Fractal and entropy analysis of traditional and modernist building facades in street-level view

The case of Sweden's growing cities

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Abstract

This study presents a quantitative analysis of traditional and modernist building facades in urban environments, focusing on the assessment of their complexity and coherence. Fractal and entropy analysis techniques were employed to objectively evaluate the differences between the two architectural styles within the preference matrix framework. The study aimed to determine variations in fractal dimensions and information entropy, describe the nature of these variations, and discuss their implications for the preference matrix.

Street-level view images capturing traditional and modernist architectural styles in Swedish cities were utilized in this study. The images underwent a process of tracing to extract detailed lines representing the building facades. Fractal analysis was applied to measure the complexity of the topology represented by these lines. Additionally, the images were mapped according to building surface, enabling the calculation of information entropy to assess the coherence and diversity of the surface distribution.

Significant differences in fractal dimensions were observed between traditional and modernist styles. Traditional architecture exhibited higher fractal dimensions, indicating a more intricate and complex topology characterized by detailed elements. In contrast, modernist architecture displayed lower fractal dimensions, reflecting a less complex arrangement of lines and edges. Regarding information entropy, no significant differences were found between the two styles, suggesting comparable levels of coherence and diversity in the distribution of building surfaces. However, a positive relationship was noted, indicating higher entropy and diversity in the traditional style.

Keywords: fractal dimension, information entropy, street-level view, building façade, preference matrix

Table of contents

List of tables

List of figures

Abbreviations

FD,fd	Fractal dimension
D_b	Fractal dimension by box-counting
DWG	Drawing file
CAD	Computer-aided design
JPEG	Joint photographic experts group
PNG	Portable network graphics
ANOVA	Analysis of variance

1. INTRODUCTION

The ongoing discourse regarding the comparison between traditional and modernist architecture is a topic of extensive discussion within academic circles and the design community. Modernist architecture has often been subject to criticism for its perceived ominous qualities, while traditional architecture is commended for its perceived salubrious attributes.

The differing levels of critique directed towards each style can be attributed mostly to their distinct visual aesthetics, as architecture inherently embodies the principles of visual art. In older urban areas of Swedish cities one can find juxtapositions of these contrasting styles. These striking combinations present a unique opportunity to revisit and re-evaluate this enduring topic. Rather than seeking a definitive conclusion, the aim is to approach the issue from a fresh and contemporary perspective, recognizing its continued relevance and implications in our society. When discerning between these two architectural styles, a significant amount of attention is dedicated to contrasting their façades, which serve as surfaces that either exhibit resemblance or stark divergence. The building facades, situated on both sides of the streets, assume a prominent role in shaping the streetscape and leaving a lasting impression. In line with K. Lynch's concept of the *Image of the City* (1960), these facades contribute to the distinct character of urban pathways. It has an undeniable importance that a specialized niche of architects aptly named façade designers, focuses on the meticulous planning and execution of this exterior element. The way a façade is designed, critiqued and appreciated in almost all cases is based on frontality. In the works of Irish playwright Oscar Wilde architecture can be compared to a performance stage (Gürün, 1971), and similarly 16th century architecture theorist Sebastian Serlio casted architecture as scenery (Read, 2014). In most cases however, one can only see architecture presented in this way in wide boulevards and in squares where an observer is free to move around and gaze. Rarely, is architecture presented in a street-level view where visual perception is greatly controlled by the width, shape, and turn of this artery.

In a normal situation, the discourse between the two styles is approach subjectively, relying in preference, opinions, and feelings. Frampton (1992) approached the issue objectively providing a critical analysis in a descriptive manner. Traditional and modernist styles in street-level view is an issue that is made more complex, nonetheless it provides a good avenue to explore the differences. The preference matrix by Kaplan & Kaplan (1989) provides a good framework as this theory sought to explain the nature of human preference, in an evolutionary context. Stephen Kaplan (1979) presented what he calls the visual array, a level of analysis involving *coherence* and *complexity* as two defining qualities of the landscape.

It is the belief of this paper that complexity and coherence, factors that explain human preferences in an environment, can be quantitatively described using two mathematical concepts: fractal dimension and information entropy. Fractal dimensions can be encountered when studying fractals, which Benoit Mandelbrot called the 'mathematics of roughness' (MIT 2019). These dimensions are non-integer values derived from the ratio of change in detail over change in scale of an object and are used to describe the complexity of forms. Information entropy, on the other hand, although related to thermodynamic entropy, emerged and developed independently. Entropy in the information context is a measure of the quantity of available information (Shannon, 1948).

The methodology involves a parallel process wherein fractal and entropy analysis are conducted using similar subject materials. These materials consist of street-level images captured in different Swedish cities, namely Lund, Malmö, Helsingborg, and Jönköping, depicting building facades of differing styles.

1.1 Objectives

The study aims to provide an objective and quantitative contrast between two prominent style of building architecture in urban environments in Sweden cities in the context of complexity and coherence from the preference matrix of landscape aesthetics through a parallel process of fractal and entropy analysis. Specifically, it aims to:

1. Evaluate the difference between the fractal dimensions of the two styles.
2. Describe the nature of the difference in fractal dimensions.
3. Evaluate the difference between the information entropy.
4. Describe the nature of the difference in information entropy values.
5. Discuss the implications of the two analysis on the preference matrix.

1.2 Hypotheses

The study is divided into two parallel parts hence there are two pairs of hypotheses.

Fractal analysis

H_0: There is no significant difference between the average fractal dimensions of traditional and modernist architecture.

H_a: There is a significant difference between the average fractal dimensions of traditional and modernist architecture.

Information entropy

H_0: There is no significant difference between entropy values of traditional and modernist architecture.

H_a: There is a significant difference between entropy values of traditional and modernist architecture.

2. THEORY

2.1 Traditionalist and Modernist

In order to delve into the comparison between traditionalist and modernist architecture, it is essential to establish clear definitions and boundaries for each style. Throughout this research, the term "traditional architecture" has been used in the title and all preceding pages. However, starting from this chapter and in the subsequent pages, the study will utilize the term "traditionalist" as a temporary placeholder.

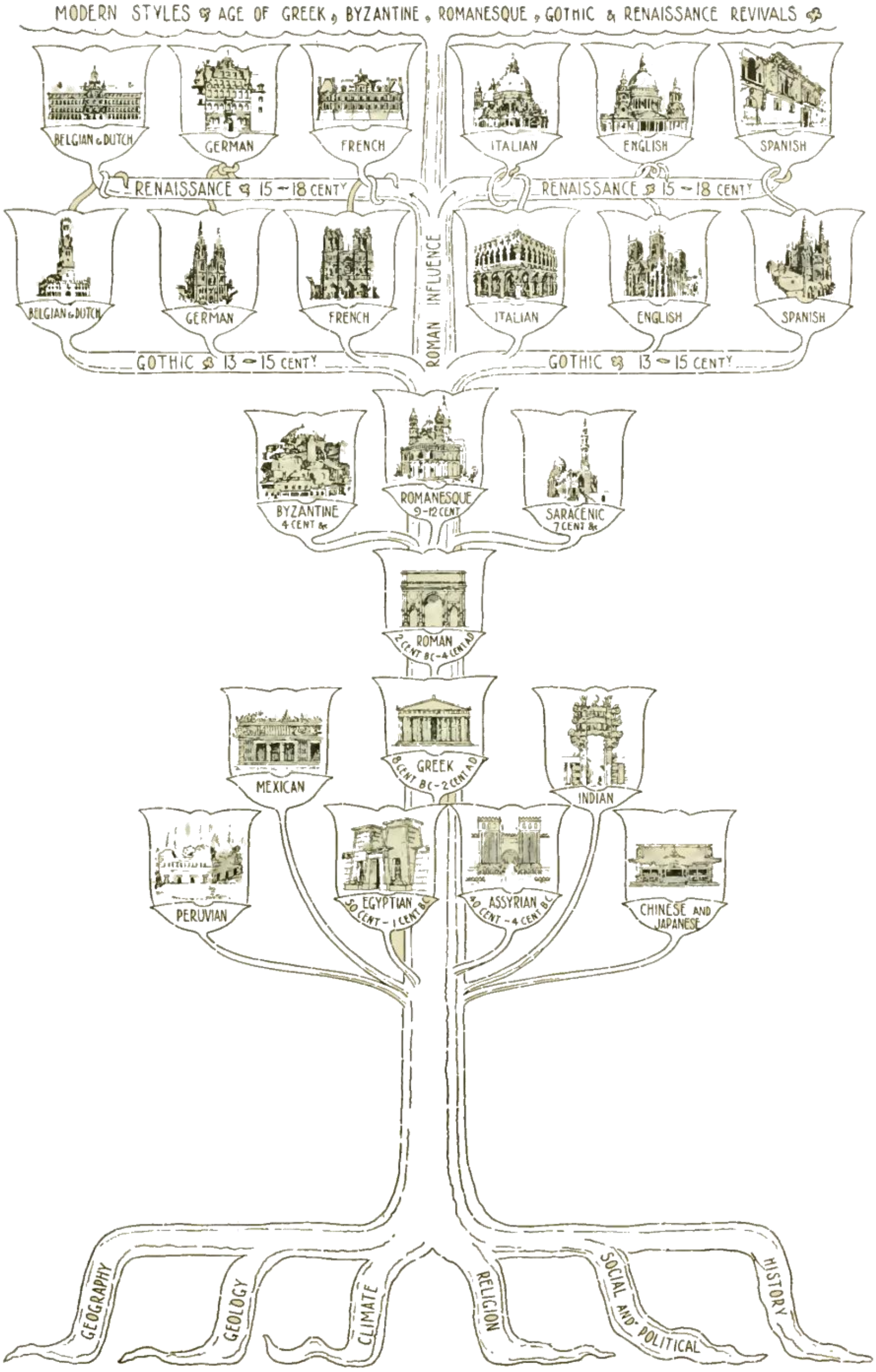
The decision to use the suffix "-ist" at the end of "traditional" and "modern" implies a state of being, and thus the term "traditionalist architecture" in this study refers to architectural styles that predate the emergence of modernism, which roughly occurred at the end of the 19th century, and exhibit the exterior characteristics of such architecture. This placeholder term signifies a temporary substitution for "traditional" due to the limitation of this study, which does not allow for a detailed architectural description of the chosen sites. This category encompasses historical styles dating back to antiquity and revivalist styles that echo the visual language of past eras.

It is important to note that the study does not categorize architecture based solely on the age or decade of construction, but rather on the visual character it manifests. For instance, the term "revivalist style" can refer to architecture built during the contemporary period that borrows from past non-modernist styles, thereby exemplifying traditionalist tendencies. Bannister Fletcher's comprehensive works on architectural history provide insight into the evolution of styles throughout the ages (Cruickshank et al., 2014), including the contemporary period. Interestingly, his Tree of Architecture does not include any Nordic styles (Figure 1).

In the Nordic region, a distinct vernacular architectural style has developed over time, exemplified by structures like stave churches. However, the region has also assimilated architectural influences from mainland Europe during certain historical periods. This is evident in the presence of historical architectural styles in Swedish cities. In contrast, the modernist architectural movement emerged in the late 19th century, driven by factors such as the industrial revolution. Modernist architecture is characterized by the utilization of materials like reinforced concrete, glass, and steel, an emphasis on functionality, and a rejection of ornamental detailing. In the context of this study, the term "modernist style" refers not to the specific time period but the visual character produced during that period. It also encompasses subsequent movements and counter-movements, such as post-modernism. Transitional styles like Art Nouveau exhibit characteristics that bridge the gap between traditionalist and modernist architecture. However, due to their elaborate ornamentation and incorporation of biomorphic forms, they lean more towards the historical style of traditionalist architecture (Figures 2 and 3).

Adolf Loos, an Austrian architect who preceded modernism, expressed his belief in the eventual divergence between modern and traditional styles (Heynen, 1999). These two styles differ in their underlying philosophies and, consequently, the architectural features of their buildings. At a cursory level, the distinction in the facades of these two styles is apparent. Traditionalist architecture often displays decorative elements, which Loos famously criticized in his famous dictum, "ornament is a crime," condemning the impracticality and superfluity of ornamentation in Secession and German Werkbund (Loos, 1908). However, this does not imply that modernist architecture, in the context of this study, completely abandons ornamentation. As will be explored later, ornamentation can also be present in modernist architecture. For instance, Art Deco, a previous style, shares many of the principles of modernism but still incorporates ornamentation.

Overall, a search query on the World Wide Web about the genealogy of 21st-century architecture that stems from modernism yields ambiguous results as to the distinct styles, unlike traditionalist architecture whose styles are already cemented in architectural history.



THE TREE OF ARCHITECTURE,
Showing the main growth or evolution of the various styles.

Figure 1.Tree of Architecture as illustrated by Sir Bannister Fletcher, English architect and architectural historian. It shows how architectural evolved into different styles throughout times as influenced by five factors. It can be noted how he used the word modern which refers to late 15th century to late 18th century Europe. (Adopted from: Banister, 1905, p.9).

Figure 2. Right: Galeasens Gränd. A plain concrete wall decorated by overhanging plant boxes. Despite not being part of the subject of analyses, this street photo during the conduct of the ocular survey provides a good example of a modernist style of ornamentation. Left: Chrysler Building with its sunburst patter and metal-clad gargoyles (Source: Wachter, 2016).

Figure 3. Casa Batlló – Barcelona. Designed by Antoni Gaudi. It is one of the most famous Art Nouveau style buildings in its Spanish version, the Catalan Modernisme. Its appearance is a stark contrast to the apartment building on its right in Neo-classical style.To differentiate the two style, one can look at the field of environmental aesthetic and contrast the two in terms of complexity and coherence ([Casa Batllò], n.d.).

2.2 Environmental aesthetics

There are two models of environmental or landscape aesthetics, the objective and subjective. As their name suggest, both differs in how they approach the subject in general. The differences between the two models can be summed in the following table.

Table 1. Summary of the differences between the two models of landscape aesthetics (Adopted from Lothian, 1999).

Model	Traits
Objectivist or physical paradigm	Landscape quality as an intrinsic physical attribute
	Assessment is through application of criteria to landscape
	Subjectivity presented as objectivity
Subjectivist or psychological paradigm	Landscape quality derived from the eyes of the beholder
	Assessment using psychophysical methods
	Objective evaluation of subjectivity

As can be seen in the summary presented in the table 1, Lothian (1999) described these two methods as a paradox due to their contrasting underlying premises. The objectivist model views landscape quality as an essential property similar to its physical features. This landscape quality can be measured in a scalar or ordinal manner, such as low, medium, or high. However, ironically, the classification of the landscape into certain criteria is conducted subjectively. On the other hand, the subjectivist model recognizes landscape quality as a product of human perception and thus, constructs that can be evoked by memories, associations, and imaginations. This model employs psychophysical methods, followed by statistical analysis, to assess a landscape. As can be seen, both existing systems cannot be truly independent of each other.

The landscape preference matrix (see Table 2) proposes that people have innate preferences for certain landscape features, such as naturalness, coherence, complexity, and legibility. These preferences are said to be influenced by evolutionary and cultural factors. However, as mentioned by van der Jagt et al., (2014), there is still ongoing debate on the explanatory attributes of this theory, particularly on the relationship between these landscape features and human preference. While a meta-analysis by Stamps (2004) was not able to support the theory's postulates, a re-assessment of the preference matrix by van der Jagt et al. (2014) yielded positive results in favor of the theory.

Table 2.The preference matrix (Adopted from Kaplan & Kaplan,1989)

Time perspective	Understanding	Exploration
immediate	Coherence	complexity
inferred	Legibility	Mystery

The theory proposed by Kaplan and Kaplan (1989) posits that humans have an inherent need to comprehend and explore their immediate and inferred environment. This evolutionary theory suggests that the human ability to assess the aesthetic qualities of the environment has developed to facilitate adaptive habitat selection. This concept can be linked to the Prospect and Refuge theory (Appleton, 1975), which suggests that humans have a preference for settings that optimize their advantages, allowing them to interact and navigate their environment while remaining protected from potential hazards. When discussing environmental aesthetics, particularly in the context of architectural design, caution should be exercised to avoid simply associating it with the *venustas* principle. In this context, aesthetics is viewed as an expression of a fundamental and underlying aspect of the human mind, representing a necessity for survival rather than mere decorative objects. The methodology is grounded in an instrumental basis, in a slightly older version of the preference matrix was presented by Stephen Kaplan in 1979 during a landscape convention in Nevada, USA (see Table 3).

Table 3. Earlier version of the preference matrix (S. Kaplan 1979)

Level of interpretation	Making sense	Involvement
The visual array	Coherence	complexity
3-dimension space	Legibility	Mystery

Both matrices essentially contain the same four variables/factors, with ‘making sense’ being equivalent to ‘understanding’ and ‘involvement’ being equivalent to ‘exploration.’ However, there are differences in the temporal perspective, where the concepts of ‘visual array’ and ‘3-dimensional space’ replace ‘immediate’ and ‘inferred.’ According to this perspective, people react to the visual environment in front of them in two ways, as specified under the level of interpretation. The visual array is likened to a photograph, and Kaplan interestingly mentions the term ‘picture plane,’ which serves as the basis for this level of interpretation or analysis. The picture plane is similar to the picture plane used in technical perspective drawing. It represents the two-dimensional surface where the observer stands while viewing the scene in front. On this surface, length and width have true dimensions, while away from it, all other dimensions decrease at a constant rate as lines marking the edges of planes vanish towards the horizon line, creating a foreshortening effect.

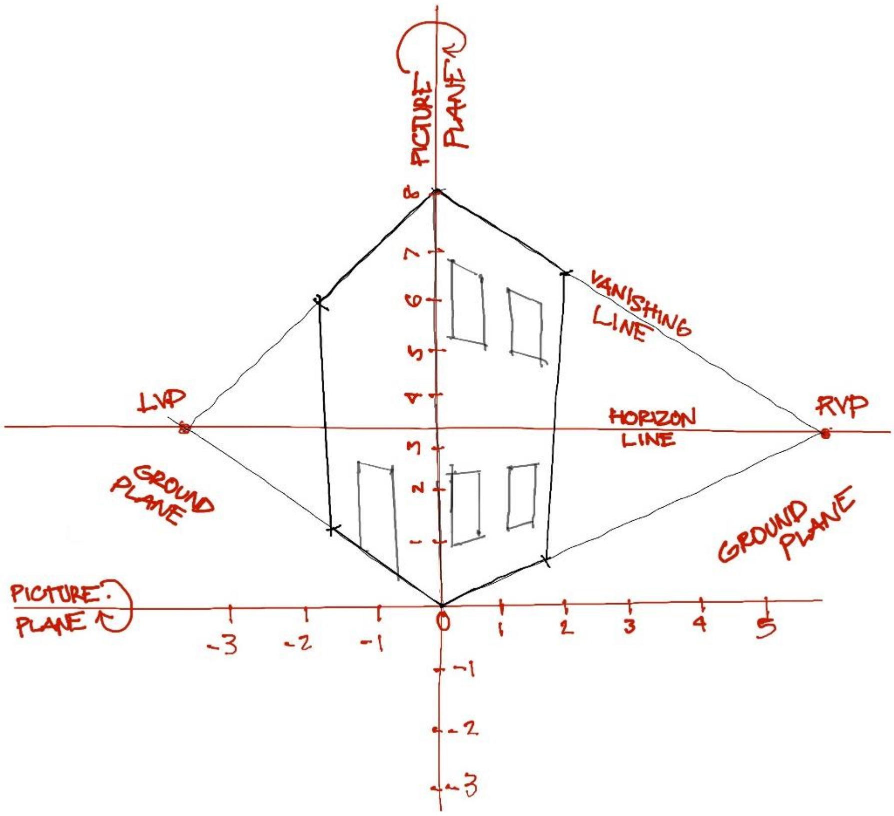


Figure 4. A basic 2-perspective drawing showing technical parts: picture plane represented by a 4-quadrant cartesian plane, ground plane, right and left vanishing point, horizon line.

Complexity is the diversity, or at the other end, the monotony of an immediate environment. One can say that a tropical jungle in the Pacific is more diverse when compared to the Mongolian steppes, while the latter is more coherent than the former. In fractal dimension terms, a line has a fractal dimension (fd) of 1.0, the Sierpinski carpet has an fd of 1.89, and a filled square has an fd of 2.0 (see figure 5).

Coherence is the comprehensibility of an environment as viewed by the observer. It talks about factors that structures a scene into an organized whole. It pertains to order and composition in landscape design terms. In mathematical terms, the environment can be seen as a discrete distribution, which can be proportioned into different factors, and thus information entropy can be quantified. The nature of coherence, in terms of the factors, entails that entropy can also be a measure of complexity

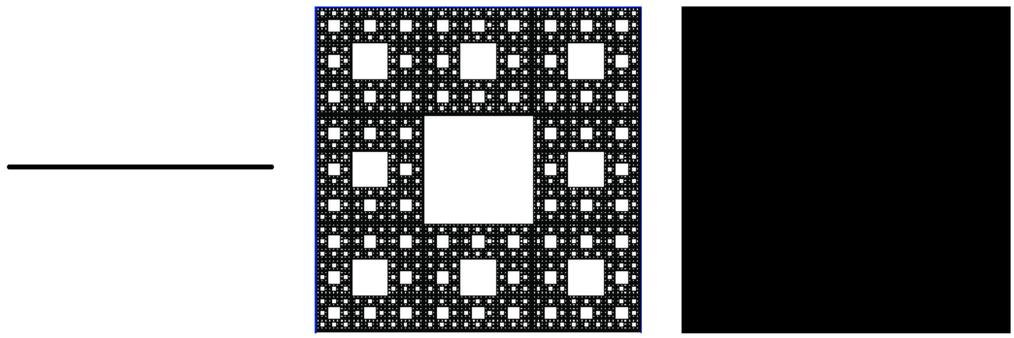


Figure 5. Right: a straight line having an fd =1.0 equal to its only existing topological dimension (length), Middle: Sierpinski Carpet with a fractal of high complexity (fd=1.89) (Source: Greig, 2010), Left: a filled-square whose fd is equal to its topological dimensions (length and width) hence 2.0.

In this study, the analysis focuses on two components of landscape qualities: the topological lines and surface types of street-level images. The topology of the street-level environment is represented by lines and geometries on its plane. The interaction between these physical elements and the depth of space creates a complex stimulus that can be measured through the calculation of the fractal dimension. Additionally, these street-level environments can be further described by analysing surface types of the facades and their distribution throughout space via information entropy thereby giving insights into the coherence and complexity of the landscape. A more thorough discussion of the tools of analysis, landscape qualities, and their components is provided in sub-chapter 2.6.

2.3 Fractals

Fractals are a mathematical concept that describes the repetition of a pattern at progressively smaller scales. Fractals can be of physical forms, but can also be spatial and temporal (imagej.nih.gov, n.d.), and according to Mandelbrot, are characterized by irregularity or roughness; non-integer dimension (fractal dimension), infinite complexity, and self-similarity. The last character is associated with the term scale invariance, wherein when magnified the fractal dimension remain the same regardless of the change in scale. Fractals can be classified as exact or statistical. Exact fractals are generated by iterating a pattern multiple times at varying scales. (Figure 6). Statistical fractals are those found in nature, and has randomness introduced to it so that no part is exactly the same with any other parts. Fractals in nature, or those illustrated in paper, or generated by a computer are not fractals in the truest sense of the word, because they are limited physically and cannot scale infinitely. True fractals are therefore theoretical abstractions.

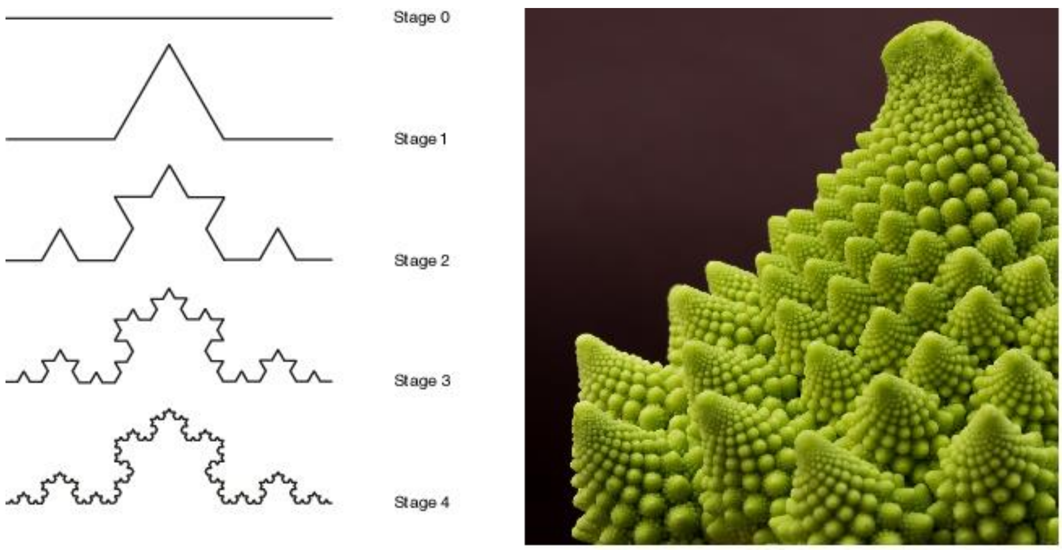


Figure 6. Right: Transformation of a straight line into a Koch curve (fd=1.26). Dividing the line by 3 equal parts and removing the middle third by two lines that has the same length as the remaining sides is the generator rule. Repeating this process over and over again creates this specific exact fractal. However, the process can only be done infinitely using the generator rules as abstract structures. Left: The spiraling meristems of the Romanesco broccoli is a statistical fractal, they look the same but not exactly the same (Source: Edney, 2020).

The concept of fractals can be traced back to four centuries ago, but it was Polish mathematician Benoit Mandelbrot who elaborated the idea in his book *Fractals: Form, Chance and Dimension* (Mandelbrot 1995). “Mathematics is be praised for having put these sets at our disposal long ago, and scolded for having discouraged us from using them" is one of his aphorisms when referring to Cantor sets, Peano curves, and Cauchy flights. In his other book *The Fractal Geometry of Nature* (1983), he mentioned how fellow mathematician Henri Lebesgue made fun of how new notions after being defined have literally no use. It had become his specific aim to establish fractal dimension in a central position in empirical sciences.

Since then after coining the term fractal and its associated fractal dimension, the study area sparked numerous interests from different fields ranging from computer science, psychology, medicine, acoustics, finance, arts and design, and many more. These included works covering biophilic architecture (Taylor 2021, Taylor et. al 2023), describing streetscape rooflines (Cooper 2003), landscape silhouettes fractal dimension as predictors of preference (Hägerhall, 2004), human brain EEG response when expose to fractals (Hägerhall, 2008) perceptual and physiological response to fractals in J. Pollocks paintings (Taylor et al., 2011), human's brain ability to comprehend fractals (Taylor et. a; 2016), investigation of fractal qualities of architecture across styles (Ostwald & Vaughan 2016), and even creating architectural finishing products based on scientific studies on fractal effects on humans (Smith et al 2020).

Majority of the studies aforementioned points towards fractal fluency. Fractal fluency is an important concept because the future applications of studies such as this in the field of architecture largely depends in this concept. The fractal fluency model asserts that humans through evolution became accustomed in processing fractal patterns found in nature and the effect of the aesthetic experience is a reduction in physiological stress level. In the context of this study, the examination of fractal dimensions is confined to its application in spatio-visual analysis. However, it is important to acknowledge that this choice is rooted in the recognition of fractals' potential to engender positive effects within the realm of design.

2.3.1 Measuring fractal dimension

Fractal analysis are techniques used to measure complex patterns that cannot described traditionalist Euclidean concepts. The main result of such analysis is an index of morphological complexity called fractal dimension. It is a ratio between the change in detail pattern and the change in scale.

One way of measuring fractal dimension is the ruler method or walker's ruler. The ruler method basically follows the famous Richardson paradox (see Figure 7). Cooper (2003) used this method to described the urban character through fractal analysis of street-level skylines in Oxford. Gonzato (1998) reviewed and suggested methodological corrections to walker's ruler, as well as to the other method that will be employed in this study, the box-counting method.

Box-counting is the most popular method in measuring fractal dimensions and has been around since the 1980's. Compared to other methods it is more stable and repeatable (Ostwald and Vaughan 2016). What does stable and repeatable means? It means that fractal analysis is just an approximation, and there is a possibility that the method losses precision and accuracy at some point owing to factors such as quality of analysis materials and the whole analysis set-up in general. Take for example the calibration suggested in Chapter 3, where two exact fractals images were subjected to a test run of the experimental setting. The resulting fd are near but not equal to their theoretical fractal dimensions. The differences can be attributed to the image quality and the physical limit of the device's screen resolution.

Figure 7. The Richardson Paradox was named after Lewis Fry Richardson who observed that the approximated length of Britain's coast would vary depending on the ruler used, resulting into a land mass of finite area but infinite parameter (Adapted from Van de Sande, 2006).

Figure 8. Box-counting. Left: Object, Middle: Object superimposed with grid size 1, Right: Object superimposed with grid size 2

To illustrate box counting, given an object of interest (Figure 8), a grid having Grid Size 1 is superimposed over the object. The boxes that contains “detail/s” of the object behind it are shaded and counted. The previous step is repeated using Grid Size 2, a scaled down size of Grid Size 1. There are several scaling methods such as using a power series (2^2,2^4,2^6….) and in this case a scaled series of ½ where the preceding box sizes are multiplied by ½.

Given that:
N_{S1}= the number of boxes having details of the object at grid size 1 =42
N_{S2}=the number of boxes having details of the object at grid size 2=90
1/s1= the number of boxes in grid size 1 at the base of the grid=8
1/s2= the number of boxes in grid size 2 at the base of the grid=16
D_b= box-counting fractal dimension

$$D_b = \frac{[\log(N_{s2}) - \log(N_{s1})]}{[\log(1/s2) - \log(1/s1)]}$$

D_b= [log 90-log42]/ [log 16-log8]

Given the values and formula above, if one would perform the calculation D_b should be equal to 1.1. This D_b=1.1 is a comparison of grid size 1 and grid size 2 only. The process has to be reiterated sufficiently to get a good result. Thus, the next step would be grid size 2 versus grid size size 3 (grid size 3= grid size 2 multiplied by ½, using our scaled series scaling of ½), followed by grid size 3 versus grid size 4. The final D_b is the mean of each comparisons. Notice how the D_b formula which is the change in detail over the change in scale is the same as the slope formula.

$$m = \frac{\textbf{rise}}{\textbf{run}} = \frac{y_2 - y_1}{x_2 - x_1}$$

Essentially, they are the same, the fractal dimension D_b is the slope of the count versus scale graph. According to Ostwald and Vaughan (2016), at least 10 or more reiterations are needed to get achieve an error rate of -+1% at most. This can be done manually with great tediousness but technology has given rise to fractal analysis software such as FracLac.

FracLac is the main software tool that was used in this study. It is a software develop in Australia that was originally intended for major scientific disciplines like medicine. biology, and chemistry but has been noticed by design related disciplines. The software is a type of plug-in for ImageJ and Fiji image processing software.

There are several software options available, especially in the open-source market, that are capable of conducting fractal analysis. However, FracLac stands out due to its notable advantages, including flexibility, strong community support, and a comprehensive range of analytical tools specifically designed for fractal analysis, such as the box-counting method.

2.4 Entropy

S. Kaplan (1979) stated that making sense (understanding) and involvement (exploration) are necessary for the survival of information-based organisms. Considering discussions in evolutionary science, this makes sense, that humans developed from it. In this study the word *entropy* is the abbreviated form of *Shannon's information entropy*. Although it originated from mathematically quantifying lost information in telecommunications, the concept is broader as it generally applies when trying to solve unknown quantities in a probability distribution, a mathematical description for a random phenomenon of which the simplest example one can cite is the event of tossing a coin and the possible outcomes of getting a head or a tail. In *A Mathematical Theory of Communication* (Shannon & Weaver 1965) is taken as broad concept that encompasses any procedure in which one mind causes effect on another whether it be oral or written speech, performing arts like music, visual arts, to mechanics and the like.

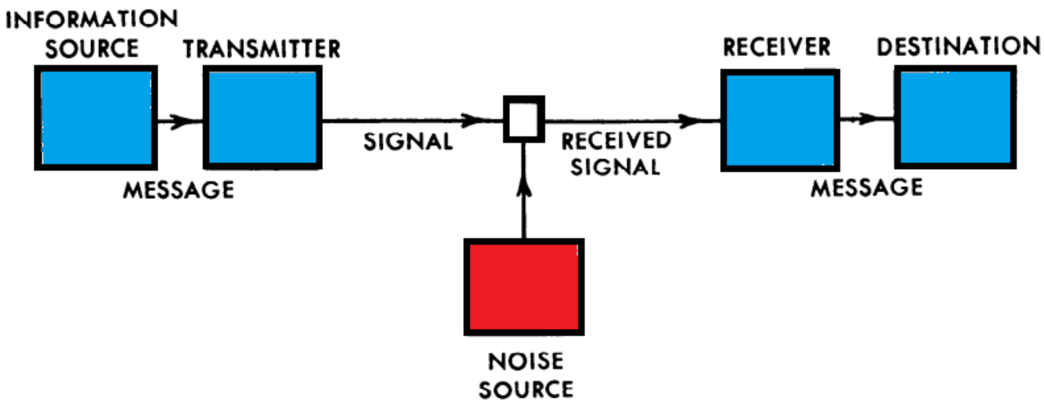


Figure 9. The convey of information in a communication system by Shannon & Weaver. The conveyance of information in any field of disciplines, can be represented by this generic model (Adopted from Shannon & Weaver, 1964, p.7).

When the model in Figure 9 is applied to this study, the translation goes this way: the information source is the environment (street-level environment), the message is the surface type (later the result of parsing or coding) which are visual signals, the transmitter is the plane and geometry (later in the methodology section the mapped areas), the noise are anything that hinders clear reception of the signal conveying the message (it could be many things such as lighting, other urban objects, and occlusions), the distance between the transmitter and the receiver is the channel (physical space), the receiver and destination as a whole is the observing person in which the eyes is the receiver and the brain is the destination.

2.4.1 Measuring entropy

As the name suggest, information entropy is the measure of information, as well as surprise and uncertainty. It is given by the equation below entropy H is the summation of the probability density p_i multiplied by the logarithm of p_i at base 2 across all levels of a factor. The symbol "I" denotes a specific level of the factor and the negative -1 is multiplied as a constant since the initial result of the summation is in negative and in a closed system (in the context of this study it is the space of a defined area that is being measure).

$$H_{factor} = -1 \left(\sum_{i=1}^{nlevels} p_i \log_2 p_i \right)$$

Take for example the classic example of a 2-sided coin. Given that it is a fair or balance coin, the probability of getting a head is ½ and the probability of getting a tail is also ½.

Substituting the probability value of possible outcomes head and tail to the equation above results into:

H_{head}= -1 (1/2*$\log_2$1/2) = -1(1/2* (-1)) = 1/2
H_{tail}= -1 (1/2*$\log_2$1/2) = -1(1/2* (-1)) = 1/2
H_{total}= $1/2_{head}$+$1/2_{tail}$= 1.

Therefore, the entropy of this coin is 1 Shannon bit of information. The total entropy is just the sum of the entropy of each individual level.

Now, consider that head side of this coin is a little heavier and has a probability of p=0.55, this makes the probability of the lighter tail side p=0.45. Substituting these probabilities to the equation will yield to:

Hhead= -1 (0.55*$\log_2$0.55) = -1(0.55* (-0.862)) = 0.474
Htail= -1 (0.45*$\log_2$0.45) = -1(0.45* (-1.15)) = 0.518
Htotal= 0.474_{head}+0.518_{tail}= 0.992 Shannon bit.

When there is uniformity in the probability of an event, such as in the case of a fair coin, the level of uncertainty, surprisal, and entropy reaches its maximum. In contrast, when dealing with an unbalanced coin, the level of uncertainty and surprisal is lower since the outcome becomes more predictable. Stamps (2004 & 2014) have provided various approaches to calculating entropy in architectural objects. One of the studies they referenced was conducted by Krampen (1979), which involved overlaying grids onto orthogonal drawings, such as elevations and floor plans. Each grid cells are then visually inspected for the type of details they contain such as door, wall, or a window and so on. These details are factor levels that resulted from the parsing or coding. This will be discussed in the next pages.

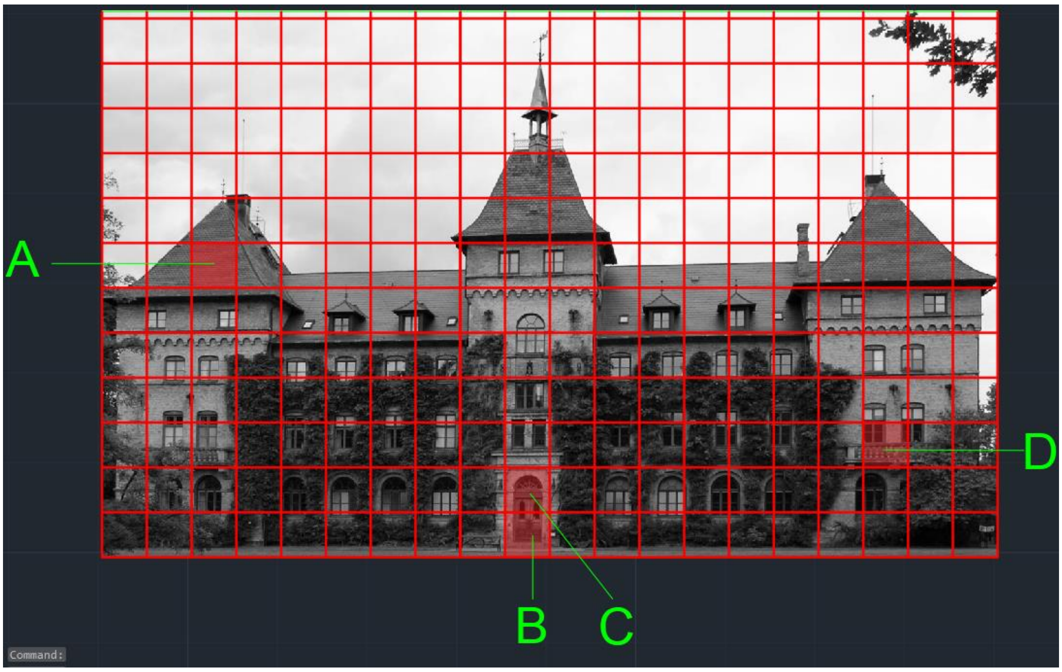


Figure 10. Originally Krampen's subject for this method are orthogonal drawings but this frontal picture is nonetheless illustrative of the method. The grids with details and type of details are counted. Take for example Grid labelled A, it contains a roof does Roof level scores=1. B and C contains door details so Door level scores=2. This will be done until all grids are covered. Grid D presents a dilemma for the method. Grid D contains a significant portion of Window level and Balcony level. Which level should be more dominant?

The dilemma encountered in Grid D (see Figure 10) regarding Krampen's method was examined and discussed by Stamps (2003). Stamps conducted an experiment to investigate the impact of grid sizes on the entropy of an image, and the results revealed a negative correlation. Based on these findings, Stamps concluded that a grid-based method is not without consequences. As an alternative, Stamps demonstrated another approach involving coding based on a parsing rule and recording the frequencies of each level. This method shares similarities with Krampen's approach, but eliminates the risks associated with using grids (see Figure 11).

Figure 11. In Stamps method an image will be coded according to the the factor windows with levels ABC (A=square-headed, B=arcuated, C=dormer). Each levels frequency will then be counted. In this case C=4. This method however, only takes frequency but does not account physical space occupied by elements in a given environment. Thus, one small circular window, does not differ from one enormous rectangular window.

Overall, the majority of studies covered by these authors on the topic of measuring entropy in the built environment utilize orthogonal views. However, this study focuses on street-level view images that show a man's eye perspective, which closely represents the human view in this environment. Unlike orthogonal views, street-level views introduce a sense of obliqueness or skewness to the observation of architectural elements.

In street-level views, the width of the streets creates an environment where an observer can observe architectural elements on both sides of the street simultaneously. This unique viewing angle adds complexity to the measurement of entropy in such scenarios. Traditionalist methods proposed by authors like Krampen and Stamps, which rely on grid-based analysis or designed stimuli, may not be directly applicable in this context.

2.5 Measuring complexity and coherence

The choice between traditionalist and modernist can be answered by the preference matrix. In the writings of S. Kaplan and R. Kaplan (1989), perception and preference are inextricably linked. Perception plays a crucial role in determining human preference, as it directly influences and shapes individual preferences. The evaluation of preference enables an investigation into the perceptual process. The empirical researches that were performed by the Kaplans led to the formulation of the preference matrix which was discussed previously.

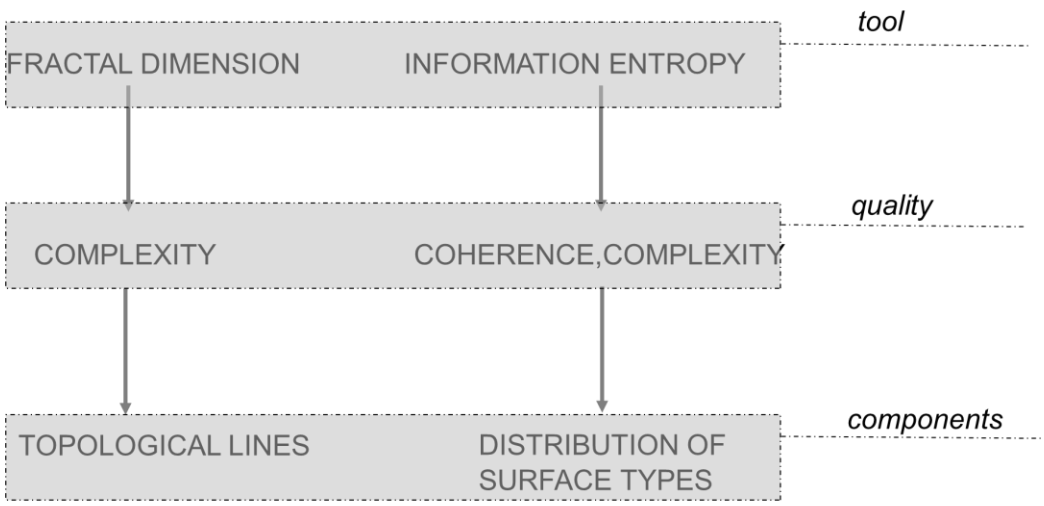


Figure 12. Landscape qualities, components, and tools for measuring.

If coherence and complexity are considered as defining qualities of the landscape, it follows that these qualities must be evident in certain ways, manners, or forms. Kaplan noted that these qualities subsumes a variety of different components (Kaplan, 1979). Consequently, if we can observe these qualities by looking at its components, it becomes possible to measure and quantify them. Inductively, through measurement, a deeper understanding of the inherent distinctions between traditionalist and modernist architecture can be gained. It is important to note that this reasoning is not limited to architecture alone but can be applied more broadly to the landscape as a whole.

This paper argues that in the context of building facades, which serve as key elements in urban streetscapes, the most prominent features are the topological lines and surface types they exhibit. When viewed at street level, topological lines are the lines that form the edges or boundaries of geometric planes on building facades, which appear to converge as the planes recede into the distance. Lines are fundamental components of objects and play a crucial role in how they are perceived. This observation holds true across different cultures and time periods, as depicted in Figure 13. Notably, regardless of the specific era, people tend to represent objects in a similar manner, relying on lines for definition.

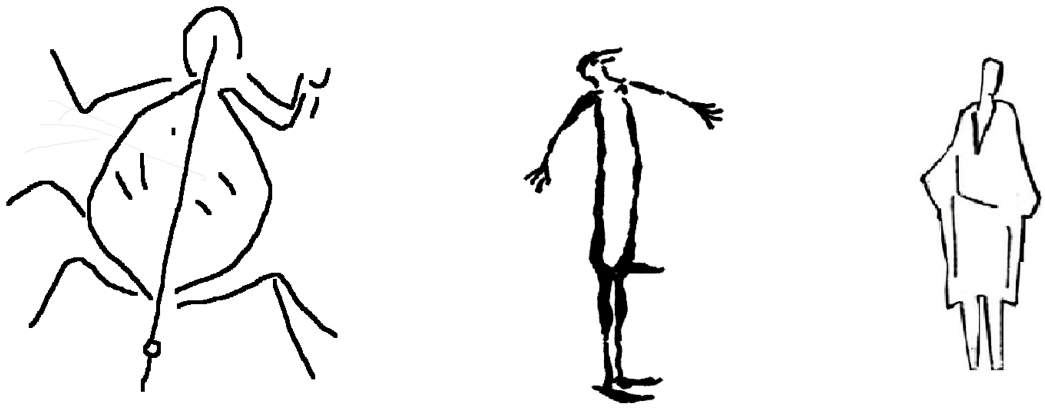


Figure 13. Human figures representation. Left: Stylized outline of 10000-year-old rock petroglyphs made by Austronesians in Angono rock formation, Philippines. Middle: One of the humanoid drawings in Lascaux cave, France dating to about 17000 years ago. Right: Human figure drawn by Walter Gropius, circa early 1900's.

The composition of topological lines in space presents itself as a pattern that cannot be simply described by traditionalist Euclidean geometry. For example, consider a street-level image of a city street in Appendix 7 and 8. When viewed through an orthographic projection, these shapes are essentially squares, rectangles, parallelograms, arches, circles, and such. However, in three-dimensional space, foreshortening occurs, and the conglomeration of different building and structures in the street environment in what the S. Kaplan (1979) called the visual array creates roughness, irregularity, and complexity. Describing this complexity using simple Euclidean terminologies becomes challenging. This is where the concept of using fractal concepts becomes relevant. Fractal dimension, a number used to describe the complexity of a pattern, can be employed to describe the complexity of the topological lines.

Another dominant and conspicuous component of building facade is surface types. While lines define the edges of a plane, surface types serve as identifiers of the planes representing the facade. In this study, they are generally considered as observable building parts at the surface level. Consider Figure 14 as a visual reference. What are the dominant facade components or elements present in all the buildings on both sides of the street? Arguably, several visual elements, such as color and texture, could be considered alongside surface types. While these elements have their own merits and should also be investigated, it is the surface types that are most perceptible. This is because solid planes or surfaces act as backdrops for color and texture to manifest. These elements, among others, are not standalone and require a ‘canvas’. On the other hand, surface types occupy space in the landscape. Specifically, architectural objects occupy volume, which influences how humans interact with each other and the immediate environment.

Figure 14. Carl Krooks Gata, Helsingborg.

A decision regarding which component to examine is a prerequisite when appraising the environment. Therefore, a category or classification must be established (Kaplan & Kaplan, 1989). Consequently, the decision to focus on topological lines and surfaces, as well as their level of detail in subsequent chapters, greatly depends on the purpose and rationale of the appraisal. This is the reason why, despite the existence of multiple components in the landscape capable of expressing its qualities, all of them are overshadowed by this choice.

Categorization or parsing aptly fits with the analytical process of information entropy. Extensive works by Stamps and others (Stamps, 2003, 2004, 2014) utilized entropy as a measure of complexity in the environment, associating different types of responses (i.e., arousal, pleasure) with different stimuli in the environment. In this study, both topological lines and surface types are considered as 'information.' As mentioned by the Kaplans (1989), the preference matrix expresses humans' informational needs, building on the pretext that humans are information-based organisms (S. Kaplan, 1973). Surface types, in particular, convey what is seen and what occupies space. Mathematically, since surface types are transcribed as information and expressed as a discrete or finite distribution, Shannon's entropy can be applied to describe the environment's complexity and coherence. In lexicography, coherence and complexity are not strictly opposite concepts but can be seen as contrasting qualities in certain contexts. Considering information entropy and the preference matrix, coherence can be seen as a means of reducing complexity by imposing structure and order, potentially resulting in lower entropy. Kaplan noted that an environment can be both coherent and complex simultaneously.

2.6 Alternative approach for street level views

An alternative approach to previous methods in both fractal and entropy analysis can be considered for the purpose of this study. One possibility is to leverage the high-resolution images of street-level views and extract specific features of interest based on pre-determined parsing rules. By mapping these features within the image according to the parsing rules, it becomes possible to quantify their prevalence, distribution, and entropy.

Parsing rules play a significant role in any method as they are essential for expressing one form into another. For instance, Krampen's (1979) parsing of building surfaces, as mentioned by Stamps (2004), includes walls, windows, decoration, roof, balcony, display window, door, advertising (signages), and sky. Communication problems, as described by Shannon and Weaver (1968), include the semantic problem, which is associated with parsing. The semantic problem arises from the difference between the interpreted meaning by the receiver and the intended meaning by the sender. For example, in Krampen's parsing, an advertising window may not be distinguished from any other window by another observer. The entropy value depends greatly on how things are parsed. Stamps (2004) advises keeping parsing simple, as simpler parsing has a higher likelihood of being correct. However, this study emphasizes the need for caution to avoid excessive simplification.

In the case of fractal analysis, mapping rules control which features will be represented as lines to be subjected to the software tool. Previous works by Ostwald and Vaughan (2016) and mathematician Carl Bovill (1996) utilized fractal analysis primarily for buildings' formal compositions. Typically, the data source for such analysis includes orthographic projections like floor plans, site layouts, elevations, sections, and similar representations. Bovill was among the first to examine perspective views, particularly in the design of houses by American architect Frank Lloyd Wright. However, due to the complex scenes present in street-level environments, which require tedious image processing to extract unwanted components, examinations of this type of environment are rarely conducted. Cooper (2003), for instance, only analyzed the skyline features of a street.

A careful examination of the collected images and observations from the ocular survey should be carried out. Based on these observations, streets that meet the established criteria will be selected as the prospective locations for the analysis. Given that the aim of the study is to compare two architectural styles, the building facades' surfaces, which are the most prominently visible aspects of street-level architecture, will be divided into levels for analysis (refer to Table 4). The first stage of the method involves mapping according to the parsing rules, all of which are described in detail in the methodology section for reference.

Table 4. Factor and levels for mapping and entropy analysis.

Factor	Levels
Building façade surface	Window, door, roof, plain wall, articulated wall, curtain wall, ornament, bay, balcony.

3. Method

Subchapters 3.1 to 3.2 in this study serve as a manual within the instructional materials. These sections provide guidance on identifying and addressing potential issues or challenges that may arise during the execution of the proposed methodology. They offer insights and recommendations to overcome obstacles, ensuring a smoother implementation of the method. A reflection on this method is provided in the discussion chapter of this study.

3.1 Important notes that influenced the methods

The methodology presented in this chapter can be broadly divided into two main sections. The first part focuses on the parsing and mapping process, while the second part delves into the fractal and entropy analysis. This section specifically addresses the former aspect, which involves the parsing and mapping of features. In this study, it is recommended to utilize computer-aided drafting software (CAD) for processing the images intended for analysis. However, it is also mentioned that alternative software tools like Photoshop, Gimp, and similar applications can be used for mapping features. It is important to note that while these alternative tools can be employed for feature mapping, they lack the flexibility provided by CAD software during the initial stages of the methodology. CAD software offers greater flexibility and capabilities for effectively conducting the first part of the methodology.

Lines play a crucial role in both analyses as they represent the shapes, edges, and details of building façade surfaces. These lines can be easily drawn in CAD software through tracing. Line detection functions can also be executed using tools like Photoshop, Gimp, Fiji/ImageJ, and MatLab. However, it is important to note that the complexity of street environment images may require both pre-processing and post-processing for line detection, which can vary from image to image. Unfortunately, the quality of the results obtained from these processes may be considered unusable for the analysis (refer to Figure 15 & 16). Edge detection algorithms have limitations in detecting changes in pixel intensity, which are highly dependent on the actual conditions in which the image was captured (refer to Appendix 6).

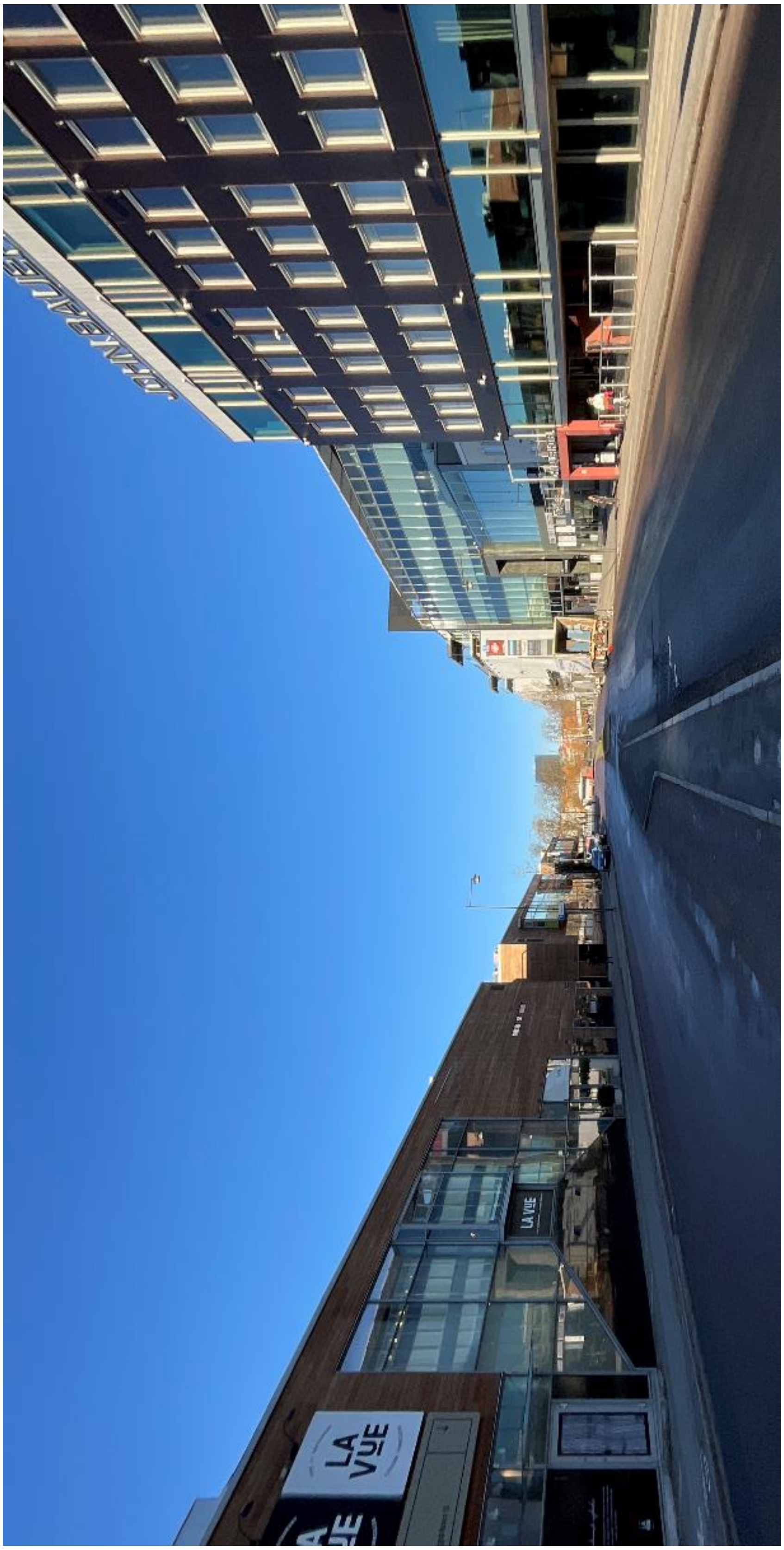


Figure 15. Reference photo for Figure 16. Södra Strandgatan, Jönköping taken at center position.

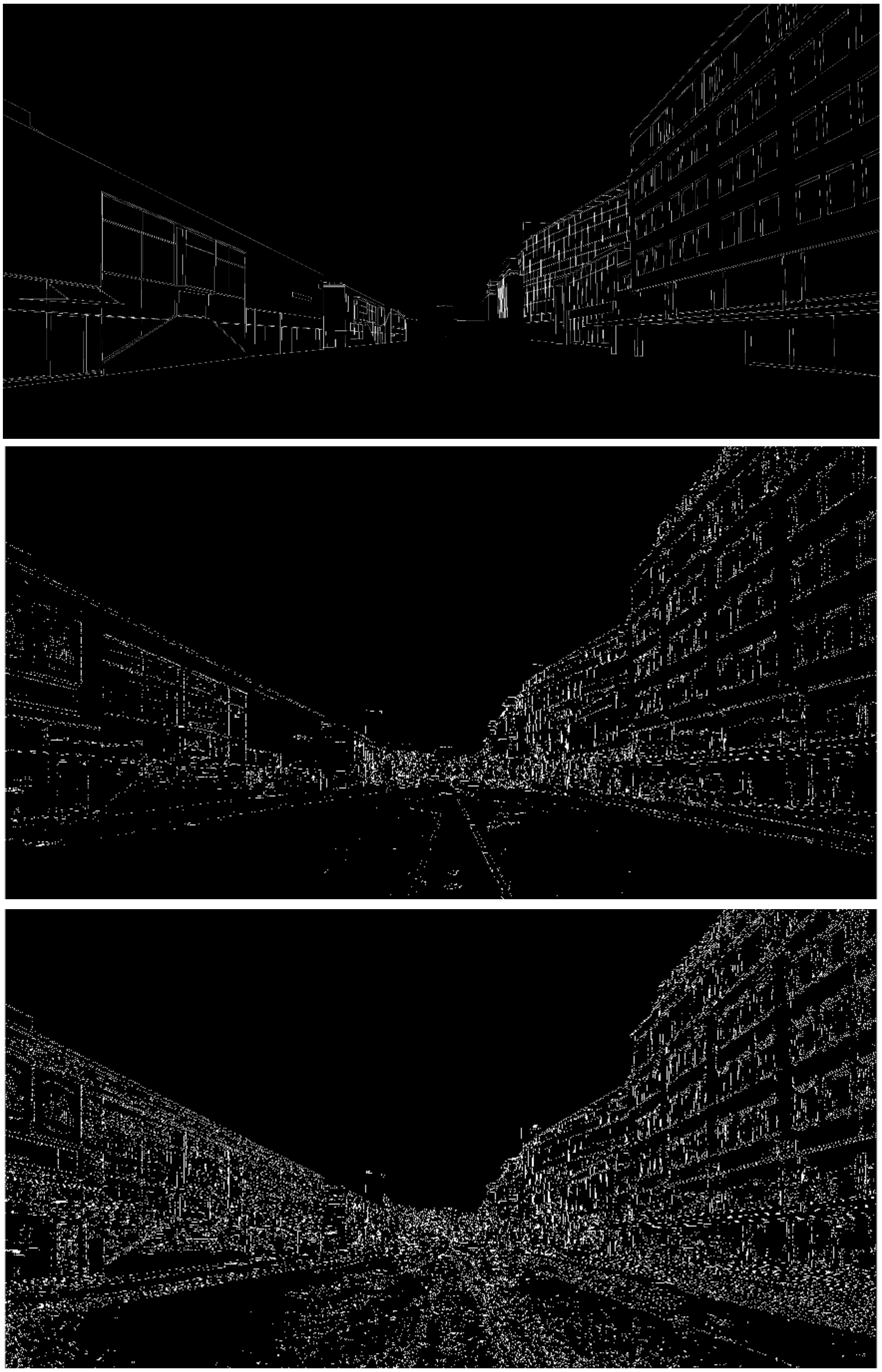


Figure 16. Top: Line tracing in AutoCAD, the lines may appear broken due to size adjustment for this page. The Fractal analysis utilizes the full 4032x3024 pixel with lines 1-pixel wide lines. Middle: Sobel Filter in MatLab, Bottom: Canny Filter in MatLab

3.2 Mapping and Parsing Rules

Prior to the actual mapping of features and line tracing, rules were established for mapping and parsing. These rules were crucial in effectively mapping the regions of interest in the image. They provided precision and consistency in mapping the different levels of factors present in the selected images (refer to Tables 4 and 5). The rules addressed the question of what should be mapped. As discussed in the previous chapter, parsing plays a significant role in computing the information entropy of visual images. In this study, it was decided to focus on a single factor, namely building surface features, which was further divided into nine different levels as described below. These rules and criteria were developed based on a preliminary evaluation of the actual characteristics observed in the street-level images collected during the data collection process. Approximately 75 photos were captured from 25 sites across 4 cities, but only a total of twelve streets met the criteria and were suitable for processing using the methodology employed in this study.

3.2.1 Building surface features

The classification of surfaces enumerated in here served as the guide for the whole mapping process.

Plain Wall

In the work of Krampen (1979), as mentioned by Stamps (2004), the concept of a wall was utilized to represent the primary opaque, solid, vertical element of a building. However, upon evaluation of the collected images, this paper contends that categorizing all walls simply as "wall" would be an oversimplification. Despite Stamps' (2003 & 2004) argument that a simpler parsing approach may be more convenient and accurate, this study maintains that labelling plain walls with a single category fails to capture their nuances. Therefore, in this study, a plain wall is characterized as encompassing a range of walls, from those with a smooth paint finish to subtly textured walls.

Articulated Wall

An articulated wall, in contrast to a plain wall, is characterized by linear jointing and indentation that creates planar divisions. It is important to note that the jointing or indentation does not necessarily have to be tactile; rather, it refers to the visual appearance of the surface being divided into distinct parts. In this study, a wall can be classified as an articulated wall if it exhibits such characteristics. Furthermore, besides walls, other elements such as windows and doors can be parsed into levels based on their fenestrations. However, to maintain simplicity, a decision was made to focus on a single factor for parsing. This approach does not complicate the mathematical calculations, as the total entropy is obtained by summing the entropy of all the factors. However, it does introduce challenges in decision-making during the parsing process. The complexity of decision-making in parsing is exemplified by the construct of the curtain wall.

Curtain Wall

During the evaluation of images and site visits, certain levels of factors present a conundrum, and the curtain wall is a prime example. Architecturally, curtain walls refer to lightweight, self-supporting walling materials that attach to the main structure of a building. They encompass a wide range of materials, including metal and stone claddings, glass systems, screens, and vents. In the context of this study, the focus is on non-opaque curtain walls. The complexity arises from the contradictory nature of the curtain wall. It can be viewed both as a fenestration, representing windows, doors, or any other openings that provide vision and ventilation, and as a wall, which constitutes the main surface envelope of a building. While predominantly associated with modernist architecture, curtain walls can also be found in traditional architecture, such as full-storey display windows or exterior wide screens and louvers. Regardless of the architectural style, curtain walls are highly noticeable features in building facades.

Windows

The term "windows" in the context of building fenestrations encompasses various types, including glazed windows, screened windows, louvered windows, or simply open portals. This level focuses on the voids or openings carved into the building envelope, allowing light, air, and visual connection between the interior and exterior spaces.

Doors

Similar to windows, doors are also considered as building fenestrations, although their primary function is to serve as entrances and exits of a building. This level specifically includes entrance doors, exit doors, and portals that provide access to different parts of the building.

Balconies

Balconies are horizontal projections located at building faces and are characterized by floor ledges. They are typically supported by cantilevers or corbels and are partially enclosed by railings or balusters at waist height. In this study, rooftop terraces are also considered as balconies. Balconies are observed to be one of the most recurring elements in streetscapes, adding architectural interest and providing outdoor spaces for building occupants.

Bay

Bays are architectural features that resemble balconies in their projection from the building face, but they differ in that they are fully enclosed with walls and windows. Bays often create a distinctive architectural element, adding depth and visual interest to the building facade. They provide additional interior space and allow for panoramic views from the enclosed area. Bays can be found in various architectural styles and are known for their aesthetic appeal and functional benefits.

Roof

Roofs in this context encompass their traditional architectural definition, including gables and hips that are prominently observed in traditional areas. However, it should be noted that the definition of roofs in this study also extends to include other architectural elements such as canopies and sheds. Canopies and sheds are architectural features that provide shelter or cover over entrances, walkways, or outdoor spaces. In modernist architectural contexts, canopies are more commonly observed compared to traditional gables and hips. The study acknowledges the significance of these roof-related elements in contributing to the overall architectural composition and visual impact of the building facades.

Ornament

Ornamentation refers to the decorative elements found on building surfaces, encompassing various embellishments such as mouldings, reliefs, carvings, and other decorative features. These ornamental details add aesthetic appeal and visual interest to the building facade. While ornamentation is more commonly associated with traditional or historical architectural styles, it is worth noting that some modernist buildings may incorporate decorative elements, albeit less frequently. The presence or absence of ornamentation can significantly influence the overall visual impact and character of the building facade.

3.2.2 Supersession and delimitation of levels and juxtaposition of styles

The problem of supersession arises when two factors coexist within the same spatial area, making it challenging to code or represent them simultaneously without one factor overshadowing or superseding the other. This issue emphasizes the importance of defining factors and their respective levels in a way that ensures their independence and avoids overlapping or conflicting interpretations. When multiple factors are present in a given space, careful consideration is needed to accurately represent each factor without compromising their individual significance. Figure 17 serves as an illustration of this challenge and highlights the potential conflicts that can arise when attempting to code multiple factors within a shared spatial context.

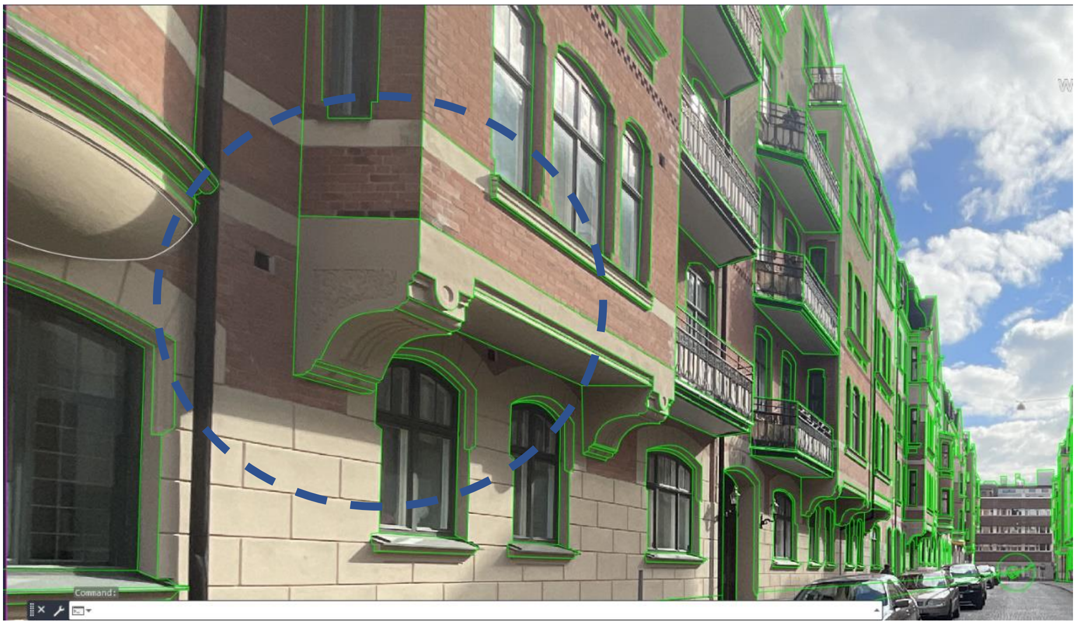


Figure 17. Magnus Stenbocksgatan, Lund. Streets highly charazterized by 3-storey high bays projecting from the façade unto the street. Blue circle highlights an ornamented corbel part of the bay which also depicts ornamental detailing.

In most cases, ornamentation takes precedence over any level it is associated with. However, there are instances where the decision of supersession requires careful consideration, such as when determining whether to code the corbel support of a bay as part of the bay itself or as an ornament. The corbel support serves both a functional purpose and adds decorative value to the bay.

When coding bays with more than one storey, like the example shown in Figure 18 on Magnus Stenbocksgatan in Lund, the areas coded as bays were limited to one storey. The extent of the coded region and the distance of the street building elements that can be traced depend heavily on the depth of field, where elements are still visually distinguishable or clear.

Furthermore, the mappable region of an image may end where it is juxtaposed by a building of the opposite architectural style. The research design requires a consistent architectural style on both sides of the street. However, there were two instances where, due to a limited number of processable sites, a workaround was implemented regarding the juxtaposition of an opposite style. This will be further discussed in the Results chapter.

Figure 18. A coded or mapped Magnus Stenbocksgatan, Lund. Inside the square outline. The bay in solid yellow-orange hatch supersedes the articulated wall level (unhatched). In turn windows (cyan), and ornament (green) supersedes bay.

3.2.3 Occlusions

In image analysis, occlusion pertains to the visual obstruction of objects or details in an image caused by other objects in the foreground. The presence of occlusions may result in challenges in tracing and mapping and can potentially impact the accuracy of entropy and fractal dimension calculations, especially when the occlusions are not part of the region of interest. Examples of occlusions include people, moving objects, parked vehicles, light poles, and signage, among others. When the obstructed detail is distinguishable, the inferred lines and details can still be mapped. However, occlusions primarily occur at ground level, making detail inference challenging. Consequently, details are typically terminated based on the outline or contour of the occlusions. Thus, in the selection of processable images, it is advisable to choose those with the least number of occluding objects. There are also occlusions that are part of the region of interest such as the situation in Figure 19.

Figure 19. A coded or mapped Lilla Varvsgatan, Malmö. Railings of the balcony (solid hatch red) partially occludes details of windows and door. Regardless of any level of transparency, the occluding details that is part of the ROI supersedes the details behind it. Overlapping in the mapping will result in the total probability (P) in the entropy calculation to exceed the value of 1.

3.2.4 Hierarchy of lines

The same principles and rules mentioned earlier were applied to line tracing. Lines play a crucial role in both fractal analysis and entropy analysis, as they capture the planar and geometric qualities of the image. In fractal analysis, lines are particularly important as they serve as the basis for determining the fractal dimensions. In entropy analysis, the focus is on the perimeter lines that bound specific levels and the overall foreground area (ROI), which are used to calculate the entropy.

However, not all lines can be successfully traced, especially those that are obscured or not sufficiently sharp in the image. Additionally, certain elements, such as organic forms and intricate ornaments, cannot be accurately represented through line tracing since require more detailed representations (as shown in Figure 20) and most often they have different scaling rules in terms of fractal dimensions. Given the scope of the study, which primarily focuses on the formal and linear composition of architectural parts, only the outlines of the spaces occupied by these elements were traced and considered in the analysis.

Figure 20. Face of a building along Östergatan, Malmö. This building is one of the most lavishly decorated building covered with organic forms found in different parts of the façade such as the Corinthian capital, human-relief keystone, and entablature. Organic forms such as these were not traced.

Certain types of lines, such as grooves in walls or jointing lines in rustication details, were not included in the line tracing process as they are considered textural in nature. This decision was particularly relevant in the case of traditional architectural styles, as including these lines would have significantly increased the number of lines and pixels associated with that style. Similarly, window glazing details like mullions and muntins were generally excluded from the analysis, except for cases where wide curtain walls in modernist style buildings required detailed representation. By focusing on the main outlines and structural lines, the analysis prioritizes the fundamental geometric features of the building facades, allowing for a more streamlined and manageable dataset for further analysis.

3.3 Data Collection

The street-level photographs used for entropy and fractal analysis in this study were captured from the perspective of an observer. These photographs were obtained from twelve different locations situated in four cities: Lund, Malmö, Helsingborg, and Jönköping. The selection of street locations was based on specific criteria. The chosen streets had to exhibit a continuous stretch of either traditionalist buildings or modernist architecture, without a mix of both styles. Alternatively, the streets needed to have a significant length where only one architectural style was present on both sides. This criterion was essential to ensure the comparability of architectural styles in the analysis.

Before conducting the actual data collection on-site, ocular surveys were conducted using tools such as Google Earth and street views. These surveys helped identify potential areas that met the predetermined criteria for the study. The data collection process itself took place during daylight hours to ensure optimal natural lighting conditions and visibility for capturing the photographs.

Table 5. Twelve selected streets depicting a similar style; 6 for modernist and 6 for traditionalist. Street attributes such as length, use, number of stories differ.

Locations	Style Depicted
Norra Storgatan, Helsingborg	Traditionalist
Möllegränden, Helsingborg	Traditionalist
Carl Krooks Gata, Helsingborg	Modernist
Lilla Varvsgatan, Malmö	Modernist
Östergatan , Malmö	Traditionalist
Adelgatan, Malmö	Traditionalist
Nordenskiöldsgatan, Malmö	Modernist
Magnus Stenbocksgatan, Lund	Traditionalist
Nils Bjelkegatan, Lund	Traditionalist
Sockerkokaregatan, Lund	Modernist
Södra Strandgatan, Jönköping	Modernist
Fiskargränd, Jönköping	Modernist

For this study, a digital camera with a resolution of 4032x3024 pixels was used to capture the images. The camera's settings were kept at their default configuration, which included an ISO sensitivity of 20, a focal length of 14mm, an aperture of 2.4, and an exposure time of 1/898s.

During the data collection process, three photos were taken at each site. One photo was captured from the middle of the left sidewalk, another from the center of the street, and a third from the right sidewalk. All photos were taken in a straight-facing direction, and the camera was positioned at eye level height relative to the photographer. In architectural perspective drawing, the term man’s eye height is universally understood at 1.6 meter taken from a global average. The camera lens height in the data collection is approximated to be at that level. The resulting images depicted specific sections of the streets and were captured in landscape orientation. Before proceeding with the analysis, minor adjustments were made to the images using photo-editing software to enhance the contrast and ensure optimal visual quality for further processing.

3.4 Line Tracing and Mapping

The primary processing of images for entropy and fractal analysis in this study was conducted using AutoCAD 2022 model space. The images were imported into AutoCAD with a 1:1 scaling, ensuring that the original 4032x3024 pixel dimensions were maintained. The images were transformed into entities within the model space, preserving their size relative to the model space scaling units.

To maintain the aspect ratio of 4:3, the images were scaled down to 72 units from the original pixel dimensions. This scaling down process did not affect the pixel size, as the DWG-JPEG conversion utilized a plot scale of 4032x3024 pixels. The purpose of scaling down the images was to reduce the computational demands on the system, particularly during the entropy analysis that involved solid hatching and when working with larger model space dimensions.

By scaling down the images, the resulting dimensions in the model space were 56x42 units, while still preserving the original pixel size and aspect ratio. This approach helped optimize the processing of the images and improve computational efficiency.

The following sequence outlines the details of the image processing phase, elucidating the specific steps involved. The line tracing and mapping parts in these procedures follow the mapping and parsing rules stipulated earlier.

1. The images' contrast was adjusted using GIMP software selectively, focusing on images with perceived poor picture quality. All images were then converted to PNG format since it is more stable as an imported object in CAD software.
2. The images were processed one at a time. These are imported to AutoCAD using the following sequence:
    - Open the image in MsPaint and press Ctrl+A to select all, then press Ctrl+C to copy.
    - In AutoCAD, activate the Pastespec command. A prompt window will appear. Select "Paste as Image entity" and click Ok.
    - Click anywhere in the model space to select the insertion point.
    - Enter a scale factor of 56 and a rotation angle of 0 degrees.
    - Create the perimeter outline of the image. Activate the dimension command (Dli) and click anywhere. This will trigger Defpoints to appear.
    - Apply Defpoints to the outline of the image to remove lineweight, as FracLac should not count the pixels associated with the outline during plotting from DWG-JPEG.
3. Trace reference lines in the image to determine a vanishing point. Theoretically, there are three vanishing points for all lines following the

three main axes (x, y, z), but in the actual environment, several factors such as design, elevation, building layout, street layout, etc., create multiple vanishing points greater than three. The most important vanishing points are those located in the area where the camera center was positioned. All lines along the Z-axis vanish in this area (Figure 21). Vanishing points are not necessary for line tracing but can enhance a person's precision in inferring occluded and low-resolution areas.

4. Line tracing can now begin. Use the Polyline command for straight lines and the Spline and Arc commands for curvilinear details.
5. The image is subjected to two types of line tracing, serving different purposes. First, trace the image based on the factor levels, focusing only on the perimeter of each level. This set is for the entropy analysis.
6. Make a duplicate of the tracing output from step 4 and proceed to a more detailed tracing, involving interior lines. This set is for the fractal analysis.

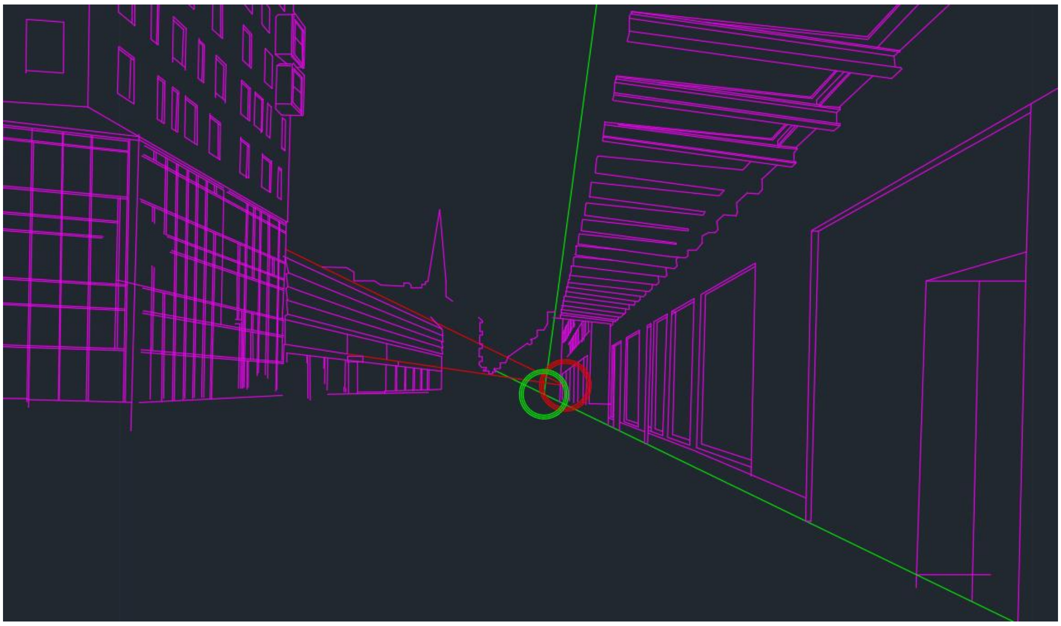


Figure 21. Line tracing of a centrally positioned image of Carl Krooks Gata, Helsingborg. Two vanishing points located in the green and red circle's center.

To ensure the reliability of the results, it is important to maintain consistency and attention to detail during the tracing and mapping process. The following steps were taken to enhance accuracy, precision, and consistency.

1. Utilize the zoom and magnification features of CAD to closely examine the details of the street-level view. This will help identify and trace the boundaries of the features more accurately.

2. Utilize guiding tools available such as snapping options for lines, trim command, construction line command (xl), together with determined vanishing points aids in aligning and mapping.
3. Validate the process by checking the images in another screen, other site images if available, and google street views. This compares the mapped areas with ground truth data or seeking independent assessment to verify accuracy of this visual process.
4. Incorporate quality control measures by reviewing progress and double-checking areas. Since the overall process is very tedious it is necessary to take breaks in between to maintain focus and reduce fatigue.

A total of 12 centrally positioned photos covering 6 streets were subjected to line tracing and mapping for both fractal and entropy analysis. Additionally, a total of 7 right-positioned and 7 left-positioned photos covering 7 streets were subjected to line tracing and mapping specifically for fractal analysis. This final set of photos is crucial for investigating the impact of a viewer's position on the fractal dimension of the buildings. Additional examples of these photos can be observed in Figure 24. Appendices 7 to 10 showcase several processed images for each analysis.

3.5 Fractal Analysis

3.5.1 Pre-analysis process

After the line tracing of an image is finished, it is plotted using a DWG-JPG scheme with a size of 4032x3024 pixels. The resulting output is saved in JPG format and then uploaded to the Fiji Image Processing software. Binarization, which entails converting the image into a binary format, can be executed using any image processing software that offers a binarize function. However, for a more efficient workflow, binarization is preferably performed within Fiji since FracLac, the primary fractal analysis tool utilized in this study, is a plugin of Fiji.

During the binarization process, the background pixels are designated as white, while the foreground pixels, which depict the features of interest for analysis, are assigned as black. A thorough examination of the histogram of each image is conducted to determine the number of pixels with a value of zero (white) and the number of pixels with a value of 255 (black). It is crucial to note that the sum of the counts of white and black pixels should equal 12,192,768, which represents the total number of pixels in the image. The count of black pixels (255-value) is recorded for future use in the correlation analysis.

3.5.2 Fractal Analysis

Prior to conducting the actual test, an initial calibration was performed to assess the analysis settings outlined in Table 5. The calibration involved processing an image of a Terdragon curve and a Sierpinski carpet (refer to Appendix 2) using the specified settings in the FracLac software. Any true or exact fractal image can be utilized as a suitable calibration sample. The expected outcome of the calibration test should yield values close to the theoretical fractal dimensions of 1.26186 and 1.8928 for each respective fractal. It should be noted that using images of true fractals does not result to the theoretical fractal dimension value. Subsequent to the calibration test, a total of 26 binarized images were processed using the FracLac software, employing the box counting method and adhering to the settings presented in Table 5.

Table 5. The FracLac setting used for the box-counting method.

Grid design	12
Scaling method	Scaled series, ½, max 20 grid calibre
Smallest sampling element	0
max size of sampling element	25 % of image's greater dimension of ROI
Regression line	Yes
Grid data	Yes

The grid positions were set to 12, as recommended by FracLac. To ensure optimal processing speed, FracLac suggests using 4-12 iterations, as excessive grid positions can significantly slow down the analysis. The scaling value followed the ½ scaling method proposed by Ostwald & Vaughan (2016). By setting the smallest sampling element to 0, the software can determine the smallest box size that retains meaningful detail. The maximum number of scaling times in the series was arbitrarily limited to 20. The maximum size of the sampling element was determined based on the larger dimension of the region of interest (ROI). For the largest element, the expected value was calculated as 4032 * 0.25 = 1008. It is recommended that the largest sampling element should not exceed 45%, as surpassing 50% can introduce errors in the sampling process. Additionally, the grid data and regression lines serve as supplementary outputs of the analysis, providing additional information beyond the calculation of fractal dimensions.

3.6 Entropy Analysis

A specific set of DWG files, which contained centrally positioned images mapped based on factor levels, was utilized for the entropy analysis. Before conducting the primary analysis, the factor levels were delineated by perimeter lines and filled with solid colors using dedicated colors for each level (refer to Figure 22). The Hatch command in AutoCAD was employed for this purpose. This approach ensured that each factor level possessed a distinct color property. By executing the Area command for a particular color, the total area of that specific color corresponding to a particular level was calculated and recorded for analysis. The total area was measured in model space units, which corresponded to the 4032x3024 pixels area, scaled down to 56x42 model space units (equivalent to 0.019% of the original size). When recording entropies, it is necessary to utilize a spreadsheet application such as MS Excel or a similar program with programmable cells. This facilitates tracking changes, ensuring correctness, and identifying errors (see Figure 23).

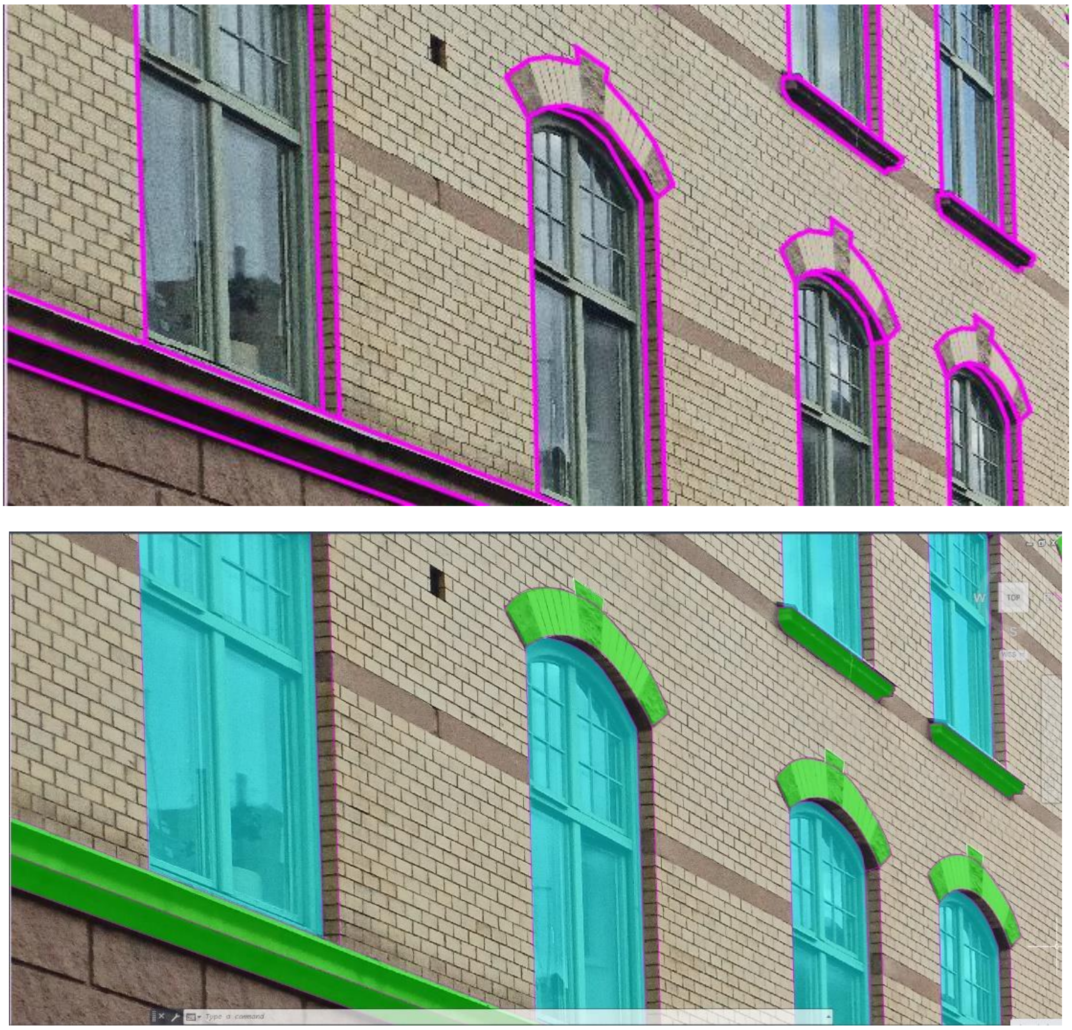


Figure 22. Top: Window (cyan) and ornament (mouldings in green) levels. The perimeter was mapped in purple lines

								TOTAL ENTROPY
AREA:	JONKOPING	Foreground Area:	646.0672	646	p(x)	$Log_2(p(x))$	$p(x)Log_2(p(x))$	$Negp(x)Log_2(p(x))$
LEVELS	9							
PLAIN WALL			33.7837	34	0.052632	-4.247927513	-0.223575132	**2.063954257**
ARTICULATED WALL			248.4158	248	0.383901	-1.381194044	-0.530241676	
CURTAIN WALL			238.1361	238	0.368421	-1.440572591	-0.530737271	
ORNMAMENTS			0					
DOORS			21.2681	21	0.032508	-4.943072932	-0.160688129	
WINDOWS			78.9531	79	0.122291	-3.031609607	-0.370738636	
BALCONIES			7.8615	8	0.012384	-6.335390355	-0.078456846	
BAY			12.1067	12	0.018576	-5.750427854	-0.106819093	
ROOF			5.5422	6	0.009288	-6.750427854	-0.062697472	
			646.0672	646	1			

Figure 23. A screenshot of MS Excel interface showing raw data for Södra Strandgatan, Jönköping. In the big yellow box are the different levels' areas that when summed should equal the foreground area (small yellow box). Values in yellow boxes are calculated areas of each factor level from AutoCAD. When using the term pixel, a correction has to made by rounding off the calculated value to whole integers since a pixel cannot be divided into fractional values (blue box). Shannon's entropy applies to discrete distribution, in this from zero pixel to the total foreground pixel. The red box is a cell that sums up level entropies and should always equal to 1. This serves as an indicator of error in pixel summation if the resulting value is not 1.

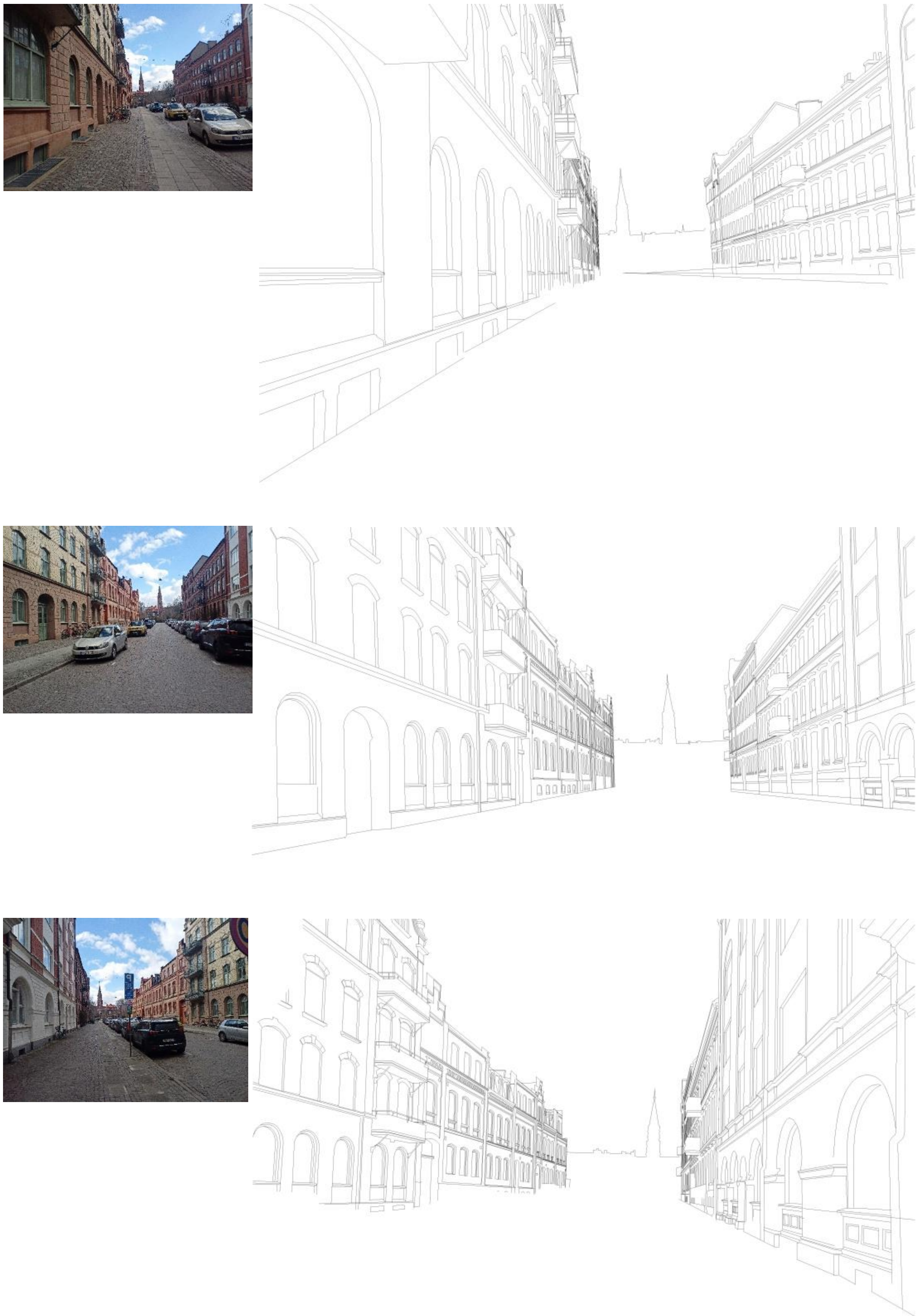


Figure 24. Example of a fully-traced street images that were processed in FracLac for box-counting. Taken from different positions in Nils Bjelkegatan, Lund. Top: Left position, Middle: Center position, Bottom: Right position.

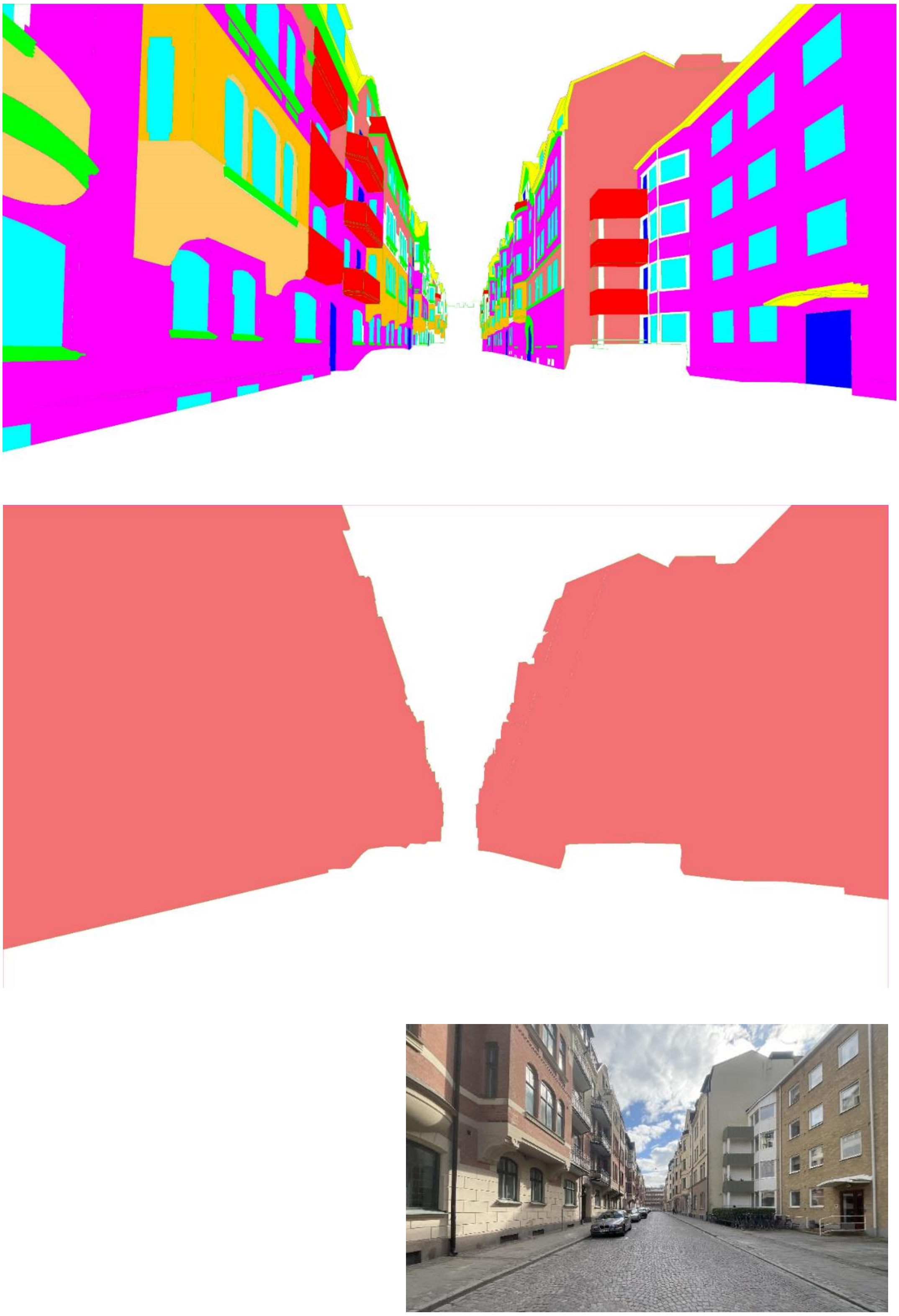


Figure 25. Top: A fully coded Magnus Stenbocksgatan, Lund in terms of levels. Middle: Foreground area (ROI). Bottom: Centrally positioned image of the street. Similar processed images can be seen in Appendices 9 and 10.

4. Results

4.1 Fractal Analysis

This section presents the fractal dimensions (D_b) obtained from the box-counting analysis of various streetscapes showcasing a particular style of building architecture. Table 6 below displays the 26 streets, categorized by different styles and captured from three distinct positions.

*Table 6. All calculated fractal dimensions lie within a boundary of 1.4-1.6, making some fall within the mid-range fractals (1.3-1.5) and some lying at the boundary between mid-range and high-range fractals (1.6-1.9). * indicates no data available as the image was not processed for analysis.*

Location	Style	D_b Left	D_b Center	D_b Right
Norra Storgatan, Helsingborg	Traditionalist	1.5297	1.576	1.5124
Möllegränden, Helsingborg	Traditionalist	*	1.5798	*
Carl Krooks Gata, Helsingborg	Modernist	1.5596	1.5518	1.5131
Lilla Varvsgatan, Malmö	Modernist	1.4616	1.4382	1.4726
Östergatan , Malmö	Traditionalist	1.5281	1.5841	1.5706
Adelgatan, Malmö	Traditionalist	*	1.514	*
Nordenskiöldsgatan, Malmö	Modernist	*	1.374	*
Magnus Stenbocksgatan, Lund	Traditionalist	*	1.5247	*
Nils Bjelkegatan, Lund	Traditionalist	1.5382	1.5926	1.596
Sockerkokaregatan, Lund	Modernist	1.4917	1.4981	1.4361
Södra Strandgatan, Jönköping	Modernist	1.4858	1.5192	1.4379
Fiskargränd, Jönköping	Modernist	*	1.5172	*

The individual D_b values represent the average D_b obtained from a specific grid orientation, which was scaled 8 times starting from a box size of 25% of the greater dimension of the region of interest (ROI). Consequently, each image undergoes a total of 96 iterations (12 grid orientations x 8 scaling) before obtaining the D_b value listed in Table 6. Appendix 3 provides a glimpse of the raw data generated from the box-counting method, while Appendix 4 displays sample regression plots for the average Db of a particular image.

4.2 Statistical treatment of fractal analysis result

4.2.1 Difference in D_b between traditionalist and modernist style

Statistical analysis was conducted using the results of the fractal analysis. The initial test aimed to determine if there is a significant difference between the traditionalist and modernist styles in terms of the dependent variable fractal dimension (D_b). The data used for the analysis consisted of the Db values obtained from centrally positioned street images, as presented in Table 7.

The results of the descriptive statistics show that the TRAD (traditionalist) group has higher values for the dependent variable D ($M = 1.56$, $SD = 0.03$) than the MOD (modernist) group ($M = 1.48$, $SD = 0.07$).

Preliminary screening of the data was conducted to check normality and equality of variance. Since sample size is small, a Shapiro Wilk Test was conducted to check the normality of the data. Since $P>0.05$ for both data groups, normality was assumed. The Levene test of equality of variance yields a p-value of 0.142, which is above the 5% significance level. The Levene test is therefore not significant and the null hypothesis that all variances of the groups are equal is retained. Thus, there is variance equality in the samples. This normality and equal variance assumptions table can be seen in Appendix 4.

A two-tailed t-test for independent samples (equal variances assumed) showed that the difference between traditionalist and modernist with respect to the dependent variable D was statistically significant, $t(10) = 2.64$, $p = .025$, 95% confidence interval [0.01, 0.15]. Thus, the null hypothesis is rejected.

Table 7. Data for T-test. 12 streets, 6 from each style with their Db taken from center position.

Location	Style	D_b Center
Norra Storgatan, Helsingborg	Traditionalist	1.576
Möllegränden, Helsingborg	Traditionalist	1.5798
Carl Krooks Gata, Helsingborg	Modernist	1.5518
Lilla Varvsgatan, Malmö	Modernist	1.4382
Östergatan , Malmö	Traditionalist	1.5841
Adelgatan, Malmö	Traditionalist	1.514
Nordenskiöldsgatan, Malmö	Modernist	1.374
Magnus Stenbocksgatan, Lund	Traditionalist	1.5247
Nils Bjelkegatan, Lund	Traditionalist	1.5926
Sockerkokaregatan, Lund	Modernist	1.4981
Södra Strandgatan, Jönköping	Modernist	1.5192
Fiskargränd, Jönköping	Modernist	1.5172

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Table 8. Two-tailed t-test for independent sample. Critical value = 2.228 from the T-distribution table of critical values at a=0.05, 10 df

							95% CI for Mean Difference			
	Test	Statistic	df	p	Mean Difference	SE Difference	Lower	Upper	Cohen's d	SE Cohen's d
D	Student	-2.640	10.000	0.025	-0.079	0.030	-0.146	-0.012	-1.524	0.726
	Welch	-2.640	7.441	0.032	-0.079	0.030	-0.149	-0.009	-1.524	0.726

Table 9. Group descriptive statistics.

	Group	N	Mean	SD	SE	Coefficient of variation
D	MOD	6	1.483	0.065	0.027	0.044
	TRAD	6	1.562	0.033	0.014	0.021

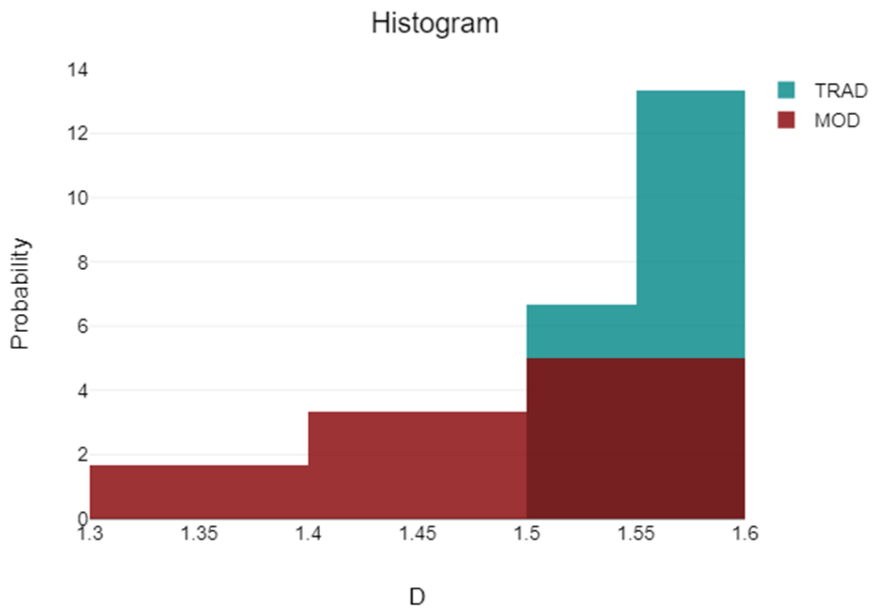

Figure 26. Histogram overlaying the range of fractal dimension D_b of the two styles

4.2.2 Association between styles and D_b

Considering architecture as a universal set A consisting of two complementary subsets A1 and A2, the universal set A can be characterized as dichotomous. To examine the correlation between styles and Db, a point-biserial correlation analysis was conducted. Data from table 7 was used.

Table 10. Hypothesis statement for point-biserial correlation test. Traditionalist and modernist architecture are the dichotomous variable. Mod=0, Trad=1.

Null hypothesis	Alternative hypothesis
There is no association between styles and fractal dimension D_b	There is an association between styles and fractal dimension D_b

A point-biserial correlation was run to determine the relationship between styles and D_b. There was a positive correlation between styles and D_b, which was statistically significant (rpb = 0.64, n = 12, p = .025).

Table 11. Correlation table.

	Values
r_{pb}	0.64
df	10
t	2.64
p (2-tailed)	.025

4.2.3 Difference between position and D_b

A repeated measure ANOVA was performed to see if observing the streets at different positions (left, center, right) affects the Fractal dimension. One test subject per style were subjected to the treatment (see Table 12).

Table 12. Fractal dimensions of 2 different style streets with respect two position that the image was taken.

Traditionalist			Modernist		
Nils Bjelkegatan, Lund			Carl Krooks Gata, Helsingborg		
LEFT D_b	CENTER D_b	RIGHT D_b	LEFT D_b	CENTER D_b	RIGHT D_b
1.5666	1.6172	1.6238	1.6049	1.6095	1.5715
1.5645	1.6247	1.6075	1.608	1.5883	1.5368
1.5627	1.6175	1.5929	1.608	1.5883	1.5368
1.568	1.6233	1.6375	1.6049	1.6095	1.5715
1.5298	1.5793	1.577	1.5649	1.549	1.5074
1.5182	1.562	1.5702	1.5142	1.496	1.4896
1.5406	1.6002	1.5897	1.5584	1.539	1.4723
1.5156	1.5661	1.5981	1.5647	1.5585	1.5118
1.5273	1.5822	1.5956	1.513	1.5227	1.4907
1.5191	1.5817	1.5757	1.5114	1.5167	1.4799
1.5228	1.5917	1.5857	1.5164	1.5055	1.481
1.5228	1.5653	1.5981	1.5462	1.539	1.5079

For the two test repeated measures ANOVA test, F=126.65, p<0.001 and F=56.56, p<0.001respectively, the null hypothesis was rejected. There is a significant relationship between position and Db.

Table 13. ANOVA table for Nils Bjelkegatan, Lund & Carl Krooks Gata, Helsingborg. Mauchly's test of sphericity indicates that the assumption of sphericity is violated (p < .05) hence sphericity correction were applied.

Within Subjects Effects │Nils Bjelkegatan, Lund

Cases	Sphericity Correction	Sum of Squares	df	Mean Square	F	p
Position	None	0.025 [a]	2.000 [a]	0.013 [a]	126.655 [a]	< .001 [a]
	Greenhouse-Geisser	0.025	1.259	0.020	126.655	< .001
	Huynh-Feldt	0.025	1.346	0.019	126.655	< .001
Residual	None	0.002	22.000	9.975×10^{-5}		
	Greenhouse-Geisser	0.002	13.848	1.585×10^{-4}		
	Huynh-Feldt	0.002	14.801	1.483×10^{-4}		

Note. Type III Sum of Squares

Within Subjects Effects│ Carl Krooks Gata, Helsingborg

Cases	Sphericity Correction	Sum of Squares	df	Mean Square	F	p
Position	None	0.015 [a]	2.000 [a]	0.007 [a]	56.458 [a]	< .001 [a]
	Greenhouse-Geisser	0.015	1.361	0.011	56.458	< .001
	Huynh-Feldt	0.015	1.486	0.010	56.458	< .001
Residual	None	0.003	22.000	1.318×10^{-4}		
	Greenhouse-Geisser	0.003	14.968	1.937×10^{-4}		
	Huynh-Feldt	0.003	16.351	1.774×10^{-4}		

Note. Type III Sum of Squares

4.2.4 Association between number of pixels and Db

A Pearson correlation was performed to test whether there was an association between fractal dimension D_b and the number pixels. The result of the Pearson correlation showed that there was a significant association between Db and pixels, $r(10) = 0.9$, $p = <.001$. There is a very high, positive correlation between the variable's D_b and pixels with $r = 0.9$.

Table 14. D_b and pixels data taken from 12 centrally positioned images. The number of pixels corresponds to the number of 255-value pixels (black), in this study called as foreground pixels

D_b	# of pixels/image
1.576	171636
1.5926	201506
1.5841	198262
1.514	136536
1.5247	148232
1.5798	160866
1.5518	151188
1.4981	119272
1.4382	101504
1.374	86235
1.5192	117814
1.5172	153611

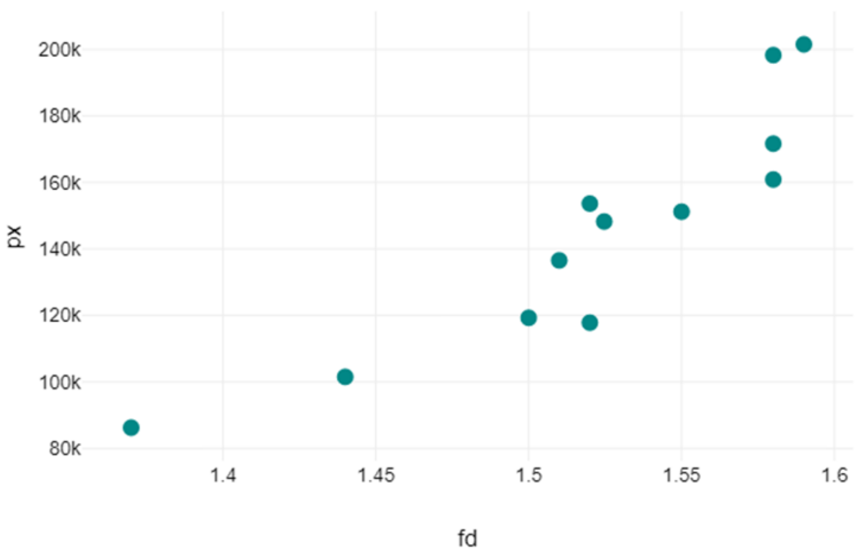

Figure 27. D_b and pixels scatter diagram.

4.3 Entropy Analysis

Entropy values for each street was subjected to statistical treatment to determine the difference between the two styles in terms of entropy. The table below is a summary of the entropy calculation tables were raw data from AutoCAD were processed.

Table 15. Entropy values of center positioned images for 12 streets.

Location	Style	Entropy_{center}
Norra Storgatan, Helsingborg	Traditionalist	2.1291
Möllegränden, Helsingborg	Traditionalist	2.3579
Östergatan , Malmö	Traditionalist	2.1698
Adelgatan, Malmö	Traditionalist	2.1527
Magnus Stenbocksgatan, Lund	Traditionalist	2.2234
Nils Bjelkegatan, Lund	Traditionalist	1.7821
Nordenskiöldsgatan, Malmö	Modernist	1.9096
Carl Krooks Gata, Helsingborg	Modernist	2.1809
Lilla Varvsgatan, Malmö	Modernist	1.7950
Sockerkokaregatan, Lund	Modernist	1.5894
Södra Strandgatan, Jönköping	Modernist	2.0640
Fiskargränd, Jönköping	Modernist	1.6823

The results of the descriptive statistics show that the modernist style has lower values for the dependent variable entropy (M = 1.87, SD = 0.23) than the traditionalist style (M = 2.14, SD = 0.19).

Preliminary screening of the data was conducted to check normality and equality of variance. Since sample size is small, a Shapiro-Wilk Test was conducted to check the normality of the data. Since P>0.05 for both data groups, normality was assumed. The Levene test of equality of variance yields a p-value of .415, which is above the 5% significance level. The Levene test is therefore not significant and the null hypothesis that all variances of the groups are equal is retained. Thus, there is variance equality in the samples.

A two-tailed t-test for independent samples (equal variances assumed) showed that the difference between modernist and traditionalist with respect to the dependent variable entropy was not statistically significant, t(10) = -2.2, p = .053, 95% confidence interval [-0.54, 0]. Thus, the null hypothesis is retained.

Table 16. Descriptive statistics of the group.

	Group	N	Mean	SD	SE	Coefficient of variation
ENTROPY	Modernist	6	1.870	0.226	0.092	0.121
	Traditionalist	6	2.136	0.192	0.078	0.090

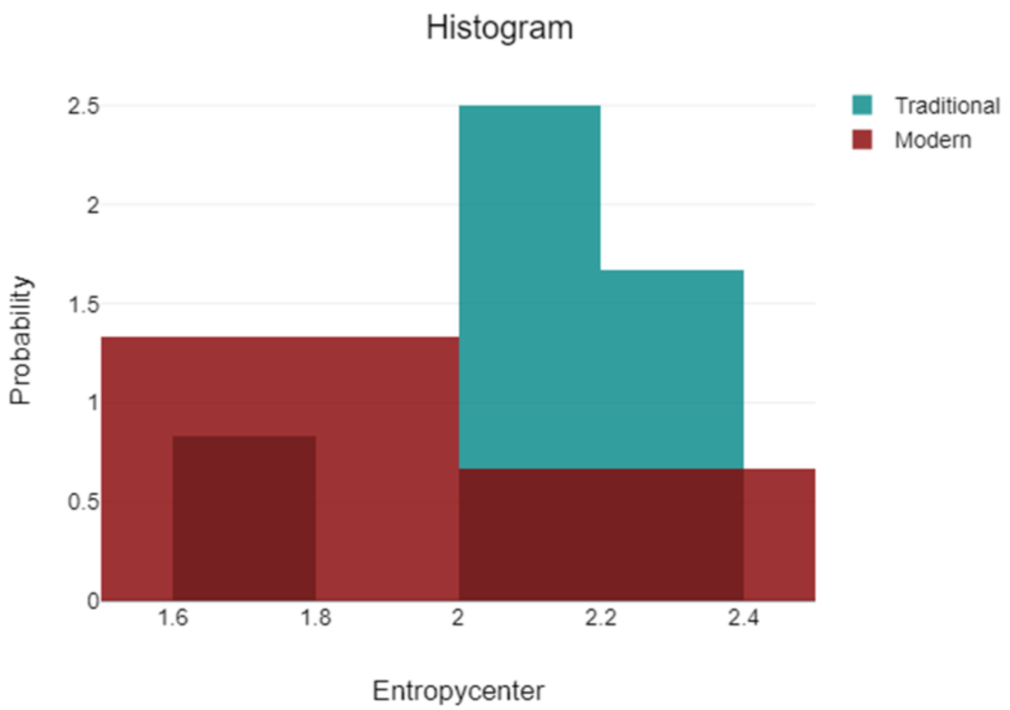

Figure 28. Histogram overlaying the range of entropy values at center between traditionalist and modernist

Table 17. Independent t-test. Also shown is Welch t-test alternative.

	Test	Statistic	df	p	Mean Difference	SE Difference	Lower	Upper	Cohen's d	SE Cohen's d
					95% CI for Mean Difference					
ENTROPY	Student	-2.196	10.000	0.053	-0.266	0.121	-0.535	0.004	-1.268	0.684
	Welch	-2.196	9.739	0.054	-0.266	0.121	-0.536	0.005	-1.268	0.684

4.3.1 Association between entropy and style

A point-biserial correlation was performed to test the relationship between the independent variable style and the dependent variable entropy. There was a positive correlation between style and entropy, which was statistically not significant (rpb = 0.57, n = 12, p = .053).

Table 18. Point-biserial correlation table and hypothesis statement. Traditionalist and modernist architecture are the dichotomous variable. Mod=0, Trad=1. Value of both t-test and point biserial are the same as they are done using the same samples.

Null hypothesis	**Alternative hypothesis**
There is no association between ENTROPY and STYLE	There is an association between ENTROPY and STYLE

	Values
r_{pb}	0.57
df	10
t	2.2
p (2-tailed)	.053

4.3.2 Variance

In Excel workspace where the calculation was done for entropy for each street, a cell was programmed to calculate for the variance of the distribution of the factor levels with respect to the foreground area. Pixel units of factor levels are altered multiple times to see its effect in the variance. It was observed that the lesser the variance the higher the entropy. By definition, variance is a measure of how much the values in a data set vary or deviate from the mean (average) value. It quantifies the spread or dispersion of the data points around the mean. Variance provides information about the variability and distribution of the data.

5. Discussion

5.1 On fractal dimensions

One of the primary objectives of this study is to assess the disparity in fractal dimensions between the traditionalist and modernist styles. The findings reveal a significant difference in their fractal dimensions when examined from a street-level perspective. Specifically, the fractal dimensions of the traditionalist style tend to be higher than those of the modernist style. The majority of the traditionalist style's fractal dimensions fall within the high fractal range (1.6-1.9), while the remaining values, including those of the modernist style, fall within the mid-fractal range.

Previous research has indicated that humans tend to have a preference for exposure to the mid fractal range (1.3-1.5), which can lead to beneficial effects such as stress reduction and a general sense of relaxation and restoration (Abboushi et al., 2019). However, it is important to note that these studies primarily focused on exact and statistical fractals that are either computer-generated or found in nature. Additionally, it is crucial to highlight that an object can possess a fractal dimension without necessarily being considered fractal. According to Mandelbrot's stipulations, for an object to be classified as fractal, it must meet all four requirements. In the context of this study, the subjects do exhibit a non-integer dimension (Db), display roughness and irregularity in the picture plane, and demonstrate self-similarity resulting from aspects such as modularity in architecture. However, they do not possess infinite complexity as the iteration process would eventually reach a stopping point.

The different viewing positions (left, center, right) showcase distinct characteristics from one another. This phenomenon has been previously investigated in a course project on environmental psychology conducted by the author, and a similar conclusion was reached in an unpublished paper for the course. From these findings, it can be tentatively inferred that the visual experience within our streetscape environment involves a dynamic and ever-changing fractal dimension as observers move within it. Planners and designers can utilize this understanding to their advantage, as certain viewpoints offer more favorable qualities than others.

The pixel-D_b correlation analysis reveals that detailing is the primary differentiating factor between traditionalist and modernist façade characters. However, it is important to note that detailing is not exclusively associated with one style, as there are instances of modernist streets with high D_b values and comparable pixel (detail) values to some traditionalist streets.

Looking at the linear composition of the picture plane represented by the edges of the facades' geometry, in what S. Kaplan (1979) refers to as the visual array, the fractal dimensions serve as descriptor values of the complexity in the topology of traditionalist and modernist style buildings at the street-level views. Fractal dimension provides a quantitative measure of this complexity. In the context of architecture, topology refers to the spatial arrangement and connectivity of elements that comprise a façade's design. The quantification of the fractal dimension as a measure of complexity in the facade's topology, offers a different way of looking at the argument between styles. This aids in understanding how the complexity of a building's topology contributes to its overall aesthetic appeal and perception.

5.2 On entropy

The second main objective of this study is to assess the difference in information entropy between traditionalist and modernist styles. The findings indicate that there is insufficient evidence to conclude that there is a significant difference in entropy when considering street-level perspectives. However, this does not diminish the potential significance of entropy as a differentiating factor between the two styles. It is important to note that the rejection of the null hypothesis does not necessarily imply that there is no difference between the styles. Instead, it suggests that the observed difference may have occurred by random chance in the particular sample used for this study. Furthermore, it is possible that the result is influenced by the sample size being insufficient rather than the absence of a true effect.

In the correlation analysis, it can be observed that as a façade exhibits more traditionalist characteristics, the entropy tends to increase. However, this relationship is considered statistically insignificant. Several factors could contribute to this result, including random chance, an insufficient sample size, or the specific way in which the factor levels were categorized. It is important to acknowledge that the number of factor levels can impact the entropy value. Additionally, the variance check demonstrated an inverse relationship between entropy and variance. This finding is expected since the factor levels represent components of a discrete distribution, specifically the defined foreground area. However, this inverse relationship has implications for how the factor levels influence the complexity and coherence of streetscapes in relation to the surrounding building facades.

Entropy has been commonly linked to the preference matrix in various studies, as highlighted by Stamps (2003 & 2014), to gain a better understanding of human perception of the landscape. When comparing traditionalist and modernist styles, entropy offers valuable insights into both the coherence and complexity of these styles.

Information entropy can provide an indication of the coherence or uniformity in the distribution of surface types within buildings. A lower entropy value suggests a more uniform or consistent distribution of surface types, indicating a higher degree of coherence in the building design. This means that the different surface types are integrated and organized in a more structured and predictable manner. Similarly, entropy can provide an indication of the complexity or diversity of surface types within buildings. A higher entropy value indicates a more diverse or varied distribution of surface types, suggesting a higher degree of complexity in the building design. This implies that the building exhibits a range of different surface types, creating a visually rich and diverse composition.

Overall, the complexity and coherence of the two style can be summed up with a verbal description of the variance: 1) low variance-high entropy-high diversity, 2) high variance-low entropy-high coherence. This represents one facet of coherence-complexity relationship, expressed in a table by Kaplan & Kaplan (1989, p.54).

5.3 On methodology

Customarily, studying images of landscape particularly those whose subjects are building uses either elevations of building or smaller parts of the façade, floor plans, or interior sections, and plan views in the case of urbanism studies. These materials are all in orthographic projections, 2-dimensional representation of -dimensional environment. It was mathematician Carl Bovill who alluded that fractal dimensions of buildings showed be measured using data from perspective views (Bovill, 1996), an approach that does not use a common orthographic reference to compare different buildings but rather to described the visual experience from different positions in space. Along the same line, these perspective views could also be subjected to entropy analysis as this study have demonstrated.

The study acknowledges that the choice of perspective and vantage point can have a significant impact on the analysis and interpretation of the street environment. In this particular study, the analysis focused on street-level views from vantage points parallel to the layout of the street, which represents the perspective of a person standing and observing the street. This perspective allows for a comprehensive view of the buildings and their arrangement along the street since it captures 2 sides of the street.

While it is true that frontal views are important part of the overall street environment experience, there are limitations of using a perpendicular perspective to the street layout that does not fit well with the study framework (see Appendix 1). From a perpendicular vantage point, the field of vision is restricted, typically capturing only a portion of the street and a limited number of buildings, depending on the distance from the viewer to the objects observed. The width of the streets largely affects the view that can be afforded, and its effect is most detrimental in perpendicular to street-layout views. This limited view may not capture the full spatial arrangement and context of the street environment. Additionally, the study suggests that from a frontal approach, the comparison tends to focus more on individual buildings rather than a holistic street-to-street comparison, as the view becomes more akin to a building-to-building scenario. Furthermore, foreshortening due to depth of space can hardly be observed at this vantage point, at least in the horizontal axis.

It is well established and emphasized by Ostwald and Vaughan (2016), as well as in other works, that working on perspective views differs from working on orthographic views (elevations, plans, layout) due to inherent variations in individuals' body physiology and capabilities (such as height, visual acuity, field of vision, etc.). In this study, the different positions of observers also contribute to the variation in fractal dimensions and entropy values. Although small physiological differences, such as the height variation between an observer say at 1.50 meters and another at 1.60 meters, will result in minute changes in fractal dimension. Changes in fractal dimension due to shifts in an observer's position in space (left side of street, center of street, right side of street) lead to a shift in the range of fractal values between the mid-range and high-range. The distance between each position, while not measured, is larger in scale compared to the difference in eye level, unless extreme variations such as comparing a person with dwarfism to a person with giantism are considered. This raises the question of the threshold at which differences in angles, height, and horizontal displacement become significant enough to cause noticeable and potent changes in entropy and fractal dimension. Unfortunately, this query remains unresolved within the scope of this study.

Similar considerations apply to entropy values, with the additional factor of occlusions in the street environment that can affect a person's view. Objects such as people, cars, and vegetation can act as obstructions, potentially impacting the visibility and perception of the surrounding buildings. These occluding factors introduce variations in the visual experience, definitively influencing the entropy values associated with different perspectives and positions.

The choice of location for data gathering was not highly restrictive, with only a few requirements such as being a city in Sweden and having streets with similar architecture on both sides for a certain distance. While it is true that social, cultural, economic, and other factors influence the physical transformation of a city, this study does not consider them directly relevant in the context of analyzing style differences. However, it is important to acknowledge that these factors have the potential to cause variations within styles. For instance, if a street block is constructed during a period of poor economic climate, the facades in that block could be more austere compared to others of the same style. These contextual factors may become more significant when comparing specific streets between different cities or regions. Nonetheless, the primary focus of this study remains on the objective nature of the physical objects observed, which can be measured using numerical style definitions.

In relation to street-level views, the method employed can be regarded as advantageous compared to those examples in the past. This is elaborated below.

- Granular Feature Representation: By mapping and measuring the pixel areas of individual features (e.g., door, window, roof), the method provides a more granular representation of the building surfaces. This allows for a detailed analysis of the specific features present in the street-level view, capturing their variations and distributions accurately.
- Flexibility and Adaptability: The method allows for the definition and include specific features of interest that are relevant to street-level views. This flexibility enables one to tailor the analysis to the unique characteristics and complexities of urban environments seen at street level.
- Quantitative Measure: Measuring the pixel areas provides a quantitative measure of the features within the image. This allows for precise calculations and comparisons of feature proportions, which can be directly used in entropy calculations.
- Objective and Reproducible Results: By using image editing software to map and measure the pixel areas, the method offers an objective and reproducible methodology. The results are based on the objective pixel counts and can be replicated by others using the same images and software tools.

- High-resolution Image Analysis: Working with high-resolution images allows for detailed feature extraction and accurate pixel measurements or any surface area unit. This enhances the reliability and quality of the analysis, enabling a more comprehensive understanding of the complexities present in the street-level view.

It's important to note that while the idea offers advantages for street-level view analysis, it also requires manual mapping and pixel measurement, which can be time-consuming. Additionally, the accuracy of the results depends on the precision of the mapping process. However, by leveraging high-resolution images and a pixel-based analysis, the approach can provide valuable insights into the complexity of building surfaces in street-level views.

5.4 Future direction

The study focusing of the particular subject matter of traditionalist versus modernist, served as an exercise for the methodology which can be applied in other scenarios in landscape research. Figure 29 below illustrates a framework derived from the results of this study. The linear components derived from the planes and geometric features of the facades represent topological attributes, the complexity of which can be quantified using fractal dimension. The distribution of façade surfaces' coherence and complexity on the other hand can be measured by information entropy.
There are issues that arose and the end the study was confronted by two dilemmas. Firstly, as stated, while entropy can measure both complexity and coherence, fractal analysis can only fully describe complexity and not coherence, at least partially. The rationale behind this lies in the following:

1. Architecture or buildings and other physical objects are not true fractals, but they can have fractal qualities such as fractal dimensions which measures its roughness or complexity (Mandelbrot, 1983).
2. In his interviews and lectures, Benoit Mandelbrot described fractal dimension as a simple rule that govern complex patterns. This rule in its basic form is denoted by *FD=log details/ log scale*. He further call fractal dimension as the 'order in roughness' and 'the invariance in roughness' (TED, 2010 & MIT, 2019). This means that a complex pattern can be described if one is able to find the 'order' or 'structure'.

3. The fractal dimensions obtained from the analysis were limited to 8 iterations. This means that the topological lines exhibited fractal characteristics only up to the 8th iteration. Beyond that point, the fractal property breaks down, and the simple rule described by the equation no longer holds true. This is evident from the regression model presented in the analysis (refer to Appendix 4). The data points beyond the 8th iteration do not align with the regression line, suggesting a deviation from monofractality and the possibility of either nonfractality or multifractality. It is important to note that the analysis in this study is based on monofractality, which utilizes a single scaling rule. When this rule breaks down, complexity does not cease to exist infact such situation could be described as more complex, as Mandelbrot put it , roughness if the extreme of complexity. So if we assume that fractal dimension is also a measure of coherence, then such coherence is not absolute, and one has to find another way of understanding or making sense of things as the Kaplans (1989) would have put it.

4. Therefore, it can be postulated that the fractal dimension, a measure of complexity by mathematical definition and the rule that gives order and invariance to a pattern is the number that describes complexity based on its legibility to the observer. In the preference matrix, coherence was built-upon (Kaplan & Kaplan, 1989) the legibility in the environment (Lynch, 1960). This makes sense because in architecture the coherence in organization of design elements to achieve a unified whole is tantamount to legibility. However, if one takes a glance at Appendix 2, displaying two different ranges of fractals, the Sierpinski carpet with a higher fractal dimension is easier to understand than the Terdragon curve with a lower fractal dimension, at least visually. Appendix 2 shows a combination of *high complexity and high coherence*. Still, this is only a single case which can be proven by a visual comparison of other fractal patterns, therefore there would be a combination of *low complexity-high coherence*, *high complexity-low coherence*, and *low complexity-low coherence* (see Figure 30). The multifacetedness of the complexity-coherence relationship, and the fact that they are not straightforwardly opposite. Fractal dimension therefore remains as a descriptor of the complexity but not of coherence. The range (number of iterations) is when the image assumes fractality. Therefore, in a system that is not a true fractal coherence is not absolute. In true fractals coherence, the simple mathematical rule that gives order is absolute up to infinity. Coherence in general is a largely under studied quality (Kaplan & Kaplan, 1989). This prompt the author to suggest that

coherence in terms of the topological lines should be investigated in a different way.

The nuances between the two qualities, as well as the limited range of fractal dimensions, prompts the author to suggest to look at coherence in the concept of lacunarity. Moreover, the result from the Pixel-D_b correlation where some views have higher fractal dimension but with lower pixel count than some views with higher pixel count. This small representative of the population goes against the general observation. A probable reason for this is coherence of design elements in a composition. Therefore, an analysis utilizing lacunarity is suitable for architectural objects due to its broader applicability in spatial analysis. Unlike a solely fractal analysis, lacunarity is not limited in its effectiveness when applied to fractals, non-fractals, and multifractals (Plotnick et. al., 1996). In principle, the coherence in terms topology can be explored using lacunarity, a complementary procedure that was not explored in this study but has the potential to describe coherence in the facades character. It is a measure of heterogeneity and gappiness of a pattern (imagej.nih.gov, n.d.). In terms of coherence in topology, it can be posited that a higher lacunarity would mean higher heterogeneity and gappiness, resulting to low coherence and vice versa. Its versatility allows for a more comprehensive understanding of spatial patterns and structures, making it a valuable tool for analyzing architectural objects.

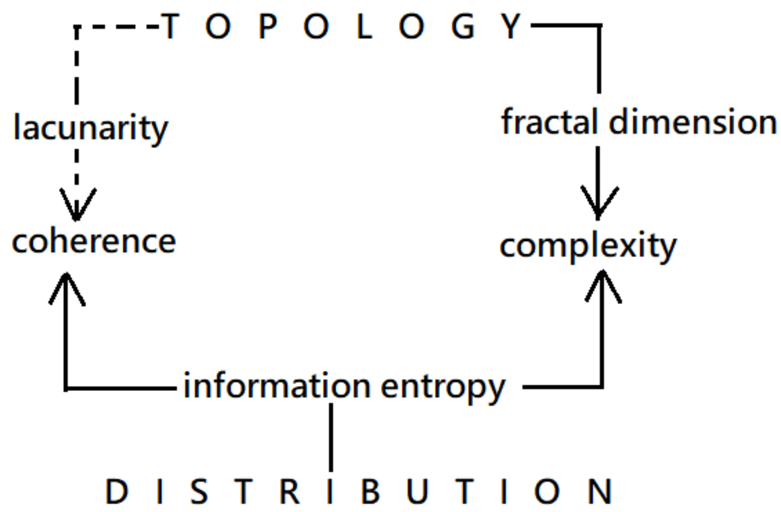

Figure 29. Fractal and entropy approach of evaluating complexity and coherence in the landscape.

The relationship between complexity and coherence in the context of information entropy of surface types is more nuanced, but not without its challenges. The study observed two combinations: 1) low variance- high entropy- high diversity, and 2) high variance- low entropy- high coherence (see Figure 30). Unlike in fractal analysis, the entropy analysis explicitly acknowledges this relationship, although due to the low sample size, its significance has not been established at this time. It is important to note that the parsing code plays a crucial role in determining the complexity and coherence. In the context of surface type distribution and entropy, coherence and complexity are contrasting. However, the effectiveness and appropriateness of information entropy and a specific parsing code can be questioned when a non-contrasting relationship arises, such as low complexity-low coherence or high complexity-high coherence. Moving forward, the study speculates that a non-contrasting relationship may result from considering multiple factors in the environment. It should be noted that due to the limitations of this study, only the factor of surface types has been taken into account.

	Coherence	
	Low	Hi
Complexity		
Low	Not much there	Visually messy
High	Clear and simple (boring)	Rich and organized

Figure 30. Trade-offs between coherence and complexity. Highlights and connected derived from research findings in the entropy of surface types (Adopted from Kaplan & Kaplan 1989, p. 54).

Taking everything into account, pinning a number to a certain image, particularly of real environments might be ambiguous considering that there is still a lot to learn about how we interact with our landscape. However, the experience with using data from images at perspective views suggests that while it is just as good as orthographic views, which are purely static, its strength lies in its nature as part of a dynamic phenomenon (i.e. walking, viewing). Therefore, it has the potential to describe the human experience as a rate of change. An entropy value and fractal dimension obtained at a certain perspective view can be seen as properties of a ‘frame frozen in time and space,’ representing a single instance in the overall experience of moving in space or walking along the street. To further illustrate this concept, a series of such "frames" can be used to measure the rate of change of these properties (dependent variables) with respect to independent variables such as eye level, position, angle, and field of vision. Consequently, the modelling of this phenomenon could be achieved through the use of calculus, including univariate, bivariate, and multivariate approaches, over a range of intervals, such as from one end of the street to the other.

6. Conclusion

The study's results demonstrate how landscape properties can be effectively examined in a quantitative manner, and provide insights into the unique characteristics of traditionalist and modernist building facades in terms of their topology and surface type distribution. The chosen method and framework were well-suited for analyzing street-level environments, successfully quantifying the differences between the two styles in the selected Swedish cities. However, it is important to acknowledge that certain nuances need to be taken into consideration.

Despite the underlying issues, the combined use of fractal analysis and entropy analysis proved to be complementary in interpreting these distinctions within the preference matrix. Nonetheless, it is worth noting that the study faced limitations due to the labour-intensive nature of the process and the limited number of qualified streets available for analysis. Consequently, the statistical power of the study, particularly in the entropy analysis, was constrained by the small sample size.

The approach of this study in evaluating landscape quality by means of getting the fractal dimensions and entropy values can be merited in the fact that we design and construct our environment with a specific standard that differs from place to place. Considering this, fractal and entropy analysis, both of which are separate concepts, can be used as critical tools in understanding and creating our environment. To illustrate, entropy analysis can be used to determine the monotony and diversity of a certain existing environment, or a project in its design development stage. Designers and planners can subjectively differentiate the monotonous from the diverse, but entropy analysis establishes a quantitative scale or index that transcends subjective ratings, relying instead on objective mathematical analysis. If desired, one can pinpoint at which exact point within this scale should we make or design our environment. A designer having a command and understanding of entropy, has the power to make the design blend or stand-out.

Along the same line, fractal analysis is useful in describing the complexity of our environment that cannot be measured by subjective metrics alone. It is effective in finding a similarity or pattern in the progression of how we build throughout history and from it applied knowledge that can be used in the future. The issue of ‘contextual fit’ is a matter that haunted designers and planners in the past, whether it is about building a modern building in a historical block, or some new developments with a natural scenery in the background. Because fractal is property of an object or space, one can generate a visually unified design that matches the site or a visually unique design that stands-out.

Moreover, objects with fractal properties have the potential to positively impact human well-being and health, as evidenced by several studies. Entropy in turn, can inform us about which environments are stimulating and which are not. However, our current understanding and ability to fully harness these positive effects are still in the early stages of research. Therefore, there is a need for landscape research that is specifically oriented towards exploring and utilizing these benefits. Looking at available tools that are currently employed by the design industry, particularly at the design development phase, there are hardly tools that is geared toward addressing the health and wellbeing of people. In connection with this, tools grounded on perception and preference of people should be explored and developed. This requires subsequent movement in allied fields such as in environmental psychology.

The use of materials depicting perspective view is the closes replication to man’s experience of the landscape. Attributing a number to a certain view could make entropy or fractal dimension inconsequential, but perspective views should be seen as a material for analysing human movement and dynamic experience thru space which can possibly be describe as a rate of change.

Current advancements in technology, such as computer-aided design (CAD) and building information modelling (BIM) tools, along with the emerging computational design paradigm, empower us to manipulate these properties to achieve desired outcomes for an enhanced environment. However, it is imperative to further our understanding of how we perceive and experience our surroundings. This entails establishing a robust correlation between individual preferences and quantifiable landscape qualities through the utilization of these analytical techniques. Furthermore, replicating similar studies employing diverse stimuli that elicit responses from individuals can significantly contribute to the knowledge base, particularly in the context of evidence-based design. By undertaking these endeavours, we can expand our insights and generate additional knowledge to inform evidence-based approaches.

Popular science summary

The landscape in which we move, is also a space where traditionalist and modernist styles clash in a never-ending the debate. The choice of which is better could be explained by a human evolutionary concept called the Preference Matrix of landscape aesthetics where man is seen as an information-based organism. In this the coherence and complexity as two qualities of the landscape are measure thru a parallel process of fractal and entropy analysis to described the difference between two styles in an objective manner

Fractals and entropy are two mathematical concepts that can tell as how we perceive our world, such as in a street-level environment. We employ these parallel processes to study street-level images of building facades captured in Lund, Malmö, Helsingborg, and Jönköping depicting traditionalist and modernist styles.

Fractal dimension was use to describe the complexity of the the topological lines present in the images while information entropy values was use to describe both coherence and complexity of the surface types (i.e. walls, windows, roof, etc.).

Through our analysis, we discover distinct differences between traditionalist and modernist architectural styles. Fractal analysis reveals that traditionalist architecture tends to exhibit higher fractal dimensions, indicating a greater level of self-similarity and complexity. In contrast, modernist architecture tends to have lower fractal dimensions, suggesting a more simplified and less intricate design approach. Additionally, entropy analysis highlights variations in the complexity and coherence of surface distributions, further distinguishing these styles.

In conclusion, this study demonstrated a novel quantitative approach in understanding our landscape. In foresight, it can be a tool in designing and creating a better environment particularly in the realm of evidenced-based and computational design.

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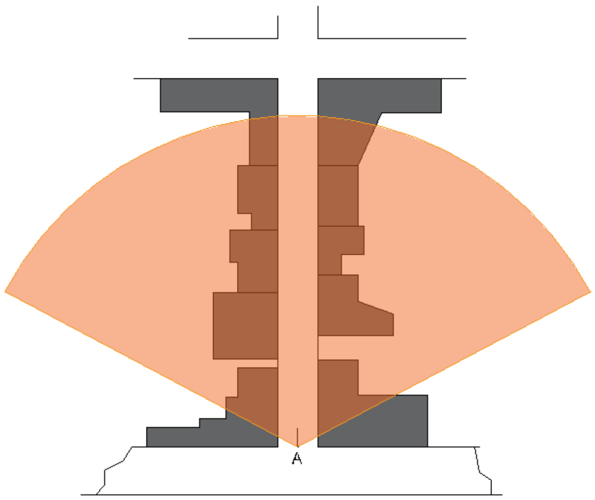
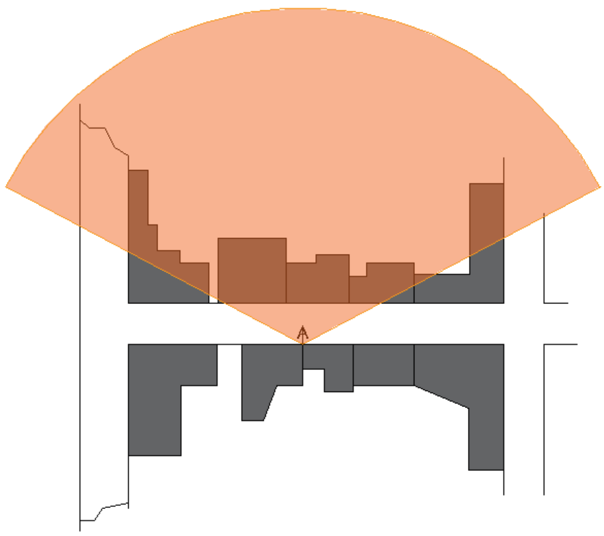
to my supervisor Caroline, whose course inspired and aroused my curiosity in the subject. It is an honour to be under your tutelage.

Lastly, special thanks to my dearest friend Kristin for everything.

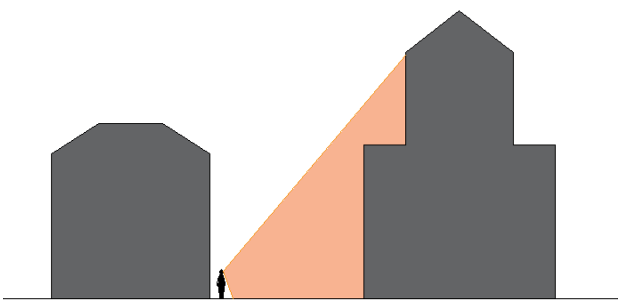
Appendix 1



Top view: Line of sight parallel to street layout. Both side of the street can be captured. 124º cone.

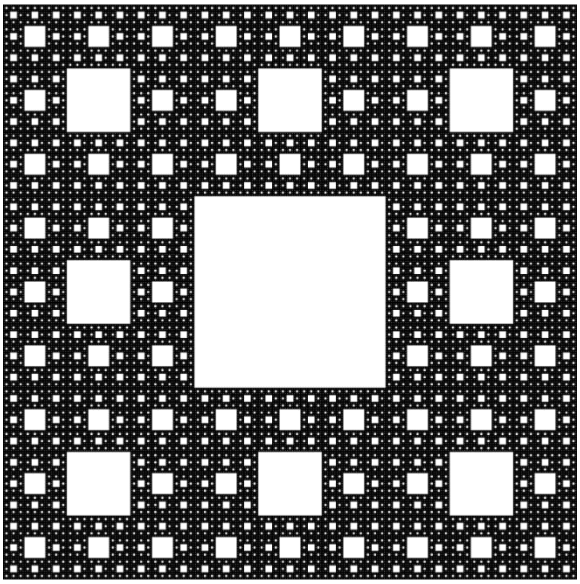


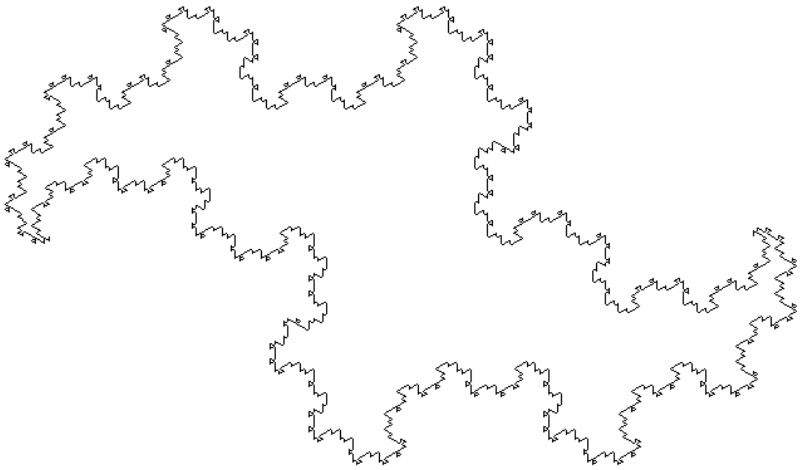
Top view: Line of sight perpendicular to street layout. Minimal view, capturing only one side. 124º cone.



Elevation: Line of sight perpendicular to street layout. Both side of the street can be captured. 120º cone.

Appendix 2





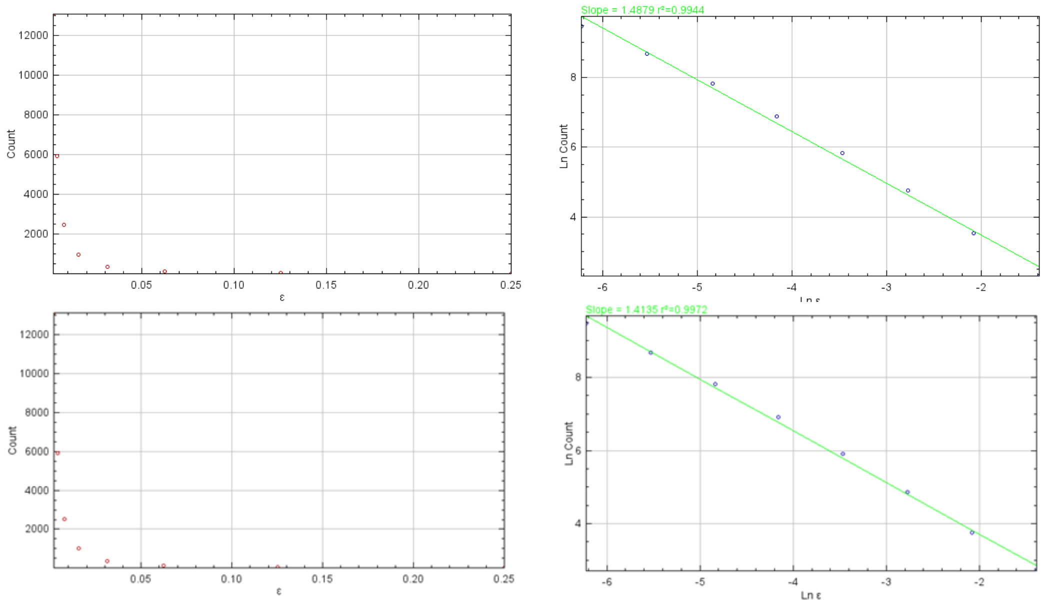
Fractal patterns used in the calibration. Top:Sierpiński carpet (FD=1.89, high-range), Bottom: Terdragon curve (FD=1.26, low-range). The higher the fractal dimension of the pattern the higher its space-filling capacity and hence more complex.

Appendix 3

Lilla Varvsgatan, Malmö					
FracLac 2015Sep090313a9330: File Slice (ROI) start position	SCAN TYPE for D_B	FRACTAL DIMENSION for D_B	r^2 for D_B	SE for D_B	Y-INT for D_B
malmoVHcenterjpg$1_ (0,0_4032x3024) 0,0--4032,2184	Box Count Binary; No filters; white; Save Results at G1	1.4879	0.9944	0.2038	0.4961
malmoVHcenterjpg$1_ (0,0_4032x3024) 0,-840--4032,2184	Box Count Binary; No filters; white; Save Results at G2	1.4574	0.996	0.1696	0.6561
malmoVHcenterjpg$1_ (0,0_4032x3024) 0,-840--4032,2184	Box Count Binary; No filters; white; Save Results at G3	1.4574	0.996	0.1696	0.6561
malmoVHcenterjpg$1_ (0,0_4032x3024) 0,0--4032,2184	Box Count Binary; No filters; white; Save Results at G4	1.4879	0.9944	0.2038	0.4961
malmoVHcenterjpg$1_ (0,0_4032x3024) -183,-271--4032,2184	Box Count Binary; No filters; white; Save Results at G5	1.4138	0.9978	0.1218	0.8707
malmoVHcenterjpg$1_ (0,0_4032x3024) -411,-169--4032,2184	Box Count Binary; No filters; white; Save Results at G6	1.4336	0.9968	0.1473	0.7779
malmoVHcenterjpg$1_ (0,0_4032x3024) -444,-861--4032,2184	Box Count Binary; No filters; white; Save Results at G7	1.4085	0.9978	0.1216	0.9021
malmoVHcenterjpg$1_ (0,0_4032x3024) -585,-367--4032,2184	Box Count Binary; No filters; white; Save Results at G8	1.425	0.9971	0.1397	0.8165
malmoVHcenterjpg$1_ (0,0_4032x3024) -143,-635--4032,2184	Box Count Binary; No filters; white; Save Results at G9	1.4261	0.9969	0.1447	0.812
malmoVHcenterjpg$1_ (0,0_4032x3024) -782,-121--4032,2184	Box Count Binary; No filters; white; Save Results at G10	1.42	0.997	0.1419	0.8486
malmoVHcenterjpg$1_ (0,0_4032x3024) -699,-58--4032,2184	Box Count Binary; No filters; white; Save Results at G11	1.4269	0.9971	0.1395	0.8076
malmoVHcenterjpg$1_ (0,0_4032x3024) -432,-439--4032,2184	Box Count Binary; No filters; white; Save Results at G12	1.4135	0.9972	0.1374	0.8866
		1.438166667			
Slopes for Data vs ε					
sampling size SIZE (G1)	sampling size SIZE (G2)	sampling size SIZE (G3)	sampling size SIZE (G4)	sampling size SIZE (G5)	sampling size SIZE (G6)
1	1	1	1	1	1
DATA					
SIZE OF SAMPLING ELEMENT (G1)	SIZE OF SAMPLING ELEMENT (G2)	SIZE OF SAMPLING ELEMENT (G3)	: OF SAMPLING ELEMENT	SIZE OF SAMPLING ELEMENT (G5)	SIZE OF SAMPLING ELEMENT (G6)
8	8	8	8	8	8
16	16	16	16	16	16
32	32	32	32	32	32
63	63	63	63	63	63
126	126	126	126	126	126
252	252	252	252	252	252
504	504	504	504	504	504
1008	1008	1008	1008	1008	1008

Raw data from FracLac box-counting analysis exported to MSExcel. Green: pixel coordinates of every grid orientation starting position, Yellow: Average Db from 8 iterations, Orange: list of sampling element for each grid that scales at ½ for every iteration, Blue: FracLac gives many data including the coefficient of variation (r^2), standard error, correlation coefficient, and y-intercept among others.

Appendix 4



sampling size SIZE (G1)	ε (G1)
1	1
DATA	
SIZE OF SAMPLING ELEMENT (G1)	Element Size/Image Di
8	0.002
16	0.004
32	0.0079
63	0.0156
126	0.0312
252	0.0625
504	0.125
1008	0.25

sampling size SIZE (G12)	ε (G12)
1	1
SIZE OF SAMPLING ELEMENT (G12)	Element Size/Image Dim
8	0.002
16	0.004
32	0.0079
63	0.0156
126	0.0312
252	0.0625
504	0.125
1008	0.25

Sample output plot from box counting analysis in FracLac. Count Vs Scale plots for G1 (top) and Grid 12(bottom) of Lilla Varvsgatan, Malmö. The Db for a specific grid orientation if the slope of the regression line. Correlation r^2 shows the strength of relationship between log of count and scale, a value of 1.0 means a perfect correlation. For both G1 and G12, the left and right plots are the exactly the same except for the fact that the right plot uses logarithm to best represent the data visually. Bottom: For all Grid orientation (G1-G12) uses the same scale. Note that at the FracLac setting in Table 5 the largest element is 1008 (25% of 4032) which is scaled down by ½ for every iteration thus 1008,504,252, so on and so forth. The x-axis of the graph is scale ε which is size of sampling element divided by 4032 pixels. The y-axis is the total number of pixels (details) inside the boxes, hence the name box-counting.

Appendix 5

Fractal-style t-test Assumptions

Test of Normality (Shapiro-Wilk)

		W	p
FD	MOD	0.970	0.842
	TRAD	0.824	0.154

Test of Equality of Variances (Levene's)

	F	df_1	df_2	p
FD	0.494	1	6	0.508

Entropy-style T-test Assumptions

Test of Normality (Shapiro-Wilk)

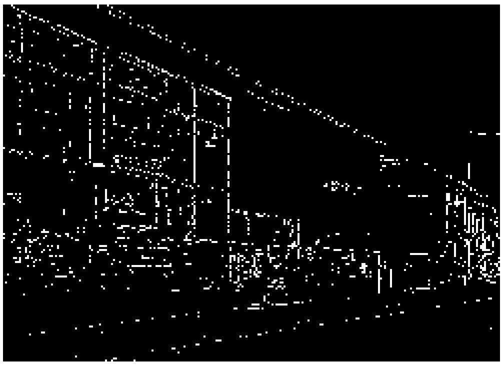
		W	p
ENTROPY	Modernist	0.969	0.887
	Traditionalist	0.864	0.202

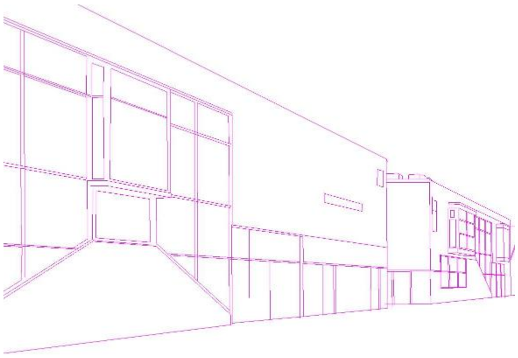
Test of Equality of Variances (Levene's)

	F	df_1	df_2	p
ENTROPY	0.723	1	10	0.415

Assumptions of normality and equal variance are required before conducting the t-test, as well as any parametric methods.

Appendix 6

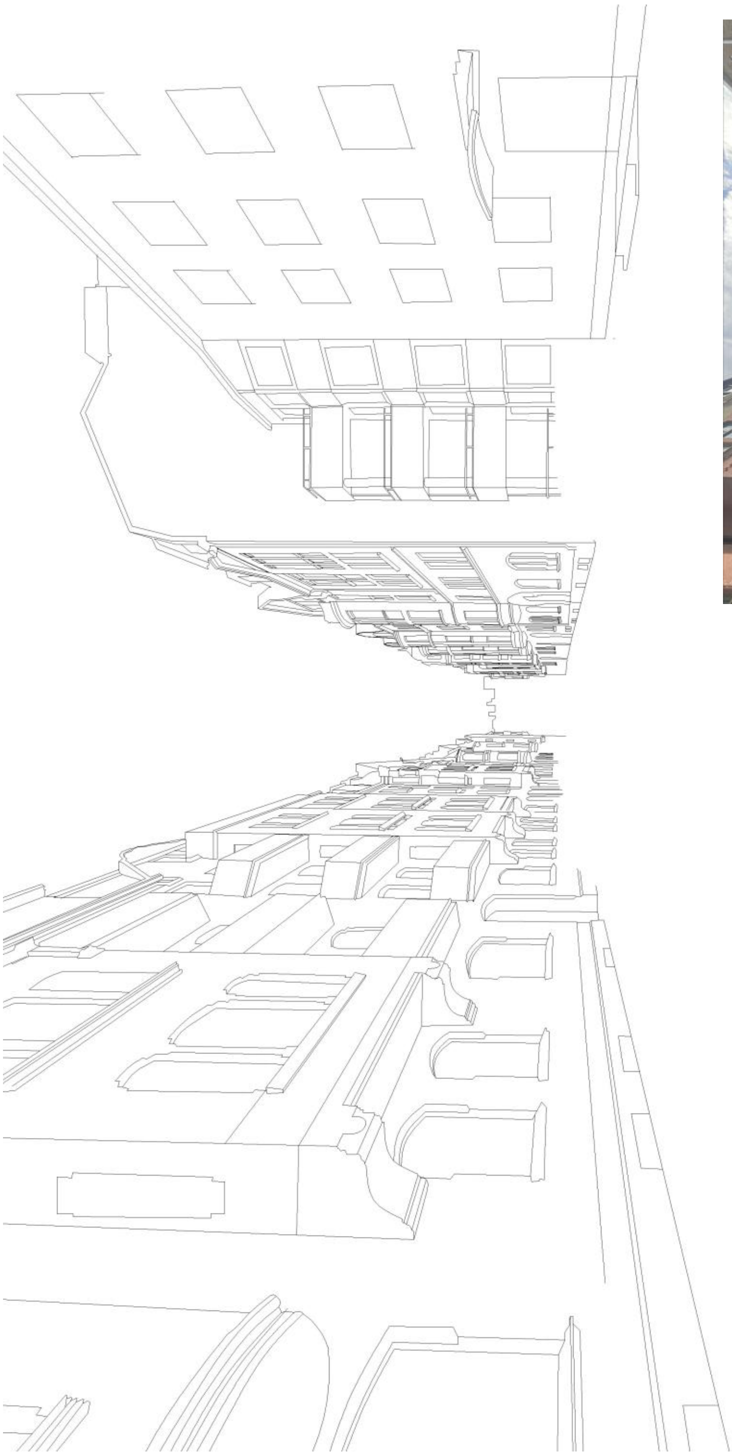




255	255	255	0	0	0
255	255	0	0	0	255
255	255	255	255	255	255
255	255	255	255	255	255
255	255	0	0	0	255
255	0	0	0	0	255

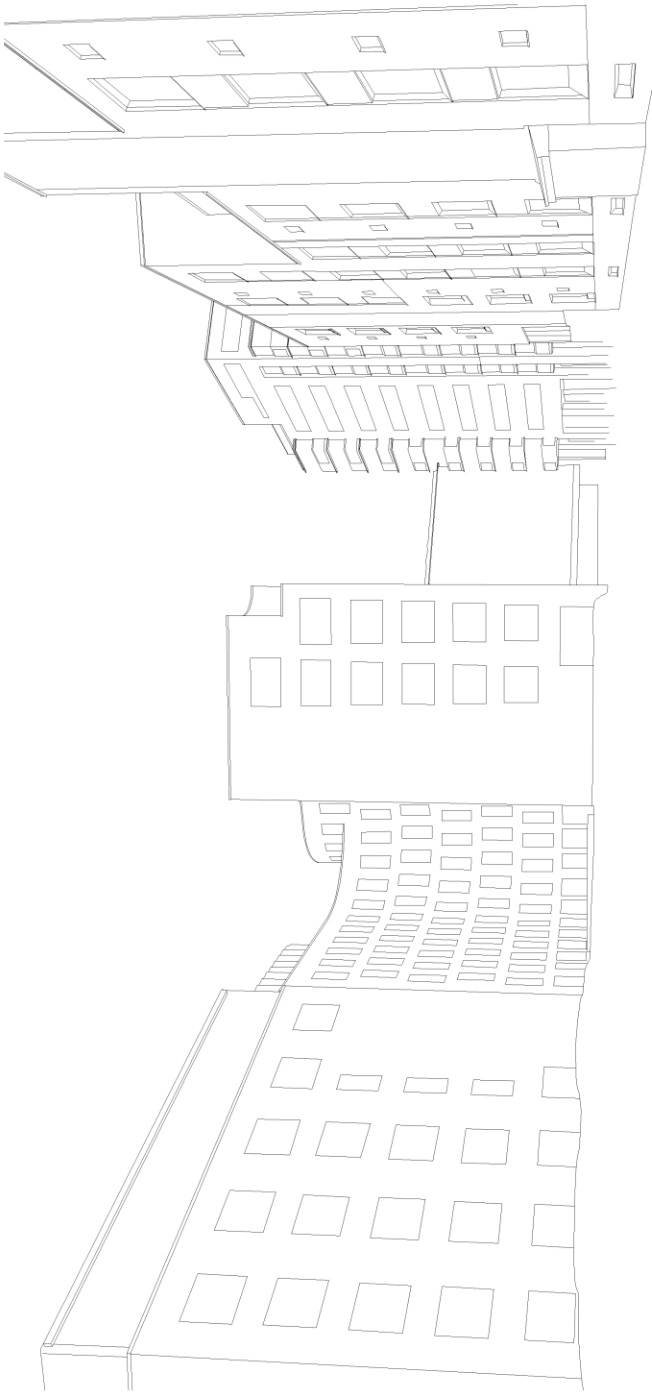
Sobel algorithm (top left) like most algorithm detects edges by detecting change in pixel intensity making these filters highly dependent in camera specifications and real-world environmental condition. Sobel for instance uses first order derivative *dy/dx*, given for example a simplistic binary bitmap (bottom left), the areas in red, would be mark as a discontinuity, forming edges below and on top of it, when in real life situation there is a physical edge of the object. Hence, broken lines are created that would affect the box-counting. The magnitude of the collective impact of these broken lines, where not determined if the resulting D_b are different from the resulting D_b when using a very well-defined edges such as the AutoCAD output (top right). As noted by Ostwald and Vaughan (2016), big changes in details may amount to small changes in D_b.

Appendix 7



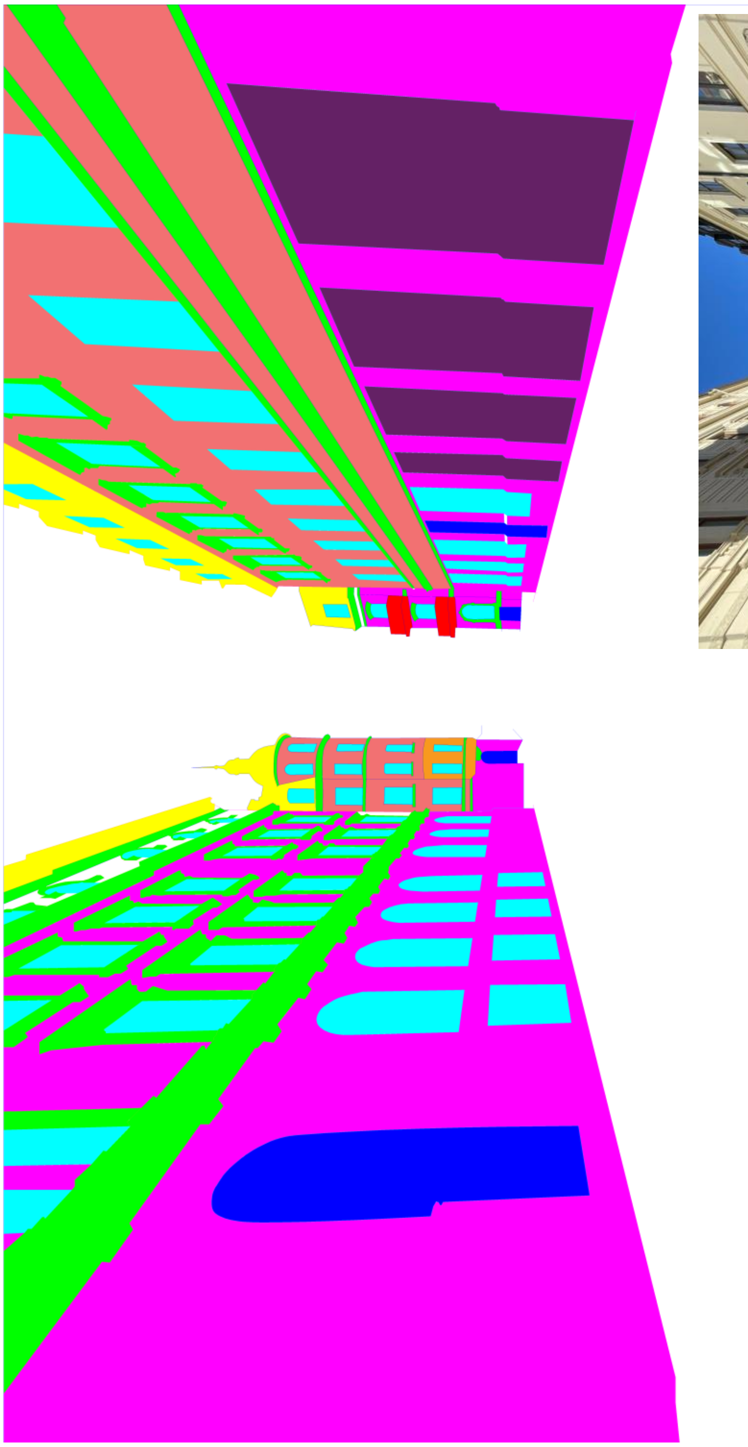
Center: Topological lines image of
Magnus Stenbocksgatan, Lund
Bottom right: Reference photo.

Appendix 8



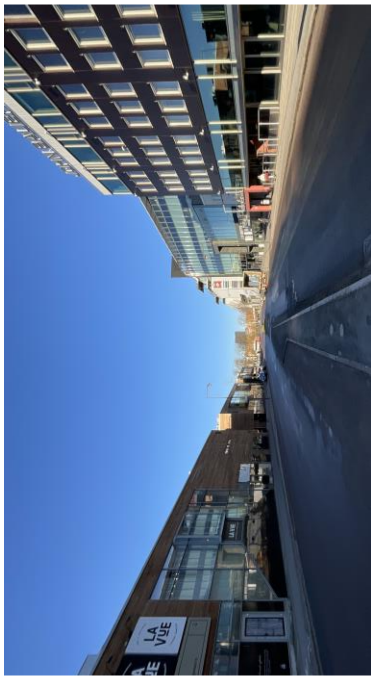
Center: Topological lines image of Sockerkokaregatan, Lund.
Bottom right: Reference photo.

Appendix 9



Center: Mapped and corded image of Möllegränden, Helsingborg.
Bottom right: Reference

Appendix 10



Center: Mapped and corded image of Södra Strandgatan, Jönköping.
Bottom right: Reference

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