VISUALIZING GIS: Urban Form and Data Structure

GINETTE WESSEL University of North Carolina at Charlotte
REMCO CHANG University of North Carolina at Charlotte
ERIC SAUDA University of North Carolina at Charlotte

1 Introduction

Our work encompasses subjects of urban planning, urban design, urban morphology, and the link between geographical information systems (GIS) and urban visualization. Our area of research focuses on the way people conceptualize the urban environment. The visualization technique discussed in this paper is an attempt to provide users with a tool to create their own sense of urban legibility, which allows them to gain an intuitive and deep understanding of the urban model and its social, cultural, and economic relationships.

Although people interpret the city differently, it is agreed upon that all people understand the city through its physical elements. The concept of urban legibility, made famous by Kevin Lynch in the 1960s, recognizes that people intuitively categorize a city's physical elements [11]. Instead of visualizing the urban environment as a collection of random physical elements, Lynch makes apparent that people aggregate the city into identifiable components. For example, he says the city can be defined by paths, edges, districts, nodes, and landmarks. This cognitive mapping approach to understanding the urban environment depicts Lynch's elements through a simplification method, and is the methodological base of our system.

Our visualization tool, *Urban Vis*, provides a way to view the spatial layout of a city and the characteristics of areas through demographic information. What is the relationship of low income areas to downtown? Do schools service a sufficient number of homes? Will rezoning an area affect a nearby neighborhood? Is an older neighborhood built upon a unique figure ground pattern? Questions about the physical and social infrastructure of the city can be analyzed using our tool.

In comparison to existing GIS systems, our tool offers a new way to understand the urban environment through a clustering algorithm allowing for various levels of abstraction to occur. The clusters represent various spatial boundaries, which contribute to the user's geographic perspective. This multi-resolution technique is a new geometric and form based way to explore the underlying foundation of a city.

In order to validate the effectiveness of our tool, we surveyed fourteen experts who regularly investigate urban environments. The examinees' occupations ranged from geographic information experts to school district planners to real estate developers. After demonstrating our tool, the experts were able to visualize the urban form and data into a cohesive image while retaining their sense of urban legibility. Collectively the experts expressed that our visualization tool offers new techniques to help them perform their daily tasks.

The collaborative efforts of the College of Architecture and the Visualization Center at UNCC have developed a rich approach to understanding complex urban environments. These efforts have also lead to technical discussions of this work at the 2007 IEEE Information Visualization Symposium [17].

2 Concepts in Urban Legibility

For purposes of this research, there is a need to differentiate between urban planning and urban design. Urban planning focuses largely on the use of social, economic, and political factors when evaluating urban growth and development [7]. Most of these factors are important to our understanding of the city, but for our research, they do not focus enough attention on the geometric forms of the city. Typically, urban planning explores the connection of social and political factors to urban form and is visualized on a local scale rather than a city or regional scale [9]. For our investigation, it is important to examine how economic factors affect the city at various scales. Urban design allows us to focus more attention on the form and geometry of the city. Traditionally, simple geometric models of the city have been the basis of discussion and design, either in planimetric view [13], in sequential perspective view [4], or using cognitive mapping [11]. We introduce a view of the city unlike prior models that can convey information to the user through multiple perspectives.

In the 1970s, Robert Venturi introduced a new perspective of the urban environment. *Learning form Las Vegas*, by Venturi and et al., examined how people understood the city through signs, symbols, space, and speed. They recognize that the city is not just a place of architecture and economic interaction, but it communicates a new urban understanding through iconology and the city's changing geometric form [18]. More recent work by Rem Koolhass at Harvard has begun to examine the urban environment with relation to technological impacts. He seeks to weave economic, political, and social factors explicitly into the development of urban form while understanding that the linkage is not methodologically the same as before but impacted through digital networks [19]. Bill Mitchell, in his book *City of Bits* [12], wrote about the emergence of urban forms that changes ideas of fixed space. He believes digital and spatial networks contribute to a new sense of urban understanding.

Our investigation covers urban concepts that offer a perspective of reading the city in modern day context. By using basic principles of urban legibility, we can then apply them to visualization techniques. The result of this work will improve user's legible construct of the complex urban environment.

3 Existing GIS Systems

Often geographical information systems can limit a user's ability to understand a 2D or 3D urban model environment. The perspective from which the user navigates the environment is important to his interpretation of its spatial layout. In most existing systems, the method by which a user navigates data may limit their perspective. These GIS systems commonly offer a zoom tool that allows the user to drag a bounding box over an area of focus. This method of navigating a scene may lose the user's sense of spatial relationships with the surrounding context. Furthermore, accurately representing complex environments requires multiple layers of data. Existing systems either represent these layers by using multiple colors thus limiting a user's ability to decipher between data, or they require procedural methods to analyze data, which may cost extensive amounts of time to perform.

In designing our tool, we incorporate highly interactive techniques for navigating and examining the urban environment as well as state of the art information visualization methods to correlate disparate layers of data. This unique combination allows the user to quickly gain intuitive and deep understanding of both urban form and data.

4 How the System Works

Urban Vis uses two views (Fig. 1): a 3D model view and a multi-dimensional data view. The two views are displayed on two separate screens or monitors providing efficient window management. Both views allow user interaction, and link the demographic data and the physical geometric objects. The 3D model view shows clusters of buildings based on urban legibility elements in order to provide persistent spatial awareness within the urban environment. The data view displays information of the clusters shown in the 3D model view adding an extra perspective for understanding the city. Together, the views allow the user to explore the urban model from both the geographical and the informational angles.

4.1 3D Model View

The 3D model view (Fig. 1, right) allows the user to recognize a sense of placement within the urban environment through geometric forms. It also provides an instant understanding of the basic framework of the urban environment. More importantly, it serves as an exploratory tool in which the user can

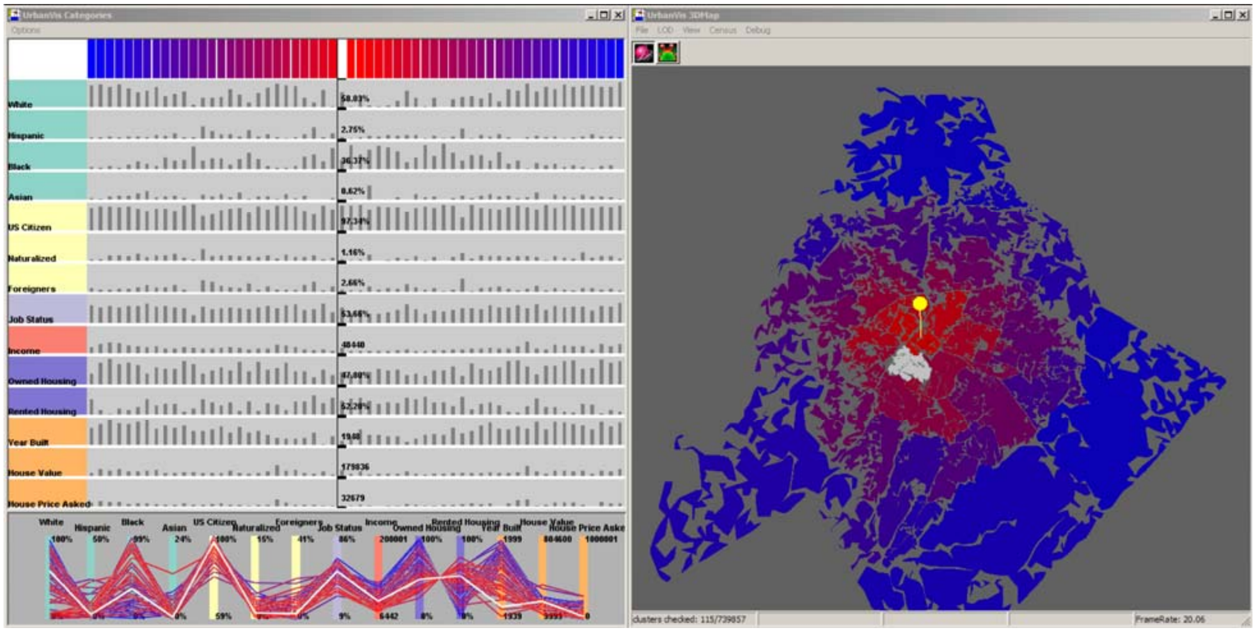
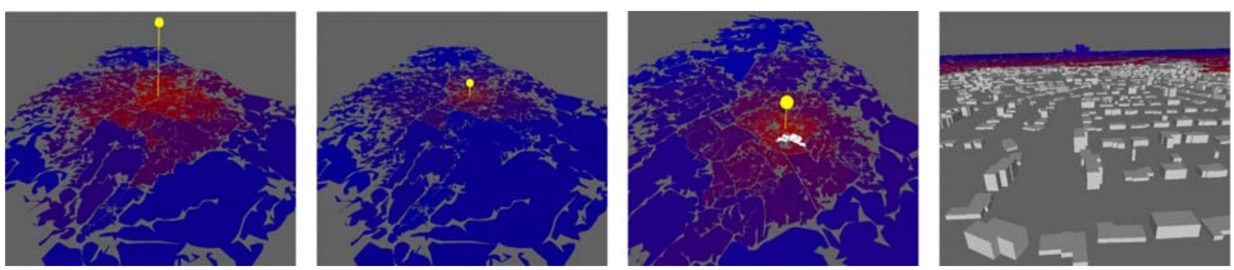


Fig. 1: *UrbanVis* overview. The data view on the left displays demographic data of the areas around the focus point (focus in the middle). The model view on the right shows the clustered building models. The color gradient indicates the distance from the focus point and provides a visual link between the two different data views (matrix view and parallel coordinates) and the model view. The data shown is the 2000 census data for the city of Charlotte in Mecklenburg County, North Carolina.



(a) (b) (c) (d)

Fig. 2: Changing the zoom level of the focal point (shown as a yellow sphere and a line connecting it to the ground). The color gradient from red to blue shows the proximity of the clusters to the focus. (a) When the sphere is far away from the ground, the region of interest is larger, and the user can see an overview of the area at a glance; (b) when the sphere is closer to the ground, the region of interest and clusters are smaller, thus allowing a more detailed inspection. (c) The user selects and highlights a cluster in the model (shown as white); (d) at any time, the user can change the view to look at individual buildings instead of clusters.

interactively navigate the city using either a mouse or keyboard while viewing the environment at any distance or angle.
The user controls the point of focus through a yellow sphere connected to the ground plane with a line (Fig. 2a). The user can move the sphere around the map and also up and down to change the level of clustering. For example, when the sphere is high above the ground, the cluster sizes are larger, allowing the user to see overviews of the entire area. Likewise, when the sphere is lower to the ground, cluster sizes under the sphere are finer, allowing the user to inspect a specific local region (Fig. 2b).

To the user's advantage, the focus region is not a fixed area or diameter but varies with distance from the focus point directly under the sphere. For a clear depiction of the area being studied, a color gradient from red to blue is displayed on the point focus. These colors provide a link between the two views and indicate to the user how narrow or wide the focus currently is.

Double-clicking on a cluster highlights it (Fig. 1 right) along with its data properties in the data view (Fig. 1 left). Also the 3D model view allows the user to view another perspective of the urban model seen as individual buildings rather than clusters for a closer inspection (Fig. 2d).

4.2 Data View

The data view (Fig. 1, left) consists of two parts that display the same information in different ways through a matrix panel and a parallel coordinates panel [17]. The panels show data for a building or building cluster relative to where the focal point is located. The data used in this paper is demographic data of Charlotte, North Carolina, from the 2000 Census, but any type of geographically referenced data (e.g., employment statistics, traffic statistics, crime rates, etc.) could be shown.

The matrix panel (top portion of the data view) has the option of switching between bar charts, line charts, or gradient charts to accommodate the user's preference (Fig. 3). The panel is organized in columns that are each linked to a cluster. To clearly understand the linkage between views, the columns are labeled with colors that correspond to cluster colors in the model view. The columns change as the user moves the focus around the city.

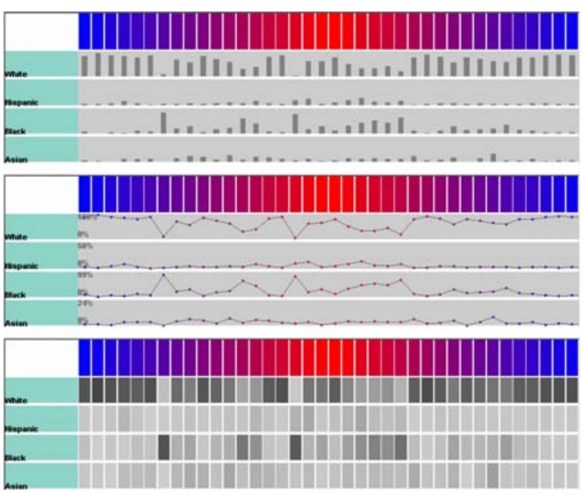


Fig. 3: Matrix panel can show different displays of the same data; (top) bar charts; (middle) line charts; (bottom) gradient grid charts. When sorting columns, the closer the clusters are to the focal point, the closer the column is to the middle of the screen (and more red in color).

Each row of the bar/line/gradient charts shows a specific dimension of the represented data. The graphs are color-coded to show groupings of related categories, making quick identification and orientation easier. In Figure 1, left, there are 14 categories of data, separated into 6 different groups (ethnicity, citizenship, job status, etc.).

The bottom section of the data view shows the same demographic data, but using the parallel coordinates technique (Fig. 4) [8]. Like the matrix panel, the lines in the parallel coordinates panel are color-coded to match the cluster colors, and they correspond to the colors of the rows in the matrix view. This parallel coordinates panel adds another perspective to visualizing relationships between dimensions of the data. For example, in Figure 4 notice the positive correlation between the Hispanic population, the percentage of foreigners, and the percentage of residents who rent their housing in these selected areas.

Although the two views depict the same data, we find that the different presentations of the data give the user different types of understanding [18]. The top matrix view shows the relationship between clusters of buildings that are close to each other. For example, the user can quickly see the homogeneity of the neighborhoods around the focal point. On the other hand, the parallel coordinates view cannot give insight to spatial relationships, but it can quickly reveal relationships between data dimensions, allowing the user to easily identify positive or negative correlations between categories.

4.3 Category Slider

This visualization system also offers a slider tool, which allows for closer investigation of specific data (Fig. 5). As the user moves the slider left to right, the model and data views update interactively, highlighting the clusters that fulfill the criterion. The clusters that do not meet the specified criteria are still visible in a darker shade on order to maintain the user's spatial awareness.

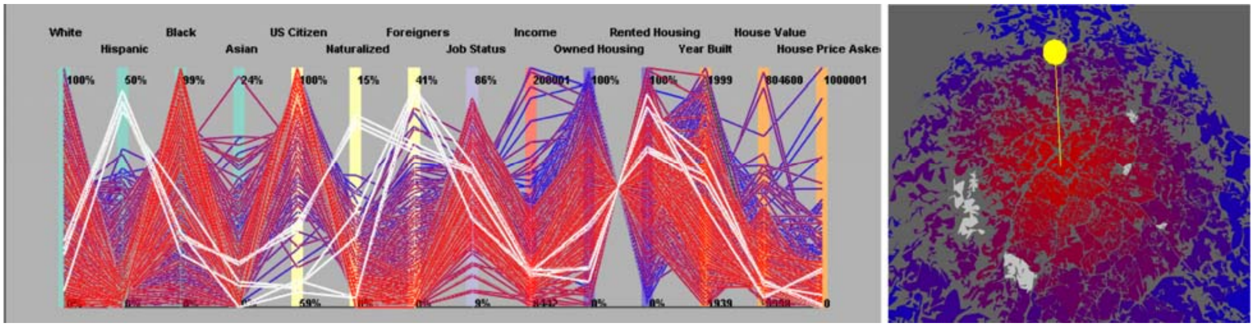


Fig. 4: User example: Finding neighborhoods with high Hispanic population near the downtown area: (right) the user starts by putting the focal point over the downtown region; (left) using brushing in the parallel coordinates window, the user highlights the regions that have high Hispanic population. Notice the positive correlation between the Hispanic population, the percentage of foreigners, and the percentage of residents who rent their housing in these selected areas.

Fig. 5: The category slider locates buildings that fit a specific criterion. In this example, only buildings in Charlotte that are built after 1985 are shown.

5 User Evaluations

To effectively evaluate our system, we asked experts who study the urban environment to give their input about the usefulness of the system. The experts have various backgrounds ranging from independent real estate development, the Center for Real Estate at UNC Charlotte, the UNC Charlotte Urban Institute, Charlotte Mecklenburg County Geographic Information Systems Office, Planning Department, and School System. To begin the evaluation, we gave the participants a questionnaire which asked questions about their knowledge skills with GIS systems. This enabled us to better understand the backgrounds of the sample population. Next we introduced the participants to our system by demonstrating its features and capabilities. After briefing the participants about the system, we then asked them to give feedback on the usefulness of the system as well as any suggestions for future improvements. With their consent, the users were tape-recorded during these sessions. Furthermore, all experts agreed to have their comments, names, and affiliations appear in this publication.

Most of the participants felt choosing their area of focus was beneficial in their exploration of the urban data. They commented that moving to different regions in the environment maintained their spatial awareness of the surrounding areas. Therefore, they were able to visualize the data not only for the area of focus but also the data for the outlying areas. The planning specialist of Charlotte Mecklenburg School System commented that using this technique would allow her to focus on the potential sites of a new school, and still show the “projections of future student populations based on surrounding new housing developments.”

Another advantage commented upon is the ability of the system to adjust spatial boundaries. As the level of abstraction changes so do the boundaries allowing the user to define their own specified area of detail. Some of the participants found the ease of adjustable boundaries to provide a way to project the impact of locating new developments. The one user who did not find this technique useful commented that most projects he worked on had strict boundary requirements. With these restrictions, it had never been necessary for him to examine surrounding areas.

The use of two integrated displays, the 3D view and the data view, also proved useful to the experts who handle large amounts of data. They felt working with a sizable amount of data is easier to organize and access through dual display systems. They also commented that the displays increase user production rates because they are integrated cohesively. Still further, another expert mentioned that the display allows the user to find where he wants to study, and then it immediately tells him the data for that location on the data view without having to use tools to find it.

A majority of experts felt the multiple ways to view data made it easier to see relationships between areas in the urban environment. A user commented, “Sometimes users have to sort through a lot of different sources of data or run statistical analysis to find relationships. Your tool is providing an on-the-fly, interactive way of instantly noticing nearby statistical data and their relationships.”

One expert noted the strengths of our system eloquently. “Essentially what you are providing with this tool is a spatially sensitive graphic display. The strength of this tool is the dynamic table that displays areas in a spatially understandable way. In other software systems, the user is required to scan the tabular listed rows of a GIS database, which gives no indication of the rows’ geospatial locations or their relationships between one another. Another strong aspect is the fact that your focus area and peripheral areas are cohesively orientated. When that aspect is combined with the ability to change the level of detail through clustering, the user gains a new dimension [of understanding]. Changing the level of detail in other software programs becomes cumbersome from running [multiple repetitive] queries.”

Our evaluation demonstrated that the system is set aside from existing GIS systems in that it allows the user to maintain a clear understanding of the area of focus and the peripheral areas at once. The system cohesively integrates the 3D Model View and the Data View allowing the user to see the relationships between the geospatial information of the urban model and related demographic information at the same time. This technique of viewing data allows for easy identification of correlations between the categories. The experts in our user study collectively found our system to contain features that fundamentally change the way users would interact with urban data, enhancing their ability to better understand the urban model.

6 Conclusions

Our research applies the combination of data with geometric modeling to transform the manner in which we read the city. If the city was once convincingly represented by its geometric limits and cohesion (e.g. the city gate), it is now represented by a loose weave of objects, paths, data, and connections. Our implementation of *UrbanVis* captures this experience.

Although one’s sense of urban legibility is inherently subjective and changes depending on one’s perspective of the city, the success of *UrbanVis* has demonstrated that maintaining the user’s sense of legibility, however difficult, is the first step in helping the user to understand the urban environment. While each user’s sense of legibility is different, we have found that there exists some commonality between identifiable elements such as the ones suggested by Lynch. As long as the legibility is preserved, the user can freely navigate and explore the urban model without losing his spatial awareness or understanding of the environment.

However, the most important step in understanding an urban environment, as shown by our evaluation of *UrbanVis*, is the combination of the old sense of legibility with the new concepts introduced by Venturi, Koolhaas, and Mitchell. Lynch’s principals in urban legibility provide a user with the spatial understanding of an urban model, but it is with the newer concepts that the user understands the complex social, cultural, and economic relationships within a city. By integrating the two sets of theories as demonstrated by *UrbanVis*, the user gets a richer, deeper understanding of a city both geographically and conceptually.

Acknowledgements

The authors wish to thank Steve Ott, Jeff Michael, Victoria Bott, Charlynn Burd, Kurt Olmsted, Todd Wilson, Tobin Bradley. Andy Goretti, Paul Martin, Lori Quinn, Christine Hamlett, Jennifer Dean, Ed Harris, and David Stewart for their time, invaluable feedback and suggestions; to Dale Loberger and Paul Gallimore of ESRI for their encouragement and comments.

Notes

[1] Remco Chang and others, *Hierarchical simplification of city models to maintain urban legibility*, sketch, 2006, SIGGRAPH '06: ACM SIGGRAPH 2006 Sketches, ACM Press: New York, NY. p 130.

[2] Remco Chang and others, "Hierarchical simplification of city models to maintain urban legibility," *Technical Report CVC-UNCC-06-01, Visualization Center, University of North Carolina at Charlotte*, (2006).

[3] Chuihua J. Chung, Jeffrey Inaba, and Rem Koolhaas, ed., *Great Leap Forward* (Köln: Taschen Publishers, 2001).

[4] Gordon Cullen, *The Concise Townscape* (New York: Van Nostrand Reinhold Company, 1975).

[5] Mark Gahegan and others, "Introducing GeoVISTAStudio: an integrated suite of visualization and computational methods for exploration and knowledge construction in geography," *Computers, Environment and Urban Systems* 26, no. 4 (2002): 267-292.

[6] Michael Garland and Yuan Zhou. "Quadric-based simplification in any dimension," *ACM Transaction on Graphics* 24, no. 2 (2005): 209-239.

[7] Alexander Garvin, *The American City: What Works and What Doesn't* (New York: Mc-Graw Hill, 2002).

[8] Alfred Inselberg and Bernard Dimsdale. "Parallel coordinates: A tool for visualizing multi-dimensional geometry," *IEEE Visualization Proceedings of the 1st conference on Visualization '90*, (1990): 361-378.

[9] Henri Lefebvre, *The Production of Space* (Oxford: Blackwell Publishers Ltd, 1991).

[10] Mark Livingston and others, "An augmented reality system for military operations in urban terrain," *Proceedings of the Interservice / Industry Training, Simulation, and Education Conference*, (2002): 89.

[11] Kevin Lynch, *The Image of the City* (Cambridge: MIT Press, 1960).

[12] William J. Mitchell, *City of Bits: Space, Place, and the Infobahn* (Cambridge: MIT Press, 1996).

[13] Colin Rowe and Fred Koetter, *Collage City* (Cambridge: MIT Press, 1978).

[14] Poonam Shanbhag, Penny Rheingans, and Marie desJardins, "Temporal Visualization of Planning Polygons for Efficient Partitioning of Geo-Spatial Data," *Proceedings of the 2005 IEEE Symposium on Information Visualization*, (2005): 28.

[15] *U.S. Census Bureau* [database online], (United States 2000 Census); available from http://www.census.gov; Internet.

[16] Peter Wonka and others, "Guided visibility sampling," *Proceedings of ACM SIGGRAPH 2006*, (2006): 494-502.

[17] Remco Chang and others, "Legible Cities: Focus-Dependent Multi-Resolution Visualization of Urban Relationships," *Proceedings of the 2007 IEEE Symposium on Information Visualization*, (2007).

[18] Robert Venturi, Denise S. Brown, and Steven Izenour, *Learning from Las Vegas: The Forgotten Symbolism of Architectural Form* (Cambridge: MIT Press, 1977).

[19] Rem Koolhaas and others, *Mutations: Harvard Project on the City* (Barcelona: ACTAR, 2000).