Visual Analytics for Urban Design

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Abstract

Here we outline the rapid development of new tools for visualising cities and their functions with an emphasis on how they can be used in the analytical phases of urban design. We begin with the most obvious examples of digital visualisation – 2D and 3D maps – from geographic information systems (GIS) and computer-aided design (CAD) technologies. These merge into augmented and virtual realities and imply that much of what has been developed for desktop applications is now shifting to the web. We then examine networks, noting the early development of space syntax but then moving to flow systems of various kinds that record interaction between the elements of a design. We look at models of flows, specifically traffic and pedestrian movement and then consider how new social media produced in real time is being used to inform small-scale interactions at the level of spatial and social networks. Scientific visualisation is also affecting design in that more abstract infographics are being used to display and visualise the complexity of design, and to this end, we show various new forms of network and connectivity. Finally we note how real time data is being delivered to designers using various forms of dashboard which summarise how cities are performing and we conclude by suggesting that these new kinds of visualisation are beginning to enrich the field of urban design by innovative display of ideas and their access through online participation.

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Defining Visual Analytics

The dominant medium in urban design has and continues to be visual. Maps and physical models provide the lens through which design is developed and communicated and pictures of the resultant designs which largely focus on views of how buildings and peoples relate functionally and aesthetically to one another, are key to the definition of design. In a world that is now fast moving to representing virtually every type of media from sound to sight and smell to hearing and touch in digital terms, the most obvious applications in urban design are based on digital representations of what traditionally was produced by hand – maps, layouts, picture perspectives and so on. But the power of the digital world for urban design is much wider than mere pictorial visualisation, although this can be as effective if not more so than traditional media. Digital visualisation provides a powerful medium in which to abstract and to analyse and it is ‘visual analytics’ that is fast becoming the cutting edge of how urban design might be progressed.

Visual analytics goes beyond pictorial representations in that it associates the functions that define how the system of interest works, in this case the cluster of buildings or neighbourhoods – the subject of design – with ways of making sense of them visually. In this sense, it always requires a model which we define as a set of abstractions embracing the functions that are central to the design. The best way to describe such analytics is to consider an urban design to be composed of elements that vary over space and time, as well as over spatial scales although here we will very much focus on localities or neighbourhoods. Such designs reflect a mix of goals pertaining to the aesthetic quality of design which reflect the efficiencies with which people use the environment as well as equitable principles that might be embodied and achieved by the design.

Without embellishing theories of the neighbourhood, there are five core features of urban design around which we can illustrate visual analytics. First, there is the physical representation of the design as 2D maps and 3D visualisations of urban form that are captured and manipulated visually and can be cast into various virtual environments that allow designers and users of the design to explore and experience the design in advance. In the last 20 years, the software to do this has evolved from geographic information systems (GIS – for maps and some networks) to computer-aided design (CAD) software and latterly to various kinds of immersive environments and animation. These kinds of system are now scaling down to Building Information Systems (BIMs) that represent much the same functions that pertain to neighbourhoods and clusters of building but with a stronger emphasis on the functional and materials aspects of buildings.

The second feature involves networks. Clearly interaction and movement is key to urban design and often layouts of buildings are complemented by their dual forms which are the connections between them. There are many new ideas about networks ranging from their morphology to their visualisation that are being rapidly deployed to articulate urban designs. The third feature is new media. When most of us are connected to the net using smart phones, then the kinds of interactions that take place on virtual social networks are often reflected in quite complex ways in the physical environment and everything from Twitter feeds to email traffic serve to illustrate new ways in which social structures are intimately tied up with physical building
structures. Our fourth feature involves new and more abstract methods of scientific visualisation based on what is often referred to as infographics. As we have implied, visual analytics is not simply about pictures of urban scenes or even about maps but one can abstract aspects of the design problem and their solution into forms that can become quite abstract but can be visualised in powerful and effective new ways. The last feature is about the online world where much of our access to it is graphical and pictorial. Planning processes are now being dramatically restructured using online information and new ways of generating participation, of using stakeholders to generate data, and of enabling much larger audiences of concerned individuals to fashion designs are possible over the net. All of this is critically dependent on visual analytics.

Figure 1: Moving to 3D Visualisation: Navigating Through the Models
(a) The virtual London model built from vector land parcel, streetline and 3D LIDAR data and visualised in ArcGIS (b) Layering a pollution surface (NO₂) across the model (c) Office (blue) and retail (yellow) floorspace visualised as 3D histograms (d) Land use mapping in Canary Wharf, London’s second central business district

The core of digital visualisation in urban design resides in 2D and 3D representation which was first illustrated for neighbourhoods and building complexes almost as soon as computers became graphical in the early 1980s. The whole panoply of GIS techniques in terms of treating attributes of buildings as layers of data is now widely exploited (Batty, Dodge, Jiang, and Hudson-Smith, 1999). Generalisation to the third dimension and thence tagging such 3D representations to data layers to exploit the power of the third dimension enables new forms of analysis to be accomplished.
Figure 1 assembles a collage of 3D content from our Virtual London model – a 3D extrusion of all the building blocks in Greater London which enables users to tag these blocks with content and render them in much greater detail if required. Besides the usual fly-throughs that are possible and the descent to the street-view level, these 3D models can be associated with layers of pollution for example, water layers which can be manipulated to simulate flooding, indeed any set of attributes that are relevant to good urban design. Once one has the content of the model in digital form, then analysis in 3D is straightforward and importing the 3D scene into a virtual world that can be accessed online is almost routine.

![Figure 1](image)

We also show in Figure 2 how a portion of Virtual London model can be entered into a virtual world with actors logging on from remote locations, appearing as avatars and engaging in discussion on various elements of the 3D scene to be manipulated (Batty and Hudson-Smith, 2001, 2005). In short, developments in 3D visualisation have

**Figure 2: Augmenting 3D Visualisation: The Virtual and the Real**

a) Creating a virtual exhibition space/ design studio where users can interact in a virtual world  
b) Easier navigation of a virtual model using gaming media  
c) The London Data Table: projecting digital media back onto a material surface  
d) A holographic like projection as seen through the headset of one of the users interacting with another
spurred on the notion of the online studio; the idea that many people can work together on the same design at the same time no matter how remote they are geographically to one another is the wave of the future that is beginning to be exploited in all kinds of collective working and design through structured crowdsourcing. There are many other ways of visualising buildings and neighbourhoods using augmented realities in which digital content is key. In Figure 2, we also show how we can move back to a more conventional reality by projecting digital analysis on conventional physical media – using a physical map – the London data table – and augmenting the reality by enabling users to interact with the design in holographic space or by flying through real space.

Figure 3: Interactions Between the Elements of Urban Form Reflecting Lines of Sight in the Village of Gassin using Space Syntax Measures
a) The strength or accessibility of the nodes defining street intersections b) the strength of the lines of sight. The interpolated surfaces defining accessibility for c) street intersections and for d) streets; from Batty (2013)

A key element in the design of any system is the way the parts are assembled to produce a synthetic whole and urban designers spend a great deal of time experimenting with packing elements into restricted spaces that optimise the efficiency of human interactions and contacts. In the last decade, there has been a revolution in thinking about how to represent and manipulate networks and many new visual tools for portraying the strength of connections between building and areas that compose a design are being developed. Rudimentary network tools have been developed for examining lines of sight and view-sheds in urban design and very early in this development, the idea of calculating proximity based on the quality of how spaces interpenetrated one another was developed under the rubric of space syntax. There have been rapid developments of late in these kinds of analysis and in Figure 3,
we show the kinds of analytics that can be used to produce the connectivity and accessibility of lines of sight and their intersections – sometimes simply streets and their junctions – which are the essence of space syntax. We show these for the French village of Gassin used by Hillier and Hanson (1984) in their original exposition of the technique and extended by Batty (2013).

![Figure 4: Flows Between Elements of the City:](https://www.youtube.com/watch?v=0jcJsY-gnEI)

Figure 4: Flows Between Elements of the City:
- a) Volumes of Public Bikes in Central London Streets, see the movie at [https://www.youtube.com/watch?v=0jcJsY-gnEI](https://www.youtube.com/watch?v=0jcJsY-gnEI)
- b) Key Passenger Flows on the London Tube

In fact urban systems based solely on simple links between spaces and routes that define any place are simplistic in that these links are always weighted by flows. In fact flows are significant because they illustrate how energy flows in an urban systems – car traffic, people walking, goods moving, email, web use, high frequency trading and so on. A couple of examples are shown in Figure 4(a) where we illustrate the flow of public bikes on streets in central London and the dominant links associated with the subway (tube) system which focus on key transport hubs – subway stations in the centre, in Figure 4(b). There are many such visualisations like this and if they are animated because flows change through time, these illustrate how energy pulses through the fabric of the city as reflected in diurnal cycles such as peak hour concentrations and other events. In fact flow systems although definable at any scale, tend to be more implicit at the urban design scale and only really come into their own once traffic flow patterns are identified that define the city at a more coarse grained scale.

In fact at finer scales, the focus is much more on how people walk and interact locally using slower modes of transport such as those illustrated in the public bikes scheme in Figure 4(a). In Figure 5(a), we show how such flow systems can be visualised at a very fine scale, where in this case, we show how we can simulate people moving in a building complex, how they crowd, flock, diffuse and cluster as they interact with others and with the buildings that they relate to. In Figure 5(b) we show an evacuation from a large building complex built in the Legion software by Zachariadis (2014). This begins to suggest that some of our work in urban design relates to much shorter term issues about the smart city where we are concerned with how design is affected by rapid movement, security and safety issues.
Figure 5: Modelling and Visualising Pedestrian Movement in Neighbourhoods and Large Building Complexes

to meet design requirements related to a) congestion, crowding, safety and b) speed of evacuation

Data that streams in real time is now beginning to be captured and mapped a very fine spatial scale. We have detailed transport flows second by second which are associated with the use of smart cards being used for payment as well as mobile devices used for communicating various kinds of social media. From these data, we are able to explore the impact of social networks and interactions in small spaces and Figure 6 shows how we can bring 2D maps and 3D visualisations to bear on locating and visualising social media – in this case geocoded short text messages – Tweets – which illustrate how data can be associated with buildings (Figure 6(a)) and places (Figure 6(b)). From this, social networks can be constructed which indicate how places are related to one another, thus complementing very nicely other flow and network data such as that we have mapped and explored in previous figures.

The beginnings of digital visualisation in the 1980s which occurred on microcomputers as well as supercomputers were more abstract from any of the examples that we have illustrated here. Scientific visualisation essentially abstracts properties of the problem and visualises their structure using networks and statistical charts of various kinds (Kaufmann and Smarr, 1993). There have been many advances, particularly involving networks and relationship diagrams. We illustrated the use of statistical histograms in 3D associated with places that at first sight look like high buildings but are not in Figure 1(c). We examined surfaces as interpolations from less abstract geometric properties based on point locations and averages over small areas in Figure 1(b) for pollution in London and in Figures 3(c) and (d) for the syntax analysis of the village of Gassin. We abstracted the key flows of transport into major subway stations by departing from the physical network of flows using smooth curvatures and various colours in Figure 4(b).
a see the full movie at https://www.youtube.com/watch?v=3fk_qxGZWFQ

b see the detailed map at high resolution http://twitter.mappinglondon.co.uk

Figure 6: New Media: The Spatial Distribution of Tweets
a) Tagged to a 3D Digital Model of London, varying over 15 hours from about 3500 Tweets: Building grow in proportion to the “data” they generate, b) Related to the Distribution of Ethnic Groups in London from an Analysis of the Language Content of the Tweets

In Figure 7, we show two very different network diagrams: for flows based on the journey to work between places – in this case London boroughs using the circular network in 7(a) and for connectivity using the proportional spheres for the degree of connectivity between subway stations in the London tube in 7(b). The real power of these visualisations is in abstracting the key points. In the case of the circular flow map shows that the dominant flows are within places but the map also shows the key flows which in this case are major commuting into the centre of London. Visualising
internal flows within places is very hard using conventional mapping in 2D hence the need for abstraction. The connectivity in 7(b) is developed using network construction that enables the spheres to be best positioned to make the graph intelligible while retaining its planar characteristics. Although we cannot show this here, the software is essential to the use of these visual analytics for it is possible to animate and reposition much of these graphics implying that the real power is the ability to explore the urban design problem and the system being designed by continuous use of the software.

![Figure 7: Infographics: Abstracting Spatial Design Problems](image)

Figure 7: Infographics: Abstracting Spatial Design Problems

a) Arranging Transport Flows Between London Boroughs in a Circular Flow Graph, starting with Barking at 12 o’clock and going clockwise around the circle to Westminster, b) Visualising the Connectivity of Locations with respect to Inner and Central London Tube Stations

This new world of visual analytics is exploding almost in front of our eyes because the internet enables all of us to become involved in these visualisations. In fact, data about urban problems is increasingly being delivered to our desktops and mobile devices through the web as we show in Figure 8 where we picture our Citydashboard that collects data from live feeds and displays it in real time for particular places. We can scale these kinds of visualisation to very local places, we can augment them with interactive capabilities that enable both designers and users to interact in generating data using crowdsourcing, and we can extend these to a variety of devices such as physical data tables and digital touch screens that enable extensive interaction of every kind of stakeholder who is involved in the process of urban design and the quality of the plans that result. In this short paper, we have sketched the possibilities that are currently being explored and as the digital revolution has always suggested what is possible today will become routine tomorrow. Many of the new technologies described in here reflect this prospect and the time is ripe for a more considered exploration and integration of the whole array of visual technologies that are fast becoming central to urban design and planning.
Figure 8: Community Design: Disseminating Real Time Urban Data using Visual Dashboards

CASA’s City Dashboard designed to show live feeds of data from weather to the FTSE 100 in real time for several cities: the prospect of such dashboards for neighbourhoods and communities is suggestive of really effective participation in community design.

References


