

A method for the visual analysis of streetscape character using digital image processing

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ABSTRACT: This paper outlines an interdisciplinary approach, utilising architectural knowledge and computer imaging, to develop an analytical tool that describes the visual characteristics of a streetscape. By segmenting a digital image into regions defined by edges, the streetscape can be studied as an arrangement of regions or elements with a particular relationship. Different parts of the street (usually defined by a single dwelling) can then be related to each other to find what similarities, if any, exist at a purely visual level.

The concept of the use of streetscape character as a planning instrument is typically discussed in terms of *imageability* and *spatial configuration* (Lynch 1960 & Hillier 1996). A method is developed in the present paper that outlines the digital image processing techniques used to record dwellings within a locality. The method utilises the Hough transform, an algorithm that provides a global measure of the geometry within an image. This algorithm is conceptually related to visual partitioning within Gestalt psychology as well as to the theory of description retrieval developed by Hillier. The process used to define variables within the algorithm and the way in which images of a streetscape have been collected are discussed. The method developed in this paper indicates that digital image processing can differentiate the visual composition of elements within a streetscape. The method will form the basis for future research concerning the visual characteristics of the built environment.

Conference theme: Computers and architecture

Keywords: streetscape, visual analysis, Hough Transform

INTRODUCTION

Planning authorities use words like *sympathetic*, *compatible*, *historically significant*, *sense of place* or *identity* when evaluating streetscape character. However such descriptions are necessarily subjective and qualitative leading to extensive debate and limited objectivity. Yet, planning authorities throughout Australia use the *character* of a streetscape as one means of determining the appropriateness of a future development for any given site (VicD.I. 2001; DIPNR 2004). In a legislative or policy sense the definition of streetscape, as described in the *Environmental Planning and Assessment Act*, is the character of a locality defined by the "spatial arrangement and visual appearance of built and landscape features when viewed from the street" (Env. Planning Act 1979). For parties in dispute over the affect of proposed building works within a streetscape this definition becomes a critical and potentially costly factor. Such policies and practices signal the importance of determining some measure or dimension that could be used for describing or defining the character of a streetscape. If such a measure could be established from an existing streetscape then future development could be independently assessed against that measure to determine the relative visual or spatial *fit*. While it may not conclude the merits or otherwise of a particular development, it could become part of the decision making processes routinely used by local councils and planning authorities. Part of the purpose of using "objective methods and metric tools" is that they produce data that can be analysed and tested subjectively (Fisher-Gewirtzman 2003), a necessary part of any planning process. However, the task of identifying the

visual or spatial attributes of a streetscape has proven problematic (Alexander 2003). With a reliance on expert evaluation, the analysis of a streetscape is essentially an individual's interpretation of what appears to be visually significant. Without a consistent approach within and between localities, the information derived about the character of streets and neighbourhoods lacks an objective basis for the discussions of a developments appropriateness that will follow (Alexander 2003). This paper posits that the application of image processing using mathematical algorithms is one possible way of describing the visual attributes of streetscape character. Image processing relies on segmenting an image into its constituent elements, the size of which depend on the scale at which the grouping of elements will be useful (Gonzalez 1992). The segmentation process generally relies on assessing intensity values within the image on the basis of discontinuity and similarity (Gonzalez 1992). The present paper describes the background research undertaken towards an investigation of the visual elements within a streetscape and the early stages of the development of an analytical method for streetscape imageability. The paper accepts that streetscape character cannot be easily distilled into a single measure but still works towards an improved comparative method of analysis that would be useful for design assessment within local government development control plans. Cultural and social dimensions of streetscape character have been observed as an important part of how one locality is distinguished from another (Green 2000), but a tool that identifies the visual characteristics of a streetscape might allow these subjective dimensions to be discussed as they relate to the built form. Ultimately such a tool would also contribute, as Lynch observed, to

the creation of more legible and psychologically satisfying urban environments (Lynch 1960). In the following three sections the paper outlines:

- Key theories of visual character and streetscape,
- Techniques used to analyse urban space and streetscapes in particular and
- The method being developed by the present authors.

1. KEY THEORIES OF VISUAL CHARACTER AND STREETSCAPE

1.1. The Visual Characteristics of a Streetscape

The character of a street, or its *genius loci*, is a unique and distinguishing quality that differentiates one place from another (Norberg-Shulz 1963). From the perspective of a resident, it can represent a collective identity (Smith 1997) and be valued for more than its purely functional quality would suggest. Part of this value is found in the meanings local communities attribute to features or elements within the street. This process is further complicated by the community's tendency to attribute value not just to singular elements but to the combination of diverse elements which contribute to the overall character of a locality (Hull IV 1993). Moreover, interpreting the meaning of such elements and their significance within the street is inevitably difficult because each individual will interpret them in a different way. Individual's from different social and cultural backgrounds will necessarily value the visual and associated emotional or phenomenological characteristics of place differently (Craglia 2004). Despite such complications, these streetscape elements are valued for a range of reasons including their ability to differentiate one place from another, define boundaries between spaces or help create a strong image of a particular area (Hull IV 1993) (Brown, 1987). This is why various scholars have attempted to come to an understanding of the way in which the visual character of a locality is constructed. In an early study into this topic Kevin Lynch hypothesised that even if each individual necessarily creates a mental image of a streetscape that must be, in some way, different from any other individual's image, there must nevertheless be some similarities. The assumption that some collective qualities must exist is in part supported by the proposition that the majority of people experiencing a particular city street or park must have shared some experiences in order for them to enter and use the space, and live in close proximity to it. Lynch showed that such resonances do actually exist and that these are, in part, a result of similar interactions between the physical reality of the space (street, park or square) and our basic human physiology (Lynch 1960).

The presence of common or shared meanings in the image of a streetscape suggests that it is possible to create or design environments that will be used and experienced by many people in comparable ways (Lynch 1960). From this research Lynch developed the concept of *imageability*; an ability for the shape, colour and arrangement of elements within an urban environment to evoke a strong image for an observer. Imageability is related to streetscape character in the way in which both are concerned with the visual arrangement of elements within the environment. Where Lynch shows how a city can be expressed diagrammatically as the combination of elements that differentiate parts of the urban fabric (Lynch 1960), streetscape character analysis attempts to do this at a much finer scale (DIPNR 2004). This is because streetscape character is specifically shaped by the boundaries between the elements that constitute the

street wall or façade, and how those elements relate to each other in patterns that are consistent within a specific streetscape (Kropf 1996).

Various scholars have independently concluded that the amount of perceived complexity within a streetscape is an important variable that determines whether or not a person might find it appealing (Imamoglu 2000) (Rapoport 1990) (Berlyne 1974) (Stamps III 2003). Environments which are either highly complex or monotonous have been shown to be least preferred by people, while those environments with a moderate level of complexity are the most preferred (Berlyne 1974) (Rapoport 1990). While the purpose of our study, which includes streetscapes within the Newcastle and Sydney regions, does not attempt to determine what level of complexity might be more desirable for any locality, an important consideration for the described method is to understand that the perceived complexity of the streetscape may affect its character. Rapoport has identified important factors which can influence visual complexity within a streetscape, they include; the proximity of the private space to the public domain, its perceived security, the amount of natural sunlight, the time of day, the number of pedestrians and cars, the type and amount of street trees. Significantly, some of these variables will play a greater role in creating streetscape character than others. For example, houses in urban areas will be strongly influenced by their proximity to pedestrian pathways, vehicles and driveways. In contrast, in suburban streets where the houses are visually detached and setback from the street edge by low lying gardens, such factors will be less important. Whatever the visual qualities of the streetscape may be, they need to be considered as part of its visual complexity and must necessarily be assessed (Alexander 2003; DIPNR 2004). Detailed architectural research into visual complexity has suggested two strategies for assessing complexity. The first involves *patterns of ambiguity* and the second, *patterns formed by elements within the environment*.

Visual ambiguity, which is associated with *complexity of meaning*, results from the juxtaposition of the physical reality of an image and what it appears to be (Venturi 1966) (Rapoport 1990). The associational qualities that may exist within an element and their relation to each other, reveal the multiplicity of meanings that can be elicited from a streetscape. However, while there appears to be less variance in associative meanings within traditional societies (Rapoport 1990), the sharing and predictability of meanings in modern Australian streetscapes is highly idiosyncratic (Boyd 1968) and difficult for planning authorities to articulate in a meaningful way (Alexander 2003). Despite this challenge, Rapoport argues that analysing the patterns that elements form within a streetscape—as opposed to attempting to understand the meaning that they might have for different individuals—can provide a more useful and sustained analysis (Rapoport 1990).

The perceived number of elements within a streetscape, and particularly the *noticeable differences* (Rapoport 1990) between them, provides a measure of visual complexity. Visual complexity relates to the rate at which usable information is made available to the viewer, or by the rate of change of the *noticeable differences* (Rapoport 1990). Depending on the way that the differences are gradually revealed, the experience of walking down a street might then feel in turn monotonous, surprising or familiar. For instance where the streetscape is visually consistent with very minor variations within it, the differences become *noticeable*

against a *familiar* background and contribute to its complexity. Where there is little noticeable difference, the street lacks complexity and can be considered uniform. Recognising where the noticeable difference forms a boundary of an element should then be an important part of a method for assessing the visual character of a streetscape.

While the visual character of any streetscape will vary when compared with another, planning authorities require that every new development consider its context in terms of its relation to the public space it addresses, which in residential areas is commonly the street (VicD.I. 2001) (DIPNR 2004). Streetscape is defined as either the transition space between the private and public realms or the delineating zone between an individual and society (Fiske 1987; VicD.I. 2001). By understanding that the outside of a dwelling is used differently from the inside, the transition space becomes a spatial record of there coexistence. The public's right to look—and indeed to share symbolic possession through active or passive surveillance—suggests that the owner of a private space has some obligation to provide a public front to their personal dwelling. The streetscape is also the home of a reciprocal relationship wherein the individual owner of a dwelling has some right to view the public and in doing so exert their influence over common space. This realisation affirms the importance of streetscape in debates concerning notions of privacy and separation (Fiske 1987). Thus the relationship between public and private spaces, expressed visually in the complexity of a streetscape, is an important determinant of neighbourhood character (Alexander 2003).

Finally, in most of the research undertaken in the past into streetscape character the isolated building plays only an in-direct role. Certainly the frequency of architectural features (gables, fences, windows) influences visual complexity but the building is just one of many elements in the street. For instance, the *style* of a house may have influenced the organization of elements and spaces in a fundamental way, as a particular structuring of the design problem (Hillier 1996). Yet, it is the assembly and composition of the elements that are of importance in a visual analysis of streetscape, not whether the architecture sustains a trained critical analysis or whether it is historic or modern, good or bad. Every element, no matter how architecturally adept or clumsy, makes a contribution to streetscape and it is the cumulative effect and interrelationship of the elements that gives a streetscape its character (VicD.I. 2001) (DIPNR 2004). In the following section various techniques for the analysis and measurement of the visual quality and complexity of urban spaces are discussed.

2. TECHNIQUES USED TO ANALYSE URBAN SPACE AND STREETSCAPES

2.1. Analytical Methods and Approaches

Any attempts to describe the urban environment requires "a geometry of order on many scales, a geometry of organized complexities" (Batty 1994). Techniques for connecting the urban texture at the scale of the individual, with the urban character of precincts within the city are difficult to find (Ratti 2004). One theory that does appear to be able to make such a connection is *Space Syntax* (Hillier 1984). The proponents of Space Syntax attempt to model an urban system by concentrating on *free spaces* between buildings (Jiang 2000). The shape of the free space is generated by the existence of a defined boundary (Norberg Shulz, 1965);

an interdependent planar surface which can extend from an individual house through to the streets that form cities (Jiang 2000). Using a configurational description of an urban structure, such as a streetscape, Space Syntax attempts to explain human behaviour as it actually occurs in those spaces. Its premise is that the configuration and character of urban space has a major influence on the perception and subsequent conduct of people who use it (Hillier 1996; Fisher-Gewirtzman 2003).

In terms of streetscape, Hillier proposes that configurations of building facades may be viewed as an arrangement of shapes which are orientated "to and away from the ground on which they stand" (Hillier 1996:120). He represents a building's façade as both a "metric tessellation" (which is then investigated to provide a measure of connectivity or "integration") and as a diagram of "the dominant elements in the facade, as a pattern of convex elements" (Hillier 1996:120). Using an example of the façade of a classical temple he shows that both diagrams are visually in opposition, creating a tension that is possibly alluring. For Hillier this is

what the human mind 'reads' when it looks at the form of a building is, or at least includes, the pattern of integration at more than one level, and the interrelations between the levels. (Hillier 1996:122)

The concepts of *information retrieval* (Hillier 1984) and the *gestalt* (Guy 2002) also discuss the way that a visual scene is understood simultaneously as both a relation between elements and as a whole. Thus the processes of visual perception may be embedded within spatial morphology (Turner 2003); or as Hillier claims, *space itself may be the machine*. This suggests that the viewer "may merely need to determine the humanly accessible topology as invoked through the process of inhabitation" (Turner 2003) to determine the merits of proposals within the urban fabric. In this way a measure of the salient geometry or patterns within a streetscape might reveal a topology that is useful in distinguishing character. Instead of increasing the complexity with which the streetscape is visually or otherwise recorded, perhaps a study that could establish a topology or patterns may prove more useful. Turner developed this method specifically as a configuration that could be studied in plan, where agents that assess the visual dynamics of the spatial morphology govern the process of visual inhabitation. This paper maintains that it is possible, in parallel to such an approach, for an analysis of the topology of the streetscape to take place. In such an elevational (rather than planar) approach it is the arrangement of the streetscape elements that are seen as a *configuration*.

An analytical method derived from Space Syntax is the concept of an *isovist*; a set of points visible from another point in space (Batty 2001). Fundamental to the operational use of the *isovist* is the belief that a person's perception of moving through an urban area is related to the shape of the associated open space. However, the *isovist* analytical technique was largely restricted to planar arrangements with no consideration of the volume of the urban space. One exception to this was developed by Fisher-Gewirtzman who considered a three dimensional viewpoint and the volume of visible space as a measure of *spatial openness* (Fisher-Gewirtzman 2003). Unfortunately this method is limited by the considerable computational power required to complete the calculations and the need for accurate three dimensional models of urban areas. Teller, another spatial researcher, similarly examined the three dimensional *openness* of streetscapes and town squares

by creating a two dimensional image from a wide angle view looking vertically towards the sky (Teller 2003). This method, despite its lack of true three-dimensionality, was nevertheless an important step towards incorporating the street elevation within a study.

A small number of researchers have attempted to consider elevational studies in the past. For example, Oku and Cooper have separately attempted to determine the fractal dimension (a measure of complexity) or character of city skylines (Oku 1990) (Cooper 2003). Another related technique places regular grids over streetscape images, either to recognise the boundaries between surfaces (Bovill 1996), or to allocate a value to a particular surface type (Krampen 1979). Generating this for the whole façade, both methods then provided a measure of how boundaries might change throughout the image. An alternative method uses the human eye to separate a streetscape into formal elements and groups of elements. The frequency of the elements can then be considered as a measure of visual diversity (Stamps III 2003) (Malhis 2003). In another study houses within a streetscape were analysed using three scales of decomposition; *overall massing*, *secondary massing*, and *differentiation of elements* such as doorways and windows (Elsheshtawy 1997). Malhis and Elsheshtawy both similarly attempted to segment the streetscape into *meaningful* elements in order to provide an objective measure of the visual character of a street. However both rely on time consuming skilled manual techniques in the segmentation process; a practical as well as possibly a methodological problem.

In an attempt to overcome such problems Ratti used digital elevation models (DEM's) to show how a simple plan of an urban area might be used to store information about a range of variables including height or pollution (Ratti 2004). The method is *computationally lean*, using algorithms that are "independent of geometric complexity and relate linearly to the area under investigation" (Ratti 2004). While not directly applied to the streetscape it nevertheless appears to be a useful way of segmenting an image. One limitation of this method is that much of the *textural* information, which is central to the visual character, is frequently filtered out of the study (Boldt 1989). Hildebrand offers an interesting reflection on this when he maintains that successful architecture results from an abstract drive to impose patterns on surfaces that otherwise appear to be random acts of inhabitation (Hildebrand 1999). These patterns are then the physical attributes of buildings that may make them appealing to us (Schira 2003). The use of digital photography that captures the physical reality of the streetscape, "as viewed from the street" (Env. Planning Act 1979), might then be able to capture its *texture*, a quality that appears overlooked in current image processing techniques.

When the texture of the streetscape is filtered from the processing it may remove significant information used to evaluate its character, particularly as the texture of a surface is one of the "characteristics used to identify objects or visual regions of interest" (Schira 2003) within the image.

3. A METHOD FOR VISUAL ANALYSIS OF THE STREETScape

3.1. Criteria for collecting digital images of the streetscape

The method used for collecting images of the streetscape involved evaluating different digital photography techniques against a number of criteria. When sequences of images using different techniques were processed using edge detection algorithms, comparisons could be made and preferences identified. This process of refinement developed the following criteria outlined in Table 1, which is not complete, but represents the current stage of our research.

3.2 Digital image processing method

The method developed to analyse the streetscape images incorporated algorithms used within robotic research, and in particular those that are able to differentiate and segment the visual environment in different ways (Boldt 1989). These algorithms have been developed to specifically analyse an image of reality such that a computer can make decisions about moving through a particular environment. They may also prove useful for an assessment of the streetscape, as they are sensitive to the cues of a perceptual boundary formed by; colour, texture, level of intensity and contextual information contained within an image (Yang 2004). The strength of this boundary may also be low or ambiguous, but nonetheless may become a *noticeable difference* that is accurately perceived by people within the street (Boldt 1989, Guy 2002). Using the Matlab software package, which provides a matrix orientated programming language and flexibility in the way that pixels within an image might meet a threshold (Ratti 2004), the image processing incorporated the *Hough Transform*. An algorithm which is able to find boundaries in an image where they may not immediately be obvious, including those of a low intensity and those that are discontinuous but of a sufficient *proximity* to be perceived by humans as a continuous edge. For instance the side of a window that is partially obscured by a tree will be considered as a straight line. The Hough transform begins by calculating the angle and magnitude of a possible line through every pixel in the image, as shown in Figure 3.



Source: Tucker 2004

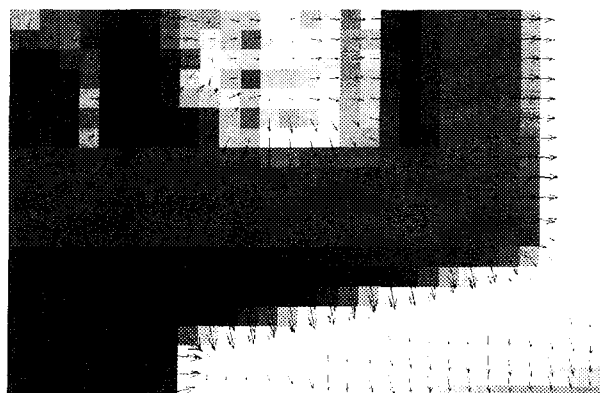
Figure 1: Using the criteria outlined in Table 1, digital images of the streetscape are *stitched* together to form a single image which is then sliced into discrete dwellings. This process represents the streetscape as an elevation and ensures streetscape elements are processed only once.

Table 1: Criteria for taking digital images of the streetscape

| Image Variable | Brief Reason |
|---|---|
| Elevation view of the streetscape | Most closely relates to existing methods of streetscape analysis (DIPNR 2004). Allows refinement of the algorithm with images that have a more regular geometry and allows all streets to be photographed in a way that a proposed development might be more easily expressed. A more perceptual image of the streetscape may become the view from the footpath, a slightly angled view of the street but in the present study this has not been evaluated. |
| Taken from a standing position | Perceptually close to walking within a streetscape, and reflects the definition of a streetscape as a visual field (Env. Planning Act 1979) |
| Viewed from ten metres | Provides a pedestrian experience of the street while allowing a two storey dwelling to be captured without requiring image stitching. |
| Attempt to capture a dwelling in a single image | Particularly for attached dwellings, 'stitching' the images together causes less distortion. Depending on the size of the dwelling this is not always possible, see Fig 1. |
| Focal length of 35mm | To more closely relate to human vision and not distort the view |
| Images taken on a cloudy day | To reduce the affect of shadow distorting the boundary between streetscape elements. |
| Many images taken at one time | For consistency between images of the streetscape, and between different streetscapes. |
| 1 megapixel image size | At this resolution the image contains significant detail, such as the mortar between bricks, and sufficient for the algorithmic processing. Standardising the pixel resolution allows images to be compared with each other more easily |

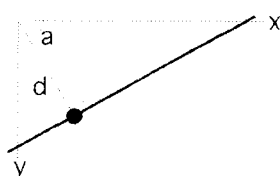
Source: Tucker 2004

Once these values have been calculated, points are then removed if they fall below a particular *magnitude of slope threshold*. This threshold is a variable that can be used to distinguish the *boundaries of the elements* within the image, removing points that are essentially inside an element. The line that passes through the remaining points is calculated as a function of its slope. These lines are then specified by an angle a and a distance d from an origin (see Fig 3). The values are then successively indexed into an accumulator array until all the points within the image have been processed. The accumulator array then identifies significant boundaries in the image as relatively high values. The array in Fig 5 shows these boundaries as white points. The brightest grouping of points corresponding to the most significant lines within the image, and as might be expected with dwelling shown in Figure 4 most points in the array are associated with either horizontal ($a = 0$) or vertical ($a = -90$) lines.



Source: Tucker 2004

Figure 2: Determining the boundaries within a balcony detail within a streetscape. The perpendicular direction and magnitude of a possible line passing through a pixel is indicated by the arrows.



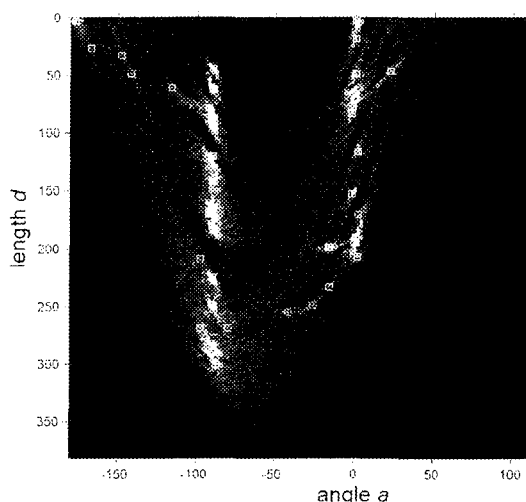
Source: Tucker 2004

Figure 3: The line passing through a point is determined using the angle a and the length d



Source: Tucker 2004

Figure 4: The original digital image of an attached dwelling taken in using the criteria outlined in Table 1.

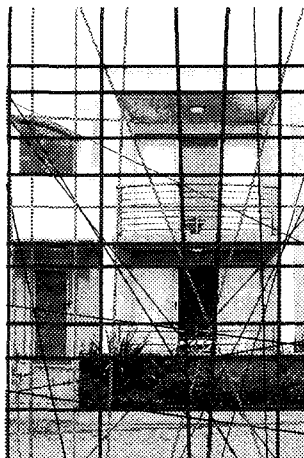


Source: Tucker 2004

Figure 5: The accumulator array for the image shown in Fig 3. The brighter points indicated with boxes are high values or significant boundaries.

Performing an *inverse Hough Transform* calculates the lines represented by these points, and again by thresholding the most significant boundaries, only the dominate lines can be shown (see Fig 5). Performing the inverse of the transformation is used to refine the algorithm, introducing thresholds and other limiting

factors that more accurately define the boundaries within in the original image (see Fig 3). However as the diagram shows lines of infinite length, where the noticeable difference may only exist within part of the image, it may be misleading if understood as a full representation of boundaries within the image.



Source: Tucker 2004

Figure 6: Inverse Hough Transform from the accumulator array, only the significant boundaries are shown as *lines of infinite length*.

3.3 Structuring the streetscape algorithm

The algorithm we are using is progressively becoming more responsive to the particular requirements of streetscape analysis. Table 2 outlines some of the variables within the algorithm and how they have been defined to provide data that is assisting this method of streetscape analysis.

At this stage of the study the digital image processing techniques being used have shown that the visual appearance of the streetscape can be considered as an arrangement of boundaries between elements. While current streetscape analysis techniques similarly rely on the determination of boundaries, the method relies on the individual to establish them. Depending on the values that each brings to such an analysis the outcome lacks a basis for comparing streetscapes and localities with each other. In this way the use of digital processing techniques may in the future provide a tool that can provide a measure of the visual cohesiveness within a street, how different streets form an identifiable visual character and how the streetscape character might vary between different localities.

Table 2: Structuring of the streetscape algorithm

| Algorithm Variable | Discussion |
|--|--|
| Magnitude of slope threshold | If <i>ten pixels</i> each register a slope and position that shows them as being in a line within a <i>one</i> degree angle then the pixel is considered as forming an edge. Both these variables are easily changed |
| Position of the origin | The origin was initially set at the upper left hand corner of the image, meaning that the position of all lines was measured from this point (Fig5 is an example of this origin position). Initially this worked well, as a smaller number of images could be cropped to give a similar relative position of the origin. However with many images being processed at once a method was required that didn't require cropping of each image to maintain a consistent origin. The algorithm was adjusted to allow a mouse click at any point within the image to set the origin. The bottom centre of the private entry is now being used as the origin. This provides the configuration within a facade to be measured relative to the ground plane (Hillier 1996) and also at a point that identifies the threshold between the private and public realms. |
| User interface and dialog box | The computer screen interface provides the user with series of single click options that allow a single or a number of images to be; opened, have the origin assigned, processed by the algorithm, the data to be expressed in three different types of array and an inverse of the algorithm to be laid over the original image. |
| Batch processing | A number of images can be selected at once, batch processed and the outputs saved to a designated folder with related file names. |
| Comparing images with a similar number of pixels | Most images have the same number of pixels, which allows different images to be processed in a comparable way. If an image is processed with a different number of pixels then the algorithm may be adjusted to compensate for a change in pixel number, however this is time consuming and requires programming skills. The algorithm is now able to make adjustments to the number of pixels within the image, making the accumulator array of different sized images comparable. |
| Comparison of data between different images | Methods for analysis of data within the accumulator array include: 1. Subtracting the points within the accumulator arrays associated with different images to establish similarities between images. 2. Considering each array as a pattern based on a rhythm of boundaries, and then comparing each array. The different methods of analysis are attempting to establish outcomes that are similar to the outcomes of traditional streetscape analysis methods (completed by eye and hand). |
| When the lines generated by the algorithm describe an object within the streetscape, such as a tree or a window | If this is to be carried out with reasonable accuracy it will require significant development of the algorithm and will necessarily increase the processing time. The benefits of doing this however are that the numbers of particular objects, their size and position within a streetscape could be accumulated. Such a measure would relate strongly to existing methods of streetscape analysis. The present study however is concerned with the location of the boundaries between elements or the <i>noticeable differences</i> within the streetscape. |

Source: Tucker 2004

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