TITLE – Alterations in Scale: Patterns of Change in Main Street Networks Across Time and Space

ABSTRACT

This paper presents a morphological study of 100 main street networks from urban areas around the world. An expansion in the scale of main street networks was revealed using a unique heuristic visual method for identifying and measuring the lengths of main street segments from each of the study areas. Case studies were selected and grouped according to corresponding urban design paradigms, ranging from antiquity to present day. This research shows that the average lengths of main street segments from networks of historic (i.e. ancient, medieval, renaissance, baroque, and industrial) and informal case studies are much smaller relative to those from networks of more contemporary case studies (i.e. Garden City, Radiant City, and New Urbanism). This study provides empirical evidence in support of prior, observational claims suggesting a consistent pattern in the smaller scale of main street networks from traditional urban areas, termed the '400-meter rule'. Additionally, it makes the case for further empirical research into similarly recursive spatial patterns within other elements of urban form (i.e., plots, blocks, etc.) that, if discovered, could aid in future urban design efforts to help provide the framework for more 'human- scale' urban environments.

KEY WORDS

Urban morphology, main street network, 400-meter rule, main streets, urban theory

MANUSCRIPT

Introduction

Cities are defined by a collection of both physical (e.g. streets, buildings and parks) and nonphysical elements (e.g. history, culture, and politics). Some of the physical features change slowly throughout time, while others are subject to more rapid transformations. This dynamic between various rates of change is vitally important in understanding how urban form is able to adapt to fluctuating economic, environmental, and social circumstances throughout time (Caniggia & Maffei, 2001; Conzen, 1960; Moudon, 1989; Slater, 1990).

As one of the more permanent features of urban form, main street networks are vitally important. Main street networks, represented as intersecting systems of main streets that form unique main street segments (edges) and points of intersection (nodes), have been shown to share similar properties to those of other spatially complex networks like power grids, mobile phone networks, and neural networks (Barthélemy, 2011). Main street networks are also known to exert significant influence on people and their ability to navigate space (Hillier, 1996; Porta, Latora, & Strano, 2010). Main streets have been found to remain central in the spatial organization of urban areas throughout time across significant social, economic, and environmental changes (Strano, Nicosia, Latora, Porta, & Barthélemy, 2012). Similarly, many (Anderson, 1986; Jacobs, 1961; Mehta & Bosson, 2010; Moughtin, 2003) have stated that careful concern should be given to the design of urban main street networks as dynamic vessels for human movement that are intimately linked throughout time to both physical and intangible elements of places.

According to Mehaffy et al. (2010), the pattern of intersecting main streets, prior to the advent of the automobile and the application of modern urban design paradigms, has followed a recurrent and consistent trend, termed the '400-meter rule'. According to this rule, urban areas comprised of quieter, mostly residential uses, also termed 'sanctuary areas' after Appleyard (1981), are bordered by main streets that intersect at intervals that seldom exceed 400 meters. Intersections occur at the junction of two or more streets, though not necessarily in the form of a rectilinear grid pattern. Main street networks connect local urban areas with their regional context and have constituted the commercial and service backbone of cities for many centuries, allowing non-residential uses to take advantage of more central locations at the local and regional scale. The scale of this spatial pattern, or 400-meter rule, reflects the limitations of pedestrian movements and the self-organizing logic of social urban life prior to the advent of the automobile, highways systems, and the application of professional urban design paradigms in the early twentieth century.

Based on preliminary observations, Mehaffy et al. (2010) argue that significant alterations to the scale of contemporary main street networks, starting at the dawn of the twentieth century, have been accompanied by a loss of a consistent spatial pattern and an expansion in the lengths of main street segments. These changes to urban form are influenced by several, interrelated factors including an increase in post-World War II housing demand, the rise of the automobile industry and federal highway systems (in the U.S.A.), the growth of middle class consumers and changes in market preferences, and several other social and political factors, including the application of professional urban design paradigms. These paradigms include Ebenezer Howard's Garden City (Howard, 1902), Clarence Perry's Neighbourhood Unit (Perry, 1929), Le Corbusier's Radiant City (Le Corbusier, 1933), and continue with contemporary place-making and New Urbanism (Calthorpe; Congress for the New Urbanism, 2013; Duany, Speck, & Lydon, 2009; Farr, 2008).

In an effort to test the observational claims behind the 400-meter rule, this paper presents the morphological analysis of 100 diverse main street networks from different historic, geographical, social, and economic systems using a unique heuristic visual method. The data gathered in this study offers empirical evidence in support of the 400-meter rule and makes the case for further empirical research into the structure of urban form and patterns linked to main street segments, that may reveal similar alterations in the urban fabric of cities corresponding to the physical application of urban design paradigms and other social factors.

Methodology

Selection of Case Studies

In order to test the 400-meter rule, measurements of main street segments of 100 case studies from 30 countries (Fig.1) were analysed to identify spatial patterns in the street network and if any alterations to this pattern occurred counter to the 400-meter rule. While this study is intended to represent an international distribution of cases, it is important to note that there exists a higher concentration of case studies from North America and Western Europe. This is a result of both the time constraints of this study and the bulk of the reference materials coming from the United States, United Kingdom, and other western European countries, where urban design is widely taught and researched.

Inset Fig. 1 here

Case studies were selected according to corresponding urban design paradigms (Table 1). Case studies were studied in their current state as reported by Google Earth (Google Inc., 2012) in the summer of 2010, and selected based on the following criteria: (1) each case study must be well researched and documented in published literature; and (2) each case study must still be universally recognized as being representative of one of the paradigms listed in Table 1 according to available literature. Historic cases (30) represent main street networks that correspond to ancient (6), medieval (6), renaissance (3), baroque (4) and industrial (11) paradigms, while contemporary cases represent those selected from the Garden City (20), Radiant City (20), and New Urbanism (10) models. Informal settlements were also examined as an exploding phenomenon which cannot be aligned with any of the paradigms of urban design mentioned above. Informal settlements are urban areas often characterized as poor places lacking access to clean water, safe sanitation, secure land tenure, or durable housing. The form and development of informal settlements, like the historic cases, lack influence from contemporary, professional urban design theories.

Insert Table 1 here

Mapping

Mapping of urban street networks was conducted using Google Earth web-based, imagery software (Google Inc., 2012), historic maps as needed, and Adobe Creative Suite 5 graphic design applications. Google Earth has been recognized as a valuable urban design tool for spatial education (Patterson, 2007) and urban analysis (Clarke, Ailshire, Melendez, Bader, & Morenoff, 2010; Farman, 2010; Sheppard & Cizek, 2009). For the purposes of this study, Google Earth was used to generate three maps of varying scales:

(1) The Regional Map – a simple diagram (Fig. 2) used to map the settlement within its regional context. This map includes the location of the study area, neighbouring towns and capital cities, regional roads, and geographical boundaries between land masses and water bodies.

Insert Fig. 2 here

(2) The Main Urban Street Network Map – a more detailed map (Fig. 3) of the urban street network for the study area. This map shows all main streets and railway lines connecting the study area with the surrounding region, identifies nodes of intersection between main streets, and locates sanctuary areas within the urban street network.

Insert Fig. 3 here

(3) The Sanctuary Area(s) Map – a scaled, satellite map of the sanctuary areas taken from the urban street network map at an altitude of ≤800m in order to generate a high resolution sanctuary areas map (Fig. 4). This map displays all main streets and nodes of intersection forming and connecting sanctuary areas within the study area. Local streets, found only within singular sanctuary areas, are not highlighted in the map and

instead are left on the layer of the background satellite image. Overall, these maps are used to measure all main street segments along the perimeters of sanctuary areas in order to compare segment lengths between all of the case studies.

Insert Fig. 4 here

It is worth noting that the selection of sanctuary areas was done in a subjective manner in order to get good representations of the urban design paradigms to which the main street network of the case belonged.

Visual Identification of Main Streets

In order to identify the main streets and nodes within the sanctuary area for each case study, the following visual, heuristic approach was applied.

(1) Using Google Earth, satellite images (with only the *Borders and Labels* & *Roads* layers) and historic maps (as needed) of the study area at the scale of the Regional and Urban Street Network maps, select as main streets those roads that can be easily identified as connecting the study area to other towns or cities. In Fig. 2 and Fig. 3, the main streets are those roads that serve as the main connections between the towns of Hertford, Hatfield, Sandridge, Oaklands, and Wheathampstead.

(2) When a main street splits into two or more directions, use visual clues such as number of lanes, width of roads, and street names (e.g. High Street, M8, county road, etc.) to establish a hierarchy of roads and determine the continuous path of the main street.

(3) Additionally, roads that traverse or serve as a connection across significant barriers in the street network (i.e. railway lines, motorways, rivers, etc.) are selected as main streets.

(4) Nodes mark the intersection of two or more main streets and serve as the endpoints to the main street segments. Thus, main streets segments are defined as sections of main streets that originate and end at nodes.

(5) In the case of squares and roundabouts, main streets can also be identified as those streets that connect the endpoint nodes of other main street segments coming into the square or roundabout.

The heuristic approach is purely visual and based on information that refers solely to geographical features and underlining considerations of connectivity of the street network. Other elements including traffic, land use, or demographics were not mapped or taken into consideration during this study.

Method Validation

The reliability of the visual identification method was tested by conducting an exercise with a group of fourth-year undergraduate architecture students. Students were selected based on their unfamiliarity with the methods used in this study. During the exercise, each student was given a computer with Google Earth, a marker, and a sanctuary areas map from a set of ten study areas randomly selected to cover each of the urban design paradigm groupings. For example, referencing Table 2, five students were given identical maps of the Palmanova study area, while six students were given identical maps of the Greendale study area and so forth. Given an hour, the students were then instructed to follow the visual method described above to identify all main streets on the corresponding sanctuary areas map using a bold marker to mark all nodes and main street segments. These results were then compared to the main street segments identified by the authors in order to determine the number of similarly identified main streets. These results are included in Table 2 below.

Insert Table 2 here

Overall, a total of 51 samples were collected from 25 students and 860 main street segments were identified. The percentage of similarly identified main streets across all of the case studies used in this experiment was 89%. When the samples included fewer main streets, the results from the student more closely matched those of the authors.

Statistical Methods

Descriptive statistics were calculated on the main street segment lengths for each of the 100 case studies using SigmaPlot 10 (Systat Software Inc., 2006). These statistics were then compiled to identify the means, standard deviations, medians, minimum values, maximum values, and outliers for each period in the history of urban design and represented using a Tukey vertical box plot (Tukey, 1977) in order to make non-parametric comparisons in the results between each period in the history of urban design and determine the validity of the 400-meter rule (Fig. 5).

Results

Both the mean and median can be used as measures of the central tendency of the sample; however, while the mean values are primarily discussed below, it is important to represent the median values, as the mean values can be affected by outliers as seen in the Garden City, Radiant City, and New Urbanism cases. In these cases, the median can be used as a better measure of the midpoint of the sample. This graph (Fig. 5) also shows the 400-meter mark to allow for easier comparisons to be made in relation to the 400-meter rule.

Insert Fig. 5 here

The average values for main streets from Ancient, Medieval, Renaissance, Baroque, Industrial, and Informal Settlement case studies are 315m ± 118m, 299m ± 146m, 257m ± 127m, 347m ± 243m, 343m ± 185m, and 354m ± 258m respectively. This suggests that most main streets from historic and informal settlement cases follow the 400-meter rule. However, the mean values for main streets from Garden City, Radiant City, and New Urbanism case studies vary greatly (1026m ± 638m, 843m ± 714m, and 788m ± 541m respectively) and are well beyond the limit set by the 400-meter rule. This suggests that a change has occurred with the advent of professional approaches to modern and postmodern urban design, the spread of the automobile and other social forces mentioned above causing the scale of urban street networks to be altered.

Discussion

Historic Cities

Since their inception, cities have been shaped by the environmental, economic, and social aims of communities (Hiorns, 1956; Morris, 1994). Historic cities, formed in the absence of automobiles, were designed according to practical principles with street networks that were limited in scale, allowing for pedestrians to walk to essential services (Newman & Kenworthy, 1999). Cities were often centred on a square, market, castle, or other civic structure with main streets leading outward from the centre in radial, rectilinear, or sometimes unplanned patterns towards the edge, marked by walls or other significant barriers (Hiorns, 1956; Morris, 1994). These principles of design allowed for cities evolve throughout time, adapting to meet the changing needs of society and adjust to new advances in technology.

In this study, for the 30 cases analysed between the periods of antiquity and the industrial revolution, the average main street segment was 331m ± 179m, indicating a pattern of urban form based on a close-grain framework of main street segments. The 95% outliers from the baroque and industrial periods came from unique main streets within the sanctuary areas of Karlsruhe, Germany and Calcutta, India respectively. In Karlsruhe, 29 individual main streets were identified, yielding an average segment length of 546m ± 325m. In Calcutta, 87 main streets were analysed, yielding an average segment length of 462m ± 236m. These deviations, while significant, do not impact the relatively small variation in average main street lengths between all cases from historic periods (331m ± 179m), and the mean and standard deviation for both Karlsruhe and Calcutta still place them within the range of the 400-meter rule. Overall, the evidence from these historic cases indicates a consistent pattern in the length of main street segments that follows the 400-meter rule.

Responses to Industrialization

The industrialization of cities built on a framework of close-grain street networks during the late eighteenth and early nineteenth centuries resulted in overcrowded, polluted, and unsanitary living conditions (Hiorns, 1956; Morris, 1994). As a consequence, by the late nineteenth and early twentieth centuries, several new theories of urban design were developed in an attempt to address these issues. This ushered in a new era in the history of urban design focused on the generation of healthier urban environments based on several important principles: improved efficiency through the use of modern transportation systems and new building materials, separation of industry and other land uses to promote public health, and the increased interaction of diverse demographics through the better use of public open space. Ebenezer Howard’s Garden City (Howard, 1902) and Le Corbusier’s Radiant City (Le Corbusier, 1933) were two of the most prominent of these new approaches to urban design based on the abovementioned theoretical principles. It is also important to understand how they became realized as expressions of ideas in the built environment, “sometimes, to be sure, almost unrecognizably distorted – of the ideas” (Hall, 2003).

Around the turn of the century, Howard proposed a relief to the urban conditions of industrial cities by envisioning cities that would provide access to country living. In his Garden City model, Howard designed detailed diagrams of concentric garden cities intended to fit on 600 acres of land and house 30,000 people, with an additional 2,000 living in the surrounding agrarian land. Boulevards, avenues, and roads separated residents from industry, which was placed on the edge of the cities neighbouring farms and forestlands. A series of greenbelts, mass transit systems, and motorways were planned to provide connection between neighbouring garden cities and a central city of 50,000 people. Theoretically, each garden city was designed to provide ample housing, jobs, manufacturing, and access to open space (Howard, 1902).

While Howard's Garden City model served as a logical alternative to the plights of urban dwellers, it was never fully realized in its original form. When the theoretical principles of the Garden City model were applied, garden cities were sometimes transformed into diluted forms, conventionally known as garden suburbs, the kind analysed in the case studies from the Garden City grouping. Some of these cases include Ciudad Guyana, Venezuela, Greendale, U.S., and Letchworth, U.K. These garden suburbs, where activity is centred, industry is separated from residential areas, and low-density residential development is clustered together on the edges, while following Howard's principles, gave rise to the physical manifestation now known as sprawl (Ward, 1992).

In the 30 cases studied from the Garden City period, the average main street segments measured 1026m ± 638m, more than double the 331m ± 179m of the 30 historic case studies. This increase in segment length and the relatively high variability in the results indicate an alteration in the scale of the urban street network counter to the 400-meter rule and the departure from traditional spatial patterns.

Like Howard, Le Corbusier also sought to improve public health, increase efficiency, and reconnect urban living with nature through his Radiant City model. Le Corbusier's Radiant City was based on the theoretical arrangement of high-density, residential skyscrapers connected through a series of aboveground highways on a rectilinear grid (Le Corbusier, 1935). In this model, traditional main streets became obsolete, and were replaced with highways elevated above the ground. This left the ground plane to be given over to open space that could be used by pedestrians. Le Corbusier embraced the technological advances of the early twentieth century, principally the use of the private automobile as means of transportation for the new masses of middle class urbanities in the machine-age, while rejecting appeals by others, including Camillo Sitte (Sitte, 1889), to reinvestigate traditional forms of urban design as a way to balance the benefits of modern technology with the essential physical characteristics of historic urban forms (Le Corbusier, 1929).

Le Corbusier was able to fully realize one Radiant City, Chandigarh, India. Like Howard, his model was immensely influential in informing, often literally and explicitly, innumerable others that have been constructed according to similar principals. These are represented in the 20 cases selected from the Radiant City grouping. These cases include Brasilia (Brazil), Regent Park, Toronto (Canada), and La Grande Borne, Grigny (France). While originally intended to be arranged on a 400-meter framework, when constructed, Le Corbusier's radiant cities resulted in reformed grids of superblocks with main street segments measuring up to 1065m ± 305m as is the case in Chandigarh. The average main street lengths for all of the cases from the Radiant City period measured 843m ± 714m, more than double that of historic main street segments. This again shows an alteration in scale and loss of consistent pattern within the urban street network.

Overall, these two theories were based on principles that were designed to provide access to open space, set urban growth boundaries, and deliver dense, transit-oriented communities. However, when fully realized, these theoretical approaches contributed to unintended consequences that include low-rise, residential sprawl, spatial and social segregation, decaying services and commerce, declining public life, and automobile dependence.

Response to the Physical Manifestations of Modernist Principles

Around the same time that Le Corbusier developed his principles for the design of the contemporary city, Clarence Perry suggested a new way of organizing and improving upon the problems of industrial cities called the Neighbourhood Unit. Neighbourhood Units were focused on principles of walkability and were organized around significant, community structures, namely schools or churches, which would be accessible by pedestrians living no more than a 400-meter radius away from the centre (Perry, 1929). Main streets formed the perimeter of each neighbourhood and were spaced in segments roughly 800m apart, the same scale as those evident in the Garden City and Radiant City paradigms. Theoretically, this was meant to ensure that a sense of community was developed and that main streets were used to form the edges of neighbourhood sanctuary areas (Ben-Joseph, 2005).

In response to the separation of land uses and sprawling designs resulting from the applications of the modernist principles mentioned above, New Urbanism was developed as a way to refocus urban design on creating walkable, mixed-use neighbourhoods built on the principles of Perry's Neighbourhood Unit (Congress for the New Urbanism, 2013). Started around the end of the twentieth century, New Urbanism focuses on creating developments based on a 400-meter radius where essential services are located within a 400-meter walk of the neighbourhood centre.

In the 10 New Urbanism cases studied, the average length of main street segments was 788m ± 541m. Cases from this period include the well-known developments of Seaside, US, Celebration, US, and Orenco Station, US. These results reflect the 800m main street network that is a physical manifestation of the 400-meter radius of the Perry's Neighbourhood Unit. Like the cases from the Garden City and Radiant City period, the New Urbanism cases also represent a clear alteration in the scale of the main street pattern when compared to those developed before the application of professional theories in urban design.

Informal Settlements

Interestingly, informal settlements represent similar patterns to those of historic urban street networks. The average main street segment measured 354m ± 258m for the 20 cases studied from this period, which is similar to the 331m ± 179m average found in 30 cases from historic cities. Cases from this period included Badli, New Dehli (India), Kibera, Nairobi (Kenya), and Rocinha, Rio De Janeiro (Brazil). According to these results, in the absence of theoretical principles of urban design, human settlements have tended to organize themselves according to the 400-meter rule. This suggests that informal settlements can serve as contemporary examples of the self-organizing logic that was present in the patterns of historic cities.

Learning from the Past: Towards Urban Sustainability

The scope of this paper is not to resort to the simplistic notion that historic cities are spontaneous and thus good, as opposed to contemporary cities that are planned and thus bad. Instead, the focus of this study is to bring new evidence in support of the disciplinary search for sustainable forms of urban design for the contemporary age. In most cases, historic cities developed over time as a result of both spontaneous and planned efforts, similar to what can be observed in contemporary informal settlements, which are often developed by non-institutional, sometimes illegal, local forms of authority.

With the increasing concerns over limited economic and environmental resources growing more acute at the turn of the century, urban design practitioners have become increasingly interested in the diverse, close-grain street networks of historic cities as a way to identify the essential characteristics of urban frameworks that provide for sustainability (DETR & CABE, 2000; Jones, Roberts, & Morris, 2007; Llewelyn Davies Yeang, 2000; Tarbatt, 2012). Some of these characteristics include the ability of close-grain street networks to encourage alternative modes of transportation, provide for well-connected, critical masses of customers to support local businesses, facilitate inclusion of diverse social groups in public places, and create safe and attractive places for people to visit and live (Jones et al., 2007). Within the past several decades, New Urbanism and Place Making have been developed as two related approaches based on these same principles; however, this research shows that when these principles become fully realized into physical urban forms, they share the same alteration in the scale of main street networks as other post-industrial, modernist developments. This alteration in scale has become a structural component of contemporary urban landscapes with impacts to the way in which cities function. By identifying consistent patterns within the forms of more resilient cities, practitioners will be better equiped to make design decisions based on sound empirical evidence of what frameworks work throughout time and allow for progressive adaptability as changing populations continue to inhabit today's cities.

Conclusion

While this research is limited by the current sample size, it does provide initial evidence suggesting that main streets networks in historic cities have predominantly followed the 400-meter rule. This research also suggests that since the advent and application of professional modern and postmodern urban design theories at the dawn of the twentieth century, the distance between main streets in cities has roughly doubled. Therefore we assert that an alteration in scale has occurred over time in coincidence with the establishment of modern and postmodern urban design paradigms. However, the alteration in scale does not appear in contemporary cities, which have developed in the absence of more formal planning and design (i.e. in informal settlements).

Explanations for the observations above may vary, and the causal role of the historic emergence of the automobile should be taken into consideration as well as other significant social and economic changes that have occurred in step with the establishment of urban design paradigms. However, all cities examined in this paper are contemporary cities and therefore they all have cars. But, only those built after the rise of the automobile and modern/post-modern urban design paradigms had been planned for the car by incorporating the neighbourhood unit and other automobile-oriented designs. Therefore, our conclusion is that the contribution of urban design models to the unsustainable, car-dominated city of today has been, and continues to be, of crucial and indeed generally underestimated importance. This conclusion is further supported by the final observation that contemporary cities when not formally planned do not exhibit signs of this alteration in scale.

This important discovery requires further research and has the potential to influence the future efforts of urban designers as they attempt to design today's sustainable cities, capable of reconciling the difference in timescales between the time required for urban places to evolve and the time these places are inhabited. The sudden increase in the scale of the main street network could imply a similar jump in the scale of other related sub-structures of urban form (e.g., plots, blocks, etc.). If this were the case, further study of these urban elements could offer an insight into different degrees of adaptability between places and uses over time and should prompt further research into more time-sensitive design.

The United Nation's (UN) 2009 report on global urbanization prospects predicted that the global urban population will grow from slightly over 50% of the total population today to 70% by 2050, with developing regions contributing to the majority of this growth (UN-Habitat, 2009). The magnitude of this reality is such that the cost of remediating planning and design inadequacies will likely be too great to bear from an economic, social, and environmental point of view. Another UN report also suggests that the majority of urban growth is to take place in smaller settlements, of less than 500,000 inhabitants, often lacking strong institutional frameworks to enforce and implement development which is socially and environmentally sustainable (UN-Habitat, 2011). Far from advocating a no-planning approach, which would naively fail to address the nature of contemporary urban market, this paper states that there is no better time than now to identify and employ well-informed design principles to guide this development. This is rather a call for better urban design and planning, an evolved and more responsive discipline which would aim at the generation of "a built-up area that keeps adapting and transforming itself in unplanned neighbourhoods" (Panerai et al., 2004, p.159).

This paper serves as a call for further research into the essential logic and principles of what generates a more adaptable, hence resilient, urban fabric.

This essential logic has to do with urban morphology: by better understanding the critical relationships between urban streets and plots, urban designers can begin to repair and develop more adaptable urban tissues, capable of adjusting to changing demographics, economies, and cultures over time.

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Table 1 - List of Case Studies According to Urban Design Paradigm Grouping

Study Area Location	**Distance to Capitol City** (m)	**Population** (people)	**Date of Origin** (year)	**Paradigm**
Bologna, Italy	300	376,800	100 - 1 BCE	Ancient
Lucca, Italy	270	84,323	180 BCE	Ancient
Pavia, Italy	450	71,000	187 BCE	Ancient
Piacenza, Italy	411	101,325	218 BCE	Ancient
Pompei, Italy	210	20,000	800 - 701 BCE	Ancient
Verona, Italy	410	265,410	550 BCE	Ancient
Grammichele, Sicily, Italy	550	13,145	1693	Baroque
Karlsruhe, Germany	525	291,959	1715	Baroque
Noto, Sicily, Italy	600	23,816	1693	Baroque
Ragusa, Italy	586	72,836	1693	Baroque
Ciudad Guyana, Venezuela	520	940,477	1961	Garden City
Cumbernauld, UK	560	49,664	1955	Garden City
East Kilbride, UK	540	73,320	1947	Garden City
Farsta, Stockholm, Sweden	0	45,463	1957	Garden City
Glenrothes, UK	560	38,927	1948	Garden City
Greenbelt, MD, United States	20	21,465	1937	Garden City
Greendale, WI, United States	1020	14,405	1938	Garden City
Greenhills, OH, United States	647	4,103	1930's	Garden City
Hilversum, The Netherlands	25	83,640	1950's	Garden City
Letchworth, UK	50	33,600	1903	Garden City
Lusaka, Zambia	0	3.1 M	1960	Garden City

Milton Keynes, UK	70	195,687	1967	Garden City
Navi Mumbai, India	1100	2.6 M	1972	Garden City
Radburn, NJ, United States	330	3,100	1928	Garden City
Riverside, IL, United States	970	8,895	1920's	Garden City
Seishin, Kobe, Japan	420	Unknown	197-	Garden City
Tama, Tokyo, Japan	0	114,348	1971	Garden City
Tapiola, Finland	10	16,000	mid 1960's	Garden City
Vallingby, Sweden	10	25,000+	1954	Garden City
Welwyn, UK	30	3,254	1920	Garden City
Barcelona, Spain	500	1.6m	1859	Industrial
Boston, MA, United States	630	645,169	1882	Industrial
Calcutta, India	1300	5.1 m	1850	Industrial
Chicago, IL, United States	968	2.8 m	1871	Industrial
Manchester, UK	260	464,200	1853	Industrial
Merchant City, Glasgow, UK	550	3,595	1700's	Industrial
Middlesbrough, UK	350	139,000	1830	Industrial
Milan, Italy	473	1.86m	1861	Industrial
Paris, France	0	2.1 m	1852	Industrial
Philadelphia, PA, United States	190	1.5m	1876	Industrial
Stockholm, Sweden	0	829,400	1897	Industrial
Badli, New Delhi, India	0	45,200	1961	Informal Settlement
Bario, Caracas, Venezuela	0	Unknown	194-	Informal Settlement
Cemetery Squatters, Port au Prince, Haiti	0	100,000	1960	Informal Settlement
Dharavi, Mumbai, India	1140	1m	1930	Informal Settlement
Hanna Nassif, Dar-es-Salaam, Tanzania	388	23,000	1960's	Informal Settlement
Kakrail, Dhaka,	0	120,000	1980	Informal Settlement

Bangladesh				
Khayelitsha, Cape Town	1300	406,779	1957	Informal Settlement
Kibera, Nairobi, Kenya	0	1m+	1960's	Informal Settlement
Kranidi, Greece	100	10,000	197-	Informal Settlement
Kricak, Yogyakarta, Indonesia	427	300,000	1950	Informal Settlement
Lagos, Lagos Island, Nigeria	530	209,000	1963	Informal Settlement
Las Colinas, Bogota, Columbia	0	10,000	1960	Informal Settlement
Lima, Hill Squatters, Peru	0	Unknown	196-	Informal Settlement
Mafalala, Maputo, Mozambique	0	22,000	pre 1975	Informal Settlement
Orangi Town, Karachi, Pakistan	1140	1.5m	1965	Informal Settlement
Rocinha, Rio De Janeiro, Brazil	930	250,000	1970's	Informal Settlement
Rufisque, Dakar, Senegal,	0	179,797	1987	Informal Settlement
Tondo, Manila, Philippines	0	630,000	900	Informal Settlement
Urban Village, Shenzhen, China	1930	70,000	1980's	Informal Settlement
West Point, Monrovia, Liberia	0	75,000	1980's	Informal Settlement
Bremen, Germany	316	547,645	1032	Medieval
Lubeck, Germany	235	210,892	1143	Medieval
Nuremberg, Germany	380	503,600	1050	Medieval
Tripoli, Libya	0	1.06m	1510	Medieval
Verdun, France	220	19,624	1374	Medieval
Vienna, Austria	0	1.7m	1440	Medieval
Brentwood CA, United	3700	4,200	2005	New Urbanism

States				
Celebration FL, United States	1200	11,860	1990	New Urbanism
Communications Hill, Sacramento, CA, USA	3800	2800 units	2010	New Urbanism
Kentlands, Gaithersburg, MD, United States	30	2000 homes	1990	New Urbanism
Laguna West, Sacramento, CA, United States	3800	8,414	1991	New Urbanism
Orenco Station, Portland OR, United States	3700	>46124	1997	New Urbanism
Poundbury, UK	186	6,000	1993	New Urbanism
Rosemary Beach, FL, United States	1250	500 homes	1995	New Urbanism
Seaside, FL, United States	1250	2,000	1979	New Urbanism
Windsor, Vero Beach, FL, United States	1286	350 homes	1989	New Urbanism
Akademgorodok, Novosibirsk, Russia	2800	65,000	1950's	Radiant City
Barbican Estate, London, UK	0	4,000	1969	Radiant City
Blue Area, Islamabad, Pakistan	0	530,000	1958	Radiant City
Brasilia, F.D. Brazil	0	2.6 m	1960	Radiant City
Cabrini Green, Chicago, IL, United States	968	15,000	1942-2008	Radiant City
Chandigarh, India	230	900,000	1953	Radiant City
Co-op city, New York, NY, United States	330	55000+	1973	Radiant City
Cumbernauld, UK	560	49,664	1956	Radiant City
Drumul Taberei,	0	63,000+	1974	Radiant City

Bucharest, Romania				
La Grande Borne, Grigny, France	22	26,790	1980's	Radiant City
Le Mirail, Toulouse, France	580	27,500	1968	Radiant City
Marzahn, Berlin, Germany	0	102,398	1977	Radiant City
Milton Keynes, UK	70	195,687	1967	Radiant City
Pendrecht, Rotterdam, The Netherlands	60	12,400	1953	Radiant City
Pruitt-Igoe, St. Louis, MO, United States	1146	2740 units	1954-1972	Radiant City
Regent Park, Toronto, ON, Canada	352	10,385	1940's	Radiant City
Roehampton, London, UK	0	13,000+	1950's	Radiant City
Stuyvesant Town, New York City, NY USA	330	25000+	1947	Radiant City
The Grand Ensemble of Sarcelles, Paris, France	0	60,196	1960's	Radiant City
Tsukuba Science City, Japan	50	207,000	1960's	Radiant City
Freudenstadt, Germany	575	23,690	1599	Renaissance
Neuf Brisach, France	390	2,219	1697	Renaissance
Palmanova, Italy	450	5,406	1593	Renaissance

Table 2 – Results from Visual Analysis Experiment

	Historical		Garden City		Radiant City	
	Palmanova (A)	Lubeck (B)	Letchworth (A)	Greendale (B)	Chandigarh (A)	Drumul Taberel (B)
Number of Samples	5	4	6	6	6	6
Number of Main Streets per Sample	6	28	27	19	8	14
Number of Main Streets	30	112	162	114	48	84
Percentage of Similarly Identified Main Streets	100%	83%	87%	94%	100%	95%

	New Urbanism		Informal Settlements	
	Kentlands (A)	Poundbury (B)	Port au Prince (A)	Bogota (B)
Number of Samples	4	5	5	4
Number of Main Streets per Sample	23	9	17	22
Number of Main Streets	92	45	85	88
Percentage of Similarly Identified Main Streets	83%	100%	86%	82%

Fig. 1 – Spatial Distribution of Case Studies Across 30 Countries

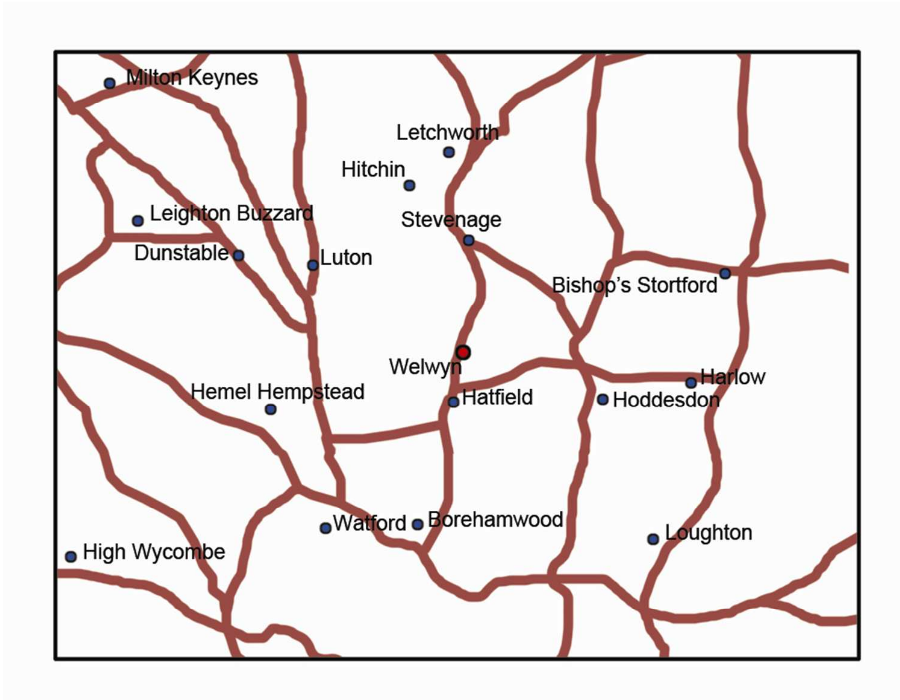

Fig. 2 – Regional Map for Welwyn, U.K.

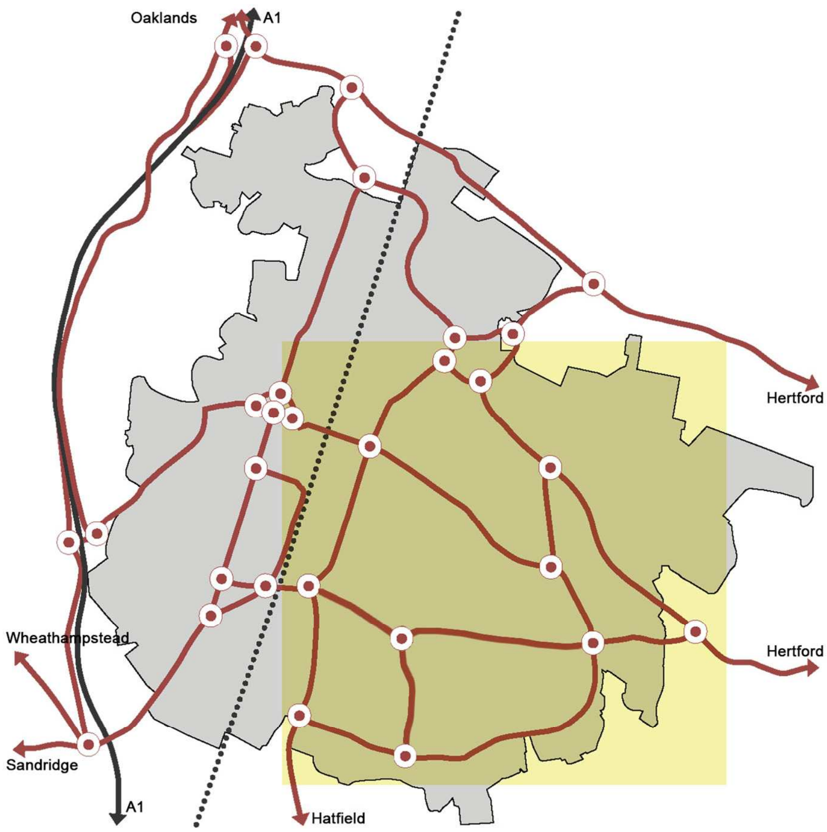

Fig. 3 – Main Urban Street Network Map for Welwyn, U.K.

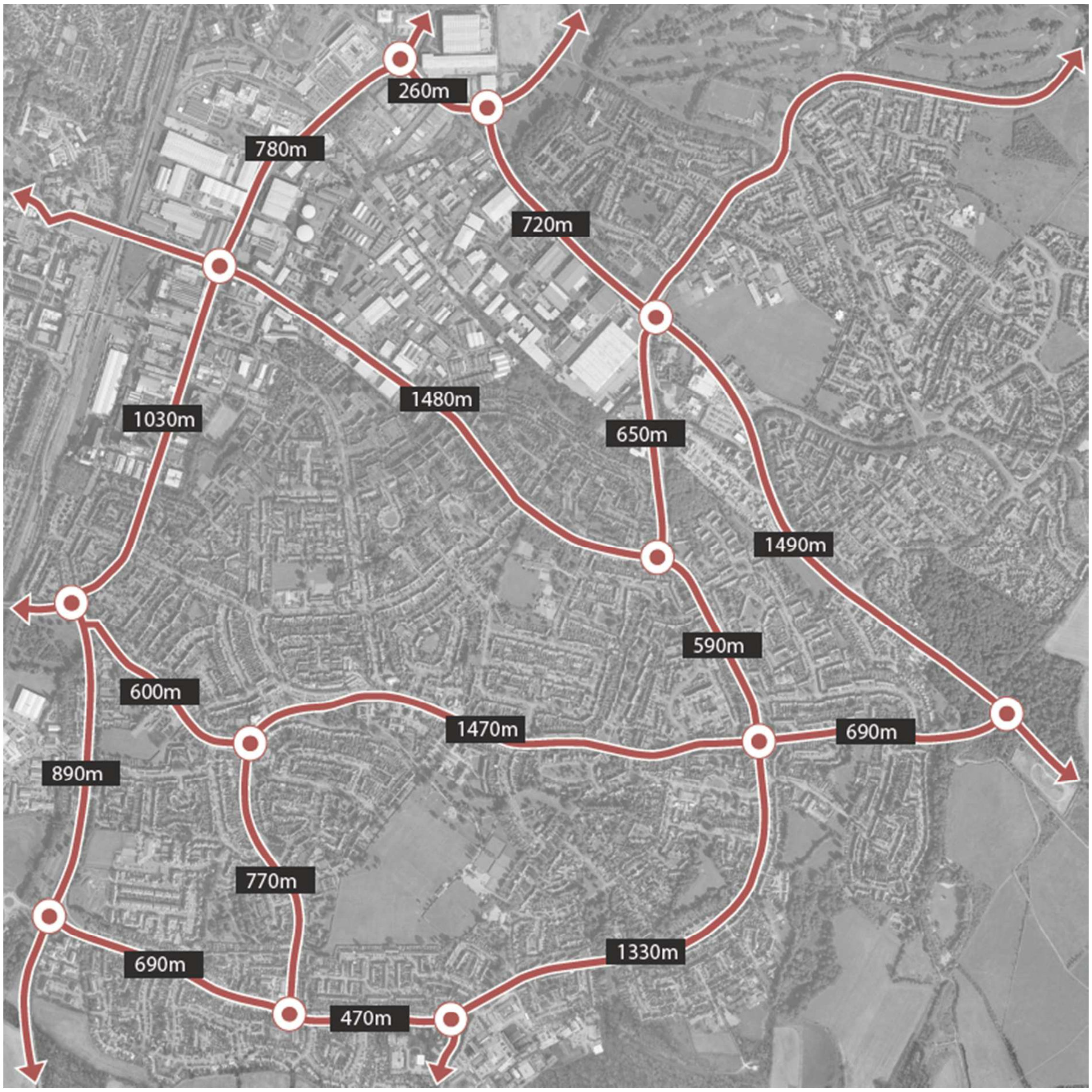

Fig. 4 – Sanctuary Area(s) Map for Welwyn, U.K.

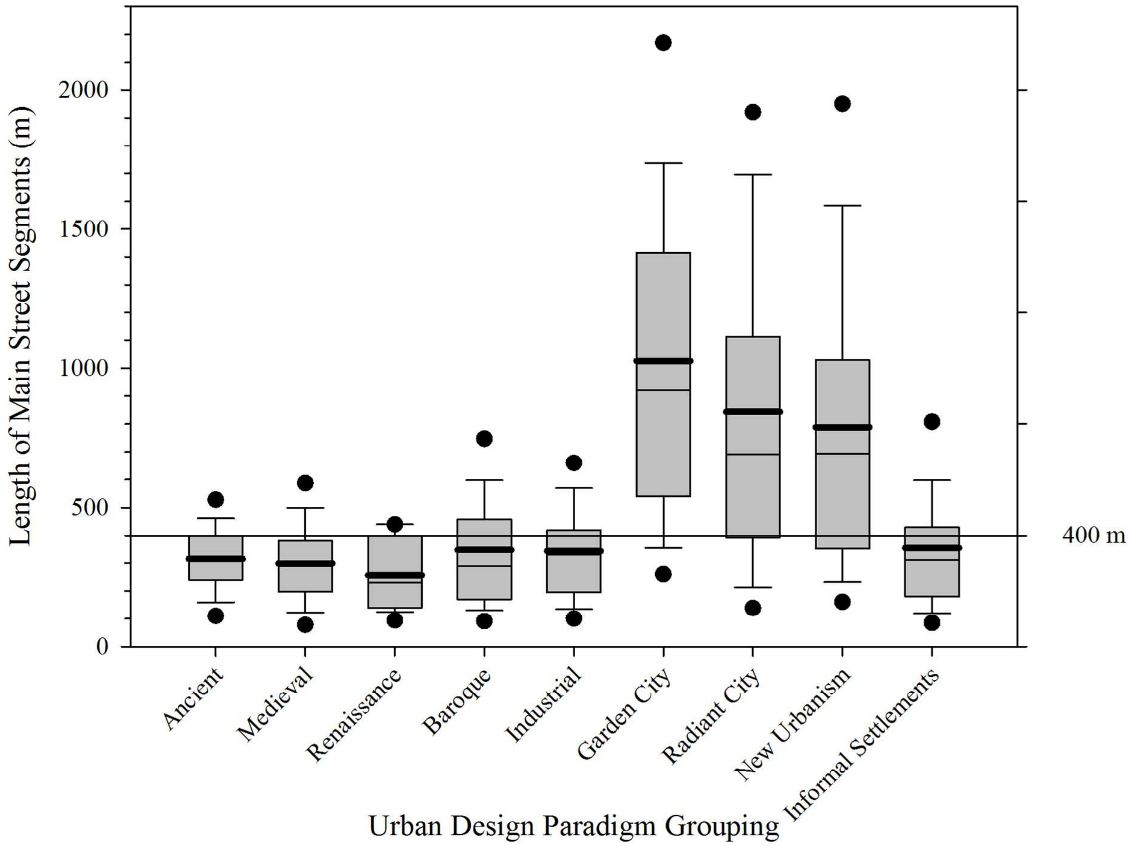

Fig. 5 – Lengths* of Main Street Segments by Urban Design Paradigm Grouping

*The bold line marks the arithmetic mean or average, the fine line represents the median, the box represents the range from 25th to the 75th percentiles, the whiskers (error bars) represent the 10th and 90th percentiles, and the dots represent the 5% & 95% outliers of each grouping.

TITLE – Alterations in Scale: Patterns of Change in Main Street Networks Across Time and Space

ABSTRACT

This paper presents a morphological study of 100 main street networks from urban areas around the world. An expansion in the scale of main street networks was revealed using a unique heuristic visual method for identifying and measuring the lengths of main street segments from each of the study areas. Case studies were selected and grouped according to corresponding urban design paradigms, ranging from antiquity to present day. This research shows that the average lengths of main street segments from networks of historic (i.e. ancient, medieval, renaissance, baroque, and industrial) and informal case studies are much smaller relative to those from networks of more contemporary case studies (i.e. Garden City, Radiant City, and New Urbanism). This study provides empirical evidence in support of prior, observational claims suggesting a consistent pattern in the smaller scale of main street networks from traditional urban areas, termed the '400-meter rule'. Additionally, it makes the case for further empirical research into similarly recursive spatial patterns within other elements of urban form (i.e., plots, blocks, etc.) that, if discovered, could aid in future urban design efforts to help provide the framework for more 'human- scale' urban environments.

KEY WORDS

Urban morphology, main street network, 400-meter rule, main streets, urban theory