

# Design and Understanding of Visualizations for Urban Modeling

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## ABSTRACT

One application of computer models in urban planning is to help evaluate alternative land use policies, particularly as these policies interact with transportation and environmental issues. The ability to simulate different scenarios provides planners with a powerful decision support tool. However, the greatly increased volume of data provided by new land use models makes their effective use difficult without suitable visualization tools. We present a new approach to visualization design and describe a user study validating the approach for the design of visualizations within the urban modeling domain.

## Keywords

Visualization, urban modeling, urban planning, task centered design, configurable directed interaction

## INTRODUCTION

Formally, visualization is the encoding of information into graphical images. Interest in visualizations and visualization design continues to grow as the quantity of data and size of systems reaches a level of complexity such that people have trouble comprehending and analyzing information presented in raw form. The human visual system can absorb information more quickly from pictures than from words and numbers, which must be parsed, interpreted, and analyzed to be understood. For this reason, researchers are interested in designing formal methods for presenting information in graphical form, with the hope that these methods will be more effective at quickly and accurately conveying content.

Pictorial and graphic media can carry considerable information in what may be a convenient and attractive form, but incorporating graphics into decision making activities requires us to understand the precise contribution that graphical representations might make to the job at hand

[1]. There are many issues to consider when designing visualizations, including the ability of users to accurately interpret information that is presented graphically [2], and the clear and concise presentation of information.

## RESEARCH APPROACH

Our approach is to study one specific domain of problems first, and subsequently to investigate whether our results can be generalized to other domains. We have chosen to study the urban modeling domain for three reasons. First, while there has been huge amounts of work on geographical information systems (GIS), very little if any rigorous research has been done on other kinds of visualizations for this domain, such as process visualizations depicting the operation of the model. Second, the domain of urban planning is large and complex enough to have diversified user and analyst tasks. Our focus in this paper is on aiding urban planning professionals; but in the longer term we want to also aid citizens' groups and elected officials in understanding the models and their outputs, thus opening the traditional black-box model to support informed civic deliberation and debate on issues of land use, growth, sprawl, and transportation choices [12]. Third, the new generation of urban model being written by our collaborators at University of Washington is several orders of magnitude more complex and disaggregate than existing models—thus making the use of new visualization techniques essential.

It seems clear that certain visualizations are extremely useful and much more effective than textual descriptions for specific contexts. However, previous studies for other task domains show very little evidence that visualizations support information processing activities [4]. We present an analysis of visualization types that provides a starting point for understanding what makes visualizations useful and how to create them for the urban planning domain.

## UrbanSim

UrbanSim [11] is a reusable land use modeling system, upon which the research reported here is based. It is designed to model the development of urban areas, in particular the interactions between land use and

transportation infrastructure, along with the resulting environmental effects. Land use and transportation interact strongly. Different kinds of transportation systems induce different patterns of land use, while at the same time, different kinds of land use induce demand for different kinds of transportation systems. For example, automobile-oriented development induces demand for more roads and parking (which in turn induces more automobile-oriented development), while compact, pedestrian-friendly urban environments can induce more walking and demand for transit.

The state of common practice in land use modeling, and integrated land use and transportation modeling, is much less advanced than that for transportation modeling alone. Typically a metropolitan region will use a very simplified, aggregate land use model (or none at all), with the unfortunate consequence that the model is not sensitive to important policy alternatives such as changing zoning, urban growth boundaries, or taxes and incentives.

UrbanSim is intended to provide a much more detailed model of land use, which explicitly allows different policy alternatives to be modeled and compared. Figure 1 illustrates the system architecture. UrbanSim is composed of a database, an aggregation layer, and numerous submodels that simulate various actors in the urban development process, including households, businesses, developers, and governments. For example, submodels simulate business creation and closure, household and business movement and location choices, and developer decisions such as the character, density, and scale of property development.

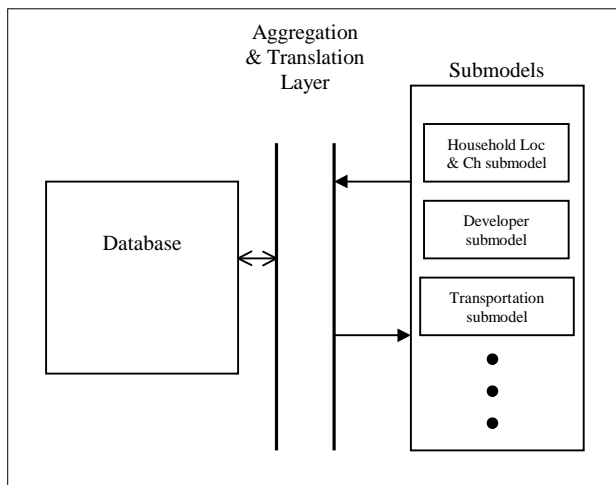


Figure 1: UrbanSim Architecture

A user interacts with UrbanSim to create scenarios that specify alternative packages of policies, economic and demographic forecasts, and other exogenous inputs. The model is then run into the future for a given scenario (for example for 20 simulated years), and the results of the different scenarios can be analyzed and compared.

The many analysis tasks a user of UrbanSim must perform to evaluate alternative policy approaches, coupled with the large amounts of simulation and output data, require the use of effective visualizations for system comprehension. Each submodel simulates different types of real-world actions, has numerous components, interacts with other submodels (including intra-model dependencies and constraints), and deals with large quantities of input data and output information. The effective use of visualizations can lessen the burden of data retrieval and allow analysts and urban planners to focus on information synthesis.

The remainder of this paper describes a user study performed to determine what types of visualizations are helpful when performing specific information gathering tasks, and what characteristics of visualizations and tasks make these visualizations useful. We then go on to describe the framework for UrbanVis, a visualization system designed to generate visualizations that facilitate the analysis of UrbanSim output during and after execution.

### USER STUDY

Research has shown that the effectiveness of a visualization is highly dependent on the particular task that a person is trying to complete [1,7]. In other words, a given visualization may be ideal for presenting information for one task but may hinder the completion of a different task. Our research and this user study are thus aimed at matching visualization types to performance tasks within the urban planning domain.

To further limit our user study we focused on two of the submodels within the UrbanSim system. These models were chosen because our urban planning experts believe these to be the two most critical submodels within the system. In addition, these submodels use different types of analyses, thus providing us with a larger task base.

The Household Location and Choice submodel simulates the decisions made by households. It determines whether or not each household relocates, and if relocating, determines the relocation site. The Developer/Redeveloper submodel simulates the decisions made by builders as to whether or not to develop or redevelop property, and if so, where, what, and how much to build.

### Study Method and Procedure

Our visualization designs focus on the understanding and explanation of land use as simulated by the UrbanSim system. Visualizations such as the ones presented to participants in this study would be used by analysts while they are studying the system's output and behavior.

Given the focus of our visualization designs, five participants (two graduate students and three professors, all from the Department of Architecture and Urban Planning at the University of Washington) took part in the user study. Each participant was given a series of tasks, enumerated in Table 1, that could be answered using the information provided by UrbanSim model output. An urban land use

expert provide us with the list of tasks, which are intended to be representative of the questions of interest to an analyst while using a system such as UrbanSim.

- |   |
|---|
| <ol style="list-style-type: none"> <li>Where is the development of different types of land occurring?</li> <li>How much of the development of each type is "greenfield" vs. redevelopment?</li> <li>How much and what types of land are being redeveloped? From what use into what use? Where?</li> <li>What is the distribution of density of new development?</li> <li>How much development is occurring in desired locations?</li> <li>How many acres of agricultural and forest land are being consumed by development? How fast?</li> <li>Why is the model building/developing the parcels/building it is?</li> <li>Where are households of each type generally locating?</li> <li>Where are the biggest population gains and losses?</li> <li>How much is employment decentralizing?</li> </ol> |
|---|

Table 1 : User Tasks

The general procedure followed by the study participants was to examine sets of visualizations for each task and provide feedback as to which visualizations they would consider useful when analyzing a system such as UrbanSim. The entire user test consisted of ten questions, each having between three and seven corresponding visualizations, for a total of 55 different visualizations. Each visualization contained all the information necessary to complete the task. Each participant was asked to evaluate, for each task, the usefulness of each of the visualizations presented on a scale of one (most useful) to five (least useful), and then to rank the visualizations in order of preference.

**DATA ANALYSIS**

Table 2 shows the raw results gathered for Task 6 during the user study. We use Task 6 as an example because it is the task with the least amount of observed variance in both rating and rank, yet even it displays substantial variance. From this we conclude that it is unlikely that there is one single correct visualization to present for a given task. Rather, the usefulness of a visualization is dependent upon both the task and the individual preferences of users.

Visualization Type	RATING					RANK				
	A	B	C	D	E	A	B	C	D	E
Pie	2.5	1	3	1	3	3	1	4	2	6
Type/Arrow Progress	3	4	3	5	2	5	5	5	6	2
2D Color Map	3	4	1	2	3	4	4	2	3	5
3D Surface Map	5	5	4	5	2	6	6	6	5	4
3D Height Map	1	3	2	4	1	2	3	3	4	1
Stacked Bar	1	1	1	1	2	1	2	1	1	3

Table 2: Rating and ranking of visualization type varieties by each participant for Task 6.

This conclusion validates our belief that it is hard if not impossible to design a visualization that is useful for every purpose, or even to create a visualization for a specific task that will be useful for every person. However, this does not mean that there is no hope for visualization design—the methods do not have to remain ad hoc. The rest of this section presents an alternative approach to visualization design. Rather than trying to determine the single correct visualization for a given task, we analyze visualizations and tasks determining the useful visualization encoding methods for each type of task. Visualizations can then be generated by first determining task type and then creating a visualization that conveys information encoded by these methods.

**Grouping Tasks by Types**

We believe the most promising approach to generating visualizations for analysis of simulation systems is to design them based on the tasks being performed. For our user study analysis we classified the ten tasks according to the ten processing activities in Table 3.

- |   |
|---|
| <ol style="list-style-type: none"> <li>Spatial determination</li> <li>Comparison of values or attributes</li> <li>Distinguishing between alternatives</li> <li>Locating optima</li> <li>Determining trends</li> <li>Relations on attributes</li> <li>Aggregation of information</li> <li>Qualitative judgements</li> <li>Quantitative information</li> <li>Description</li> </ol> |
|---|

Table 3: Processing Activities

We had to define the processing activities required for each task. Table 4 is a breakdown of each of the tasks into information processing requirements. Consider for example Task 3, one of the more complex tasks in the study. This task poses the questions "How much and what types of land are being redeveloped? From what use into what use? Where?"

Task	Spatial	Comparison	Alternatives	Optima	Trends	Relations	Aggregation	Qualitative	Quantitative	Description
1	x	x			x			x		
2		x							x	
3	x				x	x			x	
4					x	x	x	x		
5	x		x			x			x	
6							x		x	
7			x			x		x		x
8	x	x			x			x		
9	x	x		x			x	x		
10					x	x	x		x	

Table 4: Breakdown of tasks into human processing activity requirements.

Types \ Encodings	Color Intensity	Distinct Colors	Color Scale	Bars	Stacked Bars	Cluster Bars	Lines	Area Height	Terrain/Surface	Arrows	Numbers/Values	Marker Size	Marker Shape
Graphs		x		x	x	x	x						
Pie Chart		x											
2D Map	x	x	x							x	x	x	
3D Map	x	x	x	x	x			x	x	x			
Symbol Chart													x
Bubble Chart		x										x	
Progression Gr.										x	x	x	
Contribution Gr.		x		x						x	x		
Table		x									x		

Table 5: Types of visualizations cross-referenced by the encodings they can utilize effectively

This is a multi-step task. First the participants must determine the amount of land and the type of land being developed (quantitative judgements); then they must determine the change in land type over time (determining trends and looking at relations on the land type attribute); and last they need to determine relative locations of redevelopment (spatial determinations).

### Classifying Visualizations

We consider visualizations to be composed of a base type and one or more encoding methods. Base type refers to the general structure of the visualization such as map, graph, chart, or table. Encoding methods are the way in which the various dimensions of information are presented within the general structure. Examples of encoding methods are color encodings (intensity, scales, distinct colors), bars, lines, arrows, thicknesses, heights, and use of markers (sizes and shapes).

Classifying the test visualizations by type and encoding methods resulted in twenty-one distinct visualization type variations formed by the intersections of the types and encodings as shown in Table 5. Color Plate 1 shows examples of the 21 different visualization types tested, a sampling of the visualizations presented to the participants.

### Results

After analyzing the user tasks and determining the processing activities required of each, we compiled our results, matching visualization type varieties to processing activities. We performed three types of analyses. The first analysis determined the usefulness of visualization types for each processing activity. The second did the same for encoding methods. The third analyzed the visualizations with respect to each task in its entirety, instead of as its component processing activities.

Table 6 presents the top two preferred visualization type varieties for each task along with their average rating and rank. Table 7 is a summary of the most preferred visualization type varieties for each of the processing activities in Table 1. Due to the spatial nature of the urban planning domain many of our test visualizations were map

type visualizations. This bias must be considered when making conclusions about visualization type utility within this domain.

TASK	VISUALIZATION	Avg. Rating	Avg. Rank
1	2D Color Map	1.8	2.0
	3D Height/Color Map	2.3	2.8
2	Clustered Bar	1.4	1.6
	2D Color/Pattern Map	2.2	1.4
3	Datum Progress	1.7	2.2
	Stacked Bar	2.4	2.8
4	3D Height Map	2.1	3.6
	2D Intensity Map	2.2	3.6
5	Contribution Graphic	1.0	1.0
	3D Color/Height Map	1.8	1.6
6	Stacked Bar	1.2	1.6
	Pie Chart	2.1	3.2
7	2D Intensity Map	1.3	1.3
	3D Height/Color Map	2.0	2.0
8	3D Color/Height Map	2.2	2.0
	3D Height Map	2.6	2.8
9	2D Intensity Map	1.6	1.4
	3D Color/Height Map	2.2	2.4
10	2D Marker Map	1.6	2.4
	2D Intensity Map	2.4	3.8

Table 6: Preferred visualization type varieties

### Analysis of Visualization Types

The results presented in Tables 6 and 7 support four major conclusions about visualization design types within the domain of urban modeling. First, urban planners tend to find map type visualizations the most useful for the basic layout of information presentation. Second, participant observation revealed that multiple visualizations are sometimes better than single visualizations. Third,

Processing Activity	Type Variety Preference	Favored Visualization Type	Favored Encoding Method
Spatial	2D Color Map Datum Progress 3D Color/Height Map 3D Color/Height Map 2D Intensity Map	Map	N/A
Comparison	2D Color Map Clustered Bar 3D Color/Height Map 3D Color/Height Map 2D Intensity Map	Map	Distinct Color
Alternatives	Clustered Bar 3d Color/Height Map 2D Intensity Map	Map	---
Optimums	3D Height	---	---
Trends	2D Color Map Datum Progress 3D Height Map 3D Color/Height Map 2D Marker Map	Map	Area Height/ Color
Relations	Datum Progress 3D Height Map 3D Color/Height Map 2D Intensity Map 2D Marker Map	Map	Color to Area Height
Aggregation	3D Height Map Stacked Bar 2D Intensity Map 2D Marker Map	Map	Color
Qualitative	2D Color Map 3D Height Map 2D Intensity Map 3D Color/Height Map 2D Intensity Map	Map	Intensity/ Area Height
Quantitative	Clustered Bar Datum Progress Contribution Graphic Stacked Bar 2D Marker Map	Bar	Bar Size
Description	2D Intensity Contribution Graphic	---	---

Table 7: Preferred visualizations for each processing activity.

quantitative processing activities are the one type of activity for which map type visualizations are not preferred. Fourth, we found that two-dimensional maps appear to be more useful than three-dimensional maps for presentation of less than two information variables, but there was no significant preference between the two map types for encoding three or more variables. We discuss these conclusions further in the following subsections.

### Map Based Visualizations

Map type visualizations were heavily favored for all processing activities except the quantitative activity discussed below. We believe this can be partially attributed to a bias in the visualizations presented, and partially to the importance of geographic location in the urban modeling domain.

Discussions with the participants during and after the tests revealed that location of urban activity is extremely important for urban policy decisions. Because the map layout implicitly encodes the geographic location information that much of their analyses depend upon, it was not a surprise when analysis showed that the map layout visualizations were considered most useful for many of the processing activities.

### Companion Graphics

Participant comments during the user tests revealed that in many cases one all-encompassing graphic is not sufficient. Participants liked the bar charts as companion and summary graphics for making quantity judgements and comparisons between planning attributes. For describing the internal logic of the models within a simulation system, the participants preferred a visualization that presented an overview of the actual process, such as the contribution graphic.

### Quantitative Processing Activities

While urban planners tended to like map-based visualizations, the one processing activity that revealed itself to be better represented with other types of visualizations involved tasks that required them to make quantitative judgements. For quantitative judgements, our results show that even when presented with a majority of map type visualizations, participants preferred bar type graphics. Table 7 shows that a bar type graphic was favored in three out of the five tasks that required quantitative judgements.

### 2D versus 3D Map Types

We designed our tests so that we could evaluate the differences between two- and three-dimensional map visualizations. For our analysis we considered two- and three-dimensional maps as separate visualization types rather than different encodings, because we believe there are fundamental differences in the expressive styles and capacities of two- and three-dimensional map visualizations. However, analysis shows that while there is a slight preference for two-dimensional maps for almost all of the processing activities, tasks that require the same processing activity show no bias to either two- or three-dimensional maps. This implies that tasks that require encoding fewer than two pieces of information tend to favor the use of two-dimensional maps.

### Analysis of Encodings

As seen in Table 5, map type visualizations are capable of using almost all of the encoding methods. In addition, the

few encoding methods for which map type visualizations are not as suitable were still represented in the user tests.

At this point we have yet to address the problem of using multiple encodings within one visualization type. Many of the visualizations that we used in this study employed multiple encoding schemes. For the most part, this omission is not a problem. While each task may require multiple processing activities, each individual processing activity uses only one encoding scheme. The only exception to this is the *Relations* processing activity. It requires a judgement to be made about the relation between problem attributes, which in our visualizations are each encoded by one of the encoding schemes.

The last column of Table 7 shows the results of our analysis. We did not analyze encoding methods for the spatial attribute because the encoding for the spatial processing attribute is encompassed by the map layout. In six out of the remaining nine processing activities our analysis showed encoding preferences. We attribute the lack of significant results for these three activities to the scarcity of tasks requiring them. Future tests will encompass the entire domain of activities UrbanSim simulates, thus giving us a broader task base.

Color distinctions and bar height are the two most commonly preferred encoding methods for the processing activities. Because of the geographical nature of urban planning, the combination of color to distinguish values and map placement to determine relative locations was considered the most useful encoding for comparison, trend, and qualitative processing activities. The use of area/bar heights and bar sizes were considered useful for trend and quantitative tasks.

There were two processing activities where geographic location was not a favored encoding scheme. The participants rated color and bar/area height encodings the most useful for relation tasks. A color encoding was favored for aggregation activities, although participants were divided between a distinct color encoding and an intensity color encoding.

### **Task Based Analysis**

We also performed an analysis based on the entire tasks rather than on their individual processing activities. The major result of this type of analysis was that map based visualizations were not considered useful for tasks that included a time dimension.

On a task analysis level, the results show that for two of the tasks the participants did not like the map type visualizations. Table 6 shows that for Tasks 3 and 6 the participants did not rate a map type visualization as one of their top two preferences. Task 3 asked the question “How much and what types of land are being redeveloped? From what use into what use? Where?” Task 6 asks, “How many acres of agriculture and forest land are being consumed by development? How fast?”

For Task 3 a datum progress visualization and a stacked bar graph is favored, and for Task 6 a stacked bar and a pie chart is favored. Further analysis of the two tasks highlight two commonalities between them. First, both require quantitative judgements. Second, both require analysts to make judgements about the change in variable values (in this case land and its associated land use) over a time span. It is consistent with the overall test results that the most favored visualization type for a quantitative judgement task is not a map type visualization. However, results indicate that for these two tasks map type visualizations are not at all useful, where for the other quantitative tasks map visualizations were still considered somewhat useful. We hypothesize that the time change component to these questions may contribute to these observed results.

### **URBANVIS**

UrbanVis is the visualization generation system we are building that will interface with UrbanSim. The modular architecture design will allow UrbanVis to be used by other systems simply by creating interface modules to format the data information stream.

For the studies, all of the two- and three-dimensional map visualizations were generated using UrbanVis. At the time of the tests we were still implementing the other visualization types, which we have now completed. However, UrbanVis currently does not automatically choose visualization presentations. Users of the system are presented with an interface where they can choose the type of visualization, the data to be displayed, and the encoding method.

The results presented above will be used to guide the logic for the automatic generation of default visualizations. The interface will then consist of indicating to UrbanVis the performance task. UrbanVis will then present the user with a default graphic. This graphic is created by first analyzing the performance task for task type and data requirements, and then creating a graphic that encodes the relevant information using the encoding methods and general visualization type considered best for the particular task type.

### **CONCLUSIONS AND FUTURE WORK**

User testing has shown that there is great variance in which visualizations users consider effective. While there may not be one all-encompassing answer when designing useful visualizations, what we have learned from this study is that there are certain characteristics of visualization types that appear to be better for presenting the information necessary to help solve different types of tasks.

We have found that for urban planning and analysis, map type visualizations provide the geographical information that plays a critical role in analysis of systems like UrbanSim. At the same time, we have learned that for quantitative tasks bar charts and summaries better present the needed information. Of the encoding methods, planners

tended to like color and size encoding schemes. These results will be used as the basis for the decision-making component of UrbanVis.

We have presented a novel way to view the makeup of visualizations. We break a visualization down into a base type that contains the general layout of a visualization and then refine the layout by choosing appropriate encoding methods to display the individual data in such a way as to convey the relevant information. This approach to visualization design is based on the belief that the characteristics of visualizations and the information encodings make a visualization useful. Our user studies confirmed that our approach to designing visualizations for urban planning is valid and feasible.

However, there remain several problems for future research. Revisions to our user study include further investigation of the classification of user tasks by cognitive processing activities, increasing the variety of visualizations included in user studies, and expanding the domains of study beyond the visualization of the urban planning domain.

We also are in the process of integrating UrbanVis with UrbanSim. When this is complete, we will be performing user studies to determine the effectiveness of visualizations for urban planning analysis and to test the effectiveness of automatically generated visualizations.

We have learned that we can present users with default visualizations created using the guidelines from the analysis of our user studies. However, the variance in our user studies also indicate that we must provide users with the ability to change and tailor visualizations to their personal preferences. Our strategy is to provide users with a configurable but directed visualization system.

Within the realm of visualization for urban planning, this study is part of a larger project to design and implement a system that allows urban planners to trace through simulations visually. We are expanding the tool set of urban planners beyond the use of geographical information systems. UrbanVis aims to integrate and facilitate the display of simulation information using many different types and styles of visualizations.

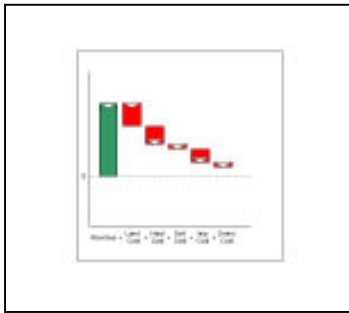
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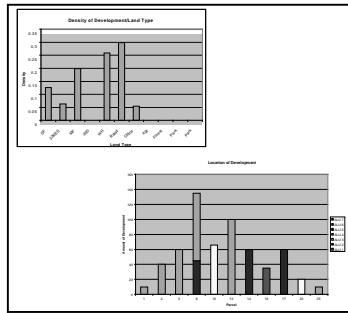
Foundation Grant No. CMS-9818378 (Urban Research Initiative), and in part by the PRISM project (University of Washington University Initiatives Fund).

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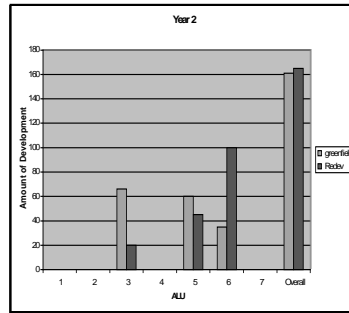
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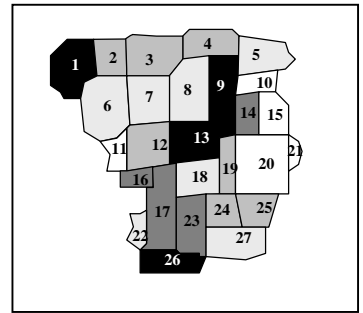
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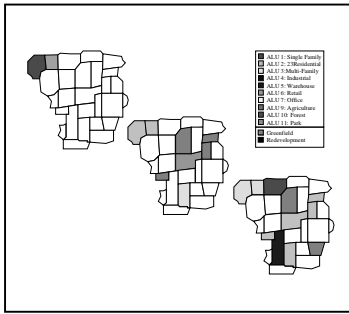
2 & 3) Bar and Stacked Bar Graphs



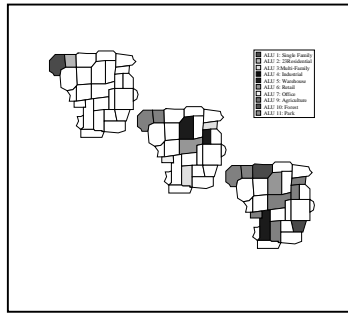
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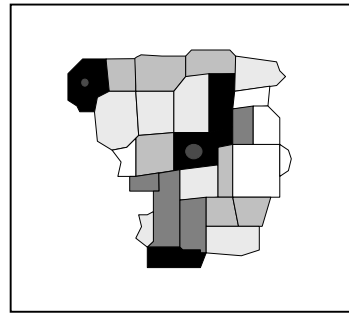
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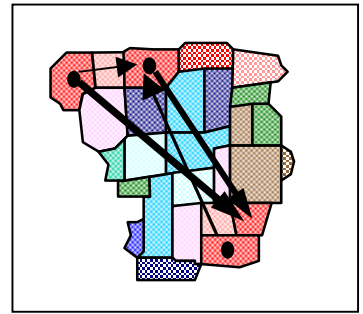
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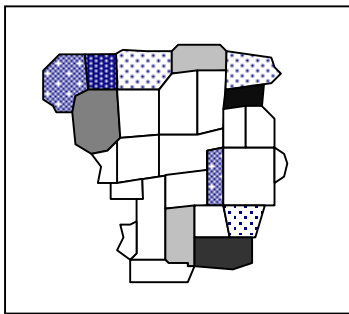
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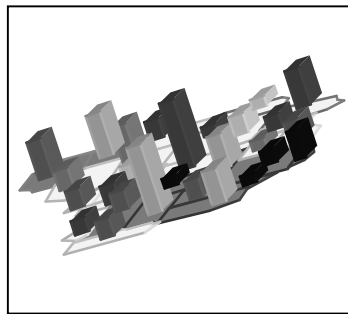
8) 2D Marker Map



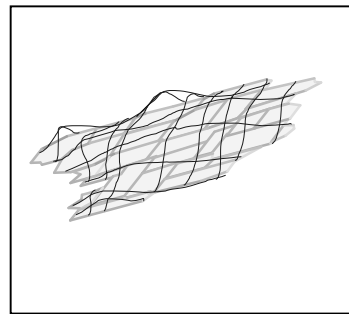
9) 2D Arrow Map



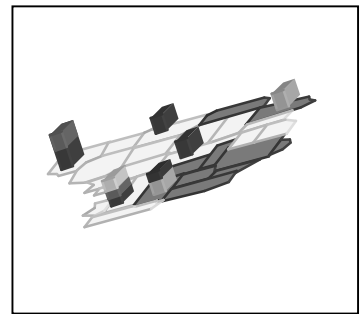
10) 2D Color Scale Map



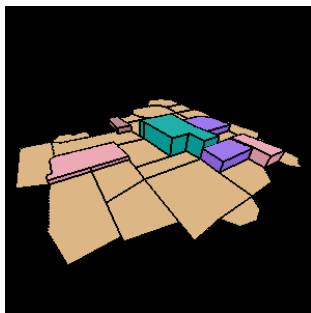
11) 3D Bar Map



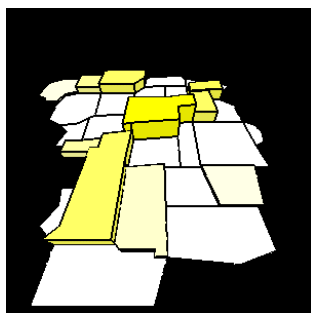
12) 3D Terrain/Surface Map



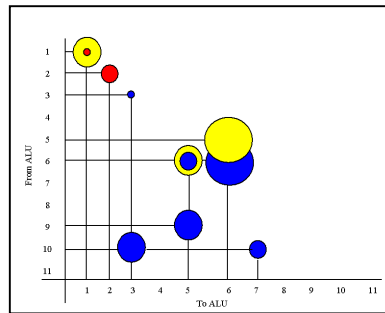
13) 3D Stacked Bar---Distinct Color Map



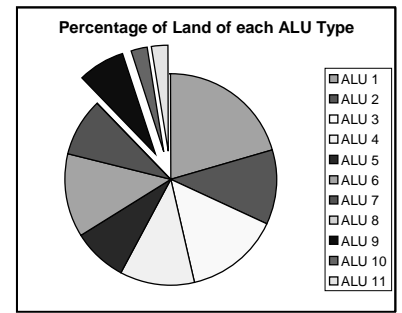
14) 3D Distinct Color --- Area Height Map



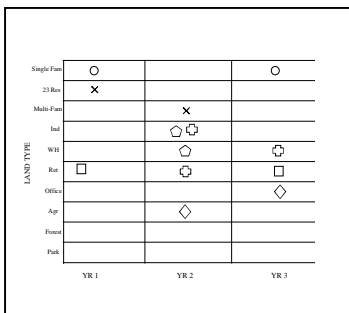
15) 3D Area Height---Intensity Map



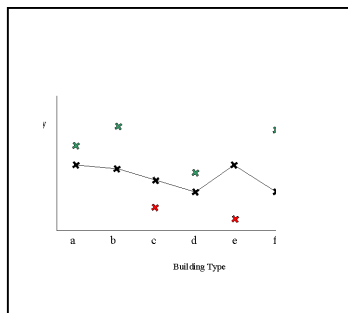
16) Bubble Chart



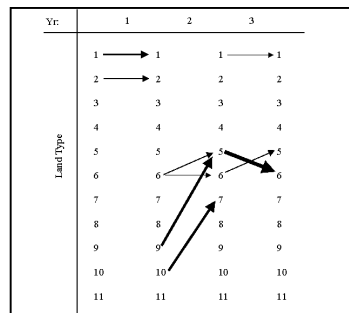
17) Pie Chart



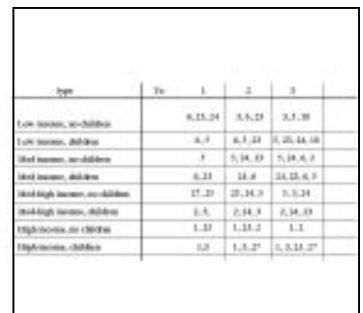
18) Symbol Chart



19) Line---Scatter Graph



20) Type---Arrow Progress Chart



21) Datum Progress