1.73 to 1.89, indicating mid-to-high complexity. Secondary commercial streets show the highest complexity, while newly built secondary cluster streets exhibit the lowest complexity. By applying fractal analysis to high-density environments, we explored possible connections between natural patterns and built environments, as well as highlighted important methodological considerations. A deeper understanding of fractal properties within urban settings can shed light on how people perceive complex environments. This study highlights significant potential for future research to explore the fractal characteristics of dense urban areas and their impact on individuals' perceptions.

Keywords: *Fractal Dimensions; Urban Villages; Stress Reduction; High-Density Cities; Visual Complexity*

1. INTRODUCTION

Increasingly fast worldwide urbanization leads to more and more dense environments within cities. High-density environments are characterised by high population density, high-rise building complexes, and crowded streets. Besides, citizens in high-density cities are facing challenging psychological stress [1], making urban stress reduction an urgent issue in contemporary urban and architectural studies [2, 3].

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Urban villages are one of the high-density environments that have developed in response to rapid urbanization processes. They are characterized by central location within the city, affordable rent, an abundance of employment opportunities, and diverse land-use types [4]. They feature extremely high-density mid-rise building blocks, often referred to as hand-shake buildings with narrow alleys and high population densities.

Urban villages in Shenzhen represent a unique urban phenomenon, reflecting the city's fast-paced urbanization from a small town into a modern metropolis. These villages effectively accommodate a substantial influx of migrant populations and foster vibrant commercial areas. The high-density construction prevalent in these villages often lacks of sufficient public open space, thereby making the streets between buildings critical as public domains. Urban villages exhibit a vibrant street system for non-motorized vehicle and pedestrian activities, diversified living services, and face-to-face interactions among people promoted by its small scale. High-density construction, combined with a lack of vegetation, significantly impacts the quality of the urban environment and the living experience of residents.

To better understand urban villages and their streets' fractal character, this study aims to provide a systematic fractal analysis within one village and its streets, a setting that has not previously been analysed for fractal dimensions. Specifically, images were collected and analysed from one of the urban villages in Shenzhen, named Tangshuiwei Village, to determine the fractal character of its streets. In the context of rapid urbanization and urban stress reduction, this study aims to detect potential natural patterns within high-density urban environments using fractal dimension analysis.

2. FRACTAL DIMENSIONS IN BUILT ENVIRONMENTS

Fractal patterns are prevalent in natural scenes [5, 6, 7, 8, 9], and they display self-similarity and scale-free characteristics. The fractal dimension (*D*) is a statistical parameter used to measure the complexity of geometric fractal patterns [10, 11] . The intrinsic link between fractals and natural environments enhances individuals' aesthetic appreciation for fractal patterns. The pervasive presence of fractals in nature, particularly those of mid-complexity, has led to the adaptation of the human visual system to process them efficiently. Humans display an aesthetic preference across fractal images, regardless of whether these images are generated by nature's processes, by mathematics, or by the human hand [6]. Studies have revealed that fractals elicit psychological reactions in people, with mid-complexity fractals linked to alleviating stress [7, 14, 32] .

The fractal character of an image can also be quantified by its fractal dimension (*D*). For fractals described by a *D* value close to 1, the patterns observed repeat in a way that builds a very smooth, sparse shape. However, a *D* value closer to 2 manifests repeating patterns building the shape of an intricate and detailed structure [15]. Therefore, fractals are widely used as a graphics tool for simulating and generating natural-like geometrics.

Within studies of the built environment, urban form, urban residential patterns, and transportation networks exhibit fractal characteristics [16, 17]. Fractal dimension analysis can be applied to these complex systems. All these examples of the measurement of urban form are focused on plan views or aerial photographs to analyse their geometrical properties. Besides, fractal dimensions have also been applied at smaller scales, such as streetscapes or street vistas.

In studies of fractal dimensions of street views, most researchers employ integrated software like ImageJ, and correlate the analysis results to physical features such as greenery, boundaries, and street furniture [18, 19, 20]. Cooper (2008, 2013) focused on everyday streets to explore the relationship between visual quality and fractal dimension and identified a positive correlation between fractal dimension and visual quality ratings, noting that a city street with a mean fractal dimension of 1.718 scored highest in visual quality. Research has also related the results to self-rating visual quality

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surveys, such as visual variety, visual interest, and visual complexity [21]. Furthermore, most research on fractal dimensions and visual perception mainly utilizes generated images instead of real-world scenes [22]. However, there are few studies measuring the overall visual perception of street scenes using real-world photographic images and a Python-based calculating program.

According to the prevalence of fractal patterns in nature and their restorative effect, the ability to quantify fractal characteristics of an image within built environments is an insightful perspective through which to investigate visual complexity in high-density settings.

3. METHOD

3.1 A case study in an urban village

Minzhi Urban Village is one of the many urban villages in Shenzhen. It is located in Longhua District, between Minzhi Avenue and Longhua Avenue. Tangshuiwei Village is one of the urban villages within the Minzhi Village complex, located in the northeastern part of Minzhi Urban Village; it is neighboured by Shaxia Village.

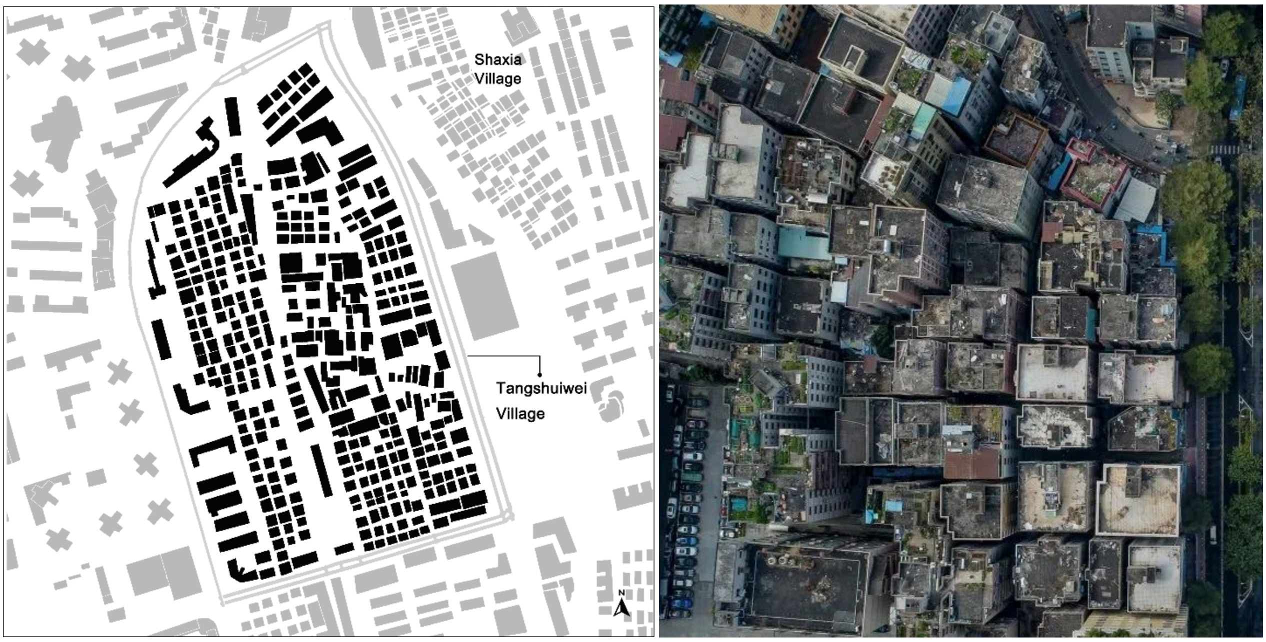

Figure 1. Tangshuiwei Village in Minzhi Urban Village (Longhua District, Shenzhen)
Image resource: https://images.app.goo.gl/bBkY9j9ut5ad5KQD8

3.2 Data collection

The images were taken using a Sony α 6400, and the collecting parameters were set at image size as 6000×3376 pixels (max), 300dpi, field of view = 50°, camera pitch = 0°, and the height of the camera was set as 1.55m. Sampling points were set at 10-meter intervals along various street types, totalling a sampling distance of 3 kilometres, to represent a sequence of views for each street typology.

Based on the Urban Residential Area Planning and Design Standards [23], and the Shenzhen City Urban Planning Standards and Guidelines [24], Table 1 summarizes urban road systems categories and typologies.

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Table 1. Classification of Shenzhen's Urban Road Systems

	Typology	Function
Urban Road System	Freeways	Handle through traffic, port traffic, and external city transport functions.
	Arterial Roads	Accommodate long-distance rapid transit and freight movement within city districts.
	Secondary Roads	Manage medium and short-distance passenger and freight traffic, distributing traffic from main arteries.
	Distribution Roads	Promote a network system of small blocks and dense road networks.
Residential Area Roads	Main Streets	Urban Secondary Roads accommodate both motorized and non-motorized traffic.
	Cluster Streets	Main access routes for entering and exiting residential neighbourhoods, usually including one bicycle lane and one pedestrian path. The road surface width should not be less than 4.0 meters.
	Alleys	Final level of access to residences, primarily used by residents for entry and exit. These roads mainly accommodate bicycle and pedestrian traffic. The road surface width should be no less than 2.5 meters.

Main Streets are the main access routes for entering and exiting residential neighbourhoods, serving as a main thoroughfare, connecting various parts of the development. In residential areas, they typically reach a minimum carriageway width of 7.3 meters to ensure adequate space for vehicles. Secondary Streets are secondary roads within a residential area intended for moderate traffic, providing access to properties or facilities. They reach a minimum width of 5.0 meters. Considering the unique characteristics of urban villages, where secondary streets also serve as important commercial streets and feature streets between building clusters, we categorized street types within urban villages into four typologies (Table 2).

Table 2. Street Typologies in Urban Villages

	Typology		Function	Circulation
1	Main Streets		Urban roads within the residential area	motor vehicle lanes, non-motor vehicle lanes
2	Secondary Streets	commercial streets	Auxiliary roads within the residential neighbourhood	non-motor vehicles, pedestrians
		cluster streets		
3	Back Alleys			non-motor vehicles, pedestrians

3.3 Fractal dimensions calculation

There are various methods for calculating fractal dimension, including standard box-counting, partitioning, and differential box-counting[25, 26, 27]. Box-counting method is frequently adopted for the estimation of fractal dimensions [11], and has been used to quantify the characteristic complexity of a city, including its growth patterns, road and rail networks, open spaces, and skylines [28].

Box-counting method involves covering computed pattern O with a grid of boxes and counting the number of non-empty boxes that contain any part of the pattern. This process is repeated while

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gradually reducing the box size. The number of grids $N(\varepsilon)$ and the size of the box ε are recorded and plotted to a log-log diagram in each repeated step [29].

$$D(O) = \boldsymbol{lim}_{\varepsilon \to 0} \frac{log(N(\epsilon n))}{log(1/\epsilon n)}$$

Previous studies analysing the fractal dimensions of built environment's images have often used integrated software such as ImageJ. With advancements in computer image processing technology and programming, it is now possible to further explore fractal analysis of built environment images. In this study, we programmed and coded the box-counting method in Python. To be processed, each image was first converted to grayscale. Gaussian blur was applied to reduce noise and smoothen the image. Otsu's thresholding method was then used to create a binary image, which segmented the image into foreground and background. Additionally, canny edge detection was applied to the blurred image to highlight edges. These edges were combined with the binary image and the resultant combined image was further cleaned for subsequent fractal analysis. Following pre-processing, the fractal dimension analysis using the box-counting method involved Box Size Determination, Box Counting, and Log-Log Plotting. The box sizes were determined through a geometric progression from half the minimum dimension of the image down to 2 pixels. The counts were plotted against the box sizes on a log-log scale. A linear regression was then performed on this plot to determine the slope. In conclusion, this method effectively combines a pre-processing step, box-counting calculation, and presentation of the fractal dimension value using a log-log diagram, providing valuable quantitative measures of the complexity of the street typology images.

4. RESULTS

Each street typology was analysed to determine its mean fractal dimension (*D*) for all images in the sample (n = 60), which quantifies the complexity of patterns within spatial streets' layout (Table 3).

Table 3. Average fractal dimension ranking of 4 street typologies

Ranking	Street Typologies in the Urban Village	Mean *D*
1	Secondary Commercial Streets	*D*=1.829
2	Main Streets	*D*=1.827
3	Back Alleys	*D*=1.823
4	Secondary Cluster Streets	*D*=1.796

In terms of mean *D*, secondary commercial streets present the highest mean *D* of 1.829. The lowest mean *D* is demonstrated by back alleys at 1.796. Secondary commercial streets present a fractal dimension of 1.829, which was the highest among the categories analysed, manifesting repeating patterns and detailed structure, likely due to their multifunctional nature. The highest index of fractal dimension was interpreted as the presence of numerous service functions within the specific zone [30]. This type of street holds multiple functions, supporting a variety of commercial activities and high pedestrian and vehicular traffic, leading to a dense and intricate road structure. These streets form vibrant commercial zones of the urban village, offering a wide range of dining and essential services. The shops are predominantly ground-floor establishments adjacent to residential areas, making them the most important and active public spaces within the urban village.

Main streets within urban villages possess a fractal dimension of 1.827, the second highest among the street typologies. This suggests the street pattern of this typology is complex, serving a broader

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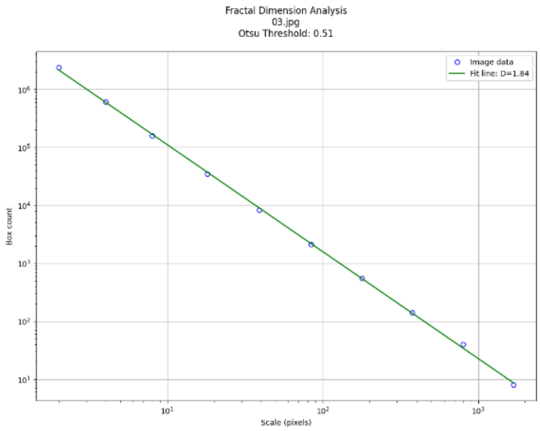
array of urban traffic demands including higher volumes and more diverse types of vehicles and pedestrians.

Back alleys, with a mean *D* value of 1.823, show slightly greater complexity compared to secondary cluster streets, reflecting the function of connecting individual residences within more compact and possibly irregular layouts, catering to very local needs.

Secondary cluster streets have a fractal dimension of 1.796, indicating a relatively high level of self-similarity typical for residential areas. These streets are likely characterized by a more regular, integrated network. This type of street is in the new district of Tangshuiwei Village, which is a newly built and designed pedestrian area. Finally, best approximation value was calculated to show the street photographic images that can best represent the four street typologies, as well as the maximum individual *D* and minimum individual *D* value in each street typology (Table 4).

Table 4. Best approximation *D* value

Main Streets	**Secondary Commercial streets**	**Secondary Cluster Streets**	**Back Alleys**
D=1.829	*D*=1.844	*D*=1.795	*D*=1.828
			



(a)

Step	Grid Size	Marked Boxes(N)
1	1688	8
2	798	40
3	377	141
4	178	547
5	84	2125
6	39	2125
7	18	34660
8	8	160586
9	4	612313
10	2	2372836

(b)

Figure 2. (a) log-log diagram (b) grid size

A log-log diagram of secondary commercial streets illustrates the appearance of a fractal dimension within an urban village's street patterns. From this diagram, the straight line indicates that from half the minimum dimension of the image down to a size of 2 pixels, the images of urban villages have self-similar textural characteristics like fractals. Spaces with a fractal structure usually appear a hierarchical order, rhythm and diversity, and such spaces offer visual quality by influencing individuals' perception positively [31, 32] .

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Table 5. Maximum and minimum *D* value and representative images

	Street typologies in Urban Villages	max_value_image	min_value_image
1	Main Streets	*D*=1.900 	*D*=1.757 
2	Secondary Commercial Streets	*D*=1.866 	*D*=1.769 
3	Secondary Cluster Streets	*D*=1.836 	*D*=1.760 
3	Back Alleys	*D*=1.882 	*D*=1.736 

The maximum individual *D* was recorded for main street and it's approximately 1.9. The minimum individual *D* was recorded for the back alley at 1.736.

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D values of four street typologies in the data set fell within 1.73-1.89, indicating a mid-to-high visual complexity range (*D*=1.5-2.0) of detailed textures that have more visual excitation and visual diversity [29, 33]. The resulting fractal dimensions of different scenarios often fall into the interval of 1.0–2.0. The intervals between 1.0–1.3 and 1.3–1.5 are defined as the low-to-mid level, where the scenarios can be seen as 'well-recognized' and 'better for goal-directed navigation'. The interval between 1.5-2.0 is defined as mid-to-high level, where the scenarios can be seen as 'arousing' and 'exciting' [29]. Meanwhile, visual diversity increases as the *D* value increases from 1.3-1.7 [33].

4. DISSCUSSION

Tangshuiwei Village in Shenzhen was selected as a case study for the exploration of its fractal characteristics. A Python-based box-counting method was used to calculate the fractal dimension of photographic images at eye-level on the streets. Data sets were pre-processed using Canny edge detection and binary images, preserving detailed architectural features and small alleyways, and clear delineation of building edges and pathways was ensured. The results obtained here manifest that urban villages show a certain fractal pattern along their streets; their fractal dimensions fall into 1.73-1.89, manifesting mid-high complexity. Secondary commercial streets show the highest complexity, while newly built secondary cluster streets exhibit the lowest complexity. The maximum individual *D* was recorded for main streets and it's approximately 1.9. The minimum individual *D* was recorded for back alleys at 1.736.

By applying fractal dimensions analysis to high-density environments, this study attempts at searching for natural patterns within built high-density. Fractal dimensions are a natural property [10, 33], showing fundamental fractal character can help describe how complex systems are organised. Like natural environments, high-density environments display self-similar textural details, leading to higher fractal dimensions due to clustered lines [35]. They have complex scenes where the human visual system tends to perceive the overall profile (e.g., building, forest) rather than finer details (e.g., building facades, leaves) [36]. Fractal characteristics at eye-level within high-density environments can support the perception of detailed textures and patterns.

Through this presented Python-based box-counting method, some considerations when using box-counting method in high-density environments can be concluded. Preserving detailed architectural features and small alleyways during preprocessing is crucial for accurate analysis. Hence, reserving clear delineation of building edges and pathways is vital for understanding the spatial organization and density of these areas. Furthermore, varied lighting conditions caused by narrow streets and high buildings can affect the thresholding methods used in preprocessing, making it important to account for shadow and light variations.

These measurements could provide pivotal insights for urban planning and development, providing new perspectives on the visual complexity of street patterns within high-density environments such as urban villages.

5. CONCLUSION

This study sheds light on an alternative method for the exploration and quantification of spatial visual complexity in high-density urban environments, and more specifically in a unique condition typical of Shenzhen: urban villages. The purpose of this study was to find natural patterns within built high-density, and further compare different street typologies of urban villages according to their fractal character. In the process, methodological considerations were provided, establishing a reference for future research.

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Further investigation can consider exploring the relationship between fractal dimensions in high-density and how people interact with and perceive complex environments, including how the visual complexity of street scenes in high-density affects visual perceptions, or how different street typologies influence psychological states (e.g. relaxation or stress). These results may inform the perception of urban high-density environments, driving design strategies to address positive visual impacts, and potentially contributing to inform design guidelines for the future of urban density.

References

[1] L. Luo and B. Jiang, "From oppressiveness to stress: A development of Stress Reduction Theory in the context of contemporary high-density city," *Journal of Environmental Psychology*, vol. 84, p. 101883, Dec. 2022, doi: 10.1016/j.jenvp.2022.101883.

[2] A. Bornioli and M. Subiza-Pérez, "Restorative urban environments for healthy cities: a theoretical model for the study of restorative experiences in urban built settings," *Landscape Research*, vol. 48, no. 1, pp. 152–163, Jan. 2023, doi: 10.1080/01426397.2022.2124962.

[3] J. Pykett, T. Osborne, and B. Resch, "From Urban Stress to Neurourbanism: How Should We Research City Well-Being?," *Annals of the American Association of Geographers*, vol. 110, no. 6, pp. 1936–1951, Nov. 2020, doi: 10.1080/24694452.2020.1736982.

[4] W. Pan and J. Du, "Towards sustainable urban transition: A critical review of strategies and policies of urban village renewal in Shenzhen, China," *Land Use Policy*, vol. 111, p. 105744, Dec. 2021, doi: 10.1016/j.landusepol.2021.105744.

[5] A. E. Stamps, "Fractals, skylines, nature and beauty," *Landscape and Urban Planning*, vol. 60, no. 3, pp. 163–184, Aug. 2002, doi: 10.1016/S0169-2046(02)00054-3.

[6] B. Spehar, C. W. G. Clifford, B. R. Newell, and R. P. Taylor, "Universal aesthetic of fractals," *Computers & Graphics*, vol. 27, no. 5, pp. 813–820, Oct. 2003, doi: 10.1016/S0097-8493(03)00154-7.

[7] C. M. Hagerhall, T. Purcell, and R. Taylor, "Fractal dimension of landscape silhouette outlines as a predictor of landscape preference," *Journal of Environmental Psychology*, vol. 24, no. 2, pp. 247–255, Jun. 2004, doi: 10.1016/j.jenvp.2003.12.004.

[8] Y. Joye and A. van den Berg, "Is love for green in our genes? A critical analysis of evolutionary assumptions in restorative environments research," *Urban Forestry & Urban Greening*, vol. 10, no. 4, pp. 261–268, Jan. 2011, doi: 10.1016/j.ufug.2011.07.004.

[9] C. M. Hägerhäll, T. Laike, M. Küller, E. Marcheschi, C. Boydston, and R. P. Taylor, "Human physiological benefits of viewing nature: EEG responses to exact and statistical fractal patterns," *Nonlinear Dynamics, Psychology, and Life Sciences*, vol. 19, no. 1, pp. 1–12, 2015.

[10] R. L. Devaney, "Fractal patterns arising in chaotic dynamical systems," in *The Science of Fractal Images*, H.-O. Peitgen and D. Saupe, Eds., New York, NY: Springer New York, 1988, pp. 137–168. doi: 10.1007/978-1-4612-3784-6_3.

[11] B. Mandelbrot, "How Long Is the Coast of Britain? Statistical Self-Similarity and Fractional Dimension," *Science*, vol. 156, no. 3775, pp. 636–638, May 1967, doi: 10.1126/science.156.3775.636.

[12] Y. Joye, "Architectural Lessons from Environmental Psychology: The Case of Biophilic Architecture," *Review of General Psychology*, vol. 11, no. 4, pp. 305–328, Dec. 2007, doi: 10.1037/1089-2680.11.4.305.

[13] R. P. Taylor, A. W. Juliani, A. J. Bies, C. R. Boydston, B. Spehar, and M. E. Sereno, "The Implications of Fractal Fluency for Biophilic Architecture".

[14] C. M. Hagerhall, T. Laike, R. P. Taylor, M. Küller, R. Küller, and T. P. Martin, "Investigations of Human EEG Response to Viewing Fractal Patterns," *Perception*, vol. 37, no. 10, pp. 1488–1494, Oct. 2008, doi: 10.1068/p5918.

[15] A. P. Pentland, "Fractal-Based Description of Natural Scenes," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. PAMI-6, no. 6, pp. 661–674, Nov. 1984, doi: 10.1109/TPAMI.1984.4767591.

[16] M. Batty, "Generating Urban Forms from Diffusive Growth," *Environ Plan A*, vol. 23, no. 4, pp. 511–544, Apr. 1991, doi: 10.1068/a230511.

Proceedings
Of the International Conference on Changing Cities VI:
Spatial, Design, Landscape, Heritage & Socio-economic Dimensions
Rhodes Island, Greece ● 24-28 June 2024
ISSN:
ISBN:

[17] M. Batty and Y. Xie, "Preliminary Evidence for a Theory of the Fractal City," *Environ Plan A*, vol. 28, no. 10, pp. 1745–1762, Oct. 1996, doi: 10.1068/a281745.

[18] J. Cooper, M.-L. Su, and R. Oskrochi, "The Influence of Fractal Dimension and Vegetation on the Perceptions of Streetscape Quality in Taipei: With Comparative Comments Made in Relation to Two British Case Studies," *Environ Plann B Plann Des*, vol. 40, no. 1, pp. 43–62, Feb. 2013, doi: 10.1068/b38010.

[19] J. Cooper and R. Oskrochi, "Fractal Analysis of Street Vistas: A Potential Tool for Assessing Levels of Visual Variety in Everyday Street Scenes," *Environ Plann B Plann Des*, vol. 35, no. 2, pp. 349–363, Apr. 2008, doi: 10.1068/b33081.

[20] E. Yaldız, D. aydın, and S. Büyükşahin, "THE APPLICATIONS OF REUSE IN ARCHITECTURE VIA SUSTAINABILITY CONCEPT," 2017, pp. 32–46.

[21] J. Cooper, D. Watkinson, and R. Oskrochi, "Fractal Analysis and Perception of Visual Quality in Everyday Street Vistas," *Environment and Planning B: Planning and Design*, vol. 37, pp. 808–822, Sep. 2010, doi: 10.1068/b34061.

[22] B. Abboushi, I. Elzeyadi, R. Taylor, and M. Sereno, "Fractals in architecture: The visual interest, preference, and mood response to projected fractal light patterns in interior spaces," *Journal of Environmental Psychology*, vol. 61, pp. 57–70, Feb. 2019, doi: 10.1016/j.jenvp.2018.12.005.

[23] "Urban Residential Area Planning and Design Standards." Accessed: May 30, 2024. [Online]. Available:http://www.moe.gov.cn/jyb_xwfb/xw_zt/moe_357/jyzt_2019n/2019_zt13/zcwj/201906/t20190606_384732.html

[24] "Shenzhen City Urban Planning Standards and Guidelines." Accessed: May 28, 2024. [Online]. Available: https://www.gd.gov.cn/zwgk/wjk/zcfgk/content/post_2532229.html

[25] J. H. Lee and M. J. Ostwald, "Fractal Dimension Calculation and Visual Attention Simulation: Assessing the Visual Character of an Architectural Façade," *Buildings*, vol. 11, no. 4, Art. no. 4, Apr. 2021, doi: 10.3390/buildings11040163.

[26] Y. Liu *et al.*, "An improved differential box-counting method to estimate fractal dimensions of gray-level images," *Journal of Visual Communication and Image Representation*, vol. 25, no. 5, pp. 1102–1111, Jul. 2014, doi: 10.1016/j.jvcir.2014.03.008.

[27] C. Panigrahy, A. Seal, N. K. Mahato, and D. Bhattacharjee, "Differential box counting methods for estimating fractal dimension of gray-scale images: A survey," *Chaos, Solitons & Fractals*, vol. 126, pp. 178–202, Sep. 2019, doi: 10.1016/j.chaos.2019.06.007.

[28] M. J. Ostwald and J. Vaughan, *The Fractal Dimension of Architecture*. Cham: Springer International Publishing, 2016. doi: 10.1007/978-3-319-32426-5.

[29] L. Ma, S. He, and M. Lu, "A Measurement of Visual Complexity for Heterogeneity in the Built Environment Based on Fractal Dimension and Its Application in Two Gardens," *Fractal and Fractional*, vol. 5, no. 4, Art. no. 4, Dec. 2021, doi: 10.3390/fractalfract5040278.

[30] V. Rodin and E. Rodina, "THE FRACTAL DIMENSION OF TOKYO'S STREETS," *Fractals*, vol. 08, no. 04, pp. 413–418, Dec. 2000, doi: 10.1142/S0218348X00000457.

[31] N. A. Salingaros, "Fractals in the New Architecture.".

[32] R. P. Taylor, "Reduction of Physiological Stress Using Fractal Art and Architecture," *Leonardo*, vol. 39, no. 3, pp. 245–251, Jun. 2006, doi: 10.1162/leon.2006.39.3.245.

[33] C. Bovill, *Fractal Geometry in Architecture and Design*. Boston, MA: Birkhäuser Boston, 1996. doi: 10.1007/978-1-4612-0843-3.

[34] R. F. Voss, "Fractals in nature: From characterization to simulation," in *The Science of Fractal Images*, M. F. Barnsley, R. L. Devaney, B. B. Mandelbrot, H.-O. Peitgen, D. Saupe, R. F. Voss, H.-O. Peitgen, and D. Saupe, Eds., New York, NY: Springer, 1988, pp. 21–70. doi: 10.1007/978-1-4612-3784-6_1.

[35] T. V. Mesev, P. A. Longley, M. Batty, and Y. Xie, "Morphology from Imagery: Detecting and Measuring the Density of Urban Land Use," *Environ Plan A*, vol. 27, no. 5, pp. 759–780, May 1995, doi: 10.1068/a270759.

[36] R. A. Kinchla, V. Solis-Macias, and J. Hoffman, "Attending to different levels of structure in a visual image," *Perception & Psychophysics*, vol. 33, no. 1, pp. 1–10, Jan. 1983, doi: 10.3758/BF03205860.

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