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Fractal analysis of street vistas – a potential tool for assessing levels of visual variety in everyday street scenes.

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Abstract.

Fractal analysis and the calculation of fractal dimension offer the potential for the numerical characterization of places by providing a synthetic measurement of place complexity. This paper provides a fractal analysis of street vistas linking the calculation of fractal dimension to the perception of levels of visual variety present in everyday urban streets. A technique for calculating street vista fractal dimensions of textures extracted from grey scale images is presented and correlations between the resultant fractal dimension and scores for perceived visual variety are discussed.

Key Words: street vista; fractal dimension; visual variety; visual perception; complexity; urban design.

1. Introduction

In the concluding comments to their 2004 paper examining the fractal characteristics of landscape silhouette outline as a predictor of landscape preference, Hagerhall, Purcell and Taylor suggest that it would be of great interest to explore the application of fractal analysis techniques to textured grey scale images in relation to perceived visual preference. This paper is a response to that suggestion and seeks to investigate the link between the urban design quality of visual variety and the fractal characteristics of a series of everyday urban street vistas presented as greyscale photographic images.

Practitioners in the field of urban design seek, through the manipulation of spaces and buildings, to produce “good” places. A broad definition of such a place would be one that was economically viable, environmentally sustainable, aesthetically pleasing and that responded well to human needs for comfort and security. At least two of these qualities – aesthetics and comfort/security - are subject to and judged by human perception. In order to create “good” places urban designers need to understand how place is perceived by users and practice applied psychology. Work such as that carried out by Hagerhall *et al* (2004) looking at human preference in relation to landscape perception is therefore of great interest to urban design practioners. This paper seeks to link work on visual perception with work carried out examining the role of fractal analysis in the field of urban design – specifically to the assessment of visual variety in everyday street scenes.

As the focus of this experiment is the relationship between fractal dimension and urban design it is important to note that the unit of focus is the street as a whole. Urban design is concerned with the overall impression of places, recognising that people’s experience of urban places is not static but dynamic. Cullen (1961) describes the experiences of place as serial vision i.e. that we experience places as we move through them. To this extent the case material examined will be focused on trying to assess lengths of street rather single snap shots of static spaces.

The use of fractal dimension in relation to urban development has already been investigated by a number of authors. For example Cooper (2000 and 2003), Heath *et al* (2000) and Oku (1990) have used fractal analysis to assess the complexity of urban and natural skylines. Cooper (2005) has examined the fractal properties of street edges. Cooper (2000), Mizuno and Kakei (1990) and Rodin and Rodina (2000) have investigated the fractal characteristics of urban street networks. A number of authors have examined fractal dimension in relation to urban structure and planning, for example Batty (1995), Batty and Longley (1994a,b), and Frankhauser (1994). In urban design Cooper (2000) and Robertson (1992, 1995) have looked at fractal dimension in regard to urban design qualities and urban character. Li (2000), Ricotta (2000) and Schmidt (2000) have investigated the use fractals in the evaluation of landscape features with regard to habitat and species distribution. In the area of landscape design, authors such as Brodie (1996) have used fractal patterns as design inspiration. In architecture Bechoefer and Bovill (1995) and Bovill (1996) have investigated the use of fractal dimension both in evaluating buildings and as potential design generators, while Jencks (1995) discusses the potential of fractals in architecture as the inspiration for a new design theory. However, there is very little work evident that links the resultant fractal dimensions of these urban design elements with the human perception of the places for which they are calculated.

In relation to human perception of place, Hagerhall *et al* (2004) identify a number of authors (such as Kaplan, Kaplan and Wendt, 1972; Kaplan and Kaplan, 1982, 1989; Purcell & Lamb, 1982; Herzog, 1985, 1987; Kaplan 1987) who have examined human visual perception through investigations of preference and other experiential studies and carried out multivariate statistical analysis to identify underlying physical elements that affect notions of preference. With regard to evaluation using fractal techniques several authors (such as Akks & Sprott, 1996; Taylor, 2001; Taylor, Newell, Spehar & Clifford, 2001; Spehar, Clifford, Newell & taylor, 2003; and Richards, 2001; Hagerhall, Purcell & Taylor, 2004) have also written attempting to calibrate levels of fractal dimension with levels of visual preference. But as Hagerhall *et al* (2004) write:

"…while this research has advanced knowledge in the area, the physical attributes identified are fuzzy…..Another difficult issue is how to accurately classify the large majority of our everyday environments that are in fact mixed scenes…..containing both built and manmade objects and vegetation" (p.247).

Taking its inspiration from the above authors, this exploratory paper examines the fractal characteristics of a series of photographic images representing a series of vistas or serial vision along a selection of everyday streets. Its main aim is to show how the calculation of fractal dimension might be carried out for a series of everyday street vistas and how the resultant numerical measurement might be related to the perception of the urban design quality of visual variety in those vistas – and by implication to the overall impression or character of the represented streets. Visual variety is defined here as the level of visual experience offered to the user as indicated by the degree to which the subject (in the case of this paper, a street) varies in terms of its visible textures, sizes, styles, materials, and surface changes. For example the image of a uniform height, plastered, white painted, wall, with a uniform degree of lighting across its surface, would rank as having a lower level of visual variety than a wall of varying height, painted in two colours and containing two windows.

Differences between a set of streets are quantified using fractal dimension as an illustration of how changes in physical character can be collapsed and recorded in a single number that might subsequently allow quick comparison to be made between places. Assessments are made of each street in relation to their characteristic level of perceived visual variety. The two data sets are then compared using ANOVA and correlation techniques. The intention is to assess the potential of using the box counting measurement method of calculating fractal dimension in gauging the perceived level of visual variety in a series of street vistas.

The paper first presents a short description of fractal dimension, followed by details of the method used to assess street vistas both in terms of their fractality and levels of perceived visual variety. It presents an analysis of the resultant fractal values and indicators of visual variety and derives some conclusions in terms of the association between fractal dimension and perception of visual variety at everyday, residential street level.

2. Fractal geometry.

Modern geometry is dominated by the concept of things as one, two or three-dimensional. A line has one dimension, length; a plane has two dimensions, length and width; a cube has three dimensions, length, width and height. This is fine for describing objects or shapes that are regular, but Mandelbrot (1977) argues that most of the ‘natural’ world, and it is suggested here much of the built environment, which in combination is inherently irregular, cannot be properly described using the concepts of only 1, 2 or 3 dimensions – Euclidean geometry. Mandelbrot (1977) derived the term "fractal" from the Latin verb “frangere”, "to break", and the adjective “fractus”, meaning irregular and fragmented, and used the term to describe objects that where not necessarily just irregular, but that demonstrate repeating patterns when examined at increasingly smaller scales - that demonstrate ‘scale invariance’ or self similarity. It is this appearance of self similarity that is quantified by the concept of fractal dimension.

2.2 Fractal dimension.

All fractal objects have in common the notion of fractal dimension: this enables the degree of irregularity of an object or pattern to be measured and represented as a number. The fractal dimension is represented as D and lies between the Euclidean dimensions of 1, 2, or 3. For example the fractal dimension of an irregular line representing a coastline would lie between 1 and 2: it is not a simple straight line, that would have only one-dimension, but it is also not a fully two-dimensional plane. The fractal dimension lies between the two and is represented as a non-integer number, whereas Euclidean dimensions are integers. Essentially, fractal dimension is a measure of how well a particular object fills the space in which it is drawn. Figure 1 illustrates the concept in relation to irregular 'dusts' or textures extracted from the photographs of street scenes used later in this paper, and shows how increased complexity and density of texture can be represented numerically (D). The texture is the set of white pixels in each image.

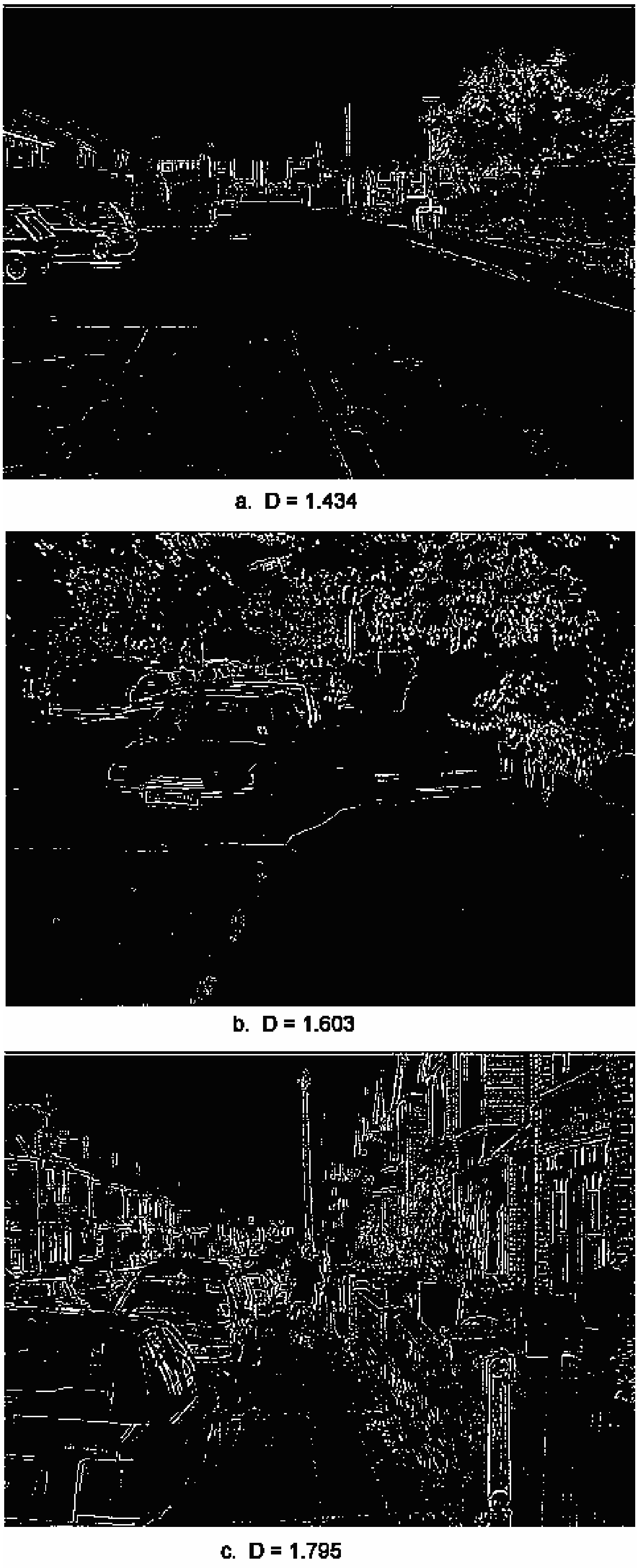

Figure 1. Fractal dimension (D) in relation to textural complexity and density.

Texture ‘a’ has a fractal dimension of 1.434 and is the least complex and least dense texture of the three examples. Texture ‘b’ has a greater degree of both complexity and density with a correspondingly higher D value at 1.603. Texture ‘c’ exhibits a further degree of complexity and density still and has a D value of 1.795.

The key to understanding fractal dimension is in the relationship between measured length and measurement scale and there are a number of methods that can be used to characterize the fractal dimension of irregular, deformed or rugged shapes. All the methods attempt to identify a correlation between measured size (length, surface or volume) and scale, by observing how length, surface, or volume increases in relation to measurement using smaller and smaller scales. The technique that will be used here and that is the most appropriate for evaluating textures or dusts is the “box counting” method, where the size of each “box” on a grid indicates the measurement scale used.

The box counting method superimposes a series of grids over the subject. The size of the grid squares (equivalent to the scale used for measurement) is recorded as d and the number of squares containing some of the subject i.e. a white pixel in this case, are counted and the resultant total is represented as N. The number of squares counted containing a white pixel depends on the size of the grid mesh used and so N is usually represented as $N(d)$, so as to ensure that the relationship between scale and number is maintained.

The mesh size d is progressively decreased and the resultant numbers of squares containing part of the subject are recorded. In its simplest form the box counting method employs a series of grids set at a number of predetermined sizes (d) to allow measurement at various scales. The various grids are then placed over the subject at each of the predetermined settings and the subsequent total numbers of grid squares that contain detail of the object (*N*) are recorded. The calculations here were carried out using software Benoit 1.3. - a proprietary software package that is specifically designed for the analysis of fractals (Hagerhall *et al* 2004) - where the grid sizes were pre-set to range from 0.25 of the image height (*l*) to 0.03 of the image height (after Koch, 1993). Using a gird size reduction coefficient of 1.3 a series of nine grids were superimposed over the subject images and the number of boxes on each grid that contained a white pixel were recorded.

In order to compare the results of measurement at different scales and subsequently to calculate the fractal dimension it is standard practice to enter the measurements into a double logarithmic graph as the log of *d* (the grid size) against the log of *N*, where *N* is the resultant number of boxes containing a white pixel at each grid size. These log/log diagrams are referred to as Richardson plots, after Richardson (1961). Examination of these plots allows the identification of the image's characteristic fractal dimension. In this paper the calculations of the resultant fractal dimension (D) are processed in Benoit 1.3. and the box-counted fractal dimension is given as the exponent *D* as follows:

$$N(d)=1/d^D$$

remembering that $N(d)$ is the number of boxes at size *d* containing part of the object being assessed across a two dimensional field. If , when plotted on a double logarithmic field, the resultant plot forms a straight line then the data set is fractal and the line will have a negative slope representing $-D$. Strictly speaking the method described here using box-counting gives the box dimension so is written Db.

When calculating fractal dimension in this way a number of cautions need to be noted. First, the resultant fractal dimension is related to observations made over a specific range of scales and relates only to those scales. This makes the selection of a useful measurement scale vital in achieving meaningful results when evaluating different characteristics. For example, it would be of little value to evaluate the facade of a building at scales ranging from 50 meters to microns, it would perhaps be more pertinent to use scales from perhaps 10 metres down to perhaps 0.01metres (Cooper, 2005). Any evaluation of D has to be done at scales that are meaningful in relation to the particular subject. Koch (1993) suggests that evaluation should take place between the parameters of l x 0.25 and l x 0.03 where l is the height of the image being evaluated. In relation to this paper, where 480 x 360 pixel grey scale, photographic images are used as the data source, the evaluation of the subject images takes place over a range from 90 to 10.72 pixels after Koch (1993).

In reality it is improbable that a single fractal dimension calculation accurately captures the character of an object like a building façade measured over a large range, because different regions of the object may have different fractal properties - referred to as multi-fractality. Cooper 2005 records that Batty and Longley (1994a) observed this multi-fractality in the urban boundary of Cardiff. Koch (1993) also illustrates this with the example of the coast of Great Britain, where the east coast is less rugged than the west coast because of differences in the degree of exposure to weathering and differing geology. Both areas display differing fractal dimensions; the overall fractal dimension is therefore an intermediate between the two, perhaps hiding interesting or significant detail.

3. Calculation of street vista fractal dimension.

This section details the experiment undertaken to examine the relationship between fractal dimension and perceived visual variety in a series of everyday street vistas. The overall method is to select a series of photographic images that are first assessed in terms of their fractality and then in terms of their perceived degree of visual variety. The case selection is first introduced and then details of the fractal survey are presented followed by details of the subjective survey. Finally the results of the two assessments are compared.

A series of ten photographic images were taken from each of twenty-six randomly selected, residential streets in Oxford, UK, giving a total of 260 images. The vistas were selected at approximately fifteen metre intervals as a serial vision sequence representing a walk of 150 metres along each case street - in order to give an overall impression of the street along its length.   The images where captured using a normal 50mm lense, giving an image size of 480 x 360 pixels, at a standardised view height of 1.63 metres.

3.1 Fractal survey of street vistas.

This sub-section develops and assesses an experimental technique for using the box counting method of calculating fractal dimension (Db) to investigate the characteristics of the vistas along the series of 26 streets.   The objective is to assess the potential of employing the box counting method of fractal dimension calculation in assessing whole pictures of street scenes as fractal textures, in effect trying to gauge the full complexity of a scene, as represented by a two dimensional image. This is carried out in order to explore later relationships between the level of fractal dimension and the subjective judgement of the vistas in relation to levels of visual variety present in that street scene. The method, calculation parameters and techniques are firstly explained, then the Db values for the case streets are assessed.

3.2 Fractal assessment method.

A review of relevant literature illustrates that the fractal assessment of photographic images is an accepted method of evaluation. The persistence of scale invariance and the calculation of fractal dimensions in photographic images of natural scenes has been highlighted by a number of authors; Pentland (1984) suggests using fractal analysis techniques to perform image texture classification; Peleg et al (1984) and Vuduc (1997) examine the use of fractal dimension in identifying image texture segmentation; Sato et al (1996) developed a technique for assessing the fractal characteristics of binary i.e black and white photographic images of natural scenes and medical tissue samples; Ruderman (1997) identifies the presence of scaling in natural images; Yang & Purves (2003) found scale invariant distributions of distances in images of natural scenes.

The work of Sato et al (1996) is of particular interest to this research as it is devised to reduce the processing time taken when carrying out fractal analysis of photographic images. The method assesses the fractal characteristics of binary, edge detected, images rather than attempting to assess a full colour or even a grey scale image. In order to check the validity of their method they compare their assessments of the fractal characteristics of a Sierpinski Gasket, a scene of a rocky shore line, an image of clouds and a colorectal cancer image with results obtained using both the theoretical fractal dimension of the Sierpinski Gasket and the fBm method (Mandelbrot, 1982) applied to the other images. They found that the resulting values were consistent and concluded that *"using the binary data is enough to calculate the* *fractal dimension…and that the 256 grey levels of data is not required"* (Sato et al 1996, p467)

After further examination of Rosenfeld and Kak's (1976) work on digital image processing it was decided to use the data reduction method employed in the assessment of both natural and medical images developed by Sato et al (1996) in calculating the fractal dimensions of the street images used in this paper.

In order to obtain fractal dimensions each street image was subjected to the following transformation sequence taken from Sato et al (1996, p464).

1. Each full colour image was separated into red, blue and green components having 256 grey levels for each pixel.
2. The green component images are then used as they carry more information regarding brightness and have better contrast than the others (Sato et al, 1996, p464).
3. The green component image is then transformed into a grey scale image.
4. Each image is then subjected to the common gradient operator for edge enhancement (Rosenfeld and Kak,1976) - using PaintshopPro 8.0.
5. The edge detected image is then converted to a binary, black and white, image which is then imported into Benoit 1.3 where it is box counted. Figures 2a and 2b, illustrate part of the process.

Figure 2a Argyle St (SVP1.2) Grey scale image

Figure 2b Argyle St (SVP1.2) binary, edge detected image - that was subjected to box counting in order to calculate its fractal dimension. Fractal dimension = 1.783

Each of the 260 images was firstly transformed and was then box-counted in Benoit 1.3. On completion of the measurements, approximately twenty images showed anomalous results, in that the Db values were very low compared to the norm. Closer examination of the images affected revealed that they were all slightly out of focus, fuzzy and in some cases over exposed. These poor quality images were removed from the set resulting in a total set number of 240 images.

3.3 Individual vista Db.

Figure 3 shows the Richardson plot for the image SVP1.2, Argyle Street. The plot shows a total of 18 points with the first nine identified as the region used to calculate the Db for this and all the other case streets. The extent of the plot presented in figure 4.0 clearly shows that the photograph of Argyle Street is multi-fractal. Three distinct parts can be identified on the plot relating to three scale ranges where different fractal dimensions can be recorded. In order to decide where on the plot the most accurate fractal dimension would be found for this data set, the standard deviation of residuals for each distinct range on the plot was examined. Benoit 1.3 allows individual points on the plot to be turned on or off and the resultant fractal dimension to be observed. Most usefully the software also indicates the standard deviation of residuals around the remaining points, thus enabling the accuracy of the resultant fractal dimension to be gauged. It was found that the fractal dimension calculated when using the grid size parameters of maximum grid size = *l* x 0.25 to minimum gird size = *l* x 0.03 (after Koch, 1993), where *l* is the height of the image, produced the most consistently low standard deviation of residuals. In terms of the accuracy of the Db - and the safety of using this particular Db set - the mean value of the standard deviation of residuals calculated for all 240 Richardson plots was only .0068 and is considered small enough for this Db set to be used as the representative fractal dimension for the image set.

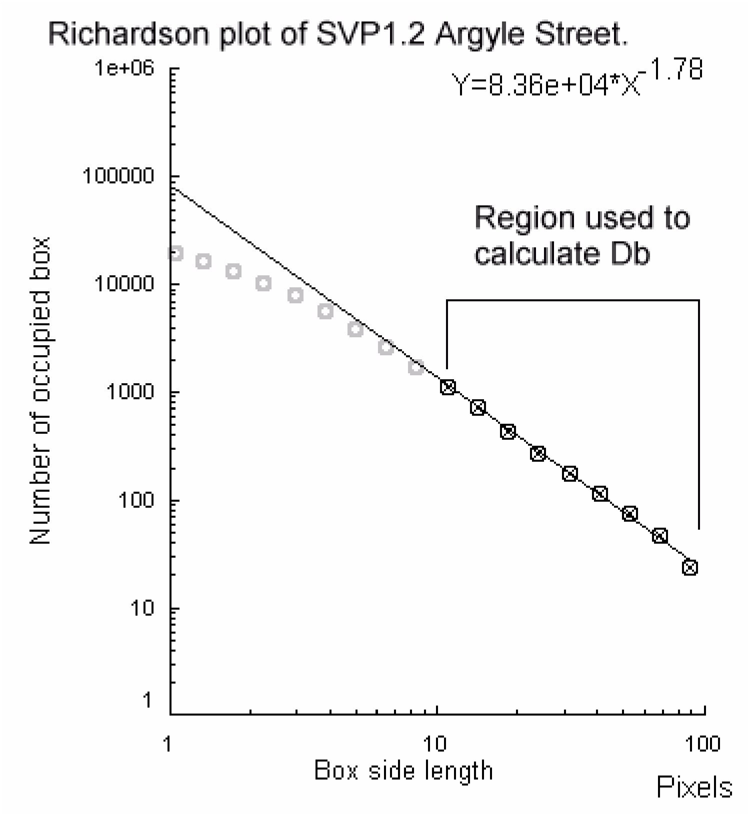

Figure 3. Richardson Plot of image SVP 1.2 Argyle Street.

As a final check on the accuracy of the selected Db set and as a means of checking on possible distortion due to image size, 30 randomly selected images where enlarged by a factor of two, to 960 x 720 pixels, and their fractal dimensions recalculated using parameters of grid sizes between *l* x 0.25 and *l* x 0.03. The resulting fractal dimensions where the same as those calculated for the smaller image sizes. It was therefore decided to maintain the original image size of 480 x 360 pixels. This also had the advantage of maintaining a small file size and reducing computer processing time. The resultant Db values for the 240 individual images range from 1.434 (Figures 4b) to 1.825 (Figure 5b).

Figure 4a Warberg Crescent (SVP23.04) greyscale image

Figure 4b Warberg Crescent (SVP23.04) binary, edge detected image - has the lowest fractal dimension of the set with Db of 1.434.

Figure 5a Park Town (SVP17.02) greyscale image

Figure 5b Park Town (SVP17.02) binary, edge detected image - has the highest fractal dimension of the set with Db of 1.825.

Assessing the homogeneity of fractal dimensions

The homogeneity of fractal dimensions, between the 26 streets, has been assessed by ANOVA test shown on table 1.0. The test rejected the homogeneity of the fractal dimensions with p-value <0.001. This means that the fractal dimensions are significantly different between streets at any significance level; collectively the fractal dimensions have identified at least 7 different homogenous subsets (i.e. the 26 streets can be categorised into 7 different categories based on their fractal dimension level).

	Sum of Squares	Degrees of freedom	F-test	p-value
Between Groups	.666	25	9.039	.000
Within Groups	.654	222		
Total	1.320	247		

Table 1. Fractal dimension ANOVA

In terms of identifying what the Db values relate to, an examination of the individual images, ranked in order of fractal dimension, leads to the suggestion that it is primarily a function of the amount of vegetation, visible building, sky, and open space - modified in some instances by shadow, view length and level of foreground detail. Vertical emphasis of building detail, railings, windows, bays, bows and projections such as porches etc, seems to raise Db. Vertical emphasis seems to concentrate texture, particularly when viewed obliquely. All these features appear to influence the 'texture' of the processed edge detected images.

4. Subjective survey.

In this second subsection, the original grey-scale photographic images from which the fractal dimensions were extracted are exposed to a subjective survey of people's perception regarding the degree of visual variety (VV) contained in each set of images. As the aim of the exercise is to explore the potential link between urban design and fractal geometry, a methodological decision was taken to use the terminology of current mainstream urban design as a means of facilitating this exploration. This decision has an important implication, as in order to facilitate the potential of linking the urban design quality of visual variety with fractal geometry, a sample of people with prior knowledge and common understanding of urban design terminology had to be identified and used. It is felt important to state here that the research does not seek to test how clearly the non-designer (”the public” for instance) understands this terminology, although this could be an interesting extension of this research.

Combined with the need to have access to a sufficiently large pool of respondents, this requirement to use “experts” lead to the utilisation of 31 urban-design students and staff from the Joint Centre for Urban Design at Oxford Brookes University, Oxford, UK. The selection of urban design experts as the participating sample leads to questions of inherent bias, in that the participants are not representative of the general population. However the purpose of this survey is not to make observations in regard to a wider population but to make comments within the sphere of urban design. As such, it is considered valid to use the “expert” group as the basis for a purposive sample, but with the recognition that generalisations about the implications for the wider public may be made only tentatively from the results (Dixon et al 1987, p139).

As the respondents were being asked to provide subjective comments regarding the urban design quality of visual variety, it was considered most appropriate to ask them to provide ordinal data - people or events are ordered or placed in ordered categories along a single dimension. The continuum or dimension in this case would be the degree to which the particular quality was perceived by the respondent to be present in the case-study material.

A perceptual recording system was identified based on a technique developed by Oku (1990) for comparing and ordering distant skylines. Prior to executing the actual survey a pilot exercise was carried out to check the practicality of the method, time involved and logistical arrangements. The pilot exercise involved 20 participants. As a result of the pilot exercise a comparative scoring system was developed and used with values from 1 to 6, where six indicated the highest score for perceived levels of visual variety. In the event of two or more images having a tied score participants were asked to provide a decimal sub-score (for example 5.1, 5.2, 5.3) indicating the high to low values. The scoring technique of firstly identifying the highest and lowest value images and then scoring the others in relation to them was given as an instruction. This had the advantage that the participants were establishing their own internal scoring range.

To allow a relatively easy comparative ranking, protected from external distractions, it was decided that a screen or wall mounted, paper-based, static display, where each case could be examined and compared simultaneously, would be the most practical option. Static photographic displays showing 26 sets of 10 grey scale images presenting serial views along the case study streets were used on four separate occasions. In order to minimise the potential for researcher bias in relation to the order of presentation, the photographic material was randomly shuffled before mounting on display boards to ensure that the material was presented in a different order on each occasion.

The participants (31) where invited to examine the case material on one of four occasions, resulting in four groups of seven or eight people viewing the material simultaneously each time. The photographic display was positioned in a large room in full natural light, between 2.00pm and 4.00pm, on mid-week days, during the summer months. Respondents took an average of 20 minutes to complete the exercise. Respondents were not allowed to confer during the exercise. The researcher was present in order to clarify instructions only. Refreshments were available and the respondents were instructed to take a break as they felt necessary. No reward was made for participation. The survey-respondents were each asked to score the image sets by relative level of visual variety based on the following written and verbalized definition: *'Visual variety relates to the level of visual experience offered to the user as indicated by the degree to which the subject varies in terms of its visible textures, sizes, styles, materials, and surface changes. For example the image of a uniform height, plastered, white painted, wall, with a uniform degree of lighting across its surface would rank as having a lower level of visual variety than a wall of varying height, painted in two colours and containing two windows. Visual variety, for the purposes of this exercise, relates to the urban design qualities of both richness and distinctiveness'.*

The participants were asked two questions in relation to the 26 sets of images: i) Do you feel it is possible to rank them according to their relative degree of visual variety? (all respondents answered positively) and ii) Indicate the relative degree of visual variety for each set of subject street images in comparison to all the other sets of images. The second question was carried out in relation to the 6 point scale described earlier.

Prior to scoring the images for each street, in order to offer the participants a degree of 'practice' and allow the researcher to clarify any issues of definition, the participants were first asked to score a series of abstract images. The abstract images used were generation sequences of Serpinski triangles and Serpinski gaskets. All respondents felt able to comment on the visual variety of the abstract shapes. A significant number of respondents agreed on the levels of visual variety represented in these different 2D patterns and there were no significant variations in terms of gender, age or nationality.

Assessing the Demographic effect of the responders

In order to assess the demographic (sex, age and nationality) effect of the responders to the street images more fully the average recorded level of Visual Variety (VV) of each individual over all 26 streets was tested for possible sex, age, and nationality effect using a t-test, a test for correlation coefficient and an ANOVA test respectively. All three tests are non-significant with p-values of 0.301, 0.379 and 0.829 respectively. This means that the perception of VV does not depend on sex, age or nationality and hence the analysis is not affected by this kind of sample selection bias.

Assessing the homogeneity of Visual Variety perception

The homogeneity of people's perception of all VVs, between the 26 streets, has been assessed by an ANOVA test as shown on table 2. The test rejected the homogeneity of the people's perception with p-value <0.001. Not surprisingly the test suggests that there are at least 6 different homogenous subsets. This means that all responders collectively and significantly (at less than 1% level) identified different levels of VV between streets; they have identified 6 different homogenous subsets of VV (i.e. the 26 streets can be categorised into at least 6 different categories based on the perception of VV level).

	Sum of Squares	Degrees of freedom	F-test	P-value
Between Groups	624.672	25	18.662	.000
Within Groups	1036.329	774		
Total	1661.001	799		

Table 2 Visual Variety ANOVA

Figure 6. Hurst Rise Road (SVP11) attracts the lowest visual variety scores.

Figure 7. Park Town (SVP17) attracts the highest visual variety scores.

A visual examination of the subject streets suggests a number of reasons for their categorization. First, the scores appear to reflect the degree to which the whole street can be seen in the first shot. The lower ranks reveal the whole street from the first image in the series. The images of the higher ranks suggest that the streets carry on, and that further detail will be incrementally revealed.

Degree of enclosure appears to be a factor. Hurst Rise Road (SVP11), Figure 6, presents the most open view of all the case streets, it is one of only two cases to include bungalows, and these are set 9 to 10 metres back from the public footpath in private gardens. The buildings lining the street are only glimpsed and the low walls and hedges bounding the front garden space dominate the view. It is also the street that presents the most distant views. This contrasts with Park Town (SVP 17) in Figure 7, where the view is foreshortened, the buildings are higher, more prominent, with a greater amount of mature vegetation and more strongly defined edges. Both extremes seem to demonstrate markedly different levels of enclosure. Park Town (SVP 17) also demonstrates a higher degree of visible building detail; it is the most sinuous of the case streets and moves from a vegetation-dominated scene to a building-dominated scene. The respondents also appear to be gauging the level of repeated similarity in the images and the grain of visible building/plot width appears to influence the ranking position. All the top examples from rank 21 to 26 have a finer, narrower grain of building frontage with a higher degree of detail, indentation and roofline than the larger plot of the lower ranks.

In summary, at the extremes, the lowest ranked cases are those with;

1. most open views;
2. lowest defining edges;
3. least visible building edge;
4. most open skyline;
5. lowest level of building detailing.

The highest ranks;

1. are the most enclosed;
2. have highly visible buildings with mature vegetation;
3. have narrow plot frontages;

4. contain a high degree of facade detail or roof line variety.

These features are similar to those observed in relation to differences in the fractal dimension of the street vistas. This initially suggests that there may be a positive relationship between the fractal dimension (Db) and the subjective visual variety scores (VV) for the case streets. Lets us now explore this hypothesis.

5. Assessing the association between VV and fractal dimension

The important question is how strongly VV and fractal dimensions are associated? We can assess this association in two different ways; i) treat the responses of all participants at once and assess the homogeneity of the VV levels between categories identified by fractal dimensions using ANOVA; ii) assessing the correlation between average VV scores and average fractal dimension scores for each street.

5.1 ANOVA method

The ANOVA test presented in table 3 shows strong association between VV level and the categories identified by fractal dimension, homogeneity or no association between VV and categories of fractal dimension is rejected with a p-value of <0.001

	Sum of Squares	Degrees of freedom	F-test	P-value
Between Groups	512.906	6	59.045	.000
Within Groups	1148.095	793		
Total	1661.001	799		

Table 3. Visual variety and fractal dimension category ANOVA

5.2 Correlation test

Assessing the correlation between average VV scores and fractal dimensions scores for each street suggest that there is strong association between these two measures. Both parametric (Pearson correlation) and non-parametric (Spearman's rank

correlation) tests are showing strong positive associations of 0.822 and 0.893 respectively. Both (2 tailed) tests are highly significant with p-value <0.001.
Both the ANOVA and correlation analyses suggest that there are strong positive associations between the VV level and fractal dimension. The higher is one measure the higher is the other measure. In other words pictures that were identified by people as informative about a street are also identified by fractal dimension as informative and vs. versa.

In terms of the visual variety of everyday urban vistas it is felt safe to say that Db can be used as an indication of the relative level of visual variety found in a streetscape. The association between the two data sets is strong. The tests carried out indicate that a high degree of Db, approaching the 1.7 plus mark, indicates a street with a relatively high level of perceived visual variety. At the opposite end of the scale a street with mean Db below 1.5 will be regarded as having a relatively low level of visual variety. In the case of street vistas, Db seems to produce a synthetic quantification of complexity.

6. Conclusions.

This paper has applied the calculation of fractal dimension to a series of grey-scale images of everyday streets and in doing so has developed comments made by Haggerhall *et al*. (2004). Additionally it has attempted to link urban design and visual perception by using the calculation of fractal dimension to gauge the level of visual variety represented in photographs of urban streets.

From the results observed it is suggested that Db can be used to record subjective judgements in terms of a street’s characteristics. Fractal dimension gives a good indication of the level of variety judged to be characteristic of a street. This is possible because the textures measured using the box counting method of fractal calculation are produced by the extraction of detail representing the physical make up of each street – buildings, vegetation etc; and it is these same physical details that are used by people in making judgements of visual variety. However, further work is needed to improve the calibration of the fractal measurements and to further identify the relationships between D values calculated across different scales and the textural features picked up by the human eye. It is speculated here that the link between D and subjective judgement has something to do with the human eye's ability to pick up edge details – the same edge details that are evident in the black and white box counted textural images. This speculation is now the subject of further ongoing investigation.

This research recorded perceptions of the urban design quality of visual variety but did not ask for those levels to be judged in terms of preference. It would be of interest to repeat the experiment asking for response in terms of preference such as levels of 'attraction' or 'interest' in an everyday street scene. It would also be interesting to move beyond the world of the urban design expert and obtain responses from the wider public, particularly those people who are involved with making design review decisions. Both of these aspects are now being pursued. The value of this is in developing the role of fractal evaluation as another tool that might be of assistance in comparing the visual quality of different everyday street views. This paper demonstrates that it is possible to use fractal dimension to help quantify the urban design qualitative.

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