Developing Computational Image Segmentation
Techniques for the Analysis of the Visual Properties
of Dwelling Facades within a Streetscape
STATEMENT OF ORIGINALITY

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying subject to the provisions of the Copyright Act 1968.

I hereby certify that the work embodied in this Thesis is the result of original research, the greater part of which was completed subsequent to admission to candidature for the degree (except in cases where the Committee has granted approval for credit to be granted from previous candidature at another institution).

Chris Tucker
# Table of Contents

## 1 Introduction

1.1 Significance of the Research ............................................................... 13

1.2 Research Method: The Development of a Computational Tool ............... 16

1.3 Limitations of the Research .................................................................... 17

1.4 Research Method: Data Collection for the Streetscape Analysis ............. 18
  1.4.1 Introduction ...................................................................................... 18
  1.4.2 Data Type ....................................................................................... 18
  1.4.3 Data Recording ................................................................................ 19
  1.4.4 Data Gathering ................................................................................. 20
  1.4.5 Data Processing .............................................................................. 21

1.5 Structure of the research .......................................................................... 22

## 2 The regulatory context and framework for assessing streetscape character 

2.1 Introduction ............................................................................................ 24

2.2 Regulations affecting dwelling design within the streetscape ............... 24
  2.2.1 Diversity versus contextual fit ....................................................... 25

2.3 The Use of a Dwelling’s Style within the Planning Process .................. 26

2.4 Studying Streetscape Character at the Scale of the Dwelling ............... 27

2.5 Methods for Visually Assessing Streetscape Character ....................... 28

2.6 Streetscape analysis using expert evaluation ........................................ 30

2.7 Place-based Qualities of the Streetscape ............................................. 33
  2.7.1 Image-ability of the Streetscape ....................................................... 34

2.8 Streetscape as Text .................................................................................. 35

## 3 Understanding the Geometric qualities of the streetscape

3.1 Introduction .............................................................................................. 36

3.2 The Texture of the Streetscape .............................................................. 36
3.2.1 Composition of elements within the streetscape 38
3.3 The significance of detail within the façade of buildings ........................................... 40
3.4 Analysing visual complexity within a streetscape .......................................................... 41
3.5 Considering the scale of elements within a streetscape ............................................... 45
3.6 Analysis of a streetscape using segmentation .............................................................. 47
3.7 The Analysis of Visual Diversity: A Fractal Method ...................................................... 49
3.7.1 Introduction 49
3.7.2 Box-Counting Method 51

4 Space Syntax and Spatial Configuration 55
4.1 Introduction ..................................................................................................................... 55
4.2 Overview of space syntax .............................................................................................. 55
4.2.1 Isovists, Convex and Axial maps 57
4.2.2 The Façade Isovist 58
4.3 Visibility analysis ......................................................................................................... 59
4.3.1 Three-dimensional Visual Analysis 60
4.4 Topology of urban space .............................................................................................. 64
4.5 Techniques for mapping the streetscape ...................................................................... 64
4.5.1 The use of computer models for planning purposes 65
4.5.2 The use of digital elevation models 66
4.5.3 Laser Mapping 67

5 Method: Computational approaches to Streetscape Image Assessment 69
5.1 Introduction ..................................................................................................................... 69
5.2 Software design of Archimage .................................................................................... 70
5.2.1 Introduction 70
5.2.2 Archimage Software Code: Developing the platform 70
5.2.3 Archimage Software Code: Developing the User Interface 71
5.2.4 Archimage Software Code: Input Screen 72
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2.5</td>
<td>Archimage Software Code: Typical output screen</td>
<td>73</td>
</tr>
<tr>
<td>5.3</td>
<td>Conceptual Approach 1: Image and Colour Segmentation</td>
<td>74</td>
</tr>
<tr>
<td>5.3.1</td>
<td>Overview of the Approach</td>
<td>74</td>
</tr>
<tr>
<td>5.3.2</td>
<td>Limitations of the Approach</td>
<td>76</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Example Process</td>
<td>77</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Discussion and Results</td>
<td>78</td>
</tr>
<tr>
<td>5.4</td>
<td>Conceptual Approach 2: Edge Detection</td>
<td>82</td>
</tr>
<tr>
<td>5.4.1</td>
<td>Overview of the Approach</td>
<td>82</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Limitations of the Approach</td>
<td>83</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Example Process</td>
<td>84</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Discussion and Results</td>
<td>84</td>
</tr>
<tr>
<td>5.5</td>
<td>Conceptual Approach 3: Fractal Dimension Calculation</td>
<td>88</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Overview of the Approach</td>
<td>88</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Limitations to the Approach</td>
<td>89</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Example process</td>
<td>90</td>
</tr>
<tr>
<td>5.5.4</td>
<td>Discussion and Results</td>
<td>93</td>
</tr>
<tr>
<td>5.6</td>
<td>Conceptual Approach 4: The Hough Transform</td>
<td>100</td>
</tr>
<tr>
<td>5.6.1</td>
<td>Overview of the Approach</td>
<td>100</td>
</tr>
<tr>
<td>5.6.2</td>
<td>Limitations of the approach</td>
<td>104</td>
</tr>
<tr>
<td>5.6.3</td>
<td>Example Process</td>
<td>107</td>
</tr>
<tr>
<td>5.6.4</td>
<td>Discussion and Results</td>
<td>107</td>
</tr>
<tr>
<td>5.7</td>
<td>Conceptual Approach 5: Line Count Calculation</td>
<td>116</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Overview of the Approach</td>
<td>116</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Limitations to the Approach</td>
<td>116</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Example Process</td>
<td>118</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Discussion and Results</td>
<td>119</td>
</tr>
<tr>
<td>5.8</td>
<td>Conceptual Approach 6: Polar Array</td>
<td>132</td>
</tr>
<tr>
<td>5.8.1</td>
<td>Overview of the Approach</td>
<td>132</td>
</tr>
<tr>
<td>5.8.2</td>
<td>Limitations of the Approach</td>
<td>133</td>
</tr>
</tbody>
</table>
5.8.3 Example Process 134
5.8.4 Discussion and Results 134
5.9 Conceptual Approach 7: Line Strength Array ...................................................... 137
5.9.1 Overview of the Approach 137
5.9.2 Limitations of the Approach 138
5.9.3 Example Process 139
5.9.4 Discussion and Results 140

6 Conclusions and further work 145
6.1 Findings from the Literature Review ................................................................. 145
6.2 Manifold Learning to detect similarities between processed images ............ 148
6.3 Application of the image processing techniques on a set of similar facades ..... 151
6.4 Further Work ...................................................................................................... 152

7 Bibliography 153
8 Appendix A 161
List of Figures

Figure 1.2-1 Row of houses stitched together from Linwood, Newcastle .............................. 21
Figure 2.6-1 A streetscape analysed using three scales of decomposition .................................. 31
Figure 3.6-1 An illustration of parsing by Krampen ...................................................................... 48
Figure 3.7-1 The fractal assessment of different skylines (Cooper 2003) ................................. 49
Figure 3.7-2 The box counting method illustrated ...................................................................... 52
Figure 4.3-1 A fish eye view of an urban open space ................................................................. 67
Figure 4.5-1 A DEM of a simulated plan view of an urban area .................................................. 67
Figure 5.1-1 Snapshot of robot vision .......................................................................................... 70
Figure 5.1-2 Competing ‘robodogs’ .............................................................................................. 70
Figure 5.2-1 Archimage input screen showing images loaded ...................................................... 73
Figure 5.2-2 The collated output screen from Archimage ............................................................ 73
Figure 5.3-1 Original image .......................................................................................................... 77
Figure 5.3-2 Red Channel ........................................................................................................... 77
Figure 5.3-3 Green Channel ........................................................................................................ 77
Figure 5.3-4 Blue Channel .......................................................................................................... 77
Figure 5.3-5 Hue band .................................................................................................................. 77
Figure 5.3-6 Saturation band ...................................................................................................... 77
Figure 5.3-7 Value band .............................................................................................................. 77
Figure 5.3-8 Grey levels .............................................................................................................. 76
Figure 5.3-9 Interface screen for the colour Classification ............................................................ 78
Figure 5.3-10 Output screen for the colour classification processing ............................................. 79
Figure 5.3-11 Original image ...................................................................................................... 80
Figure 5.3-12 Colour segmentation ............................................................................................. 79
Figure 5.3-13 Outline of the HSCA ............................................................................................. 81
Figure 5.3-14 Colour Segmentation of HSCA ............................................................................ 80
Figure 5.3-15 Material changes along one of the main roads running east - west ...................... 81
Figure 5.3-16 The HSCA with the suburb layout shown in black outline ...................................... 81
Figure 5.4-1 Original image ....................................................................................................... 83
Figure 5.4-2 Detected edges highlighted ..................................................................................... 82
Figure 5.4-3 Determining the boundaries within the balcony of Figure 7.5-1 ............................ 83
Figure 5.4-4 ED - lines greater than 3 pixels .............................................................................. 86
Figure 5.4-5 ED - lines greater than 6 pixels .............................................................................. 85
Figure 5.4-6 ED - lines greater than 9 pixels .............................................................................. 86
Figure 5.4-7 ED - lines greater than 12 pixels ......................................................................... 85
Figure 5.4-8 ED - lines greater than 15 pixels .......................................................................... 86
Figure 5.4-9 ED - lines greater than 18 pixels ......................................................................... 85
Figure 5.4-10 ED - lines greater than 21 pixels ....................................................................... 86
Figure 5.4-11 Original image .................................................................................................... 87
Figure 5.6-20 Inverse HT of modern terrace 1 .......................................................... 111
Figure 5.6-21 HTAA of modern terrace 2 ................................................................. 111
Figure 5.6-22 Inverse HT of modern terrace 2 .......................................................... 111
Figure 5.6-23 HTAA of modern terrace 1 ................................................................. 112
Figure 5.6-24 Inverse HT of a modern terrace 1 ......................................................... 112
Figure 5.6-25 HTAA of modern terrace 1 ................................................................. 112
Figure 5.6-26 Inverse HT of a modern terrace 2 ......................................................... 112
Figure 5.6-27 HTAA for 640 x 480 image ................................................................. 113
Figure 5.6-28 Inverse HT for 640 x 480 image .......................................................... 113
Figure 5.6-29 HTAA for 1280 x 960 image ................................................................. 114
Figure 5.6-30 Inverse HT for 1280 x 960 image ........................................................ 114
Figure 5.6-31 HTAA for Federation dwelling 1 .......................................................... 114
Figure 5.6-32 Inverse HT Federation dwelling 1 ....................................................... 114
Figure 5.6-33 HTAA for Federation dwelling 2 .......................................................... 115
Figure 5.6-34 Inverse HT Federation dwelling 2 ....................................................... 114
Figure 5.6-35 Inverse HT Federation dwelling 2 for image size of 2000 x 2667 pixels.... 115
Figure 5.7-1 ED of modern terrace 1 ........................................................................... 120
Figure 5.7-2 LC of modern terrace 1 ........................................................................... 118
Figure 5.7-3 Boundary length graph of modern terrace 1 ......................................... 119
Figure 5.7-4 Boundary length graph of modern terrace 2 ......................................... 120
Figure 5.7-5 Boundary length graph of modern terrace 3 ......................................... 120
Figure 5.7-6 Overlay of boundary length graph of modern terrace 1,2, and 3 ............ 121
Figure 5.7-7 Boundary length graph of modern terrace 4 ......................................... 121
Figure 5.7-8 Boundary length graph of modern terrace 5 ......................................... 122
Figure 5.7-9 Overlay of boundary length graph of modern terrace 4 and 5 .................. 122
Figure 5.7-10 Overlay of boundary length graph of modern terrace 1,2,3,4 and 5 ...... 122
Figure 5.7-11 Boundary length graph of federation dwelling 1 .................................. 123
Figure 5.7-12 Boundary length graph of federation dwelling 1 and 2 ......................... 123
Figure 5.7-13 Boundary length graph of federation dwelling 1,2 and 3 ...................... 124
Figure 5.7-14 Boundary length graph of federation dwelling 1, 2, 3 and 4 .................. 124
Figure 5.7-15 Boundary length graph for dwelling 1 .................................................. 125
Figure 5.7-16 Boundary length graph for dwelling 1 and 2 ........................................ 126
Figure 5.7-17 Boundary length graph for dwelling 1, 2 and 3 ..................................... 126
Figure 5.7-18 Boundary length graph for dwelling 1, 2, 3 and 4 ............................... 127
Figure 5.7-19 Streetscape A – traditional streetscape ................................................. 128
Figure 5.7-20 Streetscape B – modern terrace streetscape ........................................ 128
Figure 5.7-21 Streetscape C – suburban streetscape .................................................. 128
Figure 5.7-22 Lines within streetscape A ................................................................. 131
Figure 5.7-23 Lines within streetscape B ................................................................. 130
Figure 6.1-4 Reconstructed image 2 ................................................................. 149
Figure 6.1-5 Image of church ............................................................... 150
Figure 6.1-6 Reconstruction 1 ................................................................. 150
Figure 6.1-7 Reconstruction 2 ................................................................. 150
Figure 6.1-8 Reconstruction 3 ................................................................. 150

Glossary of Terms

\( D \)  Fractal Dimension calculated using the box-counting method
DCP  Development Control Plan
HT  Hough Transform
HTAA  Hough Transform Accumulator Array
IHT  Inverse Hough Transform
LC  Line Count graph
LGA  Local Government Area
LSA  Line Strength Array
ML  Manifold Learning
PA  Polar Array
LEP  Local Environment Plan
SEPP  State Environmental Planning Policy
SVM  Support Vector Machine

Acknowledgments

This dissertation would not have been possible without the support of a number of academic colleagues including Dr. Stephan Chalup, Josh Marshall, Michael Chapman and in particular my supervisor and mentor Prof. Michael Ostwald, who has provided my research with direction and rigor for a number of years. I would also like to thank Abbie, Oscar and Max for the support and time they have provided.
Abstract

The relationship between new or proposed buildings and existing urban or suburban settings has, in the past two decades, become an increasingly contentious issue in architectural, planning and public policy forums. Unlike new buildings that are sited within the natural landscape, or those that are visually removed from the public eye, those structures that are added to dense urban and suburban spaces necessarily have a visual impact on neighbouring buildings and the resultant streetscape. The present dissertation is focussed on techniques for measuring the character of existing buildings in urban and suburban spaces as a means of supporting the quantitative assessment of building proposals. The dissertation initially reviews past developments in the field, before documenting the development and pilot testing of a series of computational approaches to the analysis of the visual qualities of buildings and neighbourhoods. The dissertation does not develop these approaches to the extent needed to apply them in practice, or test them in sufficient detail to provide clear evidence for their potential. Instead, the research provides information about the approaches, expected outcomes, preliminary data and discussion of the strengths and weaknesses of each method.
1 Introduction

The present dissertation is focussed on techniques for measuring the character of existing buildings in urban and suburban spaces as a means of supporting the quantitative assessment of building proposals. The dissertation reviews past developments in the field before documenting the development and pilot testing of a series of computational approaches to the analysis of the visual qualities of buildings and streetscapes. The dissertation does not develop these approaches to the extent needed to apply them in practice, or test them in sufficient detail to provide clear evidence for their potential. Instead, the research provides information about the approaches, expected outcomes, preliminary data and discussion of the strengths and weaknesses of each method.

1.1 Significance of the Research

Computer programs, constructed from interconnected mathematical algorithms, are being used in a number of fields – including biology, medical diagnostic imaging, remote sensing, space exploration, defence and security – to understand the visual properties of physical environments. The analysis of the built environment using similar computational processes is a natural extension of this practice and might be used to determine if there are patterns in the visual properties of these environments. Such a computational approach, that is able to consistently analyse the visual characteristics of the environment, might assist the assessment of buildings by planning authorities (Wilson 2005).

The development of such a computational approach is significant because the relationship between new or proposed buildings and existing urban or suburban settings has become an increasingly contentious issue in architectural, planning and public policy forums (Groat 1988). Unlike new buildings that are sited within the natural landscape or those that are visually removed from the public eye, those structures that are added to dense urban and suburban spaces necessarily have a visual impact on neighbouring buildings and the resultant streetscape.

In a legislative or policy sense a typical definition of a “streetscape”, (as, for example, described in the
NSW 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:p36). The visual qualities present in a streetscape are regulated by a range of State Environmental Planning Policies (SEPPs), Development Control Plans (DCPs) and Local Environment Plans (LEPs). If an architect proposes a new building for a street and it fails to meet these requirements, then lengthy and expensive design modifications may be required, or the client may appeal against these rulings in the courts (in NSW the Land and Environment Court fulfils this function). For parties in dispute over the affect of proposed building works within a streetscape, the definition of visual character becomes a critical and potentially costly factor. Such legislative policies and practices signal the importance of determining some quantitative measure or dimension that could be used for describing or defining the visual character of a streetscape. It is only by describing these processes more clearly, can creative solutions be found for new buildings in areas with a well-established street character (RAIA 2004).

Planning documents, including DCPs, use words like “sympathetic”, “compatible”, “historically significant” and “sense of place” or “identity” when evaluating streetscape character. However, such descriptions are necessarily subjective and qualitative, leading to extensive and often vitriolic debate. Yet planning authorities throughout Australia continue to use the character of a streetscape as one important means for determining the appropriateness of a future development for any given site (VicD.I. 2001; DIPNR 2004; London 2008). For buildings to be approved, planning authorities must first assess qualitative aspects of existing urban areas prior to any decisions being made about future additions to the local built environment. Conventional practice in Australian local government organisations is to rely on “expert evaluation” wherein an experienced individual or team draw upon their professional skills, knowledge and abilities to derive an understanding of what is visually significant in a setting. While this approach can derive many important elements it is also potentially

1The term “streetscape character” is commonly used in legal documents and development control plans throughout New South Wales to describe the visual quality of the street. Related terms such as “neighbourhood character” and “neighbourhood identity” are also used in some texts to describe the same qualities as “streetscape character”, however neighbourhood is sometimes used to define the combined character within more than one street. For clarity “streetscape character” is used consistently through the text when it is applied to the character of a street, while neighbourhood is used to describe the character of more than street.
problematic for two key reasons. First, unless the person (or team) is employed for all such reviews and analysis in a region, it is impossible to achieve a high degree of consistency. Second, the information derived about the character of streets and neighbourhoods lacks an objective or transparent basis (Alexander 2003).

Planning authorities have a need for transparent, consistent and objective information about the visual character of dwellings, streetscapes and neighbourhoods when they undertake studies of the local environment (Ellefsen 1990/91). It is also widely understood that the visual characteristics of streetscapes affect social life within the street and are an important way of revitalizing urban areas that are socially dysfunctional (Healy 2004). However, methods that clearly articulate how the visual character of a streetscape might be evaluated and then compared with others are difficult to find. For example, Lillis and Pourmoradian (Lillis 2001) found that techniques currently used for streetscape analysis did not establish the basic information required by planning authorities and community groups for informed decision making about changes to the streetscape. Lillis’s team proposed the creation of a “toolkit” that provides a checklist of commonly found physical characteristics that an individual could then use in a consistent way. While this information might enable the development of a database of features, the method still retained a high level of subjectivity based on the expertise of the assessor and their ability to interpret the framework. In essence, the method proposed by Lillis sought to bring some order to an otherwise subjective and singular process. However, the way in which architectural and urban elements within the streetscape are located and their intricate relationship with others cannot be recorded by simply ticking boxes and selecting short descriptive statements from a list. While Lillis’s method might be able to describe some of the functional requirements of the street, the method cannot be used for the visual analysis of complex streetscape properties (DIPNR 2004). However, in the last few years a range of technological advances (including Google Earth and Google Streetview) have begun to provide a platform for undertaking a detailed quantitative and sequential (concerned with sets of data) analysis of visual character for the first time. These advances allow
multiple dwellings to be viewed at a reasonably high resolution in both plan and elevation and might offer a reliable and consistent resource for analysing streetscape images in the future.\(^2\)

### 1.2 Research Method: The Development of a Computational Tool

A computational tool, *Archimage* was developed specifically for the analysis of sequences or sets of facades; typically, houses of similar age in a streetscape. The *Archimage* program, versions 1.1 to 1.3, was conceptually developed by present author with colleagues Michael Ostwald and Stephan Chalup. This work was financially supported by an industry research grant awarded to this team. Graduate software engineers Josh Marshall and Riley Clement completed the programming and all of the initial testing was lead by the present author.

The original intention for developing this program was to provide those involved in the planning process with a range of objective visual measures that are comparable across a variety of urban conditions and geographic regions. Specifically, the software provides a range of quantitative measures of the form and complexity of the vertical surface of a façade. It is anticipated that these results would be used, at some future time, in concert with more established planar methods of urban analysis, including space syntax (Hillier 1996). The use of emerging techniques of computer visualisation within a field dominated by qualitative, professional or subjective judgements and techniques provides the possibility for planning assessments to be informed by a more objective form of data. This is important in town planning because without the capacity to apply a consistent approach within and between localities, the information derived about the character of streets and neighbourhoods lacks an objective basis for the discussion of a development’s appropriateness (Alexander 2003). The purpose of this approach was never to be used for designing dwellings, just for assessment and analysis.

In this dissertation, a range of computational methods have developed in parallel and been combined into a single software tool; *Archimage*. The seven interconnected computational methods developed

\(^2\) In the case of the Google images, the street views are gathered by a vehicle passing by the house and in terms of providing a consistent set of images of the streetscape have the advantage of being taken at the same time from the same vantage point and are published largely unaltered.
and tested on house facades in the present work include: image and colour segmentation; edge detection; fractal dimension calculation; Hough transform; line count; polar array and line strength array. Many of these computational methods are based on the Hough transform; an algorithm which provides a global measure of the geometry within the convex space of the image. This image processing technique, which has never been used in architecture before, segments an image at a fine scale on the basis of discontinuity and similarity, allowing the edges that define features within the built surface to be detected. The density of edges within the textured surface then provides a measure of how visual detail is distributed throughout an image at different scales, a concept that is closely related to fractal geometry. The approach is conceptually related to the theory of façade configuration and the façade isovist developed by Bill Hillier (Hillier 1996; Hillier 2003). The image, or sequence of images, is viewed by the Hough transform algorithm as a convex space where the visual field is constructed of elements that can be studied as an objective reality. The interrelationship of the elements or as Hillier describes, the way in which they are synchronised, might then provide an insight into how a set of images, say house facades in a street, may be understood at an experiential level.

A key feature of the computational model is that it provides a level of objectivity that is often missing from other models for the analysis of the built environment. In particular, the use of computational imaging techniques is not overtly concerned with the representational and symbolic qualities normally attributed to buildings (Tucker & Ostwald 2007b). Instead, the organisation of visual qualities or characteristics can be considered in isolation and, more importantly, the same method can be applied to similar cases (other buildings in close proximity). This is not to say that the representational and symbolic characteristics of a building are unimportant, but that an interpretation of these qualities can occur in parallel with a computational analysis and the two processes can inform each other.

1.3 Limitations of the Research

The research was limited by a number of factors relating to the extent of the literature review and the development and use of the developed software. Firstly the literature review was limited to those written in English and taken mainly from books, journal and conference proceedings. Some of the
more complex mathematical papers from the computer science field were beyond my capacity to assess and include within the dissertation. The software used to assess the images of dwellings and the streetscape has not yet been fully developed and the limitations this has for the various computational methods is discussed in the method. Had more time been available to develop the software, then there would have been greater opportunity for testing and refinement of the software.

1.4 Research Method: Data Collection for the Streetscape Analysis

1.4.1 Introduction

The present dissertation describes the development and testing of a new computational method, comprising several connected software tools, for the analysis of the visual qualities of dwelling façades within a streetscape. While the computational method may potentially be useful for a range of associated analytical subjects (including commercial buildings bordering urban spaces), for the present research it has been optimised and tested for suburban streets and houses.

The primary data used for the computational analysis described in the present dissertation are digital photographs of the street elevations of suburban houses. The street-facing elevation of dwellings was selected for the study because they are the most publicly accessible piece of visual information that records how a dwelling interacts with the street. The reason that dwellings within a street are important, as opposed to dwellings in greenfield locations, is that computational techniques like this are best suited to large sets of data drawn from similar groups of images.

This section describes the method used for collecting these images so that they can then be analysed using a set of new computational methods. It is important to note that the focus of the present research is on the computational method, rather than the data, but the reader should be aware of the way in which the raw images being analysed in the work were recorded.

1.4.2 Data Type

The primary data used in this research is sets of images of suburban houses that, in combination, can be seen to comprise typical qualities of a particular streetscape in a particular neighbourhood.
There are a number of different ways in which images can be taken of a streetscape. A movie recording of the streetscape has the benefit of displaying how different parts of the streetscape are revealed, but the computational power required for the analysis of 30 images per second of video footage was well beyond the scope of the present study. So, for practical reasons “still” images were chosen. There are also multiple ways of taking still images of a streetscape. These include: looking axially down the centre of the street with dwellings on either side; looking at an angle at dwellings on one side of the street; or from a perpendicular position in front of each house. Each view and approach has its merits, as they are all typical of a pedestrian’s experience of a street.

For the present study, the images used for the computational analysis were taken from a standing position around ten metres in front of each house and perpendicular to the typical building façade and street orientation. This means that most images were taken from a viewpoint directly facing the façade of the house with a single dominant vanishing point in their perspectival composition. A photograph from a standing position also provides a view that is closely related to a pedestrian’s experience of the street and could be systematically taken, no matter the type of streetscape; a requirement for many government instrumentalities (Env. Planning Act 1979). This position also allowed for a two-storey dwelling and those dwellings with wide frontages, to be captured.

1.4.3 Data Recording

All of the images were taken with a Canon 20D SLR digital camera. Auto focus was used with all images and a focal length of 35mm was adopted to relatively closely approximate human vision and to minimise perspectival distortions commonly associated with smaller focal lengths.

The image size was set at one megapixel because, at this resolution, the image contains enough detail for the complex computational techniques being herein employed, and it is still small enough to allow for storage and processing. The typical one megapixel images produced for the present research contained enough information to identify the mortar between bricks. The image size and pixel resolution was also standardised to ensure consistency of data format and to more readily allow multiple images to be compared.
Where possible, all photographs were taken on "grey" or “mildly cloudy” days to reduce the impact of shadows on the streetscape elements. Both very bright or sunny days and dark days distorted the results, the former because shadows were too stark and the latter because there was not enough natural light to distinguish features. While shadow is an integral part of the visual properties of the streetscape, the study attempted to minimise their impact by only undertaking data-recording on days with similar lighting conditions and where identical exposure settings could be achieved.

A consistent practice was developed for taking each of the images. If the image was obstructed by a moving object (say a vehicle) then the photographs were repeated and the originals discarded. However, if the vehicle was stationary and domestic in scale, it was accepted as being as much a part of the streetscape character as the door of a double garage.

Street trees, hedges and landscaping at the front of the house are necessarily part of the streetscape character and are sometimes a significant element within the image. While a house with thick vegetation in the front yard might obscure the dwelling almost completely, it is qualities and elements such as these that residents often find highly desirable and they were recorded “as is” (Oberholzer 2000; Nelson 2001).

1.4.4 Data Gathering

Images were collected from a number of sites within the locality of Newcastle, NSW (Australia), with most being from the Hamilton South Conservation Area (HSCA), a suburb two kilometres from the centre of Newcastle. An image of the HSCA is shown in Figure 5.3-13 (p.81) with most images of dwellings coming from the row of regular shaped blocks in the centre. The selected area consists of 9 blocks each with approximately 26 houses, providing a total of 242 images of houses. This location was chosen because local council regulations exist, articulating the required streetscape character for new or altered dwellings. The location also offered a number of detached houses that could be placed into groups based on similar architectural features and the same architectural style. The images were

---

3 Newcastle is the largest regional city in Australia, it has a population of around 300,000 with a regional population of one million. It has an industrial heritage with many of the suburban centres having a 200 year old history and originally being settled as coalmines.
taken over a period of a month in April 2007. Other sites were used to obtain photographs for computational comparison; these include the new suburb of Linwood, close to the centre of Newcastle, and Cooks Hill, an older part of Newcastle.

1.4.5 Data Processing

The photographic images collected from the streetscape were identified by the street in which they were taken, before being grouped into sets with similar architectural features. For example, in Appendix A two of these groups are shown; Double Gable with Picket Fence and Double Hip with Brick Fence. When sets of images were initially processed it was found that the vegetation typically found down the sides of houses (within the building set-back zones) provided too much ‘visual noise’ within the analysis. This was due to the high number of short boundary lengths that vegetation provides, so while the computational methods were being developed it was decided that the image edges should be consistently cropped from the image to isolate the structure of the house. The images were manually cropped using the polygonal lasso tool in Photoshop to remove all pixels outside the façade of the house. The cropped images were then processed without further adjustment. Individual images were stitched together using Adobe Photoshop to form a streetscape elevation of a complete block, an example of which is shown in Figure 1.2. The streetscape could be analysed as a single image or segmented into individual images of dwellings. This process allowed for a measure of the geometry at discrete parts of the streetscape and ensured that elements within the street façade were analysed only once (Tucker & Ostwald 2004).

Figure 1.4-1 Row of houses stitched together from Linwood, Newcastle
1.5 Structure of the research

Following the present introduction, this dissertation is structured into three main parts, a literature review, a description of the development and testing of a series of related computational methods and conclusions. The literature review begins with a discussion of the regulatory framework that affects the design of dwellings within the streetscape and is important for grounding the study in current concerns. It includes a review of the regulations affecting the design of dwellings within areas where it is desirable to retain the visual qualities of the existing streetscape; existing methods for studying streetscape character at the scale of the dwelling; whether diversity or contextual fit is a desirable outcome and finally; the importance of considering the place-based qualities of the streetscape including its image-ability.

The following section of the literature review is concerned with the geometric qualities of the streetscape, it includes a discussion of the smaller scale elements within the streetscape (such as the qualities of surface texture) and the detail smaller than the form of a house (such as fretwork and landscaping). Visual complexity and its relationship to the geometry of the streetscape is discussed together with an outline of how this relates to fractal geometry.

The final section of the literature review is concerned with the spatial configuration of elements within the streetscape and includes an overview of space syntax and how its principles might be used for the study of urban elevations as opposed to the study of plans (that it is typically associated with). The use of computers within urban analysis is discussed as well as how recent technological developments have allowed the visual qualities of the streetscape to be automatically recorded.

The second major part of the dissertation describes the conceptualisation, development and testing of the computational methods. It begins with an overview of how algorithms are being used in a number of fields to assist and determine the visual properties of objects. As the technical requirements for designing software for studying images of the streetscape are beyond the author’s expertise, it was a necessary part of the study that it be undertaken in collaboration with computer scientists skilled in the requirements of computer vision. How the software, called Archimage was developed, is discussed
from a technical viewpoint before the different conceptual approaches are outlined. The first computational approach, called Image and Colour Segmentation, partitions the image into segments based on areas of contrast. The second approach is called Edge Detection and it describes how the image is processed to isolate the pixels that form the edges of contrast within the image. Once this has been done, the resulting image can be used for further processing. The third approach is to calculate the fractal dimension of the image using the box-counting method, an existing manual technique that has been automated in Archimage. The fourth approach is to apply the Hough Transform, a digital image processing technique that extracts features within the image by considering the geometry of the entire image. The fifth approach is the Line Count calculation that studies the structure of visual boundaries within the image, calculating their length and orientation and providing graphs of how this information is distributed throughout the image. The sixth approach uses the data provided by the Hough transform and plots the most significant lines as a Polar Array. The final computational method discusses the Line Strength Array, a diagram that also uses the information of the Hough transform but instead successively plots the data in an array that captures both the significance of the detected boundary and its orientation.

The conclusion discusses how analysis of the streetscape using algorithms is a potentially useful way of understanding its visual qualities. While the present study introduces some conceptual approaches to how this might occur, further work is required to enhance the methods described, while new algorithms need to be prepared to collate the various data types and assemble them in a more meaningful way.
2 The regulatory context and framework for assessing streetscape character

2.1 Introduction

This chapter is a review of the literature concerning the regulatory context and framework used for assessing streetscape character within Local Government Authorities (LGA’s). The first section provides an overview of the guidelines that affect the form of the dwelling that fronts a street and a discussion on whether diversity or contextual fit is a more desirable outcome. The issue becomes one of how a dwelling’s style is used to identify the visual attributes of a building, without having to analyse in detail each and every dwelling within the streetscape. Methods commonly used for assessing streetscape character are then explored and include the types of elements that should be analysed within such a study and how this has been done using expert evaluation. Place-making strategies and the way in which the visual amenity of streets within a city plays an important role in creating a sense of place and community for its citizens are explored. Closely related to this is the concept of the image-ability of the streetscape; an important dimension for studying the streetscape as it identifies the presence of common or shared meanings that suggest it is possible to design urban environments that will be used and experienced by many people in comparable ways.

2.2 Regulations affecting dwelling design within the streetscape

The regulations affecting the design of the front façade, street address or front “yard” of a dwelling vary between Local Government Authorities (LGA) although, in NSW, the Department of Infrastructure, Planning and Natural Resources (DIPNR) provides standards that many LGA’s have adopted. The draft standards in NSW (DIPNR 2003) include a setback of at least 4.5m or the average setback of the two adjacent properties. Garages must also be setback one metre from the front of the house and be no wider than either 6.3m or 50% of the lot width. 30% of the front setback is to be permeable and fences at the street boundary are to be no higher than 1.2 metres high. The facade
must also include features that identify it is the “front of a house”; such features include a front door, entry deck or portico. The underlying rationale for these standards is not discussed in any detail and is likely that these requirements are based on historical trends in suburban housing.

A review of DCPs within NSW shows that streetscape character is a commonly regulated feature of a design. While some LGA’s had no legislation, controls or information concerning streetscape character, they generally had smaller populations and less regulation of most building controls (including setbacks, massing and vehicle garaging). Authorities that govern older and more dense urban areas tend to have more elaborate and better defined streetscape requirements.

2.2.1 Diversity versus contextual fit

The recent development of greenfield sites for suburban development with design guidelines affecting the physical appearance of dwellings appears to show that there is a market for visually cohesive streetscapes (Alexander 2003; Lensworth Wallarah Peninsula 2004). In preliminary design stages the architectural quality of a building in relation to its context might be discussed in terms of its response to the existing character of the street. However, those verbal descriptions will eventually become “physical materials in physical space” (Stamps III 2003:p453). Planning guidelines that require both “excessive similarity and excessive dissimilarity are not tautological but rather express the hypothesis that pleasure is an inverted-U function of similarity” (Stamps III 2003:p455).

Craglia (2004) reflects on the importance of the “reinvention of tradition as one of the strategies to enhance visibility” based on the market driven by the “urban tourist” as opposed to the more traditional resident. These sometimes conflicting requirements of the city draw a distinction between the modernist tendency to regulate space based on zoning and the post-modern approach where “fragmentation, urban mosaics and the colourfulness of cultural difference” (Craglia 2004:p52) are encouraged. Craglia argues that this “recognition of differences has resulted in a cultural shift in urban studies with the city analysed as a work of art, a representation, and a text, that take different meanings for the various actors in it” (Craglia 2004:p52). Urban planning ideas originally proposed by Sitte, Lynch, Jacobs and Alexander (Sitte 1945; Lynch 1960; Jacobs 1961; Alexander 1977) are now being discussed from a commercial point of view (Craglia 2004).
2.3 The Use of a Dwelling’s Style within the Planning Process

An architectural style is a set of visual characteristics that a group of buildings might share. These characteristics include the "relationship of the parts of the building to each other and to the building as a whole", the use of ornament and visible textures, and the scale of elements within the composition (Apperly 1994:p16). Visual analysis of dwellings within a streetscape typically involves the description of the different building styles and constitutive elements adjacent to the site, within the street and sometimes the locality. 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). Whether the proposed dwelling enhances or reinforces the existing streetscape character will often relate to whether the dwelling is of a similar style, with replication of an existing style considered an acceptable and often desirable planning solution (Alexander 2003). However, this raises significant issues, particularly in localities where the dominant character is generated from an older or traditional building stock. While there is often pressure on planning authorities to sustain the existing character of these places (Craglia 2004), contemporary building and design practices, and contemporary lifestyles require a different type of dwelling than those constructed eighty or so years ago. When a new building is proposed within a traditional streetscape, the planning issue becomes how to retain the visual character of the streetscape whilst using the forms and construction practices of a contemporary dwelling. For example, a brick veneer house with a double garage facing the street is the most common type of new dwelling available from project builders, while traditional dwellings more than 80 years old rarely have this formal arrangement. If then, the style of a traditional building can be understood as a composition of a particular set of visual qualities – can a modern building emulate these qualities whilst retaining a contemporary formal arrangement? Understanding the visual qualities of a dwelling’s style would be the starting point in responding to this question. One of the methodological qualities of computer visualisation that makes it so useful for such a comparative analysis is that the representational and symbolic meanings of a building’s style play no part. The organisation of the elements can be
analysed without having to interpret their possible meaning at the beginning of the process.

2.4 Studying Streetscape Character at the Scale of the Dwelling

Describing the urban environment requires a study of organized complexities on many scales (Batty 1994). While zoning maps concentrate on the use of land at the scale of the city, the suitability of a new house or alterations to an existing house will take into account localised issues such as sun penetration and privacy for a neighbouring property. How a single dwelling might visually relate to its adjacent neighbours and others in the street is the thematic focus of the present dissertation and, as such, it is largely focussed on the small scale decisions that affect streetscape character.

Strategies for planning the physical character of new dwellings outlined within the DCP tend to rely on performance-based criteria that concern the density, massing, setback, vehicle circulation and garaging of the new building work. Often these requirements are the same for a large number of streets that can be grouped into a defined suburb. Depending on the LGA and whether the building work is within a HCA, the requirements for streetscape character can vary between none at all, a requirement for the existing built fabric to remain intact (no demolition allowed) and for any new work to be in the architectural style of surrounding dwellings.

While planning diagrams concentrate on the functional and formal requirements of the built landscape, relatively little attention is given to obtaining information about the visual character of the urban environment that people experience.

Residential development within heritage conservation areas are regulated by Development Control Plans (DCP), which provide guidelines about the shape and form that new houses, alterations and additions should take (DIPNR 2004). By understanding that the visual amenity of streets within a city plays an important role in creating a sense of place and community for its citizens (Lynch 1960) they attempt to sustain, through regulation, an urban pattern that has become valued by the community.
2.5 Methods for Visually Assessing Streetscape Character

Establishing the existing visual character of a streetscape involves a two-step process. The first might be considered as an observation of the patterns of interrelationship between elements, a process that by its description should suit a photographic study. The second stage involves deciding the importance of particular patterns in relation to others (VicD.I. 2001; Alexander 2003; DIPNR 2004). It is this stage of the process where an individual’s interpretation of what appears to be important may provide different analytical outcomes. The emphasis that each LGA places on the importance of visual character will change, as will the meanings that each individual reads into a given scene. For buildings to be approved, planning authorities must assess these qualitative aspects of existing urban areas such that decisions can be made about proposed changes. It is this first objective stage of analysis that is of importance within this dissertation, particularly the question of how the visual properties of a dwelling within a streetscape might be interpreted without first having to interpret its ‘style’.

Fisher-Gewirtzman (2003) observes that while density measures might be relevant to planning at the scale of the city or region, they are of little use when considering the degree of enclosure or openness within a particular urban space. She reflects that understanding the relationship between the built form of the street and surrounding urban space is fundamental, “appropriate thorough work is needed to develop sharper evaluation, control methods, and predictive tools, conditioned to the human perception of space.” (Fisher-Gewirtzman: p577).

When evaluating the effect of changes to the streetscape – for example, changes to the façade of a dwelling – Alexander (2003) suggests that the analysis be undertaken at different scales and include views of the locality or “neighbourhood”, views within the street (the “character precinct”) and views from the front of “adjacent properties”. At the scale of the “neighbourhood”, elements such as the topography, street pattern, vistas and the prevailing character of the urban space are also to be examined. The “character precinct” is conceived as a fundamental unit of streetscape character as it attempts to find “those properties that have a strong visual relationship to each other within a street or other urban space” (Alexander 2003:p17). Elements to be examined at this scale include street
fixtures and furniture, patterns of lot widths, outline, composition and any symmetries of the built form, extent of light and shade within the built form and on the ground. At the scale of the adjacent properties, elements to be examined include the built form (including solid and void), horizontality and verticality of the elements within the façade, the intricacies of line within the street façade and colour and texture of the materials.

Ellefsen (1991) states that planning authorities have a need for specific and objective information about the character of dwellings and their settings when they undertake studies of the local environment.

Similarly, Lillis and Pourmoradian (Lillis 2001) have found that techniques currently used for streetscape analysis do not establish the basic information required by planning authorities and community groups for informed decision-making about changes to the streetscape. In response, they proposed a “toolkit” that relied on a checklist of commonly found elements within the streetscape. An individual would use the checklist to record the visual aspects of the street, but how this information would be used by a designer to develop a new design is difficult to understand. As Stamps (Stamps III 2003) reflects, those verbal and notated descriptions will eventually become ‘physical materials in physical space’.

So while this information might enable the development of a database of elements within the streetscape, by not visually recording the information within the street (using photography), the database would retain a subjectivity based on the expertise of the assessor, while the checklist could never be so comprehensive as to actually record the varied and intricate relationship between elements within the streetscape (Tucker & Ostwald 2005).

A photograph only records a two dimensional frame of a part of the streetscape, but it has the benefit of recording the complex relationships of visual elements in a detailed way (Tucker et al 2004). If this visual field is analysed using algorithms that segment the image in a way that identifies the visual boundaries within the image (Tucker & Ostwald 2005), then the elements are recorded without having to first identify and catalogue them. Whatever forms are within the visual frame aside from the front view of the dwelling – such as street-trees, parked vehicles, landscaped areas – need to be recorded as part of the visual complexity of the street view (Alexander 2003; DIPNR 2004). Without using
photography it is difficult, cumbersome and intrusive to describe the visual nature of an element in sufficient detail for it to actually be useful. For instance, the size of a window might be described in a statement, but its detail, as a unit and placement within the wall, its relation to other elements, material qualities and degree of weathering, which all affect the visual field, are best recorded using photography.

Aside from issues purely concerned with visual character, visualizing the form and materials of the built environment might inform urban sustainability issues such as space and energy consumption. Fisher-Gewirtzman (2003) adds that “quantitative parameters” such as the penetration of natural light, wind intensity and density measurements need to be related to other physical and psychological “qualitative parameters” such as texture, privacy, colour, and style. While qualitative measures are open to interpretation by the individual, planning authorities need to assess these aspects of existing urban areas, so that decisions can be made about proposed changes. Because these qualities are difficult to measure they can be overlooked, resulting in changes that disassociate residents from their “place-based communities” (Hull IV 1993). In cases where the character of a street or locality requires improvement, the challenge is to identify the physical attributes of the preferred character, while developing the broader infrastructure and amenity within the locality (Townsend 2001).

2.6 Streetscape analysis using expert evaluation

Researchers have studied the geometric qualities of the streetscape in an attempt to understand what characteristics are considered to be the most desirable. For example, Nasar (1988) asked 81 design professionals including planners and architects to assess the prominence of built form, shape and material quality within 60 images of different streetscapes. Each participant was asked to evaluate the streetscape in a quantitative way such that the desirability of particular streetscapes could then be assessed by another group of design professionals. While Nasar found that increases in visual richness and clarity were significant and desirable attributes of the streetscape, the method still initially relies on a subjective analysis of the physical attributes of the streetscape.

A study by Ellefsen (1990) systematically studied buildings within different districts of an American city
to provide measurements of the wall area, building volume and construction type. This study provided planners with a new way of studying urban areas that is based on materials and their organisation essentially independent of use. In other studies, houses within a streetscape were analysed using three scales of decomposition; overall massing, secondary massing, and differentiation of elements such as doorways and windows. Malhis (2003) and Elsheshtawy (1997) both similarly attempted to segment the streetscape into meaningful elements in order to provide an objective measure of the visual character of a street (a typical analysis is shown in Figure 2.6-1).

Figure 2.6-1 A streetscape analysed using three scales of decomposition; overall massing, secondary massing, and differentiation of elements such as doorways and windows (Elsheshtawy 2003: p312)
Malhis (2003) began his analysis by recording the detail within the façade of each dwelling at different scales or on different “layers”. Shapes and forms within each layer being represented by a thin line that traced the feature. The first layer outlined the overall composition of the façade, the second layer outlined significant forms within the façade, the third layer identified openings such as windows, the fourth layer showed detail surrounding and within the openings and the fifth layer showed the detail and trim around the features. A sixth layer was used that then grouped each feature within the façade under a heading bearing its common name. Malhis then used this method to classify 230 villas into eleven stylistic groups.4

From photographs of buildings, Yasser Elsheshtawy (1997) traced what he believed to be the bounding surface of each element and then grouped these elements based on their relationship with other elements (see Figure 2.6-1). Inspired by an analysis undertaken by Robinson (1908), Elsheshtawy applied four scales of composition to break down the mass of the building: overall massing, primary elements of the façade; secondary massing, elements within the façade such as balconies; horizontal and vertical differentiation, articulated by windows and doors; ornament, including smaller details within the façade. While the first three orders are used for the analysis, detail at the ornamental level was not considered. A value for the complexity within the façade was then calculated based on the number of groups formed at each level. While the process of manually grouping façade elements represents a standard architectural technique for interpreting the massing within a building’s façade, the lack of detail within the analysis limits its use as an effective tool for the analysis of visual character at the scale of a pedestrian (Clark 1996).

In a similar study Imamoglu (2000) traced photographs of buildings and then manipulated them to produce drawings of the same building with different levels of detail. Respondents were then asked to rank each image based on desirability. He found that increasing the complexity of elements within the façade that were familiar to the respondents produced a positive response. Designs that were highly complex or those with excessive unfamiliar elements or materials were more negatively regarded.

4 The method Malhis used for doing this classification is not explained, however it is implied that the author did this manually.
However both rely on time-consuming, skilled, manual techniques in the segmentation process; a practical as well as a possible methodological problem. Also, with a reliance on expert evaluation, the analysis of a streetscape is essentially an individual’s interpretation of what appears to be visually significant.

2.7 Place-based Qualities of the 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 and be valued for more than its purely functional amenity would suggest (Smith 1997). Part of this value is found in the meanings local communities attribute to features or elements within the street.

The visual amenity of streets within a city plays an important role in creating a sense of place and community for its citizens (Lynch 1960). Whether this amenity can be sustained or modified to provide a more sustainable urban pattern when undergoing change is the principle concern of a streetscape analysis conducted during the planning approval process (DIPNR 2004). While the geometric qualities of a development (such as height, volume and thermal load) might be accurately assessed, the visual effect of a development in relation to its context often relies on the subjective qualities of style and character (Hull IV 1993).

Specifically, 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 space outside a dwelling is used differently from the space inside, the transition zone becomes a formal representation of the coexistence and co-dependence of internal and external areas. 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 privately owned 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 its character (Alexander 2003).

### 2.7.1 Image-ability of the Streetscape

In an early study into the image-ability of the streetscape Kevin Lynch (1960) 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 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 image-ability; an ability for the shape, colour and arrangement of elements within an urban environment to evoke a strong image for an observer. Image-ability 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:p9), streetscape character analysis attempts to do this on 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 of the urban space. The way in which elements are organised and related in patterns within a specific urban or suburban context defines the visual character of the built environment (Kropf 1996).

The visual quality of a streetscape is different to the concept of whether a streetscape is attractive. The attractiveness of an urban space is a subjective and abstract quantity (Craglia 2004) in contrast, visual quality can be described using a number of objective methods (this is discussed further in
Chapter 5). The perceived attractiveness of a streetscape can relate to an individual's interpretation of a range of variables including a sense of safety, economic and environmental situation, provision of services and amenity, legibility of the urban landscape and its physical design. Craglia (2004) found that whether a building “fits” its location, provided a “sense of place” and was of “interest” are the most significant qualities met through the physical form of the street.

2.8 Streetscape as Text

Venturi, Scott Brown, and Izenour (1977) argued for the “symbolism of the ugly and ordinary in architecture... for the decorated shed with a rhetorical front and conventional behind”. Harries (1997) reflects on this, suggesting that the quote is not so much a demand for decoration but “a refusal of what is experienced as the muteness of modern architecture, with a longing for architecture as text, for buildings carrying messages that can be read in some sense”. The text, in this sense, is not something that is fixed to the external surface of a building, but is essentially carried by its form (Harries 1997). Boyd (1968) criticised the addition of “features” to a suburban house as a concealment of its basic structure, however, as Fiske (1987) points out, it may be that “the ‘features’ typically express a critique of dominant structures and dominant meanings” (Fiske 1987:p32). Reflecting on this, and considering the social relationship a house has with the street, perhaps the most appropriate “feature” for critique becomes the deeply covered entry space typically found at the front of a bungalow cottage (Purser 2003). Its openness to the street allows “introductions to be made and visitors [...] received in an informal manner without the obligation to introduce the visitor into the house” (Drew 1992:p38). From this space the owner can observe the public space of the street and, from the perspective of a passer-by, become part of the streetscape. It invites the public to share symbolic possession of the space through active or passive surveillance, however it remains privately controlled (Watson 1994). This relationship suggests that the owner of the house has some obligation to allow visual access for the public, and in return, the owner has a right to view the public, and exert their influence over that common space (Fiske 1987). Talen (2005) states that this conversation at the level of the streetscape is important for social interaction and ‘good urban form’.
3  Understanding the Geometric qualities of the streetscape

3.1  Introduction

In the previous chapter the frameworks and regulations that have been used for assessing streetscape character were reviewed. They included those aspects of the urban environment that are valued by the wider community and how they have become integrated within the regulations that local government authorities use to control future developments. This chapter looks at the geometric qualities of the urban environment (like streetscapes) from a more visual and formal perspective. Critical to doing this is understanding that the visual environment is a surface where the different elements can be studied as a texture and as a composition. The visual diversity or arrangement of the elements is an important variable that influences whether or not a person might find the environment appealing (Berlyne 1974; Rapoport 1990; Imamoglu 2000; Stamps III 2003), and the effect of the scale of the element is discussed in relation to this. The way that the smaller-scaled elements within the streetscape (such as fretwork and brick coursing) are detailed and are composed within the whole, identifies another geometric quality important to review, that of fractal geometry.

The most effective hierarchical scaling creates a type of fractal geometry which is independent of any associated scale (Bovill 1999), being able to reduce this complexity to a single number allows the visual complexity of a streetscape to be compared with the visual complexity of a building that is proposed for this street. In this way, fractal geometry can suggest the extent to which a proposed building is “in-keeping with”, or “sympathetic to” its visual environment (Ostwald 2007a).

3.2  The Texture of the Streetscape

The open space of the streetscape is usually defined by the volume of empty space left between, or separated by, the built surfaces. The form and texture of such a space is characterised by the relationship between the “filled elements” that are within it (Teller 2003). Nikos Salingaros (1999) states that it is the information within the surrounding surfaces of the open space that is perceived,
and is of greater importance than an analysis of a plan or empty space that is not perceived at all. While Hillier (1984) rejects this proposition because he sees the building’s purpose as being to transform space. The importance of visual perception to inform a building’s purpose has been discussed by Lynch (1960), Venturi (1966) and Alexander (1977) in some detail. Visual qualities in an open space caused by colour, texture and ornamentation are considered significant subdivisions within the surface of the streetscape even though their affect on its form may be minimal (Moughtin 1999; Salingaros 1999). The elements, planes or surfaces, in the open space between buildings that are orientated perpendicular to movement, create a local spatial boundary (Salingaros 1999), a spatial type that Alexander calls “positive space”, a fundamental property of coherent urban spaces (Alexander 1987). A related concept outlined by Batty (2002a) shows how a city might be considered as a cluster of “spatial events”; events that take place in space and time. Understanding the character of such events might tie together “a wide range of disparate ideas, which range from discussions of spatial representation in terms of objects and their ontologies, to the collection of fine-scale data on events and the processes that generate them” (Batty 2002:p1).

Texture is a property of all surfaces and is one of the characteristics used to identify visual regions bound by the edges of an object. Depending on the scale of the visual information, both symmetry and composition can be accounted for in terms of an analysis of texture (Schira 2003). For Schira, this visual information is reliant on the “structural arrangement of a surface and the relationship that one arrangement has with others surrounding it” (2003:p303). Hildebrand (1999) offers a reflection on this proposition 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. These patterns are then the physical attributes of buildings that help to identify visual regions of interest and thereby make them appealing (Schira 2003). Zucker and Terzopoulos similarly describe texture as “a global pattern arising from the repetition, either deterministically or randomly, of local sub-patterns. The structure resulting from this repetition is often important in discriminating between different textures” (1980:p293).

Capturing and analysing the texture of the vertical surfaces of the urban environment might provide valuable information about how cities are inhabited (Tucker & Ostwald 2006). While the lack of
computing power may have limited studies in the past, there are a number of current research projects that are using sophisticated methods to model the urban surface and its form with a high degree of accuracy.

Salingaros (1999) comments that contemporary building materials and methods used to replicate traditional façade styles might “minimize the information field” and subsequently might not provide the high density of textural visual field information associated with the traditional building. This is an important issue because it expands the discussion of streetscape character beyond the purely formal attributes of buildings. So while the replication of an existing style is considered an acceptable and often desirable solution from a planning perspective (Alexander 2003) regardless of the characteristics of materials used, the texture and detailing of traditional buildings should be an important consideration. The suggestion therefore is that contemporary buildings that attempt to replicate traditional buildings, need to also replicate the texture of traditional buildings at a fine scale for them to be successful contributors to the streetscape’s visual character.

The question then becomes, does replicating a Federation house within a streetscape dominated by federation houses provide a satisfactory outcome for the visual character of the street? This is a contentious topic, with many strongly held views but, as previously stated, from a planning perspective replication of an existing style is considered an acceptable and even desirable solution (Alexander 2003). Architects might disagree with the premise of this planning solution (RAIA 2004), but to satisfy the requirements of the planning process, the visual qualities of contemporary buildings must be understood in relation to the existing visual context.

3.2.1 Composition of elements within the streetscape

Alexander (2002) argues that good design consists of certain definable properties including, Levels of Scale, Strong Centres, Boundaries, Positive Space, and voids to contrast with surrounding information. According to Alexander, shapes within a composition must express a number of levels of scale in order to make them coherent with one another. Individual parts within a composition are intensified by their position within the structure and by their relation to a focus point which he calls a “centre”.

38
I use the word centre to identify an organised zone of space – that is to say, a distinct set of points in space, which, because of its organization, because of its internal coherence, and because of its relation to its context, exhibits centred-ness, forms a local zone of relative centred-ness with respect to the other parts of space. (Alexander 2002:p84)

Alexander states that “[b]oundaries do the complex work of surrounding, enclosing, separating, and connecting in various different geometric ways” (2002:p159); they should exist at various scales throughout the composition. Moreover, the boundaries weight should correlate with the scale of the shape it is binding – for example larger shapes require larger borders, smaller shapes require smaller borders. Oscar Newman famously argued that boundaries contribute to defensible space and can be either real or symbolic. Whether the boundary is a high wall or the change in surface texture, they both serve to indicate a transition from public to private space “where one’s presence requires justification” (1972:p63). Furthermore, Jan Gehl observes that conversations in streets occur more frequently when a yard is delineated by a boundary such as a low wall (Gehl 1996:p192). These boundaries create resting places which Gehl states are important for enabling people to stay longer in the semi-private area in front of their house and thereby increasing the possibility for interaction with passers by. This activity on the street is an important factor in making places liveable because “people come where people are” (Gehl 1996:p27). Gehl also observes that these characteristics are more likely to keep people in a public realm for longer periods. These areas might be what Alexander calls “positive spaces” (2002:p173). This concept could also be applied to the façade of a building. A positive space or shape is one which surrounds another shape or space and is able to be considered as a shape or space in its own right. The whole composition is then considered so “there is not a single place which is leftover” (Alexander 2002:p176). According to Alexander, a void can unify the structure of a composition by providing a focal point for surrounding details and elements (2002:p222). The porch of a bungalow could be read as a unifying void for the façade of a house. The uniform shade enabled by this space can create a place for the eye to rest, and contrasts with the higher levels of visual information in the rest of the façade.

Factors determining the perception of a building’s character are not limited to the building itself. As
Alexander points out, a view of the building as a whole means that we see it as “part of an extended and undivided continuum” (Alexander 2002:p80). The façade is not an image in itself, but part of the streetscape which includes the “gardens, walls, trees, streets beyond its boundaries and other buildings beyond those” (Alexander 2002:p80). Tree-lined streets are more visually complex, and have been found to instil positive emotional responses when compared to streets with no trees (Nelson 2001). Moreover, studies have shown that a tree is preferred in terms of how full its canopy is, with a full canopy being the most valued (Nelson 2001).

3.3 The significance of detail within the façade of buildings

Many researchers have shown that the character of a building often depends on the detail within its façade (Stamps III 1999). For instance, Brolin (2000) suggests that the visual texture “composed primarily of small scale details” is the most critical factor to consider when locating a new building within an existing built context. Methods used in architecture to determine scale within a building include massing, where the largest scale is usually defined by an outline of the building itself (Salingaros 2000b). Elements within the façade – openings, detail, trim and the material itself – will then successively identify smaller scales. Symmetry is a condition of massing and is manifested through the recurrence of shapes in a regular way, and can help connect elements forming a single element at a greater scale (Salingaros 2000b). Once formed, this arrangement can be thought of as modular, repeated through the economy of thought and action (Salingaros 2001).

Bentley, Alcock, Murrain and McGlynn (Bentley et. al. 1987) suggest that “richness” can be created through details within the walls that incorporate patterns of material and colour. Moughtin, Taner and Tiesdell suggest that decoration, ornamentation and articulation within a building’s façade are the “means by which a variety of visual experiences are introduced to the viewer” (1999:p25). Hull IV, Lam and Vigo (1993) found that decorative style or other distinguishing physical characteristics were highly valued by the residents of houses and were perhaps valued because they distinguished one place from another. The location of larger details within the façade, including doors and windows, is also important because they offer the opportunity for natural surveillance of the urban space, reducing the
likelihood of crime. Whether actual surveillance takes place may be difficult to determine, but the
capacity for buildings to provide the opportunity is an important aspect of “natural surveillance”
(Newman 1972).
Stamps III states that while empirical work on architectural detail is sparse, it tends to support the
hypothesis that “detail is an important part of preferences for buildings” (1999:p87). Salingaros, in a
similar vein, reflects that ornamentation “connects us to our environment” (2003b:p12) and that
successful building facades within an urban space feature a “continuous swath of high-density visual
structure that the eye can follow in traversing their overall form, or focal points of intense detail and
contrast arranged in the middle or at the corners of regions” (Salingaros 2003:p12). He has shown that
ornament and decoration subdivide the façades of buildings on a number of different scales, and that
the most effective hierarchical scaling creates a type of fractal geometry which is independent of any
associated scale (Salingaros 2003).

3.4 Analysing visual complexity within a streetscape

Various scholars have independently concluded that the amount of perceived complexity or visual
diversity within a streetscape is an important variable that influences whether or not a person might
find the environment appealing (Berlyne 1974; Rapoport 1990; Imamoglu 2000; Stamps III 2003).
While Hillier (1984:p1) states that a building’s purpose is to transform space, Salingaros (1999)
disagrees, asserting that it is the information within the surrounding surfaces of the open space that is
actually perceived, and is therefore of greater importance than the plan of a building; which is
something that is not perceived at all. For Salingaros (1999) and Moughtin (1999), differentiations
caused by changes in colour, texture and ornamentation are significant subdivisions within the
streetscape, even though their effect on its built form may be minimal.

A critical conceptual component in this model of understanding complex streetscapes is the boundary.
Elements in a streetscape which are visually defined in some way are said to have boundaries. The
larger the number of boundaries (and associated elements) the greater the potential visual complexity
a façade has. The capacity to visually define an element is a condition of the surface that surrounds it
and is perhaps reinforced by the juxtaposition of nearby elements (Rapoport 1990:p273). The boundaries of the elements then remain an important consideration, while the surface within the element is of less consequence.

The visual character of a streetscape is therefore shaped by the boundaries that define the elements both within the facades of buildings and in the “open space” between them. How those elements are organised and the patterns of relationships that occur between them, defines the visual character of a space (Kropf 1996). Theil, Harrison and Alden (1986) state that the visual boundaries within the surface of a space define its degree of enclosure in a more significant way than simply determining how large it is.

Research undertaken by Al-Homoud and Natheer (2000) supports this position by observing that vertical objects “determine our perception of spatial enclosures” more than horizontal elements within urban spaces do (2000:p217). Rapoport reinforces this view by stating that “noticeable differences provides the most useful way to derive hypotheses regarding the perceptual characteristics of pedestrian spaces; this can best be addressed by contrasting them with those of spaces for motorists” (1990:p276). He also identifies important factors which can influence visual diversity within a streetscape including the proximity of private space to the public domain, its perceived security, the amount of natural sunlight, the time of day, the number of pedestrians and cars and 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, intuitively, be less important. But, can we determine, with any degree of objectivity, which are the most important elements of the overall visual pattern? Past research into visual complexity has suggested two strategies for assessing the degree of visual conformity or difference in a set of facades. The first involves patterns of ambiguity and the second, patterns formed by elements within the environment. The first of these is considered briefly hereafter, before the remainder of the chapter focuses on the second approach.

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:p263). In Australia, Robin Boyd (1968) famously criticised the addition of "features" to a suburban house as the concealment of its basic structure. However, as Fiske points out, it may be that "the 'features' typically express a critique of dominant structures and dominant meanings" (Fiske 1987:p45). Reflecting on this, and considering the social relationship a house has with the street, perhaps the most appropriate "feature" for critique becomes the deeply covered entry space typically found at the front of a "bungalow" cottage (Purser 2003). Its openness to the street, allows "introductions to be made and visitors... received in an informal manner without the obligation to introduce the visitor into the house" (Drew 1992:p48). From this space the owner can observe the public space of the street and, from the perspective of a passer-by, become part of the streetscape. The covered entry invites the public to share symbolic possession of the space through active or passive surveillance, even though it remains privately controlled (Watson 1994). This relationship suggests that the owner of the house has some obligation to allow visual access for the public, and in return, the owner has a right to view the public, and exert some influence over that common space (Fiske 1987). Talen (2005) reinforces the view that this conversation at the level of the streetscape is important for social interaction and "good urban form". However, the built "text" of the bungalow entry can also be changed to such an extent that it loses its original meaning. For example, when Glenn Murcutt designed the Kempsey House he cut this space away from the bungalow house, "straightened it out and discarded the unwanted core of the house" (Drew 1992:p52), he also removed its physical nature, and, ironically, its function. The palette of materials also changed from masonry and weatherboards, to metal and glass shutters. Its function as an entry, and as a social space within the public realm of the street, was given over to the private spaces of the house. In essence, despite the architect's and the critic's claims, the meaning or message conveyed by the form, its orientation, materiality and transparency, had changed. This is one way of viewing and critiquing architectural form as "text". 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). This is why
Rapoport (1990) 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 consistent result. This is also why the present dissertation is focussed on the second analytical strategy which is concerned with *patterns formed by elements within the environment*.

The perceived number of elements within a streetscape, and particularly the “noticeable differences” (Rapoport 1990:p269) that exist between them, provides a measure of visual diversity. Visual diversity 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:p269). Depending on the way in which the differences are gradually revealed, the experience of walking down a street might then feel monotonous, surprising or familiar. For instance, where the streetscape is visually consistent with a “strong order” (Rapoport 1990:p269) minor variations become noticeable against a familiar background and contribute to its subtle complexity.⁵ Moughtin refers to the contrast between elements – such as doors and windows within the façade and the contrast of building elements based on light, shade, colour, tone and texture – as being determining factors describing “visual richness” (1999: p25).

Salingaros (1997) proposed a simple method for establishing visual diversity within a building’s façade. Adopting a variation of the concept of entropy, Salingaros proposed that facades might be measured by their “temperature”. Salingaros’s five analytical categories are: intensity and smallness of perceivable detail; density of differentiations; curvature of lines; intensity of colour hue; and contrast among colour hues. In terms of “temperature”, facades are favoured that have well-defined detail of at least 5mm at a one metre viewing distance, colours or hues on the surface which are sharply differentiated, embody lines with a high degree of curvature, richly coloured and where coloured surfaces are strongly contrasted. In terms of harmony, buildings are favoured that have a strong vertical symmetry, which repeat standard forms such as doors and windows in a regular way, have features that are self similar at varying scales, forms that connect in a positive way with the ground and finally those that have colours that blend well (Salingaros 1997). The method was applied to

---

⁵ While noticeable differences may be observed by any of five senses, this study is only concerned with visual qualities.
twenty-five free-standing buildings although it might equally be applied to the planning of new buildings. Klinger and Salingaros (2000) later developed this method to provide a measure of the “structure” or “complexity” within abstract visual arrays. They state that “[s]tructuring visual diversity based on the shape characteristics of the façade” (2000:p542) shows that their organisation is important for the building’s impact within the urban environment.

3.5 Considering the scale of elements within a streetscape

The urban environment can be analysed at both the macro scale of freeways and urban sprawls and micro scale of parks and streets (Jiang 2000). Small-scale areas typically include spaces in an urban environment that are generally continuous or interconnected and can be experienced from a single vista. Large-scale spaces are those that cannot be perceived from a conventional vantage point, but can be shown diagrammatically. Jiang states that the “perception of small-scale spaces while moving through the large-scale space provides a prerequisite for the perception of large-scale environment” (2000:p162). Rapoport supports the investigation of urban space at multiple scales stating that “a study based on perceptual characteristics of settings for an activity like walking will be easier to approach cross-culturally and over long periods of time” (1990:p261). He argues that the invariance involved with traversing small scale spaces as a pedestrian will reinforce perceptual variables. Urban spaces that have a high numbers of pedestrians may also have similar visual attributes.

In architecture, the boundary that defines an element has historically been dependent on the scale at which the element is viewed. As Norberg-Shulz observes, it is always possible to “decompose an element into a subordinate element and relations into superior elements” (1963:p132). The distribution of elements of many different sizes within urban space is also considered an important determinant of visual diversity (Batty 1994; Batty 1996; Salingaros & West 1999). Salingaros (2000a) and Crompton (2001) have considered the question of the significance of detail at different scales within building facades and the success of associated urban spaces. They contend that buildings that have significant detail at a number of scales provide better open spaces.

Modern streetscapes, lined with detached houses all of approximately the same size and fronted by
continuous low-lying lawns, feature a “peak in the distribution of urban [scale] elements at the size of a single house unit” (Salingaros & West 1999:p918). Historic streets, made up of tightly-packed or continuous row of houses, tend to have elements within their facades of a variety of sizes and it was this quality that is central to their visual diversity (Apperly 1994). Cooper (2003) argues that in more recent years it may be that the lack of formal composition in modern housing results in a more limited range of elements at different sizes and scales. Compared with the heavily articulated and ornamented facades of historic buildings, the lack of detail within modern facades reduces the impact of subtle shadows and the play of light over surfaces. A parallel argument is found in the work of Jacobs (1961) who is critical of the situation that occurs when there is a lack of diversity in urban uses leading to the presence of isolated architectural elements that are of a disproportionate size.

For Salingaros, a harmonious building – one which represents a reasonable contextual fit – should have regions or elements that are bounded by edges within a “hierarchy of scales” and with the same “definition and connections as the building’s internal subdivisions” (1998:p289). Salingaros (1999) states that the building’s façade, pavement surfaces and other urban features such as trees and street furniture can all generate these regions. It is then the perception of these regions in terms of their organisation and the differentiation between them that generates the “information field, which in turn determines the use of urban space” (Salingaros 1999:p31). As previously stated, for Salingaros, the planar organisation of space has little relevance to its occupation of visual character compared with the information within the elevational surfaces.

According to Salingaros, scale also plays an important role in the process of human cognition. “The mind of the observer groups similar objects of the same size into a single level of scale” (Salingaros & West 1999:p911). This process reduces the amount of information a person has to absorb and in doing so, allows an individual to estimate the number of similar objects on each scale and compares these numbers to what they sense about the visual complexity from naturally occurring structures. “If the distribution of scales and the relative multiplicity of elements correspond to an experientially generated internal standard, we perceive the structure as coherent” (Salingaros & West 1999:p912). The total number of elements may then not be as important as the “degree of pattern” that might exist between them (Klinger 2000). There are a number of ways in which a dwelling façade can define scale
including through symmetry and proportion (as manifested in the shape and positioning of window and
door openings, covered spaces and columns). For example, if windows are of the same size they can
create a distinct scale. They can be repeated in a symmetrical pattern to define a larger scale
(Salingaros 2000b). Subdividing a window into panes creates a smaller scale while the massing of
exterior walls and the visible roof define the largest exterior scale (Salingaros 2000b). Furthermore,
elements within a streetscape that are of roughly the same size can “couple strongly” together “to
become an element of the next-higher order in size” (Salingaros 2000a:p297). Thus, single elements
have a role in linking other elements together to form visual elements that are of a larger scale.

3.6 Analysis of a streetscape using segmentation

Stamps III (2003) developed an alternative analytical or parsing technique which involves the counting
of defined elements within a building’s façade. By sequencing particular elements such as a “square
window” within an abstract computer-drawn streetscape, he was able to determine a value for the
entropy of any given arrangement. Stamps III then used the image of the streetscape to derive human
responses to the desirability of the arrangement, and together with the calculation of visual diversity,
was able to link visual diversity with desirability.

Stamps III (1999) also used a theory of visual septaves (originally developed by Van der Laan in 1983)
to regulate the number of elements within the façade that occur at scales of one seventh. This
variation on the method is derived from the assumption that it is easier for the mind to comprehend
groups of similarly sized elements than a group of elements with no shape similarity. This concept can
be extended beyond an analysis of a single dwelling and incorporate other nearby dwellings. For
instance, a new building within an existing streetscape fabric may appear to be more sympathetic to
the visual characteristics of the streetscape if the sizes of some of its elements match those of the
existing context. This premise is reinforced by the research of Groat (1988) who compiled twenty-five
images of urban scenes that showed a variety of infill situations, ranging from those that appeared to
reflect the immediate context to those that were very different. Through an interview process (that
included people directly involved in the planning process along with residents) she showed that design
strategies that embodied a “high degree of replication, especially in aspects of the façade design” (1988:p232) were consistently preferred over other design strategies such as site organisation and massing. This finding is supported by other researchers (Moughtin 1999; Brolin 2000) who similarly observe that details within the façade are a critical part of contextual design. However, Groat’s study demonstrated that designs that had some form of façade replication together with a strategy for site organisation and massing were the most preferred.

An alternative method of segmentation uses the human eye to separate a streetscape into separate elements and sets of elements. The frequency of the elements can then be considered as a measure of visual diversity (Stamps III 1999; Malhis 2003; Stamps III 2003). This technique places regular grids over streetscape images and allocates a value to a particular surface type. Krampen (1979) used a technique known as parsing to calculate the visual diversity (or entropy) within the façade of a building. Again, by overlaying a grid on an image of a façade, he counted the occurrences where a particular material was present within a cell. A variation of this method is shown in Figure 3.6-1.

![Figure 3.6-1 An illustration of parsing by Krampen (Krampen 1979:p73). He associated the occurrences of features within the façade to letters of the alphabet, providing something like a code for the façade.](image-url)
3.7 The Analysis of Visual Diversity: A Fractal Method

3.7.1 Introduction

In the late 1970s Benoit Mandelbrot proposed that natural systems frequently possess characteristic geometric complexity over multiple scales of observation (Mandelbrot 1977). While architectural designers adopted fractal geometry within a few years of Mandelbrot’s initial formulation, more than a decade passed before fractal geometry began to be more widely used for the analysis of the built environment (Ostwald 2001). For example, Batty and Longley have each developed methods for using fractal geometry to understand the visual qualities of urban space (Batty 1994). Oku (1990) and Cooper (2003) have separately used fractal geometry to provide a comparative basis for the analysis of urban skylines (see Figure 3.7-1).

![Figure 3.7-1 The fractal assessment of different skylines (Cooper 2003)](image)

Yamagishi, Uchida and Kuga have sought to determine geometric complexity in street vistas (Yamagishi 1988) and various groups have applied fractal geometry to the analysis of historic street plans (Hidekazu 1990; Rodin 2000). While this past research relies on a range of methods, the majority of examples of the fractal analysis of architectural form possess a more common lineage.

---

6 Parts of this section were previously published in several papers co-written by the present author and his supervisor (Ostwald and Tucker 2008; Ostwald and Tucker 2007c)
Carl Bovill's (1996) *Fractal Geometry in Architecture and Design* demonstrates how Mandelbrot's "box-counting" approach to determining approximate fractal dimension can be applied to the analysis of architectural elevations and plans. Bovill (1997) has since offered an extrapolation of this method and Bechhoefer and Appleby (1997) have used this approach to examine the visual qualities of vernacular architecture. Bovill's method has also been repeated by Makhzoumi and Pungetti (1999) and Burkle-Elizondo, Sala and Valdez-Cepeda (2004). Importantly, in the original 1996 work, Bovill demonstrates how fractal dimension can be used to analyze the visual complexity of two façades; one from Frank Lloyd Wright's Robie House and the other from Le Corbusier's Villa Savoye. Bovill's analysis of the two facades has been used to support a wide range of arguments about architecture and, more specifically, a range of criticisms of modernist approaches to design although it has rarely been tested, expanded or developed (Lorenz 2003). But first, what is fractal geometry?

Mandelbrot argues that, fundamentally, Euclidean geometry, the traditional tool used in science to describe natural objects, is unable to fulfil this purpose. To paraphrase Mandelbrot, mountains are not conical in form, clouds are not spherical and rivers are not orthogonal (Ostwald & Tucker 2007b). While historically, science considered roughness and irregularity an aberration disguising underlying ordered systems with a fixed-state or finite values, Mandelbrot argues that the fragmentation of all naturally-occurring phenomena cannot be so easily disregarded (Ostwald 2003). A coastline is not straight and no Euclidean geometric construct can approximate the form of a coastline without serious abstraction or artificiality. As a result of this natural fragmentation, mathematicians have shown that the length of a coastline cannot be determined at all. However, Mandelbrot postulates that the degree of geometric irregularity or complexity that is visible in a coastline at one scale (from a satellite) may be similar to that when viewed from another scale (from a helicopter). If this is the case, then the coastline may possess a form of consistent complexity, or characteristic irregularity, that can be measured (Schroeder 1991).

The characteristic irregularity of a coastline may be measured by imagining that the increasingly complicated and detailed path of the coastline is actually somewhere between a one-dimensional line and a two-dimensional surface (Ostwald 2007b). The more complicated the line, the closer it comes to being a two-dimensional surface. Therefore, coastlines and many similar natural lines can be viewed
as being fractions of integers, or what Mandelbrot describes as fractal geometric forms. Thus, fractal
gometry describes irregular or complex lines, planes and volumes that exist between whole number
integer dimensions. This implies that instead of having a dimension, or $D$, of 1, 2, or 3, fractals might
have a $D$ of 1.51, 1.93 or 2.74. One way of determining the approximate fractal dimension of an
irregular or complex object is to apply the box-counting method.

### 3.7.2 Box-Counting Method

While a growing number of scientific or computational tools have been developed for the analysis of
architectural plans, the production of similar tools for the investigation of the visual attributes of a
building has proved more problematic (Hillier 1984). Despite this, the few methods that do exist for the
visual analysis of architecture have not been subjected to the same level of scholarly scrutiny as have
the previous generation of planning tools. As a result of this situation, there is a considerable gap in
quality and consistency between the application of methods (like Space Syntax) for the analysis of
architectural plans and those for the analysis of building elevations (encompassing visual qualities).

One of the more commonly repeated methods for the analysis of visual character in architecture is
Bovill’s (1996) extrapolation of Mandelbrot’s box-counting approach to determining fractal dimension
(Mandelbrot 1977). Bovill’s original contribution to the box-counting method rests primarily in his
explanation of its potential application in architecture, design and the arts. Bovill’s interpretation of
Mandelbrot’s box-counting method—henceforth “Bovill’s method”—has been used to analyse historic
and modern building facades along with streetscapes and skylines; all situations where visual
complexity is important and quantitative methods have not previously been available.

The box-counting approach is one of the most widely used ways of determining the approximate
fractal dimensions of an object (Skubalska 2005). In its conventional architectural application, the box-
counting method commences with an elevation, for example, of the Robie House by Frank Lloyd
Wright (Bovill 1996) (see Figure 3.7-2). To begin the box-counting approach a large grid is placed
over the elevation and each square in the grid is analysed to determine whether any lines from the
façade are present in each square. Those grid boxes that have some detail in them are recorded.
Next, a grid of smaller scale is placed over the same façade and the same determination is made of
whether detail is present in the boxes of the grid. A comparison is then constructed between the number of boxes with detail in the first grid and the number of boxes with detail in the second grid. Such a comparison is made by plotting a log-log diagram for each grid size (Bovill 1996). By repeating this process over multiple, different scale grids an estimate of the fractal dimension of the façade is produced.

![Figure 3.7-2](image) The box counting method illustrated using an elevation of the Robie House by Frank Lloyd Wright, Bovill (1996:p143)

While this describes the basic method, there are many variations of how this method is used to calculate $D$. For example, Bovill halves the grid dimension for each comparison, whereas commercial software programs use a range of scaling coefficients to gradually reduce the grid size and generate a more accurate result. Other factors that alter the way in which $D$ is determined include the width of the lines in the elevation, the position of the elevation in the image, and the way in which statistical variations are handled (Ostwald, Vaughan, Tucker 2008). The mathematical and computational solutions to these problems are discussed later in the dissertation (in the context of the methods being
developed by the author) while the philosophical solutions are described hereafter.

Bovill’s mathematical method for the analysis of façade complexity is based on a series of assumptions about the visual properties of buildings that are worth examining in further detail. For example, Bovill commences his work with the argument that architecture is necessarily produced through the manipulation of rhythmic forms. He expands this to propose that fractal geometry will allow a “quantifiable measure of the mixture of order and surprise” (Bovill 1996:p3) in such rhythmic forms to be determined and, moreover, that this will reveal the essence of the architectural composition.

Architectural composition is concerned with the progression of interesting forms from the distant view of the facade to the intimate details. This progression is necessary to maintain interest. As one approaches and enters a building, there should always be another smaller-scale, interesting detail that expresses the overall intent of the composition. This is a fractal concept. Fractal geometry is the formal study of this progression of self-similar detail from large to small scales. (Bovill 1996:p3)

In the second stage of his proposition Bovill maintains that the use of fractal analysis in architecture might explain why some modern buildings have never been fully appreciated by the general public, whereas some vernacular architecture is more widely liked (Bovill 1996:p6). Here Bovill assumes that modern architecture (by which he means the international style architecture of mid-career Le Corbusier or Mies van der Rohe) will have a lower fractal dimension and, therefore, a lower correlation with natural geometry than, say, historic architecture. In this proposition Bovill repeats Mandelbrot’s argument which has as its founding assumption the Kantian belief that nature is innately beautiful and that people are drawn to the appreciation of natural forms because of this. For Bovill, fractal images; are pleasant because they capture the character and depth of texture that nature displays. Our perceptual mechanisms evolved in nature and therefore respond to a similar textural quality. The study of fractal geometry should help the designer achieve a better understanding of the cascade of detail all around us in the natural world. (Bovill 1996:p70)

Yet, as philosophers have observed, the Kantian belief in the essential rightness, goodness or beauty of nature is not supported by strong evidence and it does not stand up to close scrutiny. Despite
Mandelbrot’s assertions, fractal dimension is not a determinant of good architecture, social responsibility or cultural meaning in the built environment. Fundamentally, there is no direct correlation between fractal dimension and successful architecture. Fractal dimension in architecture is only useful as a comparative tool: it allows, for example, the visual complexity of a neighbourhood or a street to be determined, and this may then be compared with the visual complexity of a building that is proposed for this street. In this way, fractal geometry can suggest the extent to which a proposed building is “in-keeping with”, or “sympathetic to” its visual environment (Ostwald 2007b).
4 Space Syntax and Spatial Configuration

4.1 Introduction

In the previous chapter a range of methods were discussed that have been used to analyse the visual diversity, or characteristic complexity, of urban spaces in general and streetscapes in particular. All of these disparate methods were essentially focussed on the analysis of facades. While these methods remain the primary references for the present research project, there is a second tradition of architectural and urban analysis that is slightly less relevant but which is nevertheless revealing when considered in this context. The second tradition arose from research that has been broadly grouped under the heading “space syntax”. The current chapter provides an overview of space syntax and its key concepts and goals, before describing some of the more relevant aspects of streetscape analysis.

4.2 Overview of space syntax

Analytical techniques for drawing connections between the visual texture observed by individuals and that of the urban character of street patterns, building heights and open spaces within the city, are rare (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 the free spaces between buildings. As Jiang and Klarqvist (2000) explain, “the distinction between the free spaces” or voids “and spatial obstacles” or forms “is generated by the existence of boundaries between the streets and the built environment”, both are interdependent as they share a common physical boundary (Jiang Klarqvist 2000:p163). The shape of the free space is generated by the existence of a defined boundary (Norberg Shulz, 1965); an interdependent planar surface that can extend from an individual house through to the streets that form cities (Jiang Klarqvist 2000). Using a configurational description of an urban structure, such as a streetscape, space syntax attempts to explain human behaviour and social activities as they actually occur 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).

Since the 1970s, a growing number of researchers have demonstrated that the characteristics of the physical environment, together with its spatial configuration, influence human behaviour within urban space (Alexander 1977; Hillier 1984; Fisher-Gewirtzman 2003). Spatial configuration studies have previously focused on patterns of pedestrian movement in cities (Hillier 1993; Desyllas 2001; Desyllas 2003; Turner 2003). The research in this area has also been extended to incorporate modelling urban traffic, way-finding in large buildings such as hospitals (Haq 2001), pedestrian movement in public buildings such as art galleries (Turner 1999; Turner 2001) predicting air pollution levels, assessing the occurrence of crime within housing estates (Reis 2003), and estimating the potential for retail development in streets (Ratti 2004). However, much of this research is concerned with the systems used for simulation and modelling. Typically, this involves a simplified representation of urban texture in just two dimensions and which does not take into account the dimensional properties of streets (later referred to as “metric”) but only the way they connect to each other. The method typically relies only on information derived in a planar drawing. Building heights, whether pedestrian pathways are open or covered, the permeability of the built façade and its texture play no part in this approach. Similarly, the finer grain texture of urban elements, even in plan – including the location of trees, trafficable surfaces, street signage and furniture – are not considered in this research.

The consideration of the third dimension, the building façade, tends to be limited in space syntax research but it is not completely ignored as the remainder of the chapter reveals. For example, Hillier (1996) 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” (p168). He represents a building’s facade as both a “metric tessellation” (which is then investigated to provide a measure of connectivity) and as a diagram of “the dominant elements in the facade [represented] as a pattern of convex elements” (p168). Using an example of the façade of a classical temple, Hillier also 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” (p168).
4.2.1 Isovists, Convex and Axial maps

A key concept underlying the methods developed by space syntax researchers is the “isovist”. In a simple sense, an isovist is a measure of the area in space that is visible from a single viewpoint. Generally, this visibility is considered in two dimensions only and can be imagined by locating a point on an architectural plan and tracing lines that radiate from this point until they are blocked by the walls, doors or changes in level in the plan. By connecting the endpoints of these radiating lines a shape is formed which defines the extent of visible space relative to that location. The area that is partitioned in this way, and is known as a convex map, is constructed in such a way that all spaces within its shape are mutually visible. When they are collectively shown as a diagram for an urban area, the graph formed is called a convex map and represents “the least set of fattest spaces” within the urban space (Hillier 1984:p92). Fattest in this sense are spaces that are more square-like than they are long and thin. Another reason isovists are interesting in the context of the analysis of space and perception, is that Benedikt and Burnham (1985) identified that the perceived value of “spaciousness” relates more to the complexity of the isovist than to the area of the isovist.

A concept that is related to the isovist is the axial map. It can be visualised by imaging a plan of a complex urban space. Now, draw the longest possible straight line that can be produced within the public open space. Then draw the second longest line, then the third and so on. The resultant graph of criss-crossed lines is the axial map (Hillier 1984:p99). The relative connectivity of lines within the axial map is often used to measure aspects of configuration within the urban environment such as the possible intensity of pedestrian movement (Carvalho 2004). However, Desyllas and Duxbury (2001) have shown that “isovist fields” correlate better with observed pedestrian movements in urban areas than axial maps. Turner and Penn (1999) have also demonstrated that complex methods in calculating axial lines can be avoided by using isovist methods. An isovist provides a complete description of every surface that is visible from any given location (Batty 2004). The field defined by the isovist, or the free space between an observer and a surface, is notionally available for the free movement of people. Thus the isovist replicates and simplifies the purpose of the axial map by decomposing the total amount of free space into smaller spaces that are visible from a single vantage point (Jiang
Turner (2001) goes on to show how a graph of “mutual visibility” can be generated from a set of overlapping isovists within an urban space. The resultant “visibility graph” relies on an understanding that people perceive the built environment from multiple connected perspectives as they move through or around a space (Turner 2003). Fisher-Gewirtzman (2003) describes the visibility graph as being closely related to “manifestations of spatial perception, such as ways of finding your” path across an urban space (Fisher-Gewirtzman 2003). In a similar way to the axial map, a visibility graph can be used to identify characteristics of an urban space such as having highly visually-connected streets.

4.2.2 The Façade Isovist

The concept of a façade isovist is outlined by Hillier as a method of interpreting the relationship between the shape of a public space and the facades of buildings that they appear to be visually directed towards. Hillier (1996:p238) discusses the way that the facades of significant public buildings will appear to be different, depending on the approach of an observer (Ostwald & Tucker 2007). Approaching a façade from the side changes what is seen quite rapidly, whereas approaching the same building along its axis, the façade would appear to be largely invariant. This impact of the public space addressing the facade of a building is then discussed in terms of its dominance within the urban form as a “negative attractor”. The symbolic axis does not necessarily

organise a pattern of movement and through this to generate encounter, but to use the potential of urban space for another kind of emphasis: the communication throughout space of the symbolic importance of certain buildings and locations. (Hillier 1996:p238)

As the façade isovist describes only the planar shape of the urban space that a façade is visible from, the formal and stylistic parameters of the façade remain unrepresented in the analysis. An evaluation of the facade itself might then enhance what the isovist can show about how urban areas are used (Malhis 2003; Ratti 2004).
4.3 Visibility analysis

Visibility analysis is a seemingly attractive way to understand urban spaces as it appears to apply “mathematical certainty to the experience of urban and building environments” (Turner 2003:p672). However, by concentrating on visual relationships rather than an “interpretation of direct perception” (Turner 2003:p672) the analysis will always require a level of interpretation based on how the information has been collected and how it will be used. Different cultural and social backgrounds will necessarily interpret visual information differently. Nevertheless, one characteristic of visibility analysis that makes it useful for a comparative analysis is that the representational and symbolic meanings of a building’s style play no part in the process. The organisation of the elements can be analysed without having to interpret them at the beginning of the process. This is not to say that representational meanings are unimportant to the visual character of a streetscape, but that this type of interpretation should follow a visual analysis of its constitutive elements.

The use of computational techniques and Geographic Information Systems (GIS) software to perform visibility analysis has led to “great advances in understanding the optical physics of intervisibility in landscapes, buildings, and urban environments” (Ervin 2003). However, it is far from clear whether a feature will, in reality, be visible, and if visible, whether it is in any way meaningful for the observer. Perhaps, as Ervin proposes, the burgeoning use of computer-generated visual analysis has led to the growth of techniques that are graphically alluring but analytically superficial. Whether or not this criticism is appropriate depends on the degree to which the analysis is attempting to emulate the vision of an individual (or a group of people) or simply to collect an aspect of a much larger spectrum of visual data.

Visibility analysis implies that the visual field is a key determinant of the way that the users of urban space might navigate around and populate particular parts of the urban space. However, as the visibility graph is typically generated and represented in plan, what in reality can be seen within a convex space is necessarily affected by the terrain (Steadman 2004). This lack of information concerning the elevation of objects in the visual field can result in spaces that are not in reality visually
continuous, being shown as such (Asami 2001). In turn, this might affect the number of spaces that are shown as being partitioned in a convex map (Batty 2004). The importance of this can be seen in a recent study by Desyllas, Connoly and Hebert (2003).

The research project lead by Desyllas considered the visual field provided by doorways at the ground level of both modern and traditional urban areas. Unlike many visual field analysis techniques that do not attempt to differentiate spaces based on the likelihood of an observer standing in a particular position, Desyllas’s project gave priority to the doorway space. While the traditional area showed significantly higher surveillance of the urban space, the model assumed that all doorways were of equal value (two and a half metres wide) and that windows played no part in the natural surveillance. While the affect of distance from an observer to a public space is discussed as being an important aspect of surveillance, the height of natural surveillance points to urban spaces was also not considered. The effect of trees, vehicles and other fixtures that might restrict visibility were discussed as able to potentially be modelled, but incorporating their three dimensional properties proved more difficult for Desyllas.

A much earlier version of this technique, known as “viewshed analysis”, is discussed by Lynch (1976) and originated in landscape studies. Like an isovist, a viewshed is the set of all visible points of the ground plane from a given position; the difference being that it considers the eye height of the observer within the calculation. Research has tended to focus on the relationship between the occupant and the environment within GIS and landscape studies, while little research has been done using it within urban spaces (Batty 2004).

4.3.1 Three-dimensional Visual Analysis

As a leading proponent of space syntax research, Hillier ultimately rejects the view that spatial organisation in the third dimension is as important as it is in the second dimension (Hillier 1984; Hillier 2004). While the type of urban pattern and the scale of the investigation will affect the degree to which the height of a building is significant (Penn 1998a), when moving along a two dimensional path within small scale space, the degree of enclosure will have strong perceptual effects (Teller 2003). A similar
position is held by Fisher-Gewirtzman (2003) who argues that the spatial configuration of built form strongly influences human perception and subsequently how the built environment is evaluated.

From a geographical perspective, Bishop reflects that a “two-dimensional approach to view analysis afforded by GIS is inadequate in situations with strong three-dimensional elements” (2003:p678). Batty and Rana (2004) also observes that space syntax has been unable to evaluate form in three dimensions largely because of its reliance on manual methods to determine axial lines. However, recent computational techniques, that automatically generate axial lines from a raster map might be able to compensate for changes in terrain and the effects of foreshortening ray tracing produced by actual visibility conditions (Carvalho 2004). Despite this, it will remain difficult for these methods to accommodate the form and composition of building facades (including awnings), street trees, vehicles, signage, fences and gardens (Torrens 2001). To date, most methods have argued that these factors are not important enough to be recorded in the first place (Penn 1998a). The planar information typically used for axial line extraction contains only basic information and must necessarily neglect a large number of elements which have a significant affect on pedestrian movement within urban areas (Ratti 2004).

The scale at which a spatial system is represented also has an important effect on the information that an analysis might provide. This can be seen in many of the planar visual studies that have been widely discussed since Hillier and Hanson first introduced this idea in The social logic of space (Hillier and Hanson 1984). The plan of the French town of Gassin in particular, has been analysed by multiple researchers as a way of comparing visual and configuration techniques (Hillier 1996; Jiang 2000; Batty 2004; Carvalho 2004). The Gassin plan, shown initially in The social logic of space, represents the external walls of buildings as they meet the street, with doorways that appear to be within small alcoves, but subsequent drawn plans used for axial analysis do not consider this detail at all. Batty notes in his own analysis of the plan that detail of less than two metres square would “disappear and thus many nooks and crannies essential to the visual scape would be lost” (2004:p616). When the scale is too coarse for features such as partially-enclosed entry spaces and fences to be represented, then it is clear that the built form being evaluated is only what might be called the “first scale” of an individual building, its bounding envelope (Malhis 2003). The surface of the public space is similarly
not considered in most of these examples. Changes in the level and type of pavement, the extent of
vegetation, street poles and other furniture and fixtures are unrepresented in published axial mapping
research. It might also be expected that the streetscape walls of Gassin would show variation within
the surface that, at the scale of a pedestrian a few metres away, would be quite plain to see. With the
increased capacity for computers to store information, the increased resolution in the way that the
surface of the streetscape is represented (Frueh 2005) and the development of automatic techniques
for visual analysis (Carvalho 2004), syntactical methods that include more detailed information of the
street may be close at hand.

Despite these observations about the problems with the analysis of Gassin, the scale of the analysis is
not necessarily as important as the consistent application of the method within certain scales. Thus,
Hillier (1984) argues that as long as a consistent process is applied of determining what elements of a
particular scale are to be incorporated within the study, there should be no methodological problems.
He further suggests that “fine tuning” should occur in the method to suit a particular urban space
(essentially defining the level of articulation that is incorporated) and that the researcher should
“decide when changes in the shape of buildings or boundaries are allowed to make a difference to the
convex spaces” (Hillier 1984:p98). This concession allows the study of the same urban space to be
conducted by different researchers and to potentially provide different results. However, Hillier
maintains that a study of an urban area should include a “minimal map” that includes no more than the
overall built form as well as a “fine tuned map” that includes all articulations. Perhaps because of the
amount of field work required to develop a “fine tuned map”, a comparative study of the two maps for
Gassin cannot be found in the published literature.

Batty (2004) similarly identifies that spatial analysis conducted at different scales might provide
different results. For Batty, urban forms that are significantly more detailed beyond the initial outline of
overall form might, for instance, show quite different results to those that essentially remain a flat
planar wall. The articulation of spaces at the front of a dwelling is often designed to limit visibility of
more private spaces, essentially extending the amount of private space beyond the external wall of the
dwelling itself. Buildings established for retail purposes often extend the public space of the street
beyond the external wall of the built form. These different types of buildings will provide very different
types of convex map graphs.

While the isovist analytical technique was developed largely as a means of investigating planar arrangements, there has been some recent progress to extend this approach into the third dimension. For example, Teller (2003) cleverly examines 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 (see Figure 4.3-1). This method disregards the absolute heights of buildings (as they are often recorded on planning diagrams) and instead considers the “statistical distribution of angular heights as they are observable from a given point” (Teller 2003:p354). The width and height of an urban space are considered as important variables in establishing the enclosure of an open space and importantly the actual space was used for the analysis, as opposed to a simplification of the space that two-dimensional data would have provided. Teller’s method also reduced the complexity of the analysis by reducing an image of a three dimensional space into a two dimensional surface.

![Figure 4.3-1](image)

Figure 4.3-1 A fish eye view of an urban open space allows the volume to be plotted as an area (Teller 2003:p355).

Teller’s method, despite its lack of true three-dimensionality, was nevertheless an important step towards incorporating the street elevation within a study. In 2003 Fisher-Gewirtzman considered a three-dimensional viewpoint and generated the volume of visible space from a comprehensive collection of possible views from an abstractly generated apartment. This measure of the volume of open space is called the Spatial Openness Index (SOI). While requiring considerable computational power to develop accurate three-dimensional models of urban areas, this type of analysis is becoming
more prevalent as specialised software is developed (Chalup et. al. 2007b). New techniques of viewshed analysis are also discussed by Turner (2003) with innovations in agent-based simulation and virtual reality technology seemingly having the most potential for the analysis of streetscape character.

4.4 Topology of urban space

The concept of “information retrieval” (Hillier 2003) sheds light on the way in which a visual scene is understood simultaneously as both a relationship between elements and as a whole. The process of visual perception is so innate to our understanding of the world that Hillier claims “space itself may be the machine” (1996:p11). This suggests that the viewer “may merely need to determine the humanly accessible topology as invoked through the process of inhabitation” (Turner 2003:p674) to determine the merits of proposals within the urban fabric. In this way a measure of the salient geometry within small scale spaces or streetscapes might reveal a topology that is useful in the analysis of larger urban areas (Jiang 1999). Topology, in this context, is a measurement of the properties of spaces in terms of their boundaries and connections independent of their size and shape.

Instead of increasing the complexity or recording a streetscape, a study may be able to establish a topology (or patterns) that are more useful. For example, 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 inhabitation. It may be 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 understood to have a configurational arrangement.

4.5 Techniques for mapping the streetscape

In the previous sections in this chapter a range of analytical methods associated with space syntax were described. In the remainder of the chapter the computational advances suggested by space
syntax research are considered in a wider context including their application by planning authorities, their use in virtual modelling and laser scanning. This section retains a number of conceptual links to space syntax but is otherwise focussed on more isolated examples that are of relevance to the present study.

4.5.1 The use of computer models for planning purposes

Planning authorities rely on maps of land use and density, studies of traffic movement, topography and other physical characteristics of the urban environment to understand the impact of a new development (Batty et al 2000). Physical three dimensional (3D) block models are sometimes used although their cost typically prohibits their widespread application to urban centres. More commonly, digital photography (supplemented with site visits) provides the background data for an practical analysis of a streetscape.

Computer models have been implemented within the planning process to provide flexibility in the way in which proposed buildings might be visualised and alternatives compared (Dodge 1998). Some models are essentially a visual interface for complex and interrelated social and regulatory data and are not intended to depict a visual reality (Batty 2001). They use the visual interface of the city map to manage the complexity and more quickly establish trends and patterns within the data. Many researchers believe that the need to develop models of spatial complexity within urban systems must lead to realistic 3D models (Torrens 2000). Presently though, the information required to construct 3D models lacks sufficient content or resolution to allow detailed visual analysis (Bishop 2003). While recent software programs (Canoma, Photomodeler) can take advantage of the regular shape of urban structures and construct 3D models from just a few images, the use of aerial photographs of the same scene taken from different positions has been the main source of data for most 3D models (Batty et al 2000). While the digital photographic coverage of the urban terrain is increasing, it is only in the last few years that information concerning the elevation of surfaces in the urban space has been obtained (particularly through the availability of Google Street View). The slow uptake of this information to provide texture to three dimensional planning models has meant that buildings are represented as prismatic shapes with little or no character in the building’s façade and urban spaces considered
without fixtures such as landscaping, seating and the like (Bishop 2003). An aerial photograph of a building presents the surface of the elevation as a near vertical surface, with roof overhangs and similar structures sometimes preventing accurate information being obtained at all (Batty 2000). The draping of prismatic forms, derived from aerial photography, with textures, generated from ground-based images, can represent complex façade details quickly and overcome some of the problems with purely aerial based representational methods. Using complex processing techniques to locate matching points in space, common building forms can be accurately represented. Boldt (1989) comments that not all analysis should be directly related to the interpretation of three dimensional models: “[i]f early stages of two dimensional processing are capable of producing symbolic descriptors that are usable by higher level processes, a great deal of flexibility will be gained in dealing with difficult problems in vision.”(p125) He argues further that there are varying goals in visual perception. In navigation, for instance, there is a need to know where objects are in space, not necessarily what they are. However, for visual recognition the viewer does not usually need to know the distance away each part of an object is to recognize it. Boldt adds that the human visual system has no difficulty in dealing with both tasks simultaneously. This suggests that it “should be possible to use symbolic grouping mechanisms for two-dimensional (2-D) processing without the necessity of first constructing a 3-D representation of the data” (Boldt 1989:p127).

### 4.5.2 The use of digital elevation models

In an attempt to overcome the lack of computing power needed to evaluate urban areas, Ratti used Digital Elevation Models (DEM) 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). For example, a planar image of an urban area can be processed in such a way that each pixel is given a value proportional to its height (Ratti 2003) (see Figure 4.5-1). The DEM does not represent the vertical surfaces of the streetscape, except what might be calculated from the top down view of the facade (Richens 1997).
This method is computationally “lean”, using algorithms that are “independent of geometric complexity and relate linearly to the area under investigation” (Ratti 2004:p301). Various methods of urban analysis using DEM include built volume shadow, air pollution studies, wind-effect and energy consumption. While not directly applied to the streetscape the methods demonstrate that useful information about the environment might simply be obtained through digital image processing. However, in terms of understanding the surface of the urban environment in its vertical dimension, or at the detail that users come into contact with, the technique is limited (Salingaros 1997).

4.5.3 Laser Mapping

Ground-based and air-borne laser sensing equipment provides the best method for quickly and accurately constructing geometric and photorealistic models of individual buildings and entire urban regions (Stamos 2003). A Digital Surface Map (DSM) that accurately creates the form and texture or an urban environment can be obtained by using complementary laser scans from both the ground and air (Frueh 2003). More recently Freuh, Jain and Zakhor (2005) have developed automated methods that rapidly acquire this information solely from the ground. Using fast 2D laser scanners that provide information about the shape of the urban surface and a digital camera that captures its texture and colour, the equipment is attached to a vehicle and driven at normal speeds on public roads. The information recorded is processed and can quickly construct the DSM of an urban area. To acquire 3D information more quickly, the vehicle-borne laser mapping system (VLMS) was developed by
Manandhar. The system uses laser scanners and line cameras to acquire information about urban areas. The system can determine the size and shape of elements within a building façade within one metre (Manandhar 2002). The method also has the potential to construct protrusions from the surfaces of buildings such as awnings and to place urban fixtures such as signs and trees within the model. Objects with a more complex form such as trees are more difficult to model although using remote sensing data there is some development towards automated mapping of these types of objects (Bishop 2003).

The extraction of features from an image is the process of classifying the laser points reflected by the objects being scanned into different groups that match the surfaces they strike; like walls, street furniture, landscaping and vehicles (Manandhar 2002). Building faces are extracted from vertically aligned data sets (Stamos 2003). This procedure also automatically provides surface colour and distance information which may be used directly or as a validation for content and depth analysis based on the three dimensional model (Bishop 2003).

With urban spaces and surfaces so accurately constructed within such a digital framework the potential for the analysis of how cities are inhabited and used appears to be great.
5 Method: Computational approaches to Streetscape Image Assessment

5.1 Introduction

A range of computational algorithms are being used to understand the visual properties of physical environments in a number of fields including biology, medical diagnostic imaging, remote sensing, space exploration, defence and security. The image in Figure 5.1-1 is a visual record of what the robotic “dog” in Figure 5.1-2 “sees” when it is competing in a soccer game. It is this image that computational algorithms interpret to “understand” the environment that the robotic dog operates within (Chalup et al 2007b). The analysis of the built environment using such tools might show if there are consistent visual characteristics explaining why some environments are highly valued, safe or sustainable. A tool that is also able to consistently analyse the visual characteristics of the environment might assist the assessment of buildings by planning authorities (Wilson 2005). Visibility analysis supported by computer algorithms also makes it useful for a comparative analysis because the representational and symbolic meanings attributed to a building play no part (Tucker & Ostwald 2007b). This is possible because the organisation of the elements can be analysed without having to interpret them at the beginning of the process, and any part of any streetscape can be assessed using the same processes. This is not to say that representational meanings are unimportant in a streetscape, but that an interpretation of these elements might work alongside a computationally derived visual analysis.

Figure 5.1-1 Snapshot of robot vision

Figure 5.1-2 Competing ‘robodogs’
5.2 **Software design of Archimage**

5.2.1 **Introduction**

As part of the research undertaken for the present dissertation, a computer program called *Archimage* has been developed to analyse architectural images. It utilises architectural knowledge and computer vision algorithms to provide an insight into the characteristics of the visual environment. This is of particular interest to researchers investigating the visual qualities of the streetscape.

The algorithms used in *Archimage* have been adopted from those developed within the computer visualisation field and in particular those that are able to differentiate and segment the visual environment in different ways (Boldt 1989; Marshall 2007). These algorithms have been developed to specifically analyse a photographic image of a streetscape rather than elevational drawings of a building that are themselves a simplification of the way humans experience the streetscape (Teller 2003). They may also prove useful for an assessment of a more general view of the urban environment such as aerial views, as they are sensitive to the cues of a perceptual boundary such as; colour, texture, level of intensity and contextual information contained within an image (Yang 2004).

The image processing techniques utilised are outlined within this chapter and include; Image and Colour Segmentation, Fractal Dimension (D), Hough Transform (HT), Line Count (LC), Polar Array (PA), Line Strength Array (LSA) and Learning Manifold (LM).

5.2.2 **Archimage Software Code: Developing the platform**

All of the software tools were authored by software engineers Josh Marshall and Riley Clement under the supervision of Michael Ostwald, Stephan Chalup and the present Author.

The first iteration of the algorithms was developed in *Matlab*\(^7\), which included the Hough Transform (HT) and a basic GUI (Graphical User Interface). However, this implementation was impractical for widespread use, so the code base was converted to *Python* as a Mac OS X application. It began as a set of *Matlab* scripts with a basic user interface however the difficulty in accessing *Matlab* whenever

\(^7\) [www.mathworks.com/products/matlab/](http://www.mathworks.com/products/matlab/)
the software was to be used led to the application code being updated to a platform that allowed any user with Mac OS X to use it. The porting of the image processing code to Python, and further development took place on this code base. The underlying Python libraries used were the NumPy and SciPy\textsuperscript{8} scientific libraries and the Matplotlib plotting toolkit (Marshall 2007). The former use the Accelerate framework to provide fast linear algebra and Fast Fourier Transforms (FFT), while the latter replicated much of the plotting functionality of Matlab and was easily embedded in an NSImageView for end-user visualisation. The application was distributed as a standard “.app” bundle by using the py2app build tool.

5.2.3 Archimage Software Code: Developing the User Interface

The user interface was developed using Interface Builder and standard Cocoa controls. It was connected to the image processing code through PyObjC, the Python-Cocoa bridge\textsuperscript{9} now included with Mac OS X Leopard. This allowed for the rapid development of on-screen visualisation and manipulation of the image, along with export to PDF. The ability to leverage both Cocoa and the Python standard libraries in a single application allows for greatly accelerated development times and ease of implementation for image processing and visualisation tools.

The Matplotlib plotting toolkit\textsuperscript{10} is used for generating the images and graphs. This library aims to be a replacement for Matlab’s interactive plotting capabilities, while also providing an object-oriented API for more advanced usage. The plots are displayed using a custom NSImageView subclass which wraps the Matplotlib functionality. The processing is carried out using the NumPy and SciPy libraries. NumPy provides fast N-dimensional array-manipulation for Python, while SciPy wraps various libraries, in particular the libraries exposed through Apple’s Accelerate.framework and LIBSVM for support vector machines\textsuperscript{11} The Python Imaging Library\textsuperscript{12} is used for loading the source images and colour-space conversion. Finally, the program was bundled into a standard .app distributable

---

\textsuperscript{8} NumPy and SciPy: http://www.scipy.org
\textsuperscript{9} PyObjC, included with Leopard: http://pyobjc.sourceforge.net/
\textsuperscript{10} Matplotlib: http://matplotlib.sf.net
\textsuperscript{11} LibSVM: http://www.csie.ntu.edu.tw/~cjlin/libsvm/
\textsuperscript{12} PIL: http://www.pythonware.com/products/pil/
application through the use of py2app \(^{13}\). The resulting application is also a Universal binary. Together, these Python libraries provided a suitable environment for numeric processing which can then be bundled into an easy to use, native Mac application. \(^{14}\)

### 5.2.4 Archimage Software Code: Input Screen

The *Archimage* user interface input screen shown in Figure 5.2-1 below allows the user to load a series of images. When an image has been selected, its location and a thumbnail are shown.

![Archimage input screen showing images loaded](image)

**Figure 5.2-1** Archimage input screen showing images loaded

---

\(^{13}\) py2app: http://svn.pythonmac.org/py2app/py2app/trunk/doc/index.html

\(^{14}\) The material in this section was developed with the assistance of Josh Marshall and Stephan Chalup
5.2.5 Archimage Software Code: Typical output screen

Once the suite of different algorithms had been assembled (this is outlined in the following parts of Section 7), the different results are output as a single PDF file and as a single A4 PDF sheet (see a typical result in Figure 5.2-2).

Figure 5.2-2 The collated output screen from Archimage
5.3 Conceptual Approach 1: Image and Colour Segmentation

5.3.1 Overview of the Approach

Within computer vision, segmentation refers to the process of partitioning a digital image into multiple regions or sets of pixels (Chalup 2007a). The resulting segments bound by edges simplify the image allowing them to be studied as blocks. Image segmentation results in a set of regions that collectively cover the entire image or a collection of boundary edges that show the lines of contrast within the image. In respect to a previously calculated characteristic of colour, intensity or texture, each of the pixels in a segmented region are now considered similar (Frueh 2005; Chalup 2007a). The segmentation process is well suited to the analysis of photographic images of dwellings within the streetscape because the different elements are differentiated based on the boundaries formed by colour, texture and intensity levels (Boldt 1989; Gonzalez 1992; Yang 2004).

A colour image can be considered as a series of “bands”. The traditional way for a computer to represent colour images is as a series of three greyscale or intensity images, one each to represent the red, green and blue channels. This particular division is chosen as the phosphors on a monitor are Red, Green and Blue (RGB) as shown in Figure 5.3-2, 5.3-3 and 5.3-4. RGB is an additive process, modelling the way in which primary colours combine to form new colours. However, to emulate more closely how humans perceive colour, the image can be separated into it's Hue, Saturation and Value bands (HSV) as shown in Figure 5.3-5, 5.3-6 and 5.3-7. The Hue (Figure 5.3-5) corresponds roughly to “which colour”, the continuous range of intensities is segmented into various ranges of intensity and is then recolourised based on these bins. Each particular colour value represents a range of values in the original image. Saturation (Figure 5.3-6) is a measure of the “purity” of the colour. White areas indicate high purity, or little grey, black areas are those that are “grey” and thus have low saturation. The Value (Figure 5.3-7) corresponds to how the image would look in black and white; it is a measure of the amount of light present.
Figure 5.3-1 Original image  
Figure 5.3-2 Red Channel  
figure 5.3-3 Green Channel  
figure 5.3-4 Blue Channel  
Figure 5.3-5 Hue band  
Figure 5.3-6 Saturation band
The image can also be segmented on the basis of the varying grey levels as shown in Figure 5.3-8. This is known as histogram segmentation wherein the histogram is a plot of the number of occurrences of a particular intensity in the image.

A colour segmentation feature was added to Archimage that allowed the user to select colours within the image that were subsequently grouped and identified as a particular feature within the image. This allows different elements within the image to be expressed as a percentage of the whole image.

5.3.2 Limitations of the Approach

Image segmentation will divide the image into regions based on RGB and HSV however, whether or not the region identifies a significant element within the image can be affected by how elements are separated by intensity, colour and texture. For example a dwelling’s façade in shadow will be divided along the line of the shadow even though this forms a temporal boundary that may not be of any use when trying to understand how a façade is composed. The method is also limited because each façade will contain a different range of colours and intensities, meaning that it is difficult to compare a series of images of houses using the same user-identified set of values. This can be partially remedied by further processing the images with algorithms that can automatically associate a detected segment with a known element. For example, an algorithm could be written to identify the sky because it has regular features; occupies the large segment at the top of the image, is lighter than the regions it is bound by, is pale blue in colour etc.. While this type of element-based identification is used in a
number of research fields such as medicine and vehicle identification, incorporating this higher level of processing is beyond the scope of the present study.

5.3.3 Example Process

1. A colour digital image is imported into Archimage and displayed as shown in the interface screen in Figure 5.3-9. The colour classification software is loaded into Archimage.

2. The user clicks with the mouse a number of times on the colour that represents the feature to be recorded. For instance in Figure 5.3-9 the varying parts of the image corresponding to the render have been clicked (the small circles represent each mouse click), providing the array of colours outlined in the dialog box to the bottom right of the interface screen. One of these colours is selected to represent the render once the image has been processed. For non-trivial images such as those of the streetscape, a table of slightly different colour hues and intensities is typically recorded. It is important to get a range of colours within the image that correspond to the feature because Archimage will use a one-class Support Vector Machine (SVM) in colour space to fit a suitable shape around all other pixels of similar colour. There is a parameter which can be set to control the tightness of this non-linear fit and the user can add or delete individual pixels from the initial colour table until the resulting set of pixels is satisfactory.

3. When the “Classify” button is selected a classification of the image takes place using the SVM and the percentage of coverage of each element is provided. Every pixel in the image is classified as being in one of the bins associated with the classification labels.

---

\(^{15}\)SVM's are a set of related supervised learning methods used for classification data (Marshall2007)
5.3.4 Discussion and Results

The output screen of the image shown in Figure 5.3-9 is shown in Figure 5.3-10. The percentage results, shown in the upper right of the output screen, show the amount of ‘Brick’ in the image is 16.1%. The pixels associated with “Brick” have been placed back over the image and are shown as orange. It can be seen that the amount of brick colour found is accurately recorded with only a small amount of the classification spreading to the underside of the deck awning. The relative accuracy in measurement is because the colour has a high contrast value against other colours within the image. However the mortar has been recorded as both “Render” and “Balcony” because it has a similar hue and the percentage of the “Balcony” area is much higher than would be expected because its hue is similar to those of “Window” and “Render”, confusing the SVM processing. For this reason some images work much better than others.
Figure 5.3-10 Output screen for the colour classification processing

Colour segmentation can also be used to determine the amount of shadow falling on a façade throughout the day as shown Figure 5.3-12. Studies of this type might provide information about how the fronts of dwellings are exposed to sunlight and control energy absorption.

![Original image](image1)

![Colour segmentation](image2)

Figure 5.3-11 Original image

Figure 5.3-12 Colour segmentation

The colour segmentation aspect of Archimage was intended for use with streetscape images however it can be equally applied to other images such as the aerial view of the Hamilton South Conservation
Area (HSCA) and marked with black outline in Figure 5.3-13. The HSCA has planning controls that shape the appearance of new or altered dwellings but does not differentiate between areas within the conservation area that might have a different visual character. The visual character does appear to gradually change when assessing the streetscape images however, by analysing the aerial map using colour segmentation, the differences become clear.

The colour segmentation of the image shown in Figure 5.3-13 is shown in Figure 5.3-14. The analysis distinguishes between the colours of road (25%), terracotta roofs (17%), metal roofs (15%), trees (19%) and lawn (24%). Within the suburb, terracotta tiled roofs generally means that the wall construction is brick, while metal roofs tends toward a wall construction that is timber framed and timber clad. The analysis shows that some blocks in the HSCA are entirely covered with Terracotta tiles while others have few dwellings with tiled roofs. To further investigate how this changes within the HSCA, each of the blocks running from left to right along one of the main streets was cropped from the image and each was analysed using the same user-defined colour segmentation. The different percentages of materials were then tabulated with the results shown in Figure 5.3-15. They show that the percentage of terracotta roofs diminishes from around 25% to around 8%, while the percentage of metal roofs moves from around 8% up to 20%. Being able to show that materials change within the HSCA, might provide a resource for those intending to modify dwellings within a particular block. When the outline of the suburbs within the HSCA is placed back over the colour segmentation...
diagram, as shown in Figure 5.3-16, the material changes become clearer.

**Figure 5.3-15** Material changes along one of the main roads running east - west

**Figure 5.3-16** The HSCA with the suburb layout shown in black outline
5.4 Conceptual Approach 2: Edge Detection

5.4.1 Overview of the Approach

Edge detection aims to identify points or pixels within an image where a specified threshold is reached, usually measured as a condition of brightness (Forsyth 2003:p89). The purpose of detecting these discontinuities in image brightness are that they are likely to correspond to changes within the image such as relative depth of objects, changes in the surface orientation and texture, changes in material character and variations in scene illumination (Lindeberg 1998). Ideally, the result of applying edge detection software to an image is a diagram that consists of a set of connected curves that indicate the boundaries of objects, changes in textural and illumination boundaries. This reduction in the amount of data within the image preserves the important structural properties of the image while providing reduced times for subsequent processing (Lindeberg 1998). The image shown in Figure 5.4-1 has been processed with edge detection software and the resulting edges have been highlighted in blue as shown in Figure 5.4-2. A close up of part of the balcony is shown in Figure 5.4-3 and it can be seen that each pixel is analysed in terms of its immediate context to see whether it forms part of an edge. The perpendicular direction and magnitude of a possible line passing through a pixel is then indicated by the arrows.

Figure 5.4-1 Original image  
Figure 5.4-2 Detected edges highlighted
5.4.2 Limitations of the Approach

When edge detection software is applied to images of the streetscape it is not always possible to obtain edges that are continuous and it may be necessary to apply other algorithms, such as the Hough Transform, to find complete edges. Detecting the edges within an image will also necessarily remove the areas within the image that the segmentation process described in Section 5.3 would otherwise detect; in this way the two methods complement each other. Wherever there is a condition of a boundary within the image, the associated pixels will be retained; however some of these boundaries may not have been the purpose of the study and will interfere with the results of any
further analysis. For instance a shadow cast over a wall will be recorded as an edge at the boundary of the shadow, interfering with the permanent edges within a dwelling’s façade. Because photographs are being used for the analysis, detected edges of small length provided by landscape elements such as trees can be relatively high and may possibly interfere with edge lengths within the building, such as brick coursework and roof tiles. While the vegetation is part of the streetscape view and should necessarily be part of the visual environment to be studied, its dominance in some images can obscure the form of the house. Where the vegetation is deciduous, the detected edges would also vary between different times of the year.

5.4.3 Example Process

1. A digital photographic image is imported into Archimage and the edge detection software is loaded.
2. The edge-detection (ED) algorithm removes the colour segments from the image and produces an optimised line drawing of the original image.
3. The ED is shown on the output screen and can be used for further processing, it is also provided as a PDF file

The ED is the basis of the processing outlined in the following sections, but it is not used in itself to separate streetscape images based on its visual properties.

5.4.4 Discussion and Results

When an image is differentiated, the edges will stand out, representing areas of rapid change within the image. An edge sorting process can be applied where morphological operations are performed to find the significant edges at varying pixel lengths. The series of diagrams shown in Figure 5.4-4 through to Figure 5.4-12, show segments of the found edges from the relatively small to longer edges. Being able to detect lines of particular lengths is an integral part of the image segmentation techniques outlined in the following sections in chapter 5.
Figure 5.4-4 ED - lines greater than 3 pixels

Figure 5.4-5 ED - lines greater than 6 pixels

Figure 5.4-6 ED - lines greater than 9 pixels

Figure 5.4-7 ED - lines greater than 12 pixels

Figure 5.4-8 ED - lines greater than 15 pixels

Figure 5.4-9 ED - lines greater than 18 pixels
By applying Sobel operators to the image shown in Figure 5.4-11 the horizontal edges can be segmented as shown in Figure 5.4-13, the vertical edges in Figure 5.4-14 and when these two images are combined they produce the image shown in Figure 5.4-12. The Sobel operator calculates
the intensity gradient at each point within the image and provides the direction of the largest possible change from light to dark (Marshall 2007).

Other methods that can be used to segment the image include filtering the image with combinations of four filters: level, edge, spot and ripple as shown in Figure 5.4-15. This method provides nine output values per pixel and can be used to find edge to edge conditions; that is, it finds corners within the image.

![Figure 5.4-15 Level, edge, spot and ripple filters, and placed back over the original image](image)

Other methods select a small region, determine the mean, and then scatter analysis across the image to find similar pixels for inclusion. An example of this is shown in Figure 5.4-16.

![Figure 5.4-16 Image segmentation by selecting a small part of the image, then scattering to find similar pixels](image)
5.5 Conceptual Approach 3: Fractal Dimension Calculation

5.5.1 Overview of the Approach

As previously described in the chapter concerning geometric analytical techniques for architectural façade analysis, one of the few techniques that has been successfully repeated on multiple architectural examples uses fractal analysis. While this technique has typically been undertaken “by hand” in the past, researchers have called for it to be automated to produce more consistent and useful results (Bovill 1996; Lorenz 2002). The approach relies on a process called “box-counting” to produce an approximate calculation of the characteristic visual complexity, or fractal dimension, of a two-dimensional image ($D$).

The standard architectural variation of the box-counting process takes as its starting point a line drawing, say the façade of a building. A grid is then placed over the drawing and each square in the grid is analysed to determine whether any lines from the façade are present in it. Those grid boxes that have some detail in them are then marked. This data is then processed using the following numerical values:

\[
\begin{align*}
(s) & \quad \text{the size of the grid} \\
N(s) & \quad \text{the number of boxes containing some detail} \\
1/s & \quad \text{is the number of boxes at the base of the grid}
\end{align*}
\]

Next, a grid of smaller scale is placed over the same façade and the same determination is made of whether detail is present in the boxes of the grid. A comparison is then made of the number of boxes with detail in the first grid ($N_{(s1)}$) and the number of boxes with detail in the second grid ($N_{(s2)}$). Such a comparison is made by plotting a log-log diagram ($\log[N(s)]$ versus $\log[1/s]$) for each grid size. This leads to the production of an estimate of the fractal dimension of the façade; actually it is an estimate of the box-counting dimension ($D_b$) which is sufficiently similar that most researchers don’t differentiate between the two (Bovill 1996; Lorenz 2002; Ostwald et. al. 2008).

The slope of the line ($D_b$) is given by the following formula:
\[ D_b = \frac{\log(N_{s2}) - \log(N_{s1})}{\log(1/s2) - \log(1/s1)} \]

where \((1/s)\) = the number of boxes across the bottom of the grid. (Bovill 1996: 42)

### 5.5.2 Limitations to the Approach

The box-counting process has been criticised and refined over the last decade by a number of researchers in response to known limitations. The key limitations of the approach and Archimage’s responses are as follows.

The amount by which each successive analytical grid is reduced in size is the scaling coefficient. Changes in the scaling coefficient can affect the \(D\) result produced by the method. For example, Bovill (1996) halves the grid dimension for each comparison, whereas most researchers call for a more gradual reduction in grid size to generate a more accurate result. Archimage software is flexible to accommodate a range of scaling coefficient but is typically optimised to use a 0.7 (rather than 0.5) scaling coefficient.

Other factors that alter the way in which \(D\) is determined include the width of the lines in the elevation, the position of the elevation in the image, and the way in which statistical variations are handled.

The wider the lines in the source image, the more chance they have of being counted twice when grid sizes become very small, leading to artificially increased \(D\) values. To counter this situation, Archimage software pre-processes photographic data using a line-detection algorithm that produces images for analysis that are one-pixel-wide. In addition to the line width problem, the volume and distribution of white or empty space around the source image can also alter the result. To solve this, Foroutan-Pour, Dutilleul and Smith (1999) offer a complex algorithm to optimize the way in which an image is positioned against its background and suggestions on how to derive an ideal analytical grid.

A further related issue is that the proportions of the image being analysed also influence the result in subtle ways. If the original image being analysed is not pre-sized to produce a clear starting grid, then an additional step must be added to ensure that a divisible starting grid is determined. Archimage “grows” the image by adding small amounts of empty space to the boundaries to solve this problem.
While this process does not change the elevation in the source image, it can result in a slightly increased $D$ value being recorded.

A final challenge for any application of the box-counting method is the problem of statistical divergence. The average slope of the log-log graph may be the approximate $D$ value, but the points generating the line are not always consistent with it. The $D$ value is only a reasonable approximation when most of the points in the log-log chart correspond with the resultant average line. The question then becomes, how are divergent points handled? While there is no definitive answer to this question, divergent results tend to occur primarily at the extremes of the graph; with the largest and smallest grid sizes but not normally those in between (Lorenz 2002; Ostwald & Tucker 2008). Bovill (1996) is aware of this problem and he solves it by intuitively determining where the practical limits of scaling in an image can be found. For the present research, similar settings for starting grid proportion and size minimize the number of divergent results associated with the largest grid dimensions. However, for divergences associated with small scale grids, different tactics are used. Archimage has no artificial limit on the small grid size and any divergences it produces are averaged into the log-log graph. This means that, while the actual differences will be minor, Archimage is likely to produce slightly higher results in general, as well as slightly more accurate results for objects that exhibit characteristic irregularity over a large range of scales (Ostwald 2008).

### 5.5.3 Example process

1. A digital photographic image is imported into Archimage and the fractal analysis calculator is loaded.

2. Archimage uses the edge-detection (ED) algorithm to remove colour information from the photo and produce an optimised line drawing of the original image.

3. Archimage applies the computational version of the box-counting approach to the line drawing producing a log-log graph (for example see Figure).

4. The slope or angle of the log-log graph is automatically calculated by Archimage which reports this result, the approximate fractal dimension of the image.
5. A sliding scale at the bottom of the log-log graph allows the user to select a stage containing a particular number of boxes and then have this visualised back over either the original image or the ED image.

For example, the image in Figure 5.5-1 was processed using the Fractal Dimension calculator within Archimage and the output graph is shown to the right of the image, The $D$ result is calculated as $D = 1.8$. The image that was processed measures 640 x 480 pixels with the largest grid being a third of the size of the smaller of the sides; that is, 160 pixels wide. The next box size adds another box to the smallest size and divides the pixels up once again until the smallest box size of 5 pixels wide is reached. The line of best fit is then calculated to provide the calculation of $D$ for the image.

![Figure 5.5-1 Output screen of the fractal dimension calculator for a 640 x 480 pixel image](image)

The number of pixels in the starting facade image actually has little impact on the $D$ calculation once the smallest side of the image size is above 100 pixels wide. Below this figure the ED “blurs” much of the detail within the image, losing that potential detail as part of the calculation. When the number of pixels is increased above the standard 640 x 480 image size, the calculation of $D$ also does not appear to vary very much. For example, if the same image, but now at 2000 x 2667 pixels wide (that is, 25 times the size of the original image) is processed the $D$ result only changes by 0.01 (see Figure...
5.5-2 and 5.5-3). While the \( D = 1.81 \) result is potentially a better estimation, the extra processing time, increased storage requirements and the reliance on more specialised photographic equipment does not warrant the extra precision provided.

**Figure 5.5-2** Output screen of the fractal dimension calculator for a 640 x 480 pixel image

**Figure 5.5-3** Output screen of the fractal dimension calculator for a 2000 x 2667 pixel image
5.5.4 Discussion and Results

Commencing the fractal analysis process or calculation with photographs of dwellings, as opposed to line drawings of the same, has a number of benefits. For example, a photograph more closely represents the actual experience of standing within a street. In addition, all elements and details within the street, no matter their apparent relevance, are collected. Finally, the act of photographing dwellings has the immediacy required by a tool for easily assessing the visual character of a streetscape. On the negative side, the analysis of any photographic image is affected by the environmental conditions in which the photograph was taken. The amount of shadow within the image and the differences in the shadows cast at various times during the day will have an impact on detected edges and the calculation of $D$. The amount and type of vegetation within the image will also increase the $D$ result, but perhaps this is an element within the streetscape that needs to be accurately recorded and is often not interpreted within an architectural measured drawing of a set of facades.

As Bovill (1996) suggests, the fractal dimension typically varies within different parts of an image. For example, the $D$ result for the top half of a photograph of a suburban dwelling might be 1.65 (see Figures 5.5-4 and 5.5-5). Whereas, the $D$ result for the lower portion of the same dwelling is 1.92 (see Figures 5.5-6 and 5.5-7). While the dwelling in each half is almost structurally the same (aside from the front door), it is the environmental differences within the image that account for the large difference in the calculation of $D$. In particular, in the lower part of the image, the reflections of other buildings in the glazed doors and the hedge in the front yard have caused the increased result for visual complexity.

![Figure 5.5-4 Dwelling top D=1.65](image1)
![Figure 5.5-5 ED dwelling top D=1.65](image2)
In the remainder of this section some typical results for different “styles” of architecture recorded in the streetscape data are presented and discussed. If the fractal analysis approach in general, and the fractal calculator in Archimage in particular, are to be useful they must be able to be used to differentiate types of houses with an excess of visual detail from those with a relative lack of detail. This isn’t quite the same as being able to differentiate houses in terms of aesthetic style or architectural movement because, for example, a modernist house, an art-deco house and many recent regionalist houses might all have the same level of visual detail. All three could have relatively little detail in their facades and what detail they do have will often be rectilinear and repetitive. Similarly, a federation villa and a “mock”-Tudor project home might have a similar fractal dimension, but the houses may be very different in how they generate this level of detail. Despite this caveat, in practice the Archimage software was able to produce broadly consistent results.

Consider two very similar, modern dwellings in the one development. The first has a \( D \) result of 1.79 (see Figure 5.5-8) and the second of 1.79 (see Figure 5.5-9). While there are some differences in colour, and in the shape of windows, the overall visual composition and degree of formal complexity is almost identical. Two additional dwellings in the same development have exposed brick panels with visible mortar above their entries (see Figures 5.5-10 and 5.5-11). In both cases the \( D \) result is 1.79; that is, 0.9 above the previous examples where the same façade elements were rendered and without detail. Given that the four dwellings are otherwise almost identical in their facades; the brick coursing is likely to have lead to the increased result.
Figure 5.5-8 Modern terrace 1, fractal calculation $D=1.79$

Figure 5.5-9 Modern terrace 2, fractal calculation $D=1.79$
It was anticipated that sunlight might have a minor impact on the $D$ result and this was confirmed in several of the dwelling images. For example, consider two similar dwellings with photographs taken in strong sunlight (see Figures 5.5-12 and 5.5-13). While the dwellings are, formally at least, mirror
images of each other, they cast different shadows and one has slightly more vegetation in its planter boxes than the other. These subtle variations produce a lower $D$ result of 1.80 and a higher of 1.81.

**Figure 5.5-12** Modern terrace 5, fractal calculation $D=1.80$

**Figure 5.5-13** Modern terrace 6, fractal calculation $D=1.81$
Finally, consider two typical Federation style houses in the same street (see Figures 5.5-14 and 5.5-15). The first house has trees both in front of it and behind its roofline, while the second house has only a small amount of vegetation visible above its roof. Otherwise, both have picket fences and similarly decorated veranda surrounds and, despite differently shaped roofs, they each have a degree level of horizontal visual detail in their roof forms and materiality. Despite this, the ED process reveals that the tile roof (Figure 5.5-15) creates a higher density of edges than the timber wall shingles (Figure 5.5-14). When all of these visual elements are balanced out in the software, the first house, with the trees, naturally had a higher fractal dimension ($D = 1.90$) than the second ($D = 1.85$).

Figure 5.5-14 Federation dwelling 1, fractal calculation D=1.90
Bovill (1997) and Salingaros West (1999) have separately suggested that there is a relationship between a higher fractal dimension and a successful urban or suburban spaces. The results of the Archimage testing suggest that higher $D$ results are typically produced by: foliage at the front and side of a dwelling; masonry walls where the coursework is pronounced; and dwellings that have detail around 50mm in size (typical of older-style dwellings in Australia). Typically the calculation of $D$ produced in this dissertation was much higher than that provided by Bovill (1996) in his analysis of the work of Frank Lloyd Wright and Le Corbusier, but this is mainly due to the use of photographs that contain much higher levels of detail than the line drawings used by Bovill.
5.6 Conceptual Approach 4: The Hough Transform

5.6.1 Overview of the Approach

The Hough transform (HT) is a digital image processing technique that considers the geometry of the entire image to extract features within it. The purpose of the technique is to find discontinuous edges of objects within the image by allowing edges to be determined by a “voting” process. The voting procedure is carried out in an accumulator space, from which segment candidates are ranked from most to least significant. The benefit of the HT is that it is able to find boundaries within an image where the edge detection process has found discontinuous segments or those of a low intensity but of a sufficient proximity to be perceived by the human eye as a boundary (Guy 2002; Chalup 2007a). A typical HT analysis of a house within a streetscape will find boundaries that are both continuous; such as the line of the roof against the sky, and also those that are discontinuous; such as the side of a house that is partially obscured by a bush (Boldt 1989; Guy 2002; Yang 2004). The ability of the HT to detect discontinuous boundaries is an important feature for the analysis of streetscape images where the edge detection of the image usually produces fragmented boundaries (Tucker et al 2004).

![Figure 5.6-1](image_url)

Figure 5.6-1 A three-dimensional view of the HTAA, where line intensities are plotted as heights in the z-direction above the corresponding (Angle, Distance)-point where the angle is the line’s normal vector. Dominant entries can clearly be identified as points corresponding to horizontal and vertical lines.
So that the HT analysis can be visualised, the output data is sent to an array called the Hough Transform Accumulator Array (HTAA). This graphically shows peaks within the field of potential boundaries within the image. A three-dimensional representation of the HTAA is shown in Figure 5.6-1. The HTAA process begins with an Edge Detection (ED) diagram of the image such that only pixels forming a boundary remain. Each of the remaining pixels is interrogated to assess whether it forms a boundary within its neighbourhood. If this is the case then it calculates the parameters of the line in the form of $y = ax + d$ where “$a$” is the angle of perpendicular to the line from a predetermined origin, and “$d$” is the perpendicular distance of the line from the origin (as shown in Figure 5.6-2). These calculations are successively indexed into an accumulator array until all the pixels within the ED have been processed – the lines with the most pixels within them become the most significant lines within the image and show as brighter areas in the HTAA.

Figure 5.6-2 The Hough Transform processes an input image into an output array which gives the presence and strength of any straight lines in the original image. In the output (which can also be viewed as an image), the $x$ axis is the line’s angle from the origin (the centre of the original image) and the $y$ axis is the perpendicular distance from the origin. The intensity at a particular $(x,y)$ location is then the strength of the line in the original image.

An example of the HTAA is shown in Figure 5.6-4 of the image of the dwelling shown in Figure 5.6-3. The forty brightest areas (the most significant edges within the image) are further highlighted with small red squares and, as might be expected with an analysis of a regular shaped object such as a dwelling, the most significant edges found in the array are associated with either horizontal ($a=0$) or vertical ($a=-90$) lines. The neighbourhood used to select the peaks out of the Hough array is also critical. Archimage uses a five-degree neighbourhood in the angle axis, and 15-pixel square in the distance axis to determine whether a pixel is part of an edge.
By translating two-dimensional boundaries within an image into points of one dimension, the HTAA can be more easily compared with others (Song 2005; Tucker et al 2005). An example of an HTAA is shown in Figures 5.6-4. Finding similarities and differences between the HTAA enables them to be clustered and show where dwellings may have similar visual characteristics (Tucker 2005 et al; Chalup 2007a). For instance, a streetscape with dominant vertical boundaries might exhibit feelings of privacy as compared with streets with dominant horizontal boundaries that tend be associated with feelings of more public openness (Al-Homoud 2000).

![Bungalow dwelling](Figure 5.6-3)  ![HTAA of the bungalow dwelling](Figure 5.6-4)

The HT is now beginning to be used within Space Syntax with Carvalho and Batty recently using it to automatically find the axial lines within a planar image of an urban area (Carvalho 2004). The feature of the Hough parameter space to show the strength of a line within an image as a point with an associated magnitude, makes it a useful way of finding the geometry within an image (Tucker & Ostwald 2007).
Once the most significant lines have been outlined in the HTAA, the parameter space can be inverted to show the location of the lines back over the original image, this is known as the Inverse Hough Transform. To illustrate the inverse HT refer to the images above where the image in Figure 5.6-5 has had the HT applied, to produce the inverse HT shown in Figure 5.6-6. When the HTAA is placed back over the original image, the dominant lines are shown in thick red with the next most significant shown as thinner blue lines. It can be seen that the dominant edges within the image have been found, with some diagonal lines finding the geometry of neighbouring houses and parts of the curved roof. The inverse HT can be used to refine the algorithm such that lines detected in the HTAA are similar to those found in the image through manual visual inspection. The inverse HT in Figure 5.6-7 shows how the HT finds the geometrical composition of elements within the facade. This feature of the HT relates to the way that human perception considers the whole of its visual environment and, in particular, Gestalt Theory. Gestalt theory assumes that the quality of a perceptual configuration depends on factors such as coherence, regularity, smooth continuity, unity, and simplicity (Chalup 2007b).

This implies that visual perception prefers continuous over broken or irregular transitions and that there should be neurons sensitive to collinearity (Spillmann 2004). If a structure misses parts or is disturbed by noise, it is proposed the visual system tries to fill the gaps or to filter out noise. Similarity-based grouping is driven by various features, such as colour, texture, size, and shape (Palmer 1994). When viewing elements within the streetscape, the perception of edges and boundaries plays a
dominant role in the visual evaluation of the scene (Chalup 2007b).

Figure 5.6-7 Inverse HT of the bottom half of a church

5.6.2 Limitations of the approach

The application of the Hough transform for the analysis of the facades of dwellings is a new computational approach, even though it is now being used for the analysis of plans (Carvalho 2004). The quality of the results from the HT process is highly dependent on the image developed in the edge detection process. The higher the resolution of the input image the better the HT results. If the ED contains noise that is not directly related to the edges within the image then this can alter the results in sometimes significant ways. For instance, if the significant lines of the image shown in Figure 5.6-7 were to be manually found, then the edge of the church on the right would be drawn as a similar strength to the edge on the left, however the location of the tree on this side has provided enough visual noise that the right hand edge of the building has not been completely found. It was also found
that photographing the building under different light or with movable features such as cars, could significantly alter the resulting HTAA. For this reason, the application of the HT might be more beneficial if a number of photographs of the building were taken, processed and then averaged. While this might create a better result, it does not deliver a time-efficient method required by an automated technique. Assessing line drawings of a dwelling’s façade removes this changeability within the image, but again, having to prepare such an image beforehand is not a time-efficient process. It may work well, however, with proposed buildings that are drawn like this in the first instance. If line drawings of a dwelling’s façade were to be used, then Archimage would need to be modified to remove the ED processing that precedes the HT, because the ED would find an edge on both sides of a drawn line, blurring the results. An example of this is shown in the following images where a white square within a black square (Figures 5.6-8 and 5.6-9) is contrasted against the outline of two squares (Figures 5.6-10 and 5.6-11). The differences between how each image has been processed can be seen in both the HTAA and the inverse HT. After the most significant horizontal and vertical lines have been found, the HTAA will continue to find lines that are nearly vertical or nearly horizontal and so on. Because the ED of the two square outline has more detected edges, the inverse HT shows a greater variation in the angle and location of the top 40 detected lines. This variation is not so evident in photographic images where edges are not bound by a ‘line’ but by segments with a contrasting edge.

16 The x axis in each of the HTAA in this section is incorrectly labelled, it should read from -360 (not -180) to zero. The 270 (shown as 135) and 90 (shown as 45) degree marks are the dominant horizontal lines within the image.
The application of the HT is also only efficient if the peaks of the HTAA are well-formed and isolate the significant lines within the image. This means that the “bin” that collects the detected lines must not be too small such that “votes” do not fall into neighbouring bins (Forsyth 2003). For instance, detected edges in the image that are shown in the inverse HT as two lines with similar location and angle, is a symptom of the bin being too small. The size of the bin size or its neighbourhood is a variable within
that was manipulated to obtain the best results, however the nature of photographs meant that, once established, it worked better on some images as compared with others.

5.6.3  Example Process

1. A digital photographic image is imported into Archimage and the Hough Transform (HC) is loaded.
2. Archimage uses an edge-detection (ED) algorithm to remove colour segments from the image and produce an optimised line drawing of the original image.
3. Archimage then applies the Hough Transform (HT) algorithm to the line drawing.
4. The results are provided in two PDF diagrams, the HT Accumulator Array (HTAA) and the inverse HT.
5. The on screen display allows either the original image or the inverse HT to be shown on the left. The user can select to have the peaks in the HTAA shown with red boxes, and how many peaks are to be shown.

The inverse HT is then assessed against the significant lines that can be found manually and the variables within Archimage adjusted accordingly.

5.6.4  Discussion and Results

To see how the HT can separate dwellings of similar form but dissimilar detail the following cropped images shown in Figure 5.6-12 and Figure 5.6-13 were processed.
The two images are of neighbouring houses built at the same time around 90 years ago, but have undergone different alterations over that time. The amount of detail fretwork, the type of front fencing and the lining to the gable end are different in the images. The inverse HT shown in Figure 5.6-14 and Figure 5.6-15 show the top 85 detected lines, the analysis shows: the basic structure of the houses including roof shape has been found; and the form of the deck enclosure and fencing accounts for most of the other detected edges. In Figure 5.6-14 the horizontal banding of the shingle cladding to the gable end and the outline of the deck enclosure are found. However, the shrubs on either side provide edge lengths too small to be picked in the strongest lines. In Figure 5.6-15 the fretwork around the deck enclosure and the fence provide the significant lines and provide a more even spread of the detected edges as compared with Figure 5.6-14 where the lines are more clumped around dominant edges.
The inverse HT shown in Figure 5.6-16 shows a suburban house where the detected lines are clumped around dominant edges that are found around the garage, entry and window elements. The typical suburban house has less detail at a scale less than a window through to the coursework in the brick walls and the tiled roofs and typically returns this type of inverse HT (Tucker & Ostwald 2007).

The lines shown in the inverse HT do not provide any information regarding the length or end points of the detected line segment in the image plane (Carvalho 2003), they are projected at infinite length and not bound by the pixels that created them. Archimage was developed to show the line segments only and an example is shown in the diagrams below. Figure 5.6-17 shows the original image with the line
segments overlaid, **Figure 5.6-18** showing the line segments only.

**Figure 5.6-17** Inverse HT and original line drawing  **Figure 5.6-18** Inverse HT of a line drawing

The inverse HT analysis in the following figures shows the processing of dwellings that have been analysed using other conceptual approaches in this chapter. The HTAA are measured from an origin in the centre, meaning that detected dominant boundaries close to the centre of the image will be shown at the bottom of the HTAA. The brighter yellow colouring within the HTAA shows the dominant boundaries within the image, while the areas of dark blue in the HTAA are areas within the image with few detected boundaries. The analysis shown in **Figures 5.6-19** through to **5.6-22** show that visually similar dwellings will produce a HTAA with similar characteristics. If the HTAAs are viewed in isolation (that is, without the image), the similarities might be substantial enough to allow the dwellings to be grouped. This could be tested with a systematic survey of the HTAA data produced by the dwellings in Appendix A, however, this has not been undertaken as there are still a number of processing issues with the *Archimage* software that need further work. Some of these have already been discussed and they are illustrated in the following figures.
The effect of vegetation within the analysis cannot be underestimated; the analysis of two dwellings (Figures 5.6-19 – 5.6-22) of the same but mirrored design, produce different looking HTAA, a result also shown in the inverse HT. While the overall features of the HTAA appear similar, it is uncertain whether the “noise” provided by the vegetation would disturb a systematic approach to grouping HTAA.
The analysis of some dwellings of the same design, but with different vegetation, reflections and other features, can produce very similar HTAA results (as shown in Figures 5.6-23 through to 5.6-26).

The effect of image size and the HT processing can be seen in Figures 5.6-24 and 5.6-26. While the image of the dwelling is the same, the HTAA and inverse HT diagrams are quite different. This is because the processed image in Figure 5.6-30 is a quarter the pixel count than that processed in
Figure 5.6-28. The effect of this is that the HT considers the brick coursework in the lower resolution image to be less significant – when interrogated the edge pixels in this region are considered to be either strictly vertical or horizontal instead of ‘leaning’ vertically or horizontally. The higher the resolutions of the processed image the better are the results from the HT.

The figures below show an analysis of Federation style dwellings and, typically, they show a
distribution of edges of varying length throughout the image. Because these images have a relatively low pixel count (212 x 283) many of the edges at the finer scale are lost. This was a problem with the latest version of Archimage where the amalgamation of the different processing techniques meant that the image needed to be considerably downsized to be processed.

**Figure 5.6-31** HTAA for Federation dwelling 1  
**Figure 5.6-32** Inverse HT Federation dwelling 1

**Figure 5.6-33** HTAA for Federation dwelling 2  
**Figure 5.6-34** Inverse HT Federation dwelling 2
Using an earlier version of Archimage, the difference in the proportion of vertical lines within HTAA can be seen. Again using images of a higher resolution provides better HT results.

![Image of HT analysis](image)

**Figure 5.6-35** Inverse HT Federation dwelling 2 for image size of 2000 x 2667 pixels

The HT appears to provide a valuable tool for analysis of the streetscape, because of its ability to find boundaries within an image where the edge detection process has found discontinuous segments or those of a low intensity but of a sufficient proximity to be perceived by the human eye as a boundary (Guy 2002; Chalup 2007a). However, additional software needs to be developed to analyse the HTAA directly and to segregate images based on the density and distribution of detected lines within the image.
5.7 Conceptual Approach 5: Line Count Calculation

5.7.1 Overview of the Approach

Just as space syntax researchers (Steadman 1983; Hillier 1984; Stevens 1990) have shown that there is much to be learnt from the analysis of room relationships in a plan (regardless of dimensionality) or spaces that are visible from a single point in space (the isovist), so too can a range of façade details be productively examined in isolation.

Elements in a façade are defined by edges which are typically boundaries dividing similar sections of the image. Because much of the built environment is orthogonal in plan, the majority of edges identified in the analysis of streetscape dwelling images are effectively lines. While much effort has previously been invested in various methods for understanding the elements in a façade, very little time has been focussed into the nature of the lines that define these elements (Krampen 1979; Stamps III 2003; Malhis 2003). In particular, no one appears to have asked the simple question, how many lines are there in an image and how long are they? One reason for this lack of interest may relate to the labour-intensive nature of the process of uncovering this information “by hand”, but computational methods open up the potential of this field of interest in new ways.

In much the same way that it is anticipated that fractal dimension calculations might reveal consistent patterns of visual complexity in streetscape images (for regions of particular visual character) so too it is assumed that that such patterns will be uncovered in the analysis of line count.

5.7.2 Limitations to the Approach

This is essentially a new computational approach, although it is inspired by past works on element and boundary detection in façade analysis (Stamps III 2003; Malhis 2003). As such, there are no known limitations to the method although there are several obvious areas where interpretation of these results needs careful consideration. In particular, there are some problems associated with the automated process for detecting lines and some manual support for the technique required in the data gathering and analysis stage. Both of these are considered hereafter.
The line count approach relies on the capacity of some program (or person) to accurately identify lines. This may seem obvious, but the various methods for identifying lines all have their strengths and weaknesses. The human hand can easily trace an image, and connect lines that are broken by other elements. For example, a power pole may be standing in front of an orthogonal rendered brick fence. The human intuitively knows that the fence is continuous (behind the vertical form of the pole) and can easily trace such a line, even if this is not how the real environment looks. Conversely, most computer algorithms that can detect lines, will not understand depth of field, perspective, or overlapping forms. In essence, computer programs will break the fence line into two lines on either side of the power pole. The first variation, by hand, has some advantages, but it is also impractical. The second variation is swift and efficient but will produce inaccurate results. For the present research, the decision was made to use the Hough Transform (HT) algorithm to make decisions about line continuity and detection.

One of the most powerful features of the HT algorithm is that it seeks dominant visual direction. Thus, in a suburban street where every fence is the same height, the human eye will read this height as a dominant horizontal line, even it is not continuous. The HT algorithm will also read this dominant line, mirroring our perceptions; even if the line is broken by various vertical thin elements (tree trunks and power poles for example). For this reason, the HT will tend to produce results that have a longer effective boundary length because it will tend to connect the discontinuous boundaries within the image. For example, the head of a door which lines-up with the head of a nearby window will be recorded in the histogram as a boundary of the cumulative length (Tucker 2005 et al).

The HT algorithm therefore provides a middle ground between conventional human perception and machine-driven pattern recognition. It is also necessarily inaccurate for this reason, but it will consistently apply a set of visual detection rules that are balanced in their strengths and weaknesses.

The other potential issue with the line count and line length approach is that pixels are scaleless. Unless the image contains an element of known length (which is aligned to the picture plan of the image) comparisons between images are not possible. For the present research this problem has been solved by using standard door heights, visible in almost every image, to consistently scale and compare results.
5.7.3 Example Process

1. A digital photographic image is imported into Archimage and the line count (LC) calculator is loaded.

2. Archimage uses an edge-detection (ED) algorithm to remove colour information from the photo and produce an optimised line drawing of the original image (see Figure 5.7-1).

3. Archimage then applies the Hough Transform (HT) algorithm to the line drawing that identifies continuous sequences of pixels and associated boundaries (in essence, identifying lines).

4. The number of linear boundaries in the image with a discreet orientation are counted.

5. Archimage produces a LC histogram of the results (see Figure 5.7-2). The histogram records line count (frequency) on the vertical axis and line strength (length in pixels) on the horizontal. The data can either be reported as a single set of results (the set of all lines) or divided into vertical lines, horizontal lines and diagonal lines.

To this point the process is automated. However, to construct a comparison, a scale must be manually set. For example, in a typical streetscape dwelling image (of 640 x 480 pixels), a single pixel is around 20mm in length and a door height is then around 105 pixels in length (see Figure 5.7-1).

---

Figure 5.7-1 ED of modern terrace 1

Figure 5.7-2 LC of modern terrace 1
5.7.4 Discussion and Results

If the LC results for stylistically similar facades are processed and displayed on the same graph, similarities can be seen in the data. For example, consider three similar modern dwellings in a development that has been used as an example in previous sections (see Figures 5.7-3 to 5.7-5). For each house a LC and boundary length graph is produced; typically with a frequency of lines that are around 400mm in length on the left side of the graph and those of up to 3200mm in length on the right side. The boundary-length appears to diminish at a constant rate until around 1200mm, where it flattens out. The graph that is produced for each of these three houses appears to be similar (see Figures 5.7-3 to 5.7-5) and, when they are overlaid, it becomes apparent that they are almost identical (see Figure 5.7-6).

Figure 5.7-3 Boundary length graph of modern terrace 1
The three dwellings are essentially the same design, sharing the same style and form, only some details and the extent of furniture and vegetation distinguish the images. It is the presence of these differences, together with subtle differences in the way that each photograph has been taken, that produces the differences in the marked peaks and troughs within the graph. For example, in the combined LC graphs (see Figure 5.7-6) at a length of around 1300mm, one image produces a trough while another produces a peak. The troughs and peaks become more pronounced when the boundary length increases to a dimension equivalent to the size of the formal elements within the façade (such as doors and windows). The smaller number of boundaries at these dimensions also exaggerates the
differences between them. The relative location of peaks and troughs within the graph appears to be a significant feature of the visual character of the dwelling, but at this stage this has not been fully evaluated. When this approach is repeated for two additional modern-terrace style houses in the same development that have panels of exposed brickwork, an equally strong pattern is revealed (see Figures 5.7-7 and 5.7-8) as the overlay of the two results indicates (Figure 5.7-9). When the composite graphs for all five modern terrace houses are combined, (in Figure 5.7-10) it is possible to identify the differences in LC between each group. For example, the more dense pattern of edges associated with the masonry wall produces more lengths in the 400mm – 1200mm range, but both sets of graphs are similar once the line length reaches around 2000mm. While the LC approach appears to be capable of grouping similar modern houses, the next step is to see if it will similarly group more traditional dwellings together.

Figure 5.7-6 Overlay of boundary length graph of modern terrace 1,2, and 3

Figure 5.7-7 Boundary length graph of modern terrace 4
The LC analysis of traditional dwellings that are of the same style but have a different design in terms of form and detail is described hereafter. Consider four Federation-style houses from the same street.
An LC analysis uncovers the result that most of the lines or boundaries in these houses are of less than 2000mm in length. This conforms to a conventional or intuitive expectation that a characteristic of the Federation style is that exterior forms are trimmed with detailed features that are relatively small, but create areas of high visual contrast. What is also interesting in the analysis is that, for the first of the four houses (Figures 5.7-11); the presence of a tree at the front of the streetscape has little effect on the graph shape. This is because the large number of boundary lengths created by the tree are very small – typically less than 400mm in length – and not shown in the graph, while the structural detail within the dwelling is still observed through the tree. For the remaining three houses, each successive LC graph includes the result for the previous houses as a comparison, so that by the fourth and final LC graph, all four results lines are visible (see Figures 5.7-12 to 5.7-14).

![Figure 5.7-11 Boundary length graph of federation dwelling 1](image1)

![Figure 5.7-12 Boundary length graph of federation dwelling 1 and 2](image2)
The final two houses (see Figures 5.7-13 and 5.7-14) are Federation dwellings with more pronounced detailing, particularly around the entry, deck spaces and picket fences. Their graphs, successively added to the other graphs produced by the other traditional dwellings, are of a similar shape, but the peaks and troughs are the most pronounced of those shown so far. In essence, the graph is not as “smooth” as those produced by the modern buildings, previously described, whose surfaces typically lack such levels of detail. This surface quality of modern buildings has been discussed by a number of researchers including Salingaros (1999), Alexander (1977) and Bovill (1996). How then do the modern
and traditional houses compare using the LC method?

Consider four houses that have previously been analysed. The first is a federation house, the second a two-story pitched-roof terrace with a mirrored plan, the third is a three-story apartment style façade and the final is a modern, two-level terrace design. Each of the houses is presented in sequence alongside their graph result in red, and the result of the previous house (or houses) in the set of four are shown in green for comparison. The first house, the Federation one (Figure 5.7-15) has an LC graph which is typical for dwellings of its type. When compared with the more modern, pitched-roof house (see Figure 5.7-16) it becomes clear that the Federation dwelling has higher amounts of visual information across a wider band of boundary lengths when compared with the modern terrace, and particularly between the boundary lengths of 400mm and 2500mm. The total number of boundaries within the Federation dwelling is significantly more and more evenly spread over those lengths; a visual quality of traditional buildings discussed by Salingaros (1999). This effect is even more clearly shown in the next comparison, wherein the three-story apartment-style façade (see Figure 5.7-17) has relatively little information in the 400mm – 800mm region. Curiously, the fourth façade in this set – the modern two-level terrace house – has some similarities to the Federation house, in part because it has exposed brick coursing (see Figure 5.7-18). How then, would these LC results differ if an entire modern streetscape was compared with an entirely traditional one?

![Figure 5.7-15 Boundary length graph for dwelling 1](image)
The graph in Figure 7.8-15 shows that the Federation dwelling, as presented in Figure 7.8-16, has higher amounts of visual information across a wider band of boundary lengths compared with the modern terrace, particularly between the boundary lengths of 400mm and 2500mm. The total number of boundaries within the Federation dwelling is significantly more and more evenly spread over those lengths, a visual quality of traditional buildings discussed by Salingaros (Salingaros 1999). This effect is even more clearly shown in Figure 5.7-17, where the modern townhouse has relatively little information in the 400mm – 800mm region.

Figure 5.7-16 Boundary length graph for dwelling 1 and 2

Figure 5.7-17 Boundary length graph for dwelling 1, 2 and 3
Figure 5.7-18 Boundary length graph for dwelling 1, 2, 3 and 4
To explore the LC analysis for the visual character of the streetscape, parts of three streetscapes typical of the eastern coast of Australia have been processed.

a) Streetscape A (Figure 5.7-19) is from an inner city street where dwellings have been occupied for the past 100 years. For this streetscape, landscaping and fences are close to the front boundary and it has no off street parking, so vehicles are often parked in front of the houses.

b) Streetscape B (Figure 5.7-20) is a suburban street where detached houses are setback from the road with low-lying front yards and off-street parking in the form of garages and driveways.

c) Streetscape C (Figure 5.7-21) is of a recently constructed row of townhouses within a newly-established suburb. The dwellings have little private open space at the public boundary with vehicles entering and being stored at the rear of each property.

In preparation for this analysis, each similarly proportioned streetscape image was reduced to 153,600 pixels in size (a door now being approximately 30 pixels high) and processed using the LC algorithm at increments of three pixels in length. The graphs produced are shown in Figures 5.7-22, 5.7-23 and
5.7-24 with a breakdown of the contributing horizontal and vertical lines shown in Figure 5.7-25. These graphs can be studied by looking at the distribution of the peaks at different boundary lengths and the overall trend of the graph.

When the graphs for streetscapes A and B and A and C, are compared (respectively in Figures 5.7-26 and 5.7-27), the difference between the LC graphs indicates the number of lines of a specific length that are not present in streetscape B or C (since streetscape A has more detected lines than either streetscape B or C). This would suggest that the length of edges within streetscapes B and C are less evenly distributed than those in streetscape A. However, both streetscapes B and C have more lines of smaller length; typically up to 20 pixels or 1500mm in length. The wave-like appearance of the resulting LC graphs is difficult to interpret, in part because only a limited set of streetscape composites were available for analysis. Whereas for the comparison of individual dwellings a set of two hundred was prepared for the present project and consistent patterns were uncovered, this was not possible for the composite images. In an attempt to at least partially validate the results, the trend of each line was graphed (see Figure 5.7-29). In this graph, streetscape A has peaks distributed linearly, while streetscapes B and C have peaks that diminish geometrically. Considering that streetscapes B and C have little in common spatially, it is interesting that their analysis should show such similarity (compare Figure 5.7-28).

Despite some anomalies, there is perhaps no surprise that new and old streetscapes should be differentiated by the quantity of discernable edges within their façades (Salingaros 2000), however, this approach needs to be further developed and more reliably quantified to provide a basis for further discussion about the character of the streetscape.

Although the concept of providing a measure for the visual complexity of a streetscape is in its early stages, this demonstration of the LC algorithm has shown that an automatic analysis of the length of edges within an image is potentially useful for this purpose. This approach appears to be a useful way of understanding how visual detail is distributed throughout an image at different scales; a concept that has parallels to the measures produced in the analysis of images (Batty 1994; Salingaros & West 1999). The question of how this measure might relate to the façade isovist has not, as yet, been evaluated. However, the rate at which textural information of an urban space becomes available to a
user would appear to be an important consideration (Hillier 1996). As an observer moves from a distance towards a façade, different scales of built form and detail become evident. How this effect might be quantified and developed in parallel with other methods of urban analysis is the task of further research.

**Figure 5.7-22** Lines within streetscape A  
**Figure 5.7-23** Lines within streetscape B  
**Figure 5.7-24** Lines within streetscape C  
**Figure 5.7-25** Lines within streetscape A, B and C  
**Figure 5.7-26** Lines within streetscape A and B  
**Figure 5.7-27** Lines within streetscape A and C
**Figure 5.7-28** Lines within streetscape B and C

**Figure 5.7-29** Lines within streetscape A, B and C
5.8  Conceptual Approach 6: Polar Array

5.8.1  Overview of the Approach

The Polar Array (PA) plots the angle and strength of the top 40 lines from the HT on a polar graph with the size and colour of the bubble relating to its relative strength. The area of each bubble is derived from the number of votes in each bin and the colour showing its relative significance. Blue circles are the most significant, red the least, with the HT measured relative to the centre of the image. An example PA of the image shown in Figure 5.8-1 is shown in Figure 5.8-2.

[Image: Figure 5.8-1 Modern terrace 1  Figure 5.8-2 PA of modern terrace 1]

The diagram shown in Figure 5.8-3 shows the first iteration of the PA, where the significant lines within the image are translated onto a graph similar to the HT graph, except that the “bubbles” are showing relative strength and orientation. The bubble size was thought to be too large, causing significant overlap, so the area of the bubbles was halved. The diagram in Figure 5.8-4 shows the second iteration where the HT is measured from the bottom left-hand corner of the image (meaning that the detected lines are always to the upper right of the origin). In this graph, the “bubbles” had also not been given a size and colour showing their relative strength.
5.8.2 Limitations of the Approach

The intention in developing the PA as part of Archimage was to provide a clearer way of understanding the significant lines within the image. The polar array is a different way of graphing the HT analysis, and might provide a more intuitive way of separating dwellings of different visual character. Being able to visualise the relative strength of detected edges, their angle and their distance from the centre of the image appeared to be a worthwhile technique for collating the data of the HT. However, having processed a number of streetscape images, it appears likely that algorithms will need to be developed to segregate the PA into meaningful groups. One possible way of doing this is Manifold Learning outlined in Section 6 Conclusions and Further Work. The overlapping of the bubbles (shown in Figure 5.8-3) made the graph difficult to read, while separating the bubbles by reducing their area made the more significant lines

As the PA is another way of graphing the HTAA, the approach is also limited by those issues already outlined in Section 5.6: The Hough Transform. These limitations include: the problem of noise within the processed image, producing edges that are not significant within the image; and ensuring that the neighbourhood of the HT "bins" are the correct size to collect the significant edges or geometry within the image. As also discussed in Section 5.6, the image must be of a sufficient pixel resolution such that the detected edges are a true reflection of the processed image. However, to reduce processing
time, the software design of Archimage that includes the PA, resizes the images to a resolution that removes much of the detailed information within brickwork, tiled roofs, landscape elements and fretwork. This has unfortunately made the PA a more difficult diagram to interpret and discuss in a meaningful way.

5.8.3 Example Process

1. A digital photographic image is imported into Archimage and the Polar Array (PA) is loaded.
2. Archimage uses an edge-detection (ED) algorithm to remove colour segments from the image and produce an optimised line drawing of the original image.
3. Archimage then applies the Hough Transform (HT) algorithm to the line drawing.
4. The results are provided in a single PDF diagram.

5.8.4 Discussion and Results

The series of figures below (Figure 5.8-5 - Figure 5.8-12) show the PA for the set of houses analysed in Section 5.6. Figure 5.8-6 shows that the most significant edges are horizontal and above the centre of the image, these are shown by the blue bubbles on the 270-degree angle.
The most significant edges in Figure 5.8-8 are vertical and to the left of the image’s centre (provided by the masonry element) and are indicated by the cluster of blue bubbles on the 180-degree line.

The most significant edges in Figure 5.8-10 are horizontal, are above and below the image’s centre and are indicated by the cluster of blue bubbles on the 90 and 270-degree line.
The most significant edges in Figure 5.8-12 are horizontal and are spread throughout the image. This analysis highlights some of the limitations of PA as applied by Archimage, namely: that no vertical or diagonal lines have been detected within the top 40 lines and that the structural form of the house has also not been detected. As discussed in Section 5.6, this makes further analysis of the PA (that involves a HT analysis) difficult at this stage.
5.9 Conceptual Approach 7: Line Strength Array

5.9.1 Overview of the Approach

The Line Strength Array (LSA) uses the Hough Transform (HT) to describe the distribution of edges within the image, by considering their relative strength together with their gradient. By considering that every pixel within the Edge Detection (ED) image could be part of a line at a given angle, it successively counts the number of pixels within each line detected. The sum of the lines at a given angle is then plotted at 3-degree increments within the array. The first part of the array to appear is a horizontal line at the top of the graph; and, as every pixel will at least be part of a line with one pixel within it at every angle, the value on the y axis is equal to the number of pixels within the ED. Lines with five pixels or less are then removed from consideration and the total number of lines at three-degree increments is once again plotted. This process of continually removing lines of weaker strength continues until only the significant lines within the ED remain and are plotted in the array near the bottom of the graph. An example of the LSA is shown in Figure 5.9-2, horizontal boundaries shown at the 90-degree position, horizontal at the 0 and 180-degree position.

Figure 5.9-1 Modern terrace 1

Figure 5.9-2 LSA of modern terrace 1
The LSA shows the line length decomposition of the ED image against the gradient of detected lines and can be understood in a similar way to a terrain or contour map; the "lowest" part of the terrain being at the top of the array, where the smaller line lengths are plotted, successively getting higher as it moves toward the most significant lines in the ED image. Reading the entire array as a terrain may be the most useful way of understanding how line-length is distributed within the ED image. The method allows a single pixel to be recorded in any number of discreet lines and can show the relative connectedness of a pixel in relation to others.

5.9.2 Limitations of the Approach

LSA is essentially a new computational approach, although related to the Line Count Calculation (LC) method described in Section 5.7, and is thus also susceptible to the limitations outlined in that section. There are several areas where interpretation of the graph needs careful consideration and these are discussed below. By successively counting the number of detected lines, the graph shows how boundary length is distributed in relation to angle within the image. This erosion of the least significant boundaries within the image to leave the most significant, has the potential to show how boundary lengths are positioned within the image, providing more detail than both the LC and Polar graphs are able to provide. However, because the images used within the study tend to have dominant vertical and horizontal boundaries, the detected lines of greatest strength tend to be at the 0, 90 and 180-degree angles (horizontal lines at the 90-degree angle). These areas show as strong peaks within the LSA (similar to that found in the HTAA) however, because horizontal lines are expressed as a single line in the centre of the LSA and vertical lines as a similar line at the left and right edges of the LSA, it is the lines at other angles and their relative strength that are more apparent within the array. This is the most important characteristic of the LSA as the other computational methods discussed do not isolate this visual characteristic within the image. However, it does show some of the limitations of using the LSA in isolation for the analysis of dwellings. There are typically so many horizontal and vertical boundaries within the images of dwellings that the density of these boundaries cannot be clearly expressed in the LSA; this is particularly the case with the vertical boundaries that are shown at the edges of the array. Their dominance within the image is therefore difficult to comprehend.
Because the most easily understood part of the LSA is typically for line lengths that are neither horizontal nor vertical and are of a medium length (that is, in the centre of the LSA) it might also be open to detecting more transient and unwanted dimensions within the image, such as vegetation and shadow. This is a possibility although it has not been systematically studied.

An oversight of the software development was that the LSA output has no scale on the y-axis which makes it difficult to read what pixel lengths are the most dominant within the image. Because the top of the LSA always corresponds to the number of pixels within the ED, expressing that at the top of the y-axis might also help in the comparison between images. The most significant limitation in interpreting the LSA however, is that the subtleties between the graphs is difficult to fully interpret solely through manual visual analysis. Ideally, algorithms could be prepared to separate the graphs in a more systematic way. Using such techniques might also allow the vertical and horizontal information that is “lost” to be analysed in a meaningful way.

5.9.3 Example Process

1. A digital photographic image is imported into Archimage and the LSA calculator is loaded.

2. Archimage uses the ED algorithm to remove colour information from the photo and produce an optimised line drawing of the original image.

3. Archimage then applies the HT algorithm to the line drawing.

4. The number of boundaries of a discreet length and orientation within the image are counted; the angle of the detected boundaries is measured at 3-degree increments.

5. Archimage produces an LSA histogram of the results (see for example Figure 5.9-2). The histogram records line count (frequency boundaries of a particular length at 5-pixel intervals) on the vertical y axis and the angle of that line measured from the centre of the image on the horizontal x axis. Horizontal lines are shown at the 90-degree position, vertical lines at the 0 and 180-degree positions.

6. The grey tone under each plotted line changes from black, at the top of the graph, to white for the most significant boundaries at the bottom of the graph.
5.9.4 Discussion and Results

Interpreting the LSA requires a consideration of the individual lines as a pattern based on a rhythm of separation and position of line segments. A clustering, or thickening, of line segments in a particular location within the LSA shows that this a region within the image where there is a density of detected boundaries. Some dwelling types and styles are well-suited to this type of analysis, particularly those where boundary lengths are repeated between images, such as those found in masonry-walled, tile-roofed dwellings with otherwise little other fine detail. An indication of this is provided in Appendix A where dwellings have been manually arranged into groups, based on their visual characteristics. Two examples of this type are shown in Figures 5.9-3 and 5.9-5; they are of the Post War style and have similar form and materials of construction. The LSA for both these analyses (shown in Figures 5.9-4 and 5.9-6) has the characteristic of showing a good distribution of line strength in the upper part of the graph given by the tiled roof, while brick walls provide the density in the middle of the graph as near horizontal lines. It is only the shrubs in Figure 5.9-5 that broaden the distribution of information in the middle of the LSA.

![Figure 5.9-3 Post war dwelling 1](image1.png)

![Figure 5.9-4 LSA Post war dwelling 1](image2.png)
When images of dwellings that contain less detail are processed (for example those shown in Figures 5.9-7 and 5.9-9), the difference in the LSA can be clearly seen (Figures 5.9-8 and 5.9-10). The lines of the LSA are more evenly distributed, with fewer smaller-length boundaries detected. While these dwellings are essentially the same, the images vary in detail (such as the extent and type of vegetation and furnishings) and it is this that makes the LSA similar in overall form but different in the detail.
When a dwelling of a similar form, but with a masonry element, is processed (Figure 5.9-11 and 5.9-12) the increased amount of visual information can be seen in the LSA in the upper right of the array.

The Federation-style dwelling in Figure 5.9-13 in contrast, shows a density of information in the 45 – 135-degree range, caused mainly by the tiled roof and the picket fence. Overall the LSA shows that
most boundaries are more horizontal than vertical, a characteristic that is in contrast to the LSA of the Federation dwellings shown in Figures 5.9-14, 5.9-16 & 5.9-18 where the vertical boundaries dominate. Looking at the images, this would appear to make sense as the horizontal cladding is relatively faint compared with the amount of vertical boundaries provided by the fence and facade detailing.

Figure 5.9-13 Federation house 1
Figure 5.9-14 LSA Federation house 1

Figure 5.9-15 Federation house 2
Figure 5.9-16 LSA Federation house 2
The LSA for each house of the same style shows similarities; the peaks and distribution of line strength (or gradient) having similar characteristics. The LSA is able to show the differences between the two styles; the post war style houses have peaks either side of horizontal that become more horizontal as the line strength increases. The Federation style dwellings have more vertical lines, and where the post war dwellings have peaks either side of horizontal, these tend to be ‘valleys’.

Until Archimage employs algorithms to analyse the LSA in comparison with each other in a systematic way, manually analysing the graphs is difficult and the very detail that makes this graph so interesting is likely to be missed without such an analysis.
6 Conclusions and further work

This research has three broad categories of conclusions. The first are concerned with the possibility of developing computational analytical techniques for supporting the analysis of streetscapes. In the first part of this chapter the individual results of the various methods are summarised and a final, possible future technique, Manifold Learning, is briefly outlined as a solution to some of the deficiencies identified in the present method. The second category of conclusions is concerned with the lessons learnt from the case study analysis of the HCA. While the case study was merely chosen to demonstrate the potential of the computational techniques, and is therefore only a minor part of the present research, some of the results that have been uncovered about the case study are informative.

6.1 Findings from the Literature Review

Techniques for connecting the visual urban texture at the scale of the individual with the urban character of street patterns, building heights and open spaces within the city, are difficult to find (Ratti 2004). However, the use of computer visualisation in conjunction with other established methods, including traditional streetscape analysis and space syntax theory, could offer better models for the prediction of visual amenity within urban areas. Of particular interest is whether a contextual fit between dwellings of different styles is possible, given that they might share particular visual characteristics. From an architectural perspective, software correctly calibrated and authenticated through expert judgment that supports this type of analysis, would be very useful. The proposed introduction of a contemporary building within a traditional streetscape might then be shown to be visually appropriate and remove the reliance of planners on the style of a dwelling alone to determine its visual appropriateness (streetscape character).

Visibility analysis is a seemingly attractive way to understand urban spaces as it appears to allow “mathematical certainty to the experience of urban and building environments” (Turner 2003:p673). However, by concentrating on visual relationships rather than an “interpretation of direct perception”
(Turner 2003:p673) the analysis will always require a level of interpretation based on how the information has been collected and how it will be used. Different cultural, and social backgrounds will necessarily interpret visual information differently (Turner 2003). However, one of the qualities of visibility analysis, that makes it so useful for a comparative study, is that the representational and symbolic meanings of a building’s style play no part. The organisation of the elements can be analysed without having to interpret them at the beginning of the process. This is not to say that representational meanings are insignificant or unimportant, but rather that both methods might work in parallel, to provide a more thorough study of the urban environment.

The advent of Google Earth Street View has provided a resource of streetscape images for many residential streets within Australia. The images within any neighbourhood have been taken from the same camera, from a similar position within the street, and subsequently might provide an excellent resource for streetscape analysis. The similarities in the method that the images have been taken and processed might provide a basis for many images within a neighbourhood to be visually analysed, revealing a deeper understanding of the prevailing streetscape character. However because these images are essentially a fully automatic snapshot of a neighbourhood at a particular moment they might potentially suffer from temporal visual factors such as the prevailing weather, traffic conditions, parked cars, garbage collection and the like. These features being incorporated within the visual analysis, they might provide a bias in the results. Visual studies that use these images as a basis for analysis would be of interest to this dissertation such that the effect of these variables might be better understood.

Regarding the development of Archimage, the traditional approach for numerical processing for a specific task is to first prototype algorithms in traditional mathematical software and later to implement the final product in a systems language. Rather with the development of Archimage, the combination of algorithm implementation using the numeric libraries for Python and GUI implementation with the Mac OS X development tools allows for the rapid prototyping and implementation of scientific applications that are targeted at these non-developers. The users can evaluate the software during

every phase of algorithm-development and can provide critical feedback, without increasing the time to delivery. There is no significant loss of performance either, due to the well-tested and efficient implementation of the numeric libraries.

Future work is to develop the methodology to proportionally combine the analysis of different algorithms, providing an insight into how the built environment is visually structured. The present study confirms that images of the streetscape can be segmented based on their colour in the form of Colour Segmentation, and the edges formed by surface contrast, ED. Once the edges have been found, this diagram can be used to calculate the Fractal Dimension. The present research has confirmed previous results from a range of scholars that suggest that $D$ results can be used to distinguish between dwellings of different styles. In addition, this research supports Bovill’s (1996) suggestion that it might be worthwhile calculating the $D$ for different parts of the dwelling.

The present research demonstrates for the first time in architectural scholarship that the HT provides a useful way of understanding the geometry within the entire image, even though the effect of image size and developing a method to show the found lines at different scales needs further development. The Inverse HT also offers an insight into the location of the found lines, while the PA provides a different way of graphing the information. The difficulty in visually separating the PA using manual techniques indicates that algorithms need to be involved in this process as well. The Line Count graphs can be related to the HT, however they are perhaps more useful when used straight from the ED analysis and expressed in the form of an array or LSA. The terrain-like feature of the LSA is an interesting way of understanding the spread of boundaries within the image, even though this requires another graph where algorithms should be applied to segregate the graphs into meaningful groups. Manifold Learning would appear to be one strategy for doing this, but at this stage Archimage has not been developed to do so.
6.2 Manifold Learning to detect similarities between processed images

Manifolds are locally Euclidean spaces with some other very general mathematical properties. Visually they can be seen as continuous, non-linear deformations of lines, circles, spheres and other similar objects in higher dimensions (Chalup 2007a). Manifold Learning describes a family of algorithms for empirical non-linear dimensionality reduction. Their purpose is to detect the essential underlying geometric structure of high-dimensional data sets and to extract it as a low-dimensional manifold (Chalup 2007a). A digital image is a pixel array, that is, it can be represented by a vector in an S-dimensional space where S is the number of pixels within the image. Hence a set of digital images can be seen as a point set in a D-dimensional vector space. If the set of images together describes a particular configuration or dynamics of an object or an agent, then Manifold Learning could theoretically be used to extract the essential structure of this configuration in the form of a low-dimensional manifold. For example, if the set of images describes an object moving along a one-dimensional line, then Manifold Learning would extract a one-dimensional line as the essential implicit geometric configuration that best captures the dynamics described by the set of images.

Algorithms were written to study how Manifold Learning (ML) might be applied to the clustering of images of the streetscape and to the clustering of the various graphs and diagrams outlined in the previous sections. The image shown in Figure 6.1-1 was sliced into pixel columns where each pixel corresponds to an RGB value, shown in Figure 6.1-2.
Then an algorithm based on isomap$^{18}$ was employed to find a reordering of the randomised set of independent pixel columns. In abstract terms isomap extracted through similarity calculations a one-dimensional non-linear connected curve segment from the set of high-dimensional column vectors. This approach was used for images of individual building facades as shown in Figures 6.2-1 and 6.2-5. Since there are n! possibilities to order a sequence of n columns, the combinatorial complexity of this task is very high. However isomap was able to almost fully reconstruct several of the example images if they were of sufficient quality and if the neighbourhood parameter K was selected high enough, such as K = 5. When K was smaller than 5, isomap often produced variations on the original design that are structurally and aesthetically possible. The aim of this study was to develop a method that could routinely reconstruct the image into realistic designs variations, including reforming the image exactly.

The use of the Learning Manifold to segregate the various graphs and images of the streetscape into meaningful groups has not yet been undertaken, but it would appear to be a useful study. Once the analysis has been undertaken, in particular the Hough Transform, Polar Array and Line Strength Array, the Learning Manifold could analyse the shapes of the graphs and group dwellings based on their visual properties. Doing this might provide a method for combining the different analyses, allowing the features that each has to be statistically recorded with each and provide a measure for the visual complexity.
6.3 Application of the image processing techniques on a set of similar facades

Images of houses within the Hamilton South Conservation Area (HSCA) were recorded as a database of streetscapes that had been recognised by a LGA (Newcastle City Council) as worthy of protection from future development. In this way changes to the existing character of the streetscape need to be argued to the LGA by showing how the changes respond to the prevailing architectural character of nearby dwellings and the neighbourhood. The images in the set shown in Appendix A have been identified as ‘Double Gable with Picket Fence’, a grouping that was intended to collect a common and dominant feature of around 20 dwellings within the HSCA.

Each of the images was cropped to remove all visual information outside the envelope of the house such that a comparison could be made of the architectural features of the built form alone. By isolating these characteristics within the image of the streetscape, the resulting graphs from applying the various image processing techniques might be more easily compared with each other. The processing techniques used were Edge Detection (ED); Hough Transform (HT); Inverse Hough Transform; Polar Array; Line Count; and Line Strength Diagram.

As each of the images have similar visual characteristics the differences between the resulting graphs are more subtle than the examples discussed in the Method chapter. The Line Strength Diagram appears to the graph with the most potential for separating images of houses that have substantially the same form and features. However as outlined in section 5.9.4 this type of analysis is beyond the scope of the present dissertation because the ‘terrain’ within the graph is too visually complex to consistently separate the features within the images. A similar issue exists with the other processing techniques limiting a critical evaluation of their effectiveness in dealing with images of similar dwellings.
6.4 Further Work

Ultimately, the use of computational algorithms to analyse the visual properties of the streetscape provides an insight into the visual characteristics of a building and provides an analysis of the visual environment in which it is situated, that has previously not been possible. This analysis is particularly important for localities where the visual environment is protected by heritage controls, or has become valued by its residents. While planning controls attempt to sustain these visual environments, the photographic database of houses within a conservation area has shown that much of the built work undertaken while the controls have been in place has not retained the visual character of the conservation area. There may be a number of reasons for this including: a preoccupation with the replication of the federation style even if the original building is a different style; a misunderstanding of the visual requirements of a style; the use of modern construction materials and methods to replicate a style that requires other construction methods; and a lack of recognition by planning authorities that the detail within a building’s façade provides important visual information. Understanding the visual characteristics of the built environment within heritage conservation areas might also allow new buildings to be proposed that are of a different style, but nonetheless retain the visual character of the area.
7 Bibliography

Environmental Planning and Assessment Act (1979), 127.415 cl3 Interpretation.


DIPNR (2003). Improving Local Government Development Assessment in NSW. Sydney, NSW Department of Infrastructure Planning and Natural Resources.

DIPNR, (2004). Neighbourhood Character. Sydney, NSW Department of Infrastructure Planning and Natural Resources.


155


Appendix A

Appendix A contains sets of images taken from the HSCA in Newcastle. They are of one set, being identified as ‘Double Gable with Picket Fence’. Images of dwellings within the HSCA were grouped into groups with similar architectural features before being analysed using: Edge Detection; Hough Transform; Inverse Hough Transform; Polar Array; Line Count; and Line Strength Diagram.
Double Gable with Picket Fence: CS02
Double Gable with Picket Fence: CS02
Double Gable with Picket Fence: CS02
Double Gable with Picket Fence: CS02
Double Gable with Picket Fence: Dns03
Double Gable with Picket Fence: Dns03
Double Gable with Picket Fence: Dns03
Double Gable with Picket Fence: Dns03
Double Gable with Picket Fence: Dns03
Double Gable with Picket Fence: hn12
Double Gable with Picket Fence: hn12
Double Gable with Picket Fence: hn12
Double Gable with Picket Fence: hn12
Double Gable with Picket Fence: hn12
Double Gable with Picket Fence: npe16
Double Gable with Picket Fence: npe16
Double Gable with Picket Fence: npe16
Double Gable with Picket Fence: npe16
Double Gable with Picket Fence: npw43a
Double Gable with Picket Fence: npw43a
Double Gable with Picket Fence: npw43a
Double Gable with Picket Fence: npw43a

Line strength distribution

Angle (degrees from vertical)
Double Gable with Picket Fence: npw53a
Double Gable with Picket Fence: npw53a
Double Gable with Picket Fence: npw53a
Double Gable with Picket Fence: npw53a
Double Gable with Picket Fence: npw56
Double Gable with Picket Fence: npw56
Double Gable with Picket Fence: npw56
Double Gable with Picket Fence: npw56
Double Gable with Picket Fence: ws02
Double Gable with Picket Fence: ws02
Double Gable with Picket Fence: ws02
Double Gable with Picket Fence: ws02

Line strength distribution

Angle (degrees from vertical)
Double Gable with Picket Fence: CN06
Double Gable with Picket Fence: CN06

Appendix A  42
Double Gable with Picket Fence: CN06
Double Gable with Picket Fence: CN06
Double Gable with Picket Fence: CN08
Double Gable with Picket Fence: CN08
Appendix A

Double Gable with Picket Fence: CN08
Double Gable with Picket Fence: CN08
Double Gable with Picket Fence: CN08
Double Gable with Fence: CN09
Double Gable with Fence: CN09
Double Gable with Fence: CN09
Double Gable with Fence: CN09

![Image of Double Gable with Fence]

![Diagram of Double Gable]

![Graph with line strength and counts]
Double Gable with Fence: CN09
Double Gable with Picket Fence: CN13
Double Gable with Picket Fence: CN13
Double Gable with Picket Fence: CN13
Double Gable with Picket Fence: CN13
Double Gable with Picket Fence: CN13
Double Gable with Picket Fence: CS03
Double Gable with Picket Fence: CS03
Double Gable with Picket Fence: CS03
Double Gable with Picket Fence: CS03

Line count

Line strength
Double Gable with Picket Fence: CS03

Line strength distribution

Angle (degrees from vertical)
Double Gable with Picket Fence: ee02
Double Gable with Picket Fence: ee02
Double Gable with Picket Fence: ee02
Double Gable with Picket Fence: ee02
Double Gable with Picket Fence: ee02
Double Gable with Picket Fence: ew02
Double Gable with Picket Fence: ew02
Double Gable with Picket Fence: ew02
Double Gable with Picket Fence: ew02
Double Gable with Picket Fence: ew02
Double Gable with Picket Fence: gn05
Double Gable with Picket Fence: gn05
Double Gable with Picket Fence: gn05
Double Gable with Picket Fence: gn05
Double Gable with Picket Fence: gn05
Double Gable with Picket Fence: IMG_3374
Double Gable with Picket Fence: IMG_3374
Double Gable with Picket Fence: IMG_3374
Double Gable with Picket Fence: IMG_3374
Double Gable with Picket Fence: npw45
Double Gable with Picket Fence: npw45
Double Gable with Picket Fence: npw45
Double Gable with Picket Fence: npw45
Double Gable with Picket Fence: npw45

Line strength distribution

Angle (degrees from vertical)
Double Gable with Picket Fence: npw49
Double Gable with Picket Fence: npw49
Double Gable with Picket Fence: npw49
Double Gable with Picket Fence: npw49
Double Gable with Picket Fence: tbn34
Double Gable with Picket Fence: tbn34
Double Gable with Picket Fence: tbn34
Double Gable with Picket Fence: tbn34
Double Gable with Picket Fence: tbn34
Launceston, Tasmania, UTAS.


