Multiple Scenario Interface for Visualizing Urban Structures: The Cases of the Salvadoran Cities of San Salvador and Santa Tecla

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This thesis titled
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ABSTRACT

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Multiple Scenario Interface for Visualizing Urban Structures: The Cases of the Salvadoran Cities of San Salvador and Santa Tecla (164 pp.)

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This thesis analyzes the urban structure development of two Latin American cities through an interactive longitudinal visualization of the Salvadoran cities of San Salvador (the capital of El Salvador) and Santa Tecla. To what extent is a hypothetical model relevant to either of these two cities? How can a longitudinal, interactive visualization assist with a comparative analysis of the relevance of urban expansion models to the development of San Salvador and Santa Tecla? Can such a visualization contribute to the delineation of urban expansion policies for these cities? Archival files and maps were digitized and vectorized to create animated urban evolutions for each city. These geovisualizations were compared to the hypothetical models presented by Borsdorf, Bähr, and Janoschka (2002) in order to assess their relevance. The analysis indicated that the urban structural development of each city was more complex and differentiated than the theoretical model, findings richly supported by the geovisualizations. If combined with more specific annual land use data, these visualizations can also be useful for guiding urban management.

Approved: _____________________________________________________________

Margaret W. Pearce

Assistant Professor of Geography
Esta tesis esta dedicada a Dios, mis padres, mi hermano Miguel, Diego, Andres y Bryan por su sacrificio, amor y apoyo.

This thesis is dedicated to God, my parents, my brother Miguel, Diego, Andres, and Bryan for their sacrifice, love, and support.
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>3</td>
</tr>
<tr>
<td>Dedication</td>
<td>4</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>5</td>
</tr>
<tr>
<td>List of Tables</td>
<td>10</td>
</tr>
<tr>
<td>List of Figures</td>
<td>11</td>
</tr>
<tr>
<td>Chapter 1: Conceptualization</td>
<td>14</td>
</tr>
<tr>
<td>Introduction</td>
<td>14</td>
</tr>
<tr>
<td>Research questions</td>
<td>18</td>
</tr>
<tr>
<td><em>Urban structure models</em></td>
<td>19</td>
</tr>
<tr>
<td><em>Animated cartography and pattern visualization</em></td>
<td>19</td>
</tr>
<tr>
<td>Chapter outline</td>
<td>20</td>
</tr>
<tr>
<td>Chapter 2: Literature review</td>
<td>22</td>
</tr>
<tr>
<td>Geovisualization and dynamic representation</td>
<td>22</td>
</tr>
<tr>
<td>Geovisualization for knowledge construction: visual exploration versus quantitative analysis</td>
<td>26</td>
</tr>
<tr>
<td>Limitations of the visual approach</td>
<td>28</td>
</tr>
<tr>
<td><em>Dynamic cartographic methods and techniques, their impact in geovisualization</em></td>
<td>29</td>
</tr>
<tr>
<td>Visualizing change</td>
<td>30</td>
</tr>
<tr>
<td>Dynamic maps for visual identification of clusters</td>
<td>31</td>
</tr>
<tr>
<td>Design choices and the effectiveness of the interface</td>
<td>33</td>
</tr>
</tbody>
</table>
Temporal focusing and temporal brushing ........................................................... 35
Panning and zooming ............................................................................................ 36
Representing uncertainty ...................................................................................... 40
Sound and geographic visualization ..................................................................... 42
Time-series animations in urban studies ............................................................. 49
Urban structure models ....................................................................................... 52
A new model for Latin-American cities ............................................................... 54
The colonial phase: the compact town 1500-1820 ............................................. 57
The first urbanization phase: the sector town 1820-1920 .................................... 58
The second urbanization phase: the fragmented town 1920-1970....................... 59
The contemporary urban development: the gated community town 1970 to the
present .................................................................................................................. 61
Criticisms to the Latin-American urban structure models .................................... 63
Chapter 3: Characterizing San Salvador and Santa Tecla ................................. 67
Study area ............................................................................................................. 67
Physical environment ........................................................................................... 72
Socio economic environment ............................................................................... 77
San Salvador ......................................................................................................... 82
Urban evolution .................................................................................................... 82
Colonial era: 1524-1820 ....................................................................................... 82
Independence era: 1820-1935 ............................................................................. 88
The contemporary era: 1935-2000 .................................................................... 92
The use of geovisualizations in urban structure analysis.............................. 154
Implications of the Research........................................................................... 156
Further considerations..................................................................................... 157
References....................................................................................................... 158
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1: Panning and Zooming Evaluation</td>
<td>39</td>
</tr>
<tr>
<td>Table 2: The Abstract Sound Variable and their Characteristics</td>
<td>47</td>
</tr>
<tr>
<td>Table 3: Urban Structure Models for Latin-American Cities</td>
<td>53</td>
</tr>
<tr>
<td>Table 4: The New Latin-American cities Urban Structure Model</td>
<td>56</td>
</tr>
<tr>
<td>Table 5: Evolution of Extra-Legal Subdivisions and Slums in the Metropolitan Area: 1968-1992</td>
<td>74</td>
</tr>
<tr>
<td>Table 6: Type of transportation in the metropolitan area</td>
<td>78</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1: Range of functions of visual methods in an idealized research sequence .......23
Figure 2: (Cartography)\(^3\) Functions of visualization .......................................................25
Figure 3: Colonial town, the compact city ........................................................................58
Figure 4: Town of the first urbanization phase, the sector town ...............................59
Figure 5: Town of the second urbanization phase, the polarized town ......................60
Figure 6: The contemporary city, the segregated town ..................................................62
Figure 7: Location of San Salvador and Santa Tecla ..................................................69
Figure 8: High class subdivisions built in the northern hillside of El Balsamo mountain range in the municipality of Antiguo Cuscatlán ..........................................................74
Figure 9: Map of topography showing the different elevations surrounding the metropolitan area of San Salvador ..................................................................................76
Figure 10: Population density of the metropolitan area of San Salvador and its surrounding municipalities ..................................................................................................81
Figure 11: Supposed pilgrimage of the Villa of San Salvador ......................................84
Figure 12: San Salvador in 1594 .....................................................................................85
Figure 13: Map of San Salvador in 1800 ......................................................................87
Figure 14: San Salvador in 1899 ..................................................................................90
Figure 15: Urban evolution of San Salvador .................................................................94
Figure 16: Urban evolution of Santa Tecla .....................................................................99
Figure 17: Urban evolution exhibit presented in the Museo Nacional de Antropolgía “David J. Guzman” de El Salvador .................................................................101
Figure 18: Photograph of the map portraying the different locations were the village of San Salvador was settled ..........................................................102
Figure 19: Sequence of the evolution of San Salvador’s housing during the colonial phase. ..............................................................114

Figure 20: San Salvador’s institutional evolution during the colonial phase. .............115

Figure 21: San Salvador’s commercial evolution during the colonial phase............116

Figure 22: Sequence of the evolution of San Salvador during the colonial phase ......118

Figure 23: San Salvador’s landscape at the end of the colonial period compared to Borsdorf, Bähr, and Janoschka representation of the Latin American cities structures at the end of the same period .................................................................120

Figure 24: Sequence of the evolution of San Salvador’s housing during the first urbanization period ........................................................................................................122

Figure 25: Sequence of the evolution of San Salvador’s institutional areas during the first urbanization phase. .................................................................123

Figure 26: San Salvador’s commercial evolution areas during the first urbanization phase. ........................................................................................................124

Figure 27: San Salvador’s industrial development at the end of the first urbanization phase. ........................................................................................................125

Figure 28: Sequence of the evolution of San Salvador during the first urbanization phase (1820-1920)..................................................................................127

Figure 29: San Salvador’s urban landscape in 1920 compared to the generalization presented in Borsdorf, Bähr, and Janoschka’s.............................................128

Figure 30: San Salvador’s housing in 1965 ............................................................129

Figure 31: San Salvador’s institutional spaces in 1965 ............................................130

Figure 32: San Salvador’s commercial spaces in 1965 .........................................131

Figure 33: San Salvador’s industrial spaces in 1965. ...........................................132

Figure 34: San Salvador’s urban landscape in 1965 compared to the generalization presented in Borsdorf, Bähr, and Janoschka’s.............................................134

Figure 35: San Salvador’s housing in 2000 ............................................................136
Figure 36: San Salvador’s institutional spaces in the contemporary city.....................137

Figure 37: San Salvador’s commercial spaces in the contemporary city.....................138

Figure 38: San Salvador’s industrial spaces in the contemporary city.........................139

Figure 39: San Salvador in 2000...................................................................................141

Figure 40: Land uses in Santa Tecla in 1920................................................................142

Figure 41: Santa Tecla in 1920, the end of the first urbanization period of a city founded in the colonial period ....................................................................................................143

Figure 42: Land uses in Santa Tecla in 1970.................................................................145

Figure 43: Santa Tecla in 1970, the end of the second urbanization period of a city founded in the colonial period ...............................................................146

Figure 44: Land uses in Santa Tecla in 1995.................................................................148

Figure 45: Santa Tecla in 1995.....................................................................................149
CHAPTER 1: CONCEPTUALIZATION

Introduction

The computer revolution has changed the generation, management, and analysis of data. It has expanded the urban research world in two ways, first by creating an increasing flow of information, and second by generating a new and varied set of analytical tools for building, presenting, and communicating knowledge. One of these analytical tools is geographic information systems (GIS) which together with other computer applications have been used by urban scholars to simulate spatial phenomena and processes such as urban growth and land use changes. The outcomes of these simulation routines are, then, translated into maps which serve as the visual aids to support the presentation of the findings. The researcher, however, only sees a “final” product or products depicting the results, while hiding all the combinations, transformations, and creation of new data. Moreover, the simulation creator has to be an expert to codify, understand, explain, and upgrade the simulation routine. The outcome is then known facts presented from a “black box” which “reveals” the unknown facts only to a group of experts who present them as known facts to the audience.

In addition to GIS simulations, however, the revolution has also opened a window of opportunity for revisiting the role of maps for revealing, analyzing, and communicating unknowns. This cartographic revolution is based in two important facts. First, visualizations rely on human capacity for developing mental images from which patterns are identified, created and organized (MacEachren et. al 2000, p 101). In addition, now that map production and distribution has been transformed, maps are not
only representations, descriptions, and means of communication; they are also analytical
tools from which knowledge can be constructed. These reformulated maps are capable,
then, of making visible those geological aspects and processes which may not have been
previously considered either by the map creator or the map reader (MacEachren 1995, p 355). Maps as analytical and communicating tools, then, are been turned into
visualization tools called geographic visualization (GVIS). The potential of GVIS for
revealing patterns and other unknown aspects make this tool ideal for exploring urban
patterns.

In spite of its potential, GVIS have been practically ignored in urban studies,
particularly for exploring complex phenomena such as urban structures. Urban planners
have, traditionally, used static (low interactive) maps in their analysis of urban processes,
and mostly as visual aids rather than as analytical tools. However, those static images do
not completely portray how the development process takes place. GVIS, especially the
use of dynamic, interactive maps developed to promote the understanding of spatial
processes through the conceptualization of geographic change (Harrower 2004), is a
better method for analyzing the urban transformations which generate and are affected by
changes to the urban structure.

The potential to explore spatial processes is not the only reason for using of
GVIS. Currently, it is relatively easy to create interactive maps which may also include
“nonconventional” representation variables such as sound to represent complex
phenomena. Thus, considering the potential of dynamic maps to reveal and ease the
understanding of processes, and that they can communicate scientific knowledge to
broader audiences, I argue that it is useful to explore the extent to which a dynamic visualization of the urban expansion may be modeled using GVIS as the tool. GVIS is particularly ideal for exploring the little known and complex Latin American urban landscape, as spontaneous as the culture that creates it.

The process by which cities redefine their borders and structures has long been of interest to urban scholars. City landscapes materialize communities’ political, economic, and social characteristics and conditions. Through the exploration of urban architecture styles, typologies, conditions (new, maintained, old but in use, abandoned, vandalized, transformed, gentrified), and social spatial distributions, the dynamics, factors, and forces controlling and shaping urban transformations can be revealed. An exploration of urban landscape expansion not only reveals growth patterns and tendencies, it also exposes the transformations of the urban structure. As a result, there has been extensive research to theories which might explain the continuous transformations of urban structures through simplified models. How accurately do those structure models synthesize the structure of the cities?

Many conceptual models have been developed to explain cities’ spatial structure, especially for North American cities; although other latitudes and cultures have not been ignored (Griffin and Ford 1980). In general, most models try to reflect either the structure of cities at a specific point in time, or a generalized spatial distribution of land use. They do not consider the social and economic transformations that have led to a particular structure. This limitation was addressed by Borsdorf, Bähr, and Janoschka in 2002 in their four-stage model of the development of the urban structure of Latin American cities.
This longitudinal model depicts the urbanization process from the colonial era to the present, incorporating those social and/or economic changes that have affected urban expansion, and consequently, urban structure. In doing so, this model represents a holistic approach which explores the evolving transformation of a Latin urban structure. But, is this structural development model representative of the transformation process in all Latin American cities?

This thesis analyzes the urban structure development of two Latin American cities through an interactive longitudinal visualization of the Salvadoran cities of San Salvador (the capital of El Salvador) and Santa Tecla. Almost forty years after the first dynamic visualization of urban growth, the use of animations for exploring urban processes remains relatively low, in contrast to the relatively extensive use of automatic models. A dynamic map of urban expansion can be used as an analytical tool to assess both the relevance of an urban structure development model and the influences of these two cities on each other and their structures. Such map will exemplify the use of dynamic visualizations for exploring, understanding, and synthesizing urban structures, in addition to analyzing the influences of central cities on peripheral cities, and considering innovative approaches including the potential to use sound as a representation variable.

This thesis reviews the theory and concepts of GVIS for building a multiple scenario interface for exploring the relevance of the urban structure development model for the cities of San Salvador and Santa Tecla. In addition, it presents the urbanization process of these Salvadoran cities in order to understand (visualize) their structure. In the closing chapters, the results of the interface will be compared to the urban structure
development model and analyzed to determine whether these cities exemplify such model. Determining the relevance of the model requires the exploration and understanding of the architecture styles, typologies, conditions, and social spatial distribution presented in the urban landscape, as indicator of the dynamics, factors, and forces controlling and shaping urban transformations. This research then presents findings on the urban structure of San Salvador and Santa Tecla, their urban expansion, and insights about potential policies to manage their growth by analyzing the expansion phenomena and their social, political, economic, and spatial contexts, assisted by the use of geographic, interactive, visualizations.

Research questions

The present research merges two themes of interest geovisualizations and urban structure models. The purpose is not to review structure models in order to create one based on the characteristics of the studied cities. Rather, this thesis utilizes the capabilities of geovisualizations for exploring and revealing spatial patterns to locate, identify, categorize, compare, reveal, and encode the patterns which result in the urban structure of the studied cities. These operations lie at the core of visualization and cartography, and they constitute the fundamental link between them (Ogao and Kraak 2002, p 28). To explore the potential of geovisualizations for understanding and exploring urban structures, the thesis revolves around two central themes of study and answers the following questions:
Urban structure models

- To which extent is Borsdorf, Bähr, and Janoschka’s model relevant to either of these two cities?

With respect of urban structure models, there is little evidence of research contrasting existing models to empirical examples. Though scholars have cited examples of their models ((Baker (1970), Griffin and Ford (1980), Crowley (1995)), no research has assessed the model’s relevance to other empirical examples. This utilizes visualization to challenge the relevance of the model with greatest potential relevance created by Borsdorf, Bähr, and Janoschka (2002).

Animated cartography and pattern visualization

- How can a longitudinal, interactive visualization assist with the comparison of urban expansion models for visualizing the urban structure development of San Salvador and Santa Tecla?

- How can such a visualization contribute to the delineation of urban expansion policies for these cities?

One of the criticisms of existing urban structures models for Latin American cities is their failure for representing the structure they are intended to explain (Crowley 1995, p11). Thus the first question is not limited to enlighten to which extend a geovisualization reveal an urban structure. The answer to this question may also provide evidence of how an environment which is not limited solely to representations composed by point, lines, and areas may improve the representation of Latin American urban structures. At least, it may help to better represent the urban structures of the cities of San Salvador and Santa
Tecla. Additionally, a longitudinal animation of the urban expansion of these Salvadoran cities may reveal some insights regarding the management of their expansion.

Chapter outline

The process for answering the research questions is organized in five chapters: conceptualization, analytical framework, characterization of the urban expansion and land use transformation of both cities, analyzing urban structures using geographic visualization, and drawing conclusions. The present chapter constitutes the conceptualization of the research.

The next section, analytical framework, presents a conceptualization of the geographic visualization and an exploration of the urban structure model presented by German geographers Borsdorf, Bähr, and Janoschka in 2002. In the geographic visualization sub-section, the concept of geovisualization is defined; moreover, this part discusses the utility of geovisualization as an analytical tool and knowledge builder, the role of cartography as an exploratory tool, and its limitations. Due to the fact that geovisualization heavily relies on the use of maps, this sub-section also includes a review of those cartographic techniques and concepts used to present data in the simplest and clear way without compromising the dimensions of the information. This sub-section also includes a review of the concepts and techniques applied in dynamic maps including the use of data exploration tools such as zooming and brushing, the representation of uncertainty, and the use of sound as a representation variable. Finally, this section ends
with a review of applications of geographic visualizations and dynamic representations in urban studies.

Chapters three and four are focused on the characterization of the urban expansion of San Salvador and Santa Tecla and with the analysis of such expansion through the use of the geovisualization. Particularly, chapter three explores the urban expansion of both cities through available historical data of urban expansion, the effects of environmental disasters (floods, earthquakes, volcanic eruptions, etc), and land use transformations. In this study provides the basis for visualizing in the animated map, further explored through a dynamic and interactive interface. Chapter four, on the other hand, is focused on the exploration of urban expansion land use transformations. The findings of chapter four provide are the answers for the research questions, and those answers and other insights are compiled in the closing chapter.
CHAPTER 2: LITERATURE REVIEW

Geovisualization and dynamic representation

Historically, imagery has always been an aid for problem solving. Notorious and well documented is the use of images in science to reveal or explain concepts or theories such as Copernicus’ recognition of the two components of the motion of celestial bodies, or Wegener’s theory of continental drift based on the visual comparison of the shapes of the coast of South America and Africa (DiBiase 1990). In spite this history, the term visualization has just recently gained currency, and finally, it has been formally defined. MacCormick (1987, p 15) defines scientific visualization as a computational process by which imagery and signals are processed and presented, then abstractions of such images are transformed into symbols and structures that are finally synthesized. MacEachren (1992, p 101) agreed and added that scientific visualization is not limited to computing. He argues that visualization is “… [it is] first and foremost an act of cognition, a human ability to develop mental representations that allow us to identify patterns and create or impose order (p 101).” This definition is actually supported and expanded by Dibiase who in his four stages of the idealized research process: exploration, confirmation, synthesis, and presentation (figure 1).
According to DiBiase (1990), these four stages are the result of two main activities: visual thinking and visual communication. Dibiase defines visual thinking as “… the generation of ideas through the creation, inspection, and interpretation of visual representation of the previously non-visible.” In his model, visual thinking constitutes the beginning of the process and is characterized by the exploration of data which leads to the formulation of questions and hypothesis which will be confirmed or refuted by the relationships revealed by the data. Finally, the synthesis and findings are communicated and distributed using visual forms.

This idealization and the development of visualization theory were not ignored in geography. Based on this and in the theory supporting the scientific use of images as exploratory tools, MacEachren (1998 p 576) revalorized cartographic products, especially the use of maps. He recognized that cartography was being transformed by a flood of
spatial data, new user demands, needs, and information technologies. Such transformation, in combination with the consolidation of scientific visualization, allowed the emergence of geographic visualization or geovisualization (GViS). He defined geovisualization as “both a process for leveraging [datasets] to meet scientific and societal needs and a research field that develops visual methods and tools to support a wide array of geospatial data applications” (MacEachren, Gahegan, Pike, Brewer, Cai, and Lengerich, and Hardisty 2004, p 13). According to these authors, this “new” process and research method and tool is, indeed, the result of cartography’s revolution, geographic information systems, and visual information technologies, exploratory data analysis (EDA), and image analysis (p 13).

The relevance and centrality of cartography for geovisualization resulted in the redefinition of the role of maps in the research process. At the time of the emergence of geovisualization, specifically in the period comprised from 1950s through the 1980s, maps were limited and oriented to users retrieving specific information. According to Edsall, Adrienko, Adrienko, and Buttenfield (2008), most maps’ function, especially those created with GIS, depend on the researcher or researchers’ needs. In other words, maps were specifically designed to allow the user to find specifics during the problem exploration stage (Edsall, Adrienko, Adrienko, and Buttenfield 2008). Because of the human capability to create mental maps, recognize pattern, and impose order, the use of maps can be based on the goals of the map use (presenting known or reveal unknowns), the flexibility of use (static or interactive), and the target audience (private or public).
These goals were translated into the axis of a cube (figure 2) which defined a space where cartographic products may fall in deferent areas depending on their characteristics.

Figure 2. (Cartography)\(^3\) Functions of visualization (MacEachren 2004).

Maps are not only silent representations from which information can be retrieved. Indeed, these representations allow a sort of dialog between the data and the user, as the user not only reads the map, but also interacts with and re-represents the data, and creates new models (Edsall, Adrienko, Adrienko, and Buttenfield 2008). Maps also accomplish four different functions besides as data source, as tools for exploring, analyzing, synthesizing, and communicating knowledge through interactive interfaces. This “new” type of map incorporates time and a set of tools to enhance the interaction of the user. This multidimensionality and interactivity are the characteristics which turn animated
maps into geovisualizations, due to the fact that they accomplish the same goals as geovisualizations interfaces (to explore, analyze, synthesize, and communicate).

In spite of the fact that an animated map may not have the versatility and openness of a geovisualization as MacEachren suggests, an animated map may offer enough options for the user to explore the data, hypothesize and question, and confirm theories. In addition, their functions are not the unique reason for considering animated maps as geovisualizations. Patrick Ogao and Mennon J. Kraak (2002) recognize that animated maps as well as geovisualizations share the same basic operations: identify, locate, associate, and compare. Thus, an animated map may be as powerful as a geovisualization instance. This only depends on the degree on interactivity, variables, and operations an animation offers to support knowledge construction.

Geovisualization for knowledge construction: visual exploration versus quantitative analysis

Knowledge can be constructed in many different ways. According to MacEachren, Wachowics, Edsall, Haug, and Masters (1998) knowledge construction is “[…] the active process of manipulating data [which can be numerical or abstractions of real world] to arrive at abstract models of relationships among phenomena in the real world that facilitate our understanding of those phenomena and, ultimately, of the world” (p 312). With the advent of geovisualization and the role of maps reevaluated and upgraded from solely representations, knowledge can be constructed through interactive interfaces which connect the user with the data at a deeper level. This revolutionized the way research was done.
For decades, most research, spatial or not, was done using numerical, non-trivial methods. Those methods have as a central piece algorithms for extracting patterns from the data. Conversely, geovisualizations are based on intuitive methods, especially the human capacity for recognizing patterns and creating mental maps. Although both methods have relied on computational methods, they differ to the extent that they trust human recognition of patterns or “cold” algorithms, formulas, and generalizations. In spite of the fact that geovisualizations also require generalizations in order to simplify and ease the understanding of phenomena and the context in which they take place, geovisualizations are mostly processes, part concrete and part mental (MacEachren, Wachowics, Edsall, Haug, and Masters 1998, p 313) which offer the advantage of exploring an event without disassociation from its context. Quantitative analysis, on the other hand, requires such disassociation. Thus, the analysis is performed over “isolated” phenomena, a situation that may lead to partial or inaccurate results.

This situation has to be carefully evaluated because it may lead to an abrupt conclusion. Relying on purely qualitative methods such as visual analysis may lead to partial result, too. This situation was not ignored when visualization methods where conceived. Actually, the merge between cartography and geographic information systems validates geovisualizations by incorporating a quantitative component into the exploration process. For this reason, geovisualizations are considered by many to be the ultimate exploratory tool.
**Limitations of the visual approach**

Despite these potential uses, there are also many limitations that this emerging field has to overcome. One of the most significant barriers is the fact that visualizations do not provide tools for quantitative analysis (Gahegan 1999, p 289). Although visualizations are flexible and relaxed environments in which different data types can be overlaid based only on their spatial (or graphic) dimensions, they still lack the consistency and objectivity that quantitative methods provide (Gahegan 1999, p 290). This is especially important because, visual analysis results vary from viewer to viewer, depending on the viewer’s visual experience (1999, p 296). This limitation could be enough for some scientific fields to avoid the use of visualizations in their analysis; however, as Yeung asserts, “While statistical methods rank high in objectivity and in handling highly dimensionalized data sets, there is a need for pattern recognition by the human mind” (1980, p 1120). Based on humans’ cognitive capacity for recognizing and classifying shapes without applying a special analysis, but lacking the consistency and objectivity that quantitative evidence can provide (Yeung 1980, p 1120), geovisualizations are the complementary tool for quantitative analysis.

Another limitation that visualizations have to overcome is the technical hurdles of rendering large and complex data sets. In this respect, the complexity and size of the interface hinders the performance of the interface (Gahegan 1999, p 292). Though technological advances have facilitated the production and distribution of visualizations, there are still some limitations, including the software and method used to produce the interfaces, not fully automatic, (Gahegan 1999, p292; Harrower 2004, p 22), and in the
case of online interfaces, the slowness of the internet connection speed to stream the data (Harrower 2004, p 21). Among these, Gahegan highlights that due to the fact that the software used to encode the data is not specifically designed to process geographic data, the representations exceed the resolution necessary to display the phenomena, inflating the size of the interface and the streaming of the data.

Finally, this field could not benefit from a protocol to organize the production of visualizations. Due to the interdisciplinary nature of scientific visualization (which combines computer science, graphic design, graphic information design) it is necessary to develop a framework to organize and guide the increasing number of applications. Along these lines, several efforts have been done to strengthen the research agenda of the field, through uncertainty representation; interface development, tools, and concepts have been investigated and framed. These efforts and advances, however, lack a unification which would provide the grounds for a more organized and structured interdisciplinary visualization production process.

*Dynamic cartographic methods and techniques, their impact in geovisualization*

The development of animated maps has been a break trough for spatial analysis. This is mostly due to the incorporation of time as a representation variable rather than a temporal reference. Before the computer revolution, maps presented change over time using a set of maps portraying an instance, a picture of a particular moment. Thus, exploring change over time was a matter of analyzing a map summarizing such change, or a set of maps in normal size, or ultimately, a single “map” with a group of small representations organized in chronological order. At the end, it was a laborious process in
which change was initially mentally visualized and then summarized in the map. Now, this process is reduced to the production of a dynamic map which offers to the researcher the opportunity of reviewing change in “real time.”

Animated cartography is not only about the representation of change over time through motion, it is also about sharpening the resolution of the information, expanding the dimensions and resolution of information presented, and increasing the density of information that can be displayed in a reduced space. These represent one of the major inputs for geovisualizations because, differently than traditional quantitative analyses, the multidimensionality of dynamic representations is the means for revealing to the eyes and mind the causes, effects, and spatial relationships which transform space. Thus, it is critical to explore the conceptualization of change over time in the context of spatial animation as well as the cartographic concepts and techniques that sharpen the resolution and density of the information.

**Visualizing change**

One of the fundamental aspects of dynamic representations is their representation of change over time. Indeed, dynamic representations were created to ease the understanding of spatial processes through the conceptualization of geographic change (Harrower 2004). In an animation, change is observed when a feature or variable disappears or its location changes as time passes. According to Ogao and Kraak (2002), these variations can be continuous (as in motion), cyclical, or discrete (p 26). They may occur abruptly, fast, or slowly; to a single feature or to a group (Ogao and Kraak 2002, p26). Change may be a referenced, self-referenced, or “static” variation; it may vary in
location, shape, size, extent, feature, existence or state; and may vary in level measurement from ratio, to interval, ordinal, or nominal (Harrower 2002). For this reason, animations are the first step in pattern exploration before applying a numerical or computational analysis to quantitatively measure change, and, they may also assist with the selection of parameters for improving the result of traditional change detection techniques (Harrower 2002).

Dynamic maps for visual identification of clusters

Animated maps have been widely promoted as the most effective vehicle to portray change over time. However, there is little evidence of the effectiveness of animated maps as a tool to identify spatial clusters. In this respect, there has been an ongoing debate regarding the use of animated maps or static small multiples for cluster identification. The investigation developed to determine the superiority of the former or the latter have not returned conclusive results (Griffin, MacEachren, Hardisty, Steiner, and Li 2006, p 740). Griffin, MacEachren, Hardisty, Steiner, and Li presented noted that most comparison between these two forms of cartographic representations suggest that an animation’s frame rate may produce extra mental work in addition to difficulties for the reader to concentrate on a feature change. They argue that these limitations can be easily overcome with the use of interactive tools to control the animation. Despite this fact, these authors explored whether the Gestalt principle of the common fate contributes to the make animations more effective in the identification of clusters.

According to the Gestalt psychologists, animated features which move together, in the same direction and with the same speed rate are associated as being part of the
same group. Based on the hypothesis that animations are taking advantage of this principle, Griffin, MacEachren, Hardisty, Steiner, and Li tested whether statistically-constructed clusters would be better identified in an animation or in a static, small multiples map. For this purpose, they developed an interface, as well as a static small multiple map, to test two aspects: the capacity of the subjects to identify clusters (if present) at different frame rates, and the superiority of animations over static, small multiples maps. In spite of the fact that the interface they developed did not allow any interaction with the animated “patches,” their results were promising.

In general, their results report that subjects more effectively identified clusters using an animated model rather than using a static map. One of the most significant findings of this test was the fact that the subjects’ success was proportional to the pace of the animation, with an interesting twist: too fast animations prevent the identification of clusters; too slow ones, on the other hand disabled the activation of “common fate.” Animations with an average pace of nine seconds were more effective for representation of clusters and cluster patterns (Griffin, MacEachren, Hardisty, Steiner, and Li highlight 2006, p 746). These results provided evidence to support the hypothesis that an appropriate pace is central the identification of patterns (Griffin, MacEachren, Hardisty, Steiner, and Li 2006, p 749).
Design choices and the effectiveness of the interface

The effectiveness of a visualization or animated map interface involves more than a good map (Harrower and Sheesley 2005, p 80). On the one hand, a good map is the result of the application of visual and information techniques. On the other hand, an animated map or geo-visualization is effective only when it is functional or when clearly conveys such functionality (Harrower and Sheesley 2005, p 80). Thus in order to create a successful map, it is critical to explore design information techniques as well as those tools which enable knowledge discovery such as temporal focusing, temporal brushing, panning, zooming, and data uncertainty representation. Together, these interface elements are the keystone for creating an effective, functional, and reliable map. By ensuring a “friendly” environment, the interface also builds the confidence of the reader, and in so doing, enhances the knowledge construction.

According to Tufte, arbitrary and biased figures or features may lead to the misinterpretation of the information (1998, p 23). For this reason, Tufte created an information design framework for assisting in the creation of effective images. He asserts that an interface has to contain elements such as grids, scales, or self-represented scale elements in order to “quantify” or frame the data. In addition, Tufte explains, attention has to be paid to the context in which the data is represented. Such context or ground together with an adequate graphical display, may provide evidence or cues to the causes, effects, and agents affecting the represented phenomena (Tufte 1998, p 30). Statistical tools are also an important consideration for the creation of a comparative framework among variables. And finally, a critical part of visual explanation is the inclusion of
uncertainty of in the data and consideration of other possible explanations or causes of the processes or phenomena being portrayed (Tufte 1998, p 34).

This framework represents the starting point for designing and creating a good map. In order to effectively communicate data, it is important to include a global or macro view, and a micro view, for the analysis of the data, at both a macro and micro level (Tufte 2001, p 38). Detailed and complex views let the viewer contrast and compare details, creating a personal reading of the information. The “free reading,” as Tufte calls it, is based on a human capacity to personalize the analysis in order to understand the complex world around him. Micro/macro analysis provides “multifunctioning” elements which visually condense the information and do not overuse the reader’s visual memory (Tufte 2001, p 50).

A key piece for this strategy though is the data layering (Tufte 2001 p 53). Good visualization design is that whose data is strategically layered in order to convey the multidimensionality of the phenomena. Such layering, together with interactive tools designed to allow the representation of the data, are the keystone of visualizations because they provide the flexible and interactive environment in which new hypotheses are generated. More importantly, they confer the control of what is been seen, and how is being seen, to the viewer.

These design considerations are complemented with color and space and time narrations. According to Tufte (2001, p 81), based on the fact that human eyes are sensitive to color, data variation uses color to classify data, emulate reality, and establish the relationship between figure and ground. To differentiate the data changes and
variables represented, Tufte says, the designer can use color to establish a clear relation
the phenomenon – ground or context and the variables represented. As a consequence,
the viewer is not overwhelmed with confusing or contradictory images. Finally,
movement or change can be depicted by the sequence of time and the angle at which it is
represented.

Space-time experience is an important aspect of envisioning information because
it conveys the path-time and displacement-time of a phenomenon (Tufte 2001, p 105).
The most effective way to express the time-space and displacement-time experience is
through diagrams. In the case of time-space, its representation is done through a
multifunctional diagram which is the combination of a map and a data table where a clear
and well defined structure keeps the relationship of places and trajectories. Displacement-
time, Tufte explains, is represented through graphic diagrams which capture the
movements. More importantly, displacement and time narrations is activated through
small frames, figure/ground combinations, time series, micro/macro readings, different
layers, and a density of choreography of movements (Tufte 2001, p).

Temporal focusing and temporal brushing

At this point, it is clear that visualizations’ effectiveness relies heavily on the
degree, kind, and type of control of the viewer provided through tools which enhance the
viewer’s analysis. According to Harrower, Griffin, and MacEachren (1999), geographic
analysis through visualization has been transformed by the adoption of concepts from
exploratory data analysis (EDA) such as focusing and brushing. In EDA, brushing is a
technique used to aid the viewer to select features (or a set of variables which seem to be
related to other variables), outliers, or relevant elements (MacEachren, Wachowics, Edsall, Haug, and Masters 1999, p 324). Applied in visualizations, brushing may be used to search for spatial patterns or behaviors appearing or taking place at specific times or intervals (Harrower, Griffin, and MacEachren 1999).

Focusing, on the other hand, allows the viewer to manipulate the number of classes and their definitions (MacEachren, Wachowics, Edsall, Haug, and Masters 1999, p 324). Conversely to brushing, which allows the user to highlight entities or set of them, focusing allows the direct interaction with the data and their re-representation. Applied to temporal visualizations, focusing interacts with the starting and ending times of animation (Harrower, Griffin, and MacEachren 1999). Together, these tools improve the viewer’s understanding of phenomena, and are helpful in the testing of hypotheses (Harrower, Griffin, and MacEachren 1999). This makes these tools indispensable for the exploration of continuously changing phenomena and cyclical processes.

**Panning and zooming**

It is clear that the effectiveness of an interface relies on letting the reader control the way data is classified and represented, because these actions are critical for the data exploration. In addition, effective interfaces commonly also include spatial exploration tools such as panning and zooming. Acknowledging the fact that the users’ experience is enhanced or inhibited by what they can do or how well they can perform a task (Harrower and Sheesley 2005, p 78), panning and zooming contribute to the completion of a task such as searching for an address, point, feature or simply to “re-position” themselves in the spatial context displayed.
According to Harrower and Sheesley (2005, p 78), panning is an indispensable companion of zooming and it is used to re-center and reposition the map. Zooming, on the other hand, is the ability to modify the scale at which the map is visualized. Together, panning and zooming constitute the viewpoint controls (Harrower and Sheesley 2005, p 78) with which the reader manipulates the scale of observation and navigate throughout the display. Thus, the reader can explore the data at their full extent or re-center the view at a specific region, area, or point.

Furthermore, Harrower and Sheesley analyzed which of these methods is more effective and functional, using two simple criteria, what can be done and how much work is needed to perform the task. Their evaluation results are summarized in table 1, Harrower and Sheesley (2005, 82) assert that the best panning and zooming controls are those which allow the user both to define the scale they want to see as well as to choose from pre-set reference scales. This, they explain, is due to the fact that the users’ experience is limited; as a result, the interface should provide them with signals or references to guide them.

In addition, they explain that detail-context overviews have to be included in the interfaces to enhance the users’ orientation. The local-context overview, commonly in the form of a navigator, helps the user to keep track of his or her location while navigating the map. More importantly, Harrower and Sheesley highlight the fact that the tools should not create a sense of separation, nor should zooming and re-centering the display require too many manipulations. Indeed, in order to avoid users’ “navigational trauma,”
a solution would be a live-linked navigation which consists of displacements as the mouse is moved over the display.

To complete their analysis, Harrower and Sheesley compared nine of the most common methods, including grabbing and dragging, smart scroll bars, rate-based scrolling, keyboard controls, zoom and re-center controlled by the mouse, interactive compass, navigator, precise coordinates and scale, and simultaneous pan and zoom. From this comparison, summarized in Table 1, they conclude that there is no single method which is fully effective and efficient, although navigators and smart bars are the more capable and flexible methods. Nevertheless, the methods’ mixed qualities indicate that they are better implemented when combined and selected based on the target audience (Harrower and Sheesley 2005, p 88).
<table>
<thead>
<tr>
<th>Method</th>
<th>Type</th>
<th>Description</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grab and drag</strong></td>
<td>Sequential, direct</td>
<td>It may be turn of or on</td>
<td>- It can be activated or deactivated,</td>
</tr>
<tr>
<td></td>
<td>manipulation</td>
<td></td>
<td>- Entire map can be used to pan,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Emulates real life</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- There is no direct relationship between panning and scale</td>
</tr>
<tr>
<td><strong>Smart scroll bars</strong></td>
<td>Sequential</td>
<td>Horizontal and vertical scrollbars which appear only when map exceeds</td>
<td>- Provide an idea of local-context</td>
</tr>
<tr>
<td></td>
<td></td>
<td>display window</td>
<td>- Small displacement of the bar is equivalent to a large jump in the map</td>
</tr>
<tr>
<td><strong>Rate-based scrolling</strong></td>
<td>Sequential</td>
<td>Panning by re-positioning the mouse which is always located at the center</td>
<td>- This method does not use too many interface space</td>
</tr>
<tr>
<td></td>
<td></td>
<td>of the display</td>
<td>- Involuntary mouse movements may cause disorientation and motion sickness</td>
</tr>
<tr>
<td><strong>Keyboard controls</strong></td>
<td>Sequential</td>
<td>Zooming and panning executed through keyboard shortcuts</td>
<td>- It does not use interface space</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It may allow the user to do two things simultaneously (e.g., zooming and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>selecting)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- However, novices may not take advantage of it</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It only supports continuous movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Common keyboards restrict the panning to vertical and horizontal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>displacements</td>
</tr>
<tr>
<td><strong>Zoom and re-center</strong></td>
<td>Sequential</td>
<td>With a single mouse click, the display is re-centered and zoomed with a</td>
<td>- Good when target is visible in the display (direct to target ), but</td>
</tr>
<tr>
<td></td>
<td></td>
<td>preset ratio</td>
<td>poor when it is not</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It allows a precise extent</td>
</tr>
<tr>
<td><strong>Navigator tabs/interactive</strong></td>
<td>sequential</td>
<td>Tabs and direction indicators limits the panning to eight directions</td>
<td>- Mistakenly considered easy, it does not provide local-context</td>
</tr>
<tr>
<td><strong>compass</strong></td>
<td></td>
<td></td>
<td>orientation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It works poorly jumping large distances</td>
</tr>
</tbody>
</table>
Table 1 cont.

<table>
<thead>
<tr>
<th>Method</th>
<th>Type</th>
<th>Description</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navigator</td>
<td>Non-sequential</td>
<td>Precise zooming and panning with a single grab and drag</td>
<td>- Jump and re-center to a location with minimal pixel movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It keeps local-global orientation</td>
</tr>
<tr>
<td>Specific coordinates or scale</td>
<td>Non-sequential</td>
<td>Precise zooming and panning</td>
<td>- Good when the location if the target is known</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It can also be used with addresses, cues, widths, and names</td>
</tr>
<tr>
<td>Zoom box</td>
<td>Non-sequential</td>
<td>Simultaneous panning and zooming after dragging and drawing a box which defines the new map extent</td>
<td>- Lacks local-context orientation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Works poorly when the target is not visible in the display</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- It does not allows zooming out</td>
</tr>
</tbody>
</table>

Source: Harrower and Sheeleys 2005

Representing uncertainty

In Deitrick and Edsall’s words, “uncertainty broadly refers to incompleteness in knowledge, unknown or unknowable information about the discrepancy between an actual value and its representation in language, mathematics, databases or other forms of expression” (2008). Tufte (34) clearly identifies the power of uncertainty his examination of John Snow’s pioneer visual analysis of the causes of a cholera epidemic. Tufte explains that the context in which Snow place the data led him to discover the causes and effects of the epidemic. But Snow also considered other possible explanations to his hypothesis and cases with different communication of the disease, as well as possible
errors to his data, missing recorded cases, and additional related information. This evaluation of certainty and uncertainty, Tufte states, established the credibility of Snow’s data by clarifying elements that could certify or discredit his hypothesis.

In addition, uncertainty is instrumental to the identification of patterns (MacEachren, Brewer, and Pickle 1998, p 1547). If uncertainty is a critical element in visualization, how is it represented? Answering this question demands the understanding of the forms in which uncertainty can be present in a cartographic representation. According to MacEachren (1992) there are three types of data: “inaccuracy,” spatial and attribute data quality (incomplete data, misreported, or incorrectly recorded), variability (attribute aggregation), and temporal uncertainty (resolution changes from the recording time to the time of use, time difference between recording time and the data use, and data veracity which decreases as time difference increases).

For representation of uncertainty, it is first necessary to determine which the type of information the uncertainty belongs to (MacEachren 1992), then, consider which is the corresponding conventional representation variable (hue, texture, orientation, size, and shape). The best variable for representing nominal information uncertainty is hue (saturation), shape, and maybe orientation. For numerical information uncertainty, size and value are the appropriate representation variables. Texture can be used for representing binary certainty either for nominal or numerical information (MacEachren 1992). Uncertainty can also be represented simply by varying the fuzziness or “crispness,” the clarity of the symbols, the resolution, or by creating a “fog effect” over the data (MacEachren 1992).
The last component of uncertainty representation analysis is strategies to merge uncertainty and data. MacEachren (1992) suggests the representation of uncertainty through pairs of maps, one for the data and for the representation of the uncertainty. Uncertainty may also be presented to the reader as a sequence of maps: data first, followed by the uncertainty map, with a warning to the reader about the difference. Finally MacEachren explores the use bivariate maps in which both data and uncertainty are represented altogether.

Although the last method may confuse the reader, MacEachren, Brewer, and Pickle (1998, p 1550) tested it for representing health data, presenting to a group two sets of maps, one in which data uncertainty was represented as bivariate maps and uncertainty represented as an overlaid texture, and the second in which uncertainty was represented through map pairs. Their results showed that bivariate maps did not distract the reader’s attention and the use of texture was more effective for indicating which data should be evaluated with caution (MacEachren, Brewer, and Pickle 1998, p 1559). This method also reduced the viewer’s workload and enhanced their analysis.

**Sound and geographic visualization**

One of the most exciting challenges for envisioning information is the use of sound. Due to the fact that geovisualization relies heavily on human cognitive capacities, adding sound to visualization takes advantage of the opportunities offered by the second primary tool for gathering information (Edsall 2008). After all, sound has always represented an important source of information from which humans have been able to
recognize patterns, locations, relationships, colors, and qualities (Edsall 2008). Thus, its use as representation variable represents an alternative to visual methods.

In spite of the fact that the use of sound in scientific, and particularly in geographic, visualization is relatively new, its use in science is not new. More than 20 years ago, Yueng reviewed the potential of sound for data encoding. In this early study he explained how, due to the quantifiable nature of sound’s properties such as pitch, loudness, damping, duration/repetition, and direction, sciences have been using it to codify data and communicate data. The most familiar examples of this use are the cases of the sonar and Geiger counters. In addition, voiceprints have been used for forensic analyses and to distinguish between earthquakes and nuclear explosions in seismograph records (Yueng 1980, p 1120). What it is more significant from this research is the fact that Yueng ranks sound above visualization. He asserts that because visual methods are qualitative while some sound properties are quantifiable, scientific data should be conveyed through sound rather than through images.

Yeung presented a study exemplifying the sonification of chemical data for pattern recognition. The basis for it was simple: Young’s noted that because humans are capable of recognizing and classifying shapes and forms without going through a particular mental analysis of their details, they are also capable of recognizing different sounds and their changes, and that these sounds can be quantified and standardized. In his study, a data set consisting of elemental concentrations of ten metals from 63 obsidian samples, from which 40 data vectors were normalized, was converted into sound through the application of mathematical equations. These equations determine the pitch, damping,
duration, direction, and rest of a sound (Yeung 1980, p 1123). When those “sound vectors” were played to a group of three subjects, they reported 90% accuracy for classifying the vectors during a “training” session, after a second training, two subjects reported an accuracy of 98% while a third subject reported a 100% accuracy. In Yeung’s words, “… audio representation of multivariable data […] is superior to the known visual methods” (1980, p 1123).

Though these results were promising and revealing, their impact in scientific visualization was mild. More recent applications of sound to scientific analysis have been developed in tandem with visual methods. For example, Kaper, Wiebel, and Tipei (1999) developed a visualization interface which renders scientific data into sound. Using the latest available technology in 1999, they produced an environment in which sounds were converted into streams of numbers which were mathematically manipulated to produce a music score. The resulting score was then plotted altogether with the data to produce “envelopes.” As data vary, sound gets louder or quieter (Kaper, Wiebel, and Tipei 1999, p 55). Finally, sound was “visualized” as stacks of spheres which correspond to a sound’s partials (sound’s sine wave which is composed of partials such as a starting point, duration, phase, amplitude, and frequency) in a tridimensional room. The dimensions of the spheres along their position in a vertical axis and their location in room are determined by the partial’s amplitude, frequency, and position in the stereo field respectively. Resulting from this “visualization,” the most remarkable finding is that the most significant conceptual problem for the sonification of data is finding the right
mapping for the shape (or space) of data and the shape of sound (Kaper, Wiebel, and Tipei 1999, p 55).

This acoustic revolution in the sciences was not ignored by cartography and the emergent geo-visualization field. John Krygier pioneered the investigation of the use of sound to represent spatial data in 1994. Conversely to the scientific sonification of data (data conveyed through sound), Krygier acknowledges and honors sound's qualitative nature. He asserts that in geo-visualizations, sound can be used in two forms: as realistic sound (as vocal narration or as mimetic symbol) and as an abstract sound (as an alarm, as a redundant variable, as an alternative for visual patterns, for the identification of anomalies, for reducing visual distraction, for reordering data, for adding non-visual dimensions, and for representing location in sound space) (1994, p 150). Focusing on abstract sound or the sound variables, he borrowed the theory developed by the human-computer interaction (HCI) community and the graphic semiology developed by Jacques Bertin to create a framework for representing geographic variables through sound (Edsall 2008).

According to Krygier’s framework, the process of working with sound for cartographic representation begins with the addition of a temporal component in order to make sound variables distinguishable (1994, p 152). This process continues, he explains, with the analysis of each sound variable and its possible application (p 156). Such analysis, summarized in table 2, is one of the most relevant findings of Krygier’s analysis of sound as a representation variable.
With respect to change over time, Krygier explains spatial change can be used in tandem with voice-over and mimetic sounds to guide the reader through the animation. In addition, he explains that sound variables such as loudness can be utilized to add extra information to chronological displays (p 154). In the end, he explains that sound variables such as pitch are used to replace time bars (p 154). As a result, the user can be focused on the progress of the phenomena that is being mapped. Additionally, pitch is useful to identify spatial patterns, especially in animations depicting cyclical data. Voice-over, realistic sounds, and abstract sounds can also be used in interactive multimedia displays to improve the analytical and creative understanding of processes and phenomenon (Krygier1994, p 149, Edsall 2008).
Table 2

The Abstract Sound Variables and their Characteristics

<table>
<thead>
<tr>
<th>Sound</th>
<th>Nominal data</th>
<th>Ordinal data</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location, position on a bi or three dimensional space</td>
<td>Possibly effective</td>
<td>Effective</td>
<td>It requires stereo display</td>
</tr>
<tr>
<td>Loudness: scale of sound</td>
<td>Not effective</td>
<td>Effective</td>
<td>Loudness can be used to show direction. It can vary overtime</td>
</tr>
<tr>
<td>Pitch: highness or lowness</td>
<td>Not effective</td>
<td>Effective</td>
<td>It can implies direction, but it is not identified identically by the users</td>
</tr>
<tr>
<td>Register: relative position of pitch in a series of pitches</td>
<td>Not effective</td>
<td>Effective</td>
<td>It can represent high, medium, or lowest of pitches</td>
</tr>
<tr>
<td>Timbre: main sound quality or characteristic</td>
<td>Effective</td>
<td>Not effective</td>
<td>It can attract user’s attention using evocative sounds</td>
</tr>
<tr>
<td>Duration: time in which a sound is or is not heard</td>
<td>Not effective</td>
<td>Effective</td>
<td>It has to be used with silence to identify the duration of different sounds</td>
</tr>
<tr>
<td>Rate of change: overtime variation of a sound</td>
<td>Not effective</td>
<td>Effective</td>
<td>It has to be used to represent consistent or inconsistent changes</td>
</tr>
<tr>
<td>Order: overtime series of sounds</td>
<td>Not effective</td>
<td>Effective</td>
<td>“Data disorders” or different orders can be represented by a manipulation of the natural order of sound</td>
</tr>
<tr>
<td>Attack/decay: time in which a sound gets its maximum/minimum</td>
<td>Not effective</td>
<td>Effective</td>
<td>It can represent the spread of a variable</td>
</tr>
</tbody>
</table>

Source: Krygier (1994).

Scientific knowledge about the human capacity to perceive sound as a data representation is essential to understand the possibilities and limitations of sound as a design tool (Krygier 1994, p 192). As Krygier explains, sound can be used to locate map data itself or direct user’s attention (p 160); however, for geographic representations, there is still long way to go, especially the need for software and hardware capable of...
creating the sound space in which the data can be located. Nevertheless, this has not limited the exploration of more elaborated forms of sound such as music.

Extending the investigation of sound as a representation variable, Robert Edsall in 2008 explored the connections between visualizations and music. In contrast to most applications that use individual sounds to represent data, Edsall proposed the use of combinations of pitches, timings, and dynamics. The basis for this is the idea that as a film’s score produces different intuitive and emotional responses, a map or visualization with visual and musical symbolization may nurture the analytical and creative understanding of the represented phenomenon (Edsall 2008). In doing so, spatial (both qualitative and a quantitative) data, patterns, temporal trends, and spatiotemporal trends may be represented by an interrelationship of melody (sequence of pitches played in a specific order, timing, phrasing, and loudness), interval key (distance between pitches), harmony (relationships among pitches and the contexts of these pitches), rhythm, meter, tempo, decay, loudness, shape, and attack.

In particular, Edsall hypothesizes that melody can be used to create a sequence which could be easily remembered due to humans capacity to remember melodies instead of trying to make the reader remember the order of the frames as in traditional animation. In addition, he suggests that regions could be easily identified if they were associated with harmonic sounds. Specifically, Edsall proposes the use of tonality and vocals to make the users “hear” the regions, producing regionalized sounds which could easily be identified and remembered by the map user. Nevertheless, this sonification has to be coupled with the data aggregation system used to regionalize the space.
Moreover, correlation between variables can be “illustrated,” he explains, with the use of different tones and scales to aid in the understanding of legends. One of the most significant limitations of the use of sound for data representation is the fact that most people do not have the capacity to remember a pitch after other notes have been played. However, interactive and also “sonified” legends can overcome this limitation (Edsall 2008) due to the primary role of legends for explaining the meaning of symbols presented in the visualization (Edsall, Kraak, MacEachren, and Peuquet 1997). As a result, the design of sonic legends becomes critical because the map reader would constantly refer to it in order to overcome his or her poor memory (Edsall, 2008).

Finally, another important application of sound is as a means to represent the uncertainty of the data which is represented. Some scholars have evaluated the use of pitch to indicate to the user when he is “reading” uncertain data. However, Krygier (1994) writes that the viability of sound as a geographic visualization tool is limited by the costs of producing and using sound have, though this is being overcome with the sophistication of computers. In other words, nowadays it is feasible to add sound to visual displays.

Time-series animations in urban studies

In spite the potential of visualizations and animated maps, their application in analysis of urban change and evolution is minimal. Two applications exemplify the use of animation for the exploration of urban change. The first one was developed by Aldo Tobler in 1969 to describe the population growth of Detroit, with special emphasis on the
spatial distribution of such growth. Tobler’s was the first animated model of the urban expansion of a city.

In contrast to traditional urban explorations, which usually portray urban change through a series of maps integrating the temporal and spatial changes at specific time instances (Hansen 2001), Tobler empirically designed a graphic model which uses population growth lines matching extrapolations of the orthogonal trajectories of population densities. Thus, the population of the map unit (a square cell with a 1.5 mile per side) was calculated as a linear function based on the neighboring cell at the preceding time instance. In doing so, Tobler’s model depicted, and predicted, the growth of Detroit based on the growth of its population through inhabited cells which depend on the distance to the CBD. This dependency, Tobler explained seemed to depict the real situation.

The second example was developed by William Acevedo and Penny Masuoka to portray the urban growth of the Baltimore-Washington region. Instead of developing a mathematical model, they based their animation on a GIS temporal database which included data about urban development, transportation networks, population density, topography, hydrography, soils, geology, and wetlands. Thus, they developed a time series animation using images depicting the evolution of the region. This animation exemplified both the use of visualizations for exploring urban growth as well as the use of geographic information systems to generate the layering for the animation.

Acevedo and Masuoka focused on exploring which animation techniques were more effective for visualizing urban change. First, they identified three types of
animations: one panning and zooming through static images, a two-dimensional time series, and one three-dimensional with a fixed viewpoint. These animations could be produced through frames depicting time instances, although a better animation would include frames, generated through interpolations, which would reduce the time interval between frames and the final speed of the animation (Acevedo and Masuoka 1997, p 424). In doing so, they demonstrated that the perception of change is enhanced, although it may lead to an overall misinterpretation of the phenomenon being represented (Acevedo and Masuoka 1997, p 426).

Their important findings included the identification of the challenges for animating transportation networks, the requirements for creating the intermediate frames, and the relationship between speed and number of frames. As Acevedo and Masuoka explain, in order to accurately portrait urban development, road development has to be animated, too. This represents a challenge, however, because animation theory is focused on the animation of areas and not lineal features changing their relevance over time.

Their next relevant finding, that animating a phenomenon such as urban growth requires a deep understanding of the phenomenon (Acevedo and Masuoka 1997, p 434), due to the fact that an understanding of the phenomenon clarifies both the factors or layers that have to be animated and the technique and methodology to animate them. This understanding was instrumental for the creation of the intermediate frames to improve the representation of the case and the perception of change (Acevedo and Masuoka 1997, p 434).
Urban structure models

The exploration of urban structural principles through conceptual models is not new. The notion of generalizing those structural principles or concepts of a city stems from a long tradition begun in the 1920s by the influential Chicago School of Sociology (Borsdorf 2003). This school developed several theoretical generalizations such as Burgess’ concentric model (invasion-succession process resulting in concentric rings, with a central business district, CBD, at the center) model, and Hoyt’s sector model (sector determined by housing types and uses). These models were primarily aimed to conceptualize American cities (Kaplan, Wheeler, and Holloway 2004). Later, this initiative was taken on by German geographers who developed models for European cities (Borsdorf 2003).

In the case of Latin American cities, the first models did not appear until 1970. As part of his doctoral dissertation, Marvin Baker developed a four stages model (a combination of the concentric and the sector models) for Mexican cities in order to conceptualize their land use transition. Many other followed Baker steps, table 3 summarizes the most relevant of these models developed for Latin cities. Most of these are oversimplified models representing the structure of the cities at particular time instance hiding the essence of the cities and raising the question of whether the cities of this region are now under similar development conditions.
<table>
<thead>
<tr>
<th>Model</th>
<th>Author (s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marvin Baker, 1970</td>
<td>This model captured the current (1970) situation of Mexican cities through a grouping of the cities’ land use. Baker’s model did not differentiate squatter areas from low-income residential areas, but he did include middle and high class areas located close to a commercial strip as a “spine” connected to the omnipresent central business district (CBD).</td>
</tr>
<tr>
<td></td>
<td>Ernst Griffin and Larry Ford, 1980</td>
<td>It follows the tradition of the Chicago school focus on residential classification based on building consolidation. In this model, the city is composed by a CBD and a spine zones which concentrates all the commercial and industrial activities (Griffin and Ford 1980). The residential use is generalized in three classes, an elite section located around the spine, a maturity zone surrounding the CBD, a zone of in situ accretion characterized by self-build houses, and a peripheral zone of squatter settlements</td>
</tr>
</tbody>
</table>
Table 3 Cont.

<table>
<thead>
<tr>
<th>Model</th>
<th>Author (s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>William Crowley</td>
<td>This model does not conceptualize a single structure but three: commercial, residential, and industrial. Thus the city’s structure is the combination of the three.</td>
</tr>
</tbody>
</table>


*A new model for Latin-American cities*

After considering the fact that the globalization process was altering the way cities were functioning and growing, Borsdorf, Bähr, and Janoschka in 2002 published a new model which includes what they believe is the new Latin-American city model, the gated communities. Rather than just portraying the “current” structure of the cities, their model explores the evolution of the structure. Focusing on Hispanic-American cities, they presented an urban structure development model which captures the urban structure at the end of four historic urbanization periods (Table 4). Thus, they present a compact city which corresponds to the colonial epoch, a first rapid urbanization city resulting from the transformation produced by the independence epoch, a second fast urbanization city identified with the early years of the twentieth century, a polarized city corresponding to the period between the 1930s and the 1970s, and finally, a gated communities city which reflects the effects of globalization.
In general, these German geographers represented in their development model two important components: the socio-spatial and socio-economic elements (spatial distribution of social classes, industry, commerce infrastructure, and transportation infrastructure) and urban development elements (consolidation of barrios, communities, sectors, or zones, etc). In addition, their model captures the intensification of urban processes such as polarization, segregation, and the emergence of the gated communities which they classified as urban, sub-urban, and mega-residential projects or ciudad-pueblo. Thus, their model is an integral conceptualization of the urban development of Latin cities. Despite the fact that precious models have also based their conceptualization in socio-economic figures, Borsdorf, Bähr, and Janoschka temporally correlated the socio-political-economic factors to urban development. In doing so, they provided a holistic abstraction of the development process typified by the cities of the Latin-American region.
Table 4

*The new Latin-American cities urban structure model*

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Urban development</strong></td>
<td>Colonial town</td>
<td>First urbanization</td>
<td>Second urbanization</td>
<td>Segmented town</td>
</tr>
<tr>
<td><strong>Structural principal</strong></td>
<td>Core-outskirts slope</td>
<td>Lineal</td>
<td>Polarized</td>
<td>Fragmented</td>
</tr>
<tr>
<td><strong>Urban symbol</strong></td>
<td>Square</td>
<td>Boulevard</td>
<td>Rich neighborhood-poor neighborhood</td>
<td>Gated communities, malls, business parks</td>
</tr>
<tr>
<td><strong>Characteristic growth</strong></td>
<td>Natural growth</td>
<td>European immigration</td>
<td>Internal migration</td>
<td>Demographic stagnation in metropolitan areas</td>
</tr>
<tr>
<td><strong>Transportation type</strong></td>
<td>Animal traction</td>
<td>Streetcar</td>
<td>Buses, metro, suburban buses, automobile</td>
<td>Highway, private cars</td>
</tr>
<tr>
<td><strong>Political administration</strong></td>
<td>Colonia</td>
<td>Hispanic Pan-Americanism→State, Continental Pan-Americanism</td>
<td>Autarky, position between worlds</td>
<td>Military Pan-Americanism→American colonialism</td>
</tr>
<tr>
<td><strong>Economic development</strong></td>
<td>Exploitation</td>
<td>Agrarian economy → Resource exploitation</td>
<td>Inward development, industrialization through imports substitution</td>
<td>“Developmentism” →dependence, →neo-liberalism, Globalization</td>
</tr>
<tr>
<td><strong>Socio-political development</strong></td>
<td>Colonial society</td>
<td>Conservatism→liberalism</td>
<td>Populism, socialism</td>
<td>Re-democratization after military governments, capitalist governments</td>
</tr>
</tbody>
</table>

Source Borsdorf (2003), Borsdorf, Bahr, and Janoschka (2002), and Borsdorf, Hidalgo, and Sánchez (2007)
The colonial phase: the compact town 1500-1820

The first epoch or phase in Borsdorf, Bähr, and Janoschka’s model comprises the colonial epoch of the Latin-American region. During this period, the location, foundation, and planning of the cities in the region were directly controlled by Spain. According to its rules, capital cities should be located at the center of their administrative regions in valleys and basins with healthy environments because their major role was to administrate the exploitation of the resources (Borsdorf 2003). Due to its administrative nature, the core of the city was the central public square or plaza mayor (originally known as plaza de armas), around which the administrative powers and the nobles who controlled them had their residences (Borsdorf 2003, Borsdorf, Bahr, and Janoschka 2002). The plaza was the center of the network of roads and the nuclei of the social life; as a result, the urban growth is relatively slow (Borsdorf 2003). For this reason, cities in this phase described a compact shape (Figure 3) in which the social position of citizens was determined by their proximity to the plaza. Commonly, the social stratum was characterized by a core-outskirts slope in which the nobles were at the center, followed by officials and administrators, then the craftsmen, and finally the Indians.
The second major period identified by these German geographers coincides with the independence era. Basically, changes in political and administrative power were reflected in the urban structure, although with a little delay, especially in the social and economic structure (Borsdorf 2003). Borsdorf, Bahr, and Janoschka (2003) identified the influence of the European immigrants, mostly businessmen, craftsmen, industry entrepreneurs, and farmers who brought urban concepts such as Haussmann’s boulevard and the villas. As a result, during this period, elites started to abandon the center and settle around boulevards, and the first industrial zones were established close to railroads.

With respect to the urban evolution, this period was characterized by a lineal pattern of development (Figure 4), when the core lineally expanded and changed from an administrative core to a commercial one. Borsdorf described that this lineal growth followed the tendency of rich neighborhoods spreading from boulevards and paseos. This
change, he explains, was also enforced by the consolidation of labor sectors which took over the houses abandoned by the elites, breaking the compactness around the center, which also lost its centrality due to an economy based on natural resources exports to European and North-American markets.

The second urbanization phase: the fragmented town 1920-1970

With the import substitution policy, more changes arrived to the Latin cities. The state was now controlling industries which flourished along railroads and highways. Due to such industrial consolidation, cities started facing a greater rural-urban migration which generated the appearance of new housing types such as “mesons,” arrangements of efficiency rooms around a central patio, located in the periphery of cities’ core (Borsdorf
2003). In addition to mesones, this period registered the creation of social housing and extralegal subdivisions commonly located in urban empty lots and lots in the outskirts of cities. These housing types also contrasted with the proliferation of rich neighborhoods characterized by wide roads, big houses, and large green areas (Borsdorf 2003). At the end of this period, the first malls and shopping centers where erected producing the creation of new rich neighborhoods and country clubs which consolidated the fragmentation of the cities (Figure 6) (Borsdorf 2003).

Figure 5. Town of the second urbanization phase, the polarized town. Source: Borsdorf, Bähr, Janoschka (2002), Borsdorf (2003), and Borsdorf, Hidalgo, Sanchez (2007).
The contemporary urban development: the gated community town 1970 to the present

According to Borsdorf, Bahr, and Janoschka, only two structural principles remain current today, the sector and the cellular or concentric growth, yet with different approaches. Borsdorf (2003) claims that, in cities characterized by concentrations of extreme poverty, private investment in highways has revived the interest of elites in settling along the outskirts of cities (Borsdorf, Hidalgo, and Sanchez 2007, p 372). As a result, nuclei in the form of gated communities are located outside of the urban areas (Figure 6) where poor neighborhoods, social housing, and extralegal subdivisions can be found (Borsdorf 2003).

Two other concepts are fragmenting the towns. The construction of walls and gates for enclosing “islands” of similar (or even equal) life styles and social classes equipped with most urban amenities (parks, sport courts, clubs, etc) have coupled malls, shopping centers, and entertainment centers in the transformation of the city (Borsdorf, Hidalgo, and Sanchez 2007, p 367). Yet, today the relevance of malls and shopping centers has also evolved; they have escaped the rich neighborhoods and are located throughout the urban landscape independently of the status of the area (Borsdorf 2003, Borsdorf, Hidalgo, Sanchez 2007, 372). The devaluation of the location is not limited to the location of commercial hubs; industrial and business parks are also built in non-traditional places (Borsdorf, Hidalgo, and Sanchez 2007, 372), in a process called it the liberalization of the location, which is, indeed, a trademark of the fragmented city.

Finally, old extralegal communities have “formalized” buildings formerly made with cardboard, tin layers, and plastic (Borsdorf 2003). Now, these materials have been
replaced by bricks, concrete, and other materials, and are served with basic infrastructure such as power, water, and sewage (Borsdorf 2003). Conversely, “formal” house such as the mesones started to decline due to land use pressures and renovation programs (Borsdorf 2003).

Figure 6. The contemporary city, the segregated town. Source: Borsdorf, Bähr, Janoschka (2002), Borsdorf (2003), and Borsdorf, Hidalgo, Sanchez (2007).
Criticisms to the Latin-American urban structure models

In spite of how well these models may or may not represent the structure of Latin cities, Crowley (1995) identified several limitations in the representation of the urban structure. Crowley critiqued their cartographic representation, the cultural background of the creator, and the characteristics considered for building the models. In this regard, one of the major limitations is the representation of the urban complexity of the Latin cities. It may be thought that because cartographic language provides a limited number of graphic variables (point, lines, and areas) to represent the spatial dimensionality of features, then representing the complexity of the landscape would also be limited. The problem, however, actually stems from the conceptualization of the model rather than from the cartographic language.

Most models present highly generalized land use. In order to synthesize the flavor of the Latin American city structure, most scholars have drawn the cities’ structure as land use areas which group often over generalized, important elements of the landscape such as centers of agglomeration, governmental administration quarters, and health service districts. In so doing, rather than synthesizing the organic, natural, and “spontaneous” nature of the urban growth of Latin America, these models tend to represent the city as planned and organized. For example, only a few models (Crowley 1995 and Borsdorf, Bähr, and Janoschka 2002) have used the graphic variable of points to detail important components of the urban structure. Though these models are more
complicated, they are perhaps more representative of the Latin American urban structure. Accurate representations of the complex Latin American urban structure may demand further expansion into graphic variable, including movement and sound in order to address this need for better visual explanation of the urban landscape (Krygier 1994).

Another important limitation of existing models is the cultural background of the researcher (Crowley 1995). Most model builders working on Latin cities are either from North America or Europe (Borsdorf, Bähr, Mertins, and Janoschka are German; Baker, Ford, Griffin, Arriola, Curtis, and Crowley are American). Their conceptualization of Latin cities has thus been influenced by their limited experience, failing to conceptualize cities whose disorder or difference contrasts with the characteristic order of American and European counterparts. This failure has resulted in the creation of models that rather emulate the models produced by the Chicago school (Crowley 1995).

In addition, some scholars of urban structure models have confused organic growth with the visual disorder Latin cities exhibit. By definition, organic growth is led by people migrating from rural areas looking for opportunities in the cities (Savitch and Kantor 2002). This organic growth may lead to urban disamenities such as lack or irregular water supply, lack of electric power supply, and underdeveloped roads, among others. In these cases, unfortunately, the city management apparatus moves at slower pace than the rural-urban migration, producing a contrasting landscape characterized by areas neatly developed and poor and underdeveloped neighborhoods.

That seems to be the case of many Latin American cities where the lack of standards and regulations results in complex and intricate landscapes. Besides incomplete
buildings, neglected gardens, and abandoned houses, Latin American urban landscapes are composed by mixed land uses and street vendors. That contrasts with the zoned and regularized North American and European cities. Not surprisingly, Griffin and Lord (1980) described cities’ urban structures as concentric zones mostly depicting the consolidation of neighborhoods. They represent the urban structures as being composed by an elite section located around a spine or central strip, a maturity zone (or area where buildings are finished and maybe old) surrounding the CBD, then a zone of in situ accretion characterized by self-build houses, and finally a peripheral zone of squatter settlements. This is simpler, and maybe easier, than synthesizing and encoding the heterogeneity of their landscapes.

In addition, if European or North American cities are compared to Latin American ones, the difference can be dramatic. In the former cities for example, city officers control land uses through zoning and other ordinances; as a result, commercial activities are concentrated in certain areas, and more importantly, not all commercial activities can be developed in all urban zonal divisions. In Latin American cities, the land uses are as spontaneous as the culture itself. Every landowner can decide to run a business on his or her property, and the city officers may only charge some additional revenues. With respect to land use, however, the controls are limited or null. Thus, the characteristic of these cities can be described as disorderly and chaotic landscapes.

That leads to the other criticisms of the models. Model builders are influenced by the models built for American or European cities. Those models are very simple because either they describe process (as in the Burgess invasion-succession) or land use (or as in
the Hoyt sector model), both of which are more regulated in America and Europe than in Latin America. In addition, the model builders’ education has taught them to create neat cartographic representations (Crowley 1995). This interpretation of “neatness” has apparently limited the use of graphic variables for displaying their results. How, then, can “disorder” be graphically synthesized and portrayed in a simple urban model? The neat representation of “disorder” is a matter of looking for its optimal representation.
CHAPTER 3: CHARACTERIZING SAN SALVADOR AND SANTA TECLA

Study area

Along these lines, most of the urban structure investigation in Latin cities has been done based on North (Mexican) or South American cities (Argentinean, Chilean, Peruvian). Little has been done to study these regions’ less developed cities and incorporate in the analysis the impact of environmental hazards, specifically floods, earthquakes, and volcanic eruptions in cities’ structural development. In spite of the fact that many cities are constantly exposed to these conditions, two cities from El Salvador, the smallest country in the American continent were selected as study cases for this research. These cities, San Salvador (the capital of the country and several times destroyed by floods, earthquakes, and volcanic eruptions) and Santa Tecla (the city founded to relocate the capital after several catastrophes), offer two distinct scenarios to explore Borsdorf, Bähr, and Janoschka’s model.

According to official reports, El Salvador has an area of approximately 22,000 square kilometers (MARN, standing for Ministerio del Medio Ambiente y Recursos Naturales 2000), which is approximately the same as the state of Massachusetts (CIA). The country, according to reports extracted from the fifth national census of population and households held in March 2007, counts a population of approximately 5,744,113 (Giron and Belloso 2008). The same reports also inform that San Salvador and the 13 surrounding municipalities (including Santa Tecla) which constitute its metropolitan area known as Area Metropolitana de San Salvador- AMSS (Figure 7) have a population density of about 1,768 inhabitants per square kilometers (Giron and Belloso 2008). In
other words, San Salvador houses 1.5 million of the total population of the country, constituting the very core of the country not only economically, politically, administratively, and culturally, but also with respect to the concentration of the population.

In addition to their relevance in the country’s urban organization, San Salvador and Santa Tecla were selected because they represent two cases which may challenge the urban structure development model presented by Borsdorf, Bähr, and Janoschka in 2002. In their model they explain the development of urban structure as a four-stage process beginning in the colonial epoch. It is believed that San Salvador was founded as a villa in 1525 by Gonzalo de Alvarado (Larde y Larín 2000, p 82). The villa became city in 1546 and in 1835, just 14 years after the independence from Spain, and it was designated as capital of the country (IGN, standing for Instituto Geográfico Nacional, 1990, p 117). As such, due its foundation during the colonial epoch, San Salvador emerges as a potential example of Borsdorf, Bähr, and Janoschka’s model.
Figure 7. Location of the Study area, the municipality of Santa Tecla, and the MASS. Source: Mojica 2007
San Salvador is also a city regularly affected by environmental disasters, located in El Salvador’s central valley called Zalcoyotitan which is surrounded by an active volcano. The geological characteristics constantly “shake” this valley; for this reason, it is believed that this valley was nicknamed by the Spanish settlers as the “hammock valley.” (Larde y Larín 1957, p 265) As a matter of fact, an earthquake in 1854 destroyed the city (Larde y Larín 2000, 167), resulting in the decision of relocating the capital to a new settlement. This change was not fully enforced, but it provided the second case for this analysis. Borsdorf, Bähr, and Janoschka’s model seems to be a lineal four stage process which does not consider eventualities such as an earthquake, raising the question of how the suggested four-stages are affected by these eventualities. San Salvador, then, may exemplify what happens to the development of a city urban structure under constant reconstruction.

The case of Santa Tecla offers an interesting comparison. First of all, it is a city which was founded in 1854, almost 300 years after the foundation of San Salvador, and almost 35 years after the end of the colonial period. This may be enough reason for using Santa Tecla as a study case; however, there are more aspects that justify its selection. Santa Tecla was created with the specific purpose of replacing San Salvador as capital of the country. Due to the constant seismic and volcanic activity which severely damaged San Salvador in several occasions (and especially in 1854), it was decided to move the political, legal, and administrative powers to a new settlement designed specifically to replace the “old” capital. Yet known as Santa Tecla, the name of the “hacienda” which during the colonial period was part of the San Jacinto parish (Cortés y Larraz 2000, p106)
(now a San Salvador neighborhood) were it was erected in 1854, it was originally titled
Nueva San Salvador or New San Salvador. Unfortunately, the powers were never
transferred and in 1859 the capital “returned” to the old settlement, although Santa Tecla
remained as an important destiny for internal migrants.

In addition, Santa Tecla offers an opportunity to explore the influence of closed
cities over development of the urban structure. It is located approximately 12 kilometers
from San Salvador and functions as one of its dormitory cities (Alcaldía Municipal de
Santa Tecla 2003). Indeed, according to official estimates of the municipality, only 24%
of Santa Tecla’s residents live and work in the city. In 2004, the Oficina de Planificación
del Área Metropolitana de San Salvador (OPAMSS, or San Salvador Metropolitan
Planning Office) attributed to the concentration of jobs in San Salvador approximately
2.5 million of trips between the San Salvador and its satellites (OPAMSS 2004). This
characteristic will offer evidence of how the influence of surrounding cities and the
dependency on them affects the development of urban structure.

In addition to the characteristics already discussed, the following sections review
the physical and socio-economic environments in which and by which these cities are
transformed, and describes the general characteristics of these cities’ environments. More
importantly, these reviews present the conditions in which the cities are evolving and
redefining their functions and structures. Thus, the analysis of the urban structure would
not be complete without an understanding of the factors and conditions affecting both
urban centers.
Physical environment

Part of the reasons contributing to the centrality and importance of San Salvador and Santa Tecla is their geographic location, the climate, vegetation, topography, and hydrology. These characteristics have shaped the area’s capability and attractiveness. In general, this review describes those characteristics introducing the assets and limitations of the area.

One of the factors affecting the location of San Salvador and Santa Tecla is the weather conditions which are determined by the latitude at which the country is located. Due to its location, topography, proximity to the sea, the region has two clear seasons (IGN, 1982): a dry season (October-April) with scarce rain, and a humid season (May-September) with constant rain and warm temperatures of approximately 22°C - 28°C (VMVDU, 2000). During this humid season, Santa Tecla receives an average of 2000 to 2200 cc of rain a year. This constitutes one of the major assets of the city because it has relatively more rain than San Salvador which receives an average of approximately 1800-2000cc but less than the surrounding mountains.

The average precipitation is an important factor affecting the occurrence of landslides, due to the fact that the concentrations of water in potential failure planes increase the risk of landslides (Cammerat et al, 2005). As a result, the surrounding elevations represent a risk for the subdivisions located close or on hillsides. Considering that Santa Tecla has experienced in the last 20 years an annual urban growth of approximately just 2.2 square kilometers, this also represents a serious hazard for both cities.
Unfortunately, there are no official measurements of the hectares of agricultural land lost to urbanization to assist with the management of urban growth. According to Lungo and Baires (1996), a relative indicator which has been used for planning purposes is the change of the urban-rural population structure, especially in the peripheral municipalities. They explain that the relationship between the urban and rural populations in the Metropolitan area of San Salvador as a whole has remained constant since 1961 (85% urban population, 15% rural population). However, in Soyapango, the most populated municipality in the region, rural population changed from 57.28% in 1950 to 8.17% in 1992 (Lungo and Baires, 1996).

Another indicator used to infer the conversion of agricultural land is the number of “colonias ilegales” or extra-legal subdivisions (Lungo & Baires, 1996). During the political conflict of 1980s migration from rural areas to urban centers, especially the metropolitan area, increased, resulting in more than half of migrants went to live in extra-legal settlements or high density populated slums (The World Bank Group, 2001). Table 1.4 presents the evolution of extra-legal subdivisions and slums in the MASS between 1968 and 1992. Due to the fact that this urban growth did not have any precedent, the municipalities were not able to provide and maintain the basic services of their residents, thus worsening the living conditions in the area.
Table 5


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<tr>
<th></th>
<th>1968</th>
<th>1974</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extra-legal subdivisions</td>
<td>-</td>
<td>380</td>
<td>498</td>
</tr>
<tr>
<td>Slums</td>
<td>31</td>
<td>-</td>
<td>293</td>
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The second important element shaping the study area is the relief. The study area comprises part of the valley of San Salvador as well as part of the San Andres valley, which is one of the most agriculturally productive areas of the country. In recent years, flat areas have become more and more crowded as surrounding elevations became the greatest points of interest in the area. Taking advantage of the view and “isolation” provided by these elevations, elites have moved onto these hills (Figure 8). In so doing, these “McMansion” sorts of subdivisions are contributing to the destruction of the surrounding ecosystems.

*Figure 8.* High class subdivisions built in the northern hillside of El Balsamo mountain range in the municipality of Antiguo Cuscatlán. Source: Mojica 2007
This landscape is drained by approximately 1200 streams which are distributed in sixteen river basins grouped in three major hydrographic regions. In general, the study area is bisected by two major hydrographic regions recognized as macro basins (Figure 9). The northern region corresponds to the Lempa’s river basin which is one the most important rivers in the country. The southern region is a compound of river basins, which are the result of the intricate topography resulting from the mountain range, and discharge to the Pacific Ocean. That constitutes one of the major assets of the area, but one that could be severely damaged if urban growth is not properly managed.
Figure 9. Map of topography showing the different elevations surrounding the MASS. Source: Mojica 2007.
Socio economic environment

In general, the area of influence of San Salvador comprises approximately 35 municipalities. With an extension of 929.19km², this region concentrates about 35% of the total population of the country or approximately 2.26 million people. This represents a population density of approximately 2432 people per square kilometer, most of them living in urban areas. According to the Vice-Ministerio de Vivienda y Desarrollo Urbano in its Diagnóstico Territorial (spatial Diagnosis) for the Plan Maestro de Desarrollo Urbano del Area Metropolitana de San Salvador (Master Urban Development Plan for the Metropolitan Area of San Salvador), between 1950 and 1992 the population of the metropolitan area grew approximately 420%. This represents 142% more than the growth of the total population of the country during the same period (VMVDU 1997, p 101). As a result, the centrality and primacy of the metropolitan area eclipses the rest of cities and turned them into satellite cities.

As a result of such centrality, 55% of El Salvador’s GPD, OPAMSS (2004) reports, is produced in the metropolitan area of San Salvador. In other words, the metropolitan area constitutes the major hub of employment, marketing, business, commerce, education, and health. Further evidence of this centrality is the fact that 60% of trips in the morning’s rush hour have San Salvador as destination (OPAMSS, 2004). The same source reports that only 24% of the population of the metropolitan area work where they live, resulting in the total number of trips to San Salvador at approximately 2.5 million a day. These trips have different origins; OPAMSS (2004) reports that 70% of the total of trips started in the one of the 13 surrounding municipalities. Table 6
summarizes the number of rides and the type of transportation used to go to San Salvador. According to OPAMSS (2004), 70% of the trips use public transportation, either busses or shuttles. In 44% of these rides, passengers transfer to a second unit to arrive at their destination.

Table 6

<table>
<thead>
<tr>
<th>Type of transportation</th>
<th>Rides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>39</td>
</tr>
<tr>
<td>More than one bus to the final destination</td>
<td>21</td>
</tr>
<tr>
<td>Shuttle</td>
<td>9</td>
</tr>
<tr>
<td>Private car (one rider)</td>
<td>22</td>
</tr>
<tr>
<td>Private car (at least one passenger)</td>
<td>7</td>
</tr>
<tr>
<td>Others (Taxi, bicycle, bike, walking)</td>
<td>2</td>
</tr>
</tbody>
</table>

Source: Oficina de Planificación del Área Metropolitana de San Salvador, 2004

With respect to land use, in recent years official institutions have not reported on its current state. One of the last reports on the topic dates from 1997 and informs that the metropolitan area of San Salvador has an urbanized area of approximately 10160 Ha (VMVDU 1997, p 125). This report also informed that the municipality of San Salvador contributed to the total urbanized area with 38.50% while Santa Tecla allocates 8.70% of this area. In general, the Metropolitan area of San Salvador has an average housing density of 187 houses per Ha (VMVDU 1997, p 125). This density represents approximately 69.70% (7087 Ha) of the total urbanized area which is completed with 1209.98 Ha of commercial use, 915 Ha use for institutional activities, 549.1 of Industrial use, and 406.71 Ha used for green and recreation spaces (VMVDU 1997, p 125).
Explored in detail, the land use of the metropolitan area presents some interesting characteristics. For example, in San Salvador, Santa Tecla, and Antiguo Cuscatlán, the amount of land used for housing (62.4%, 62.7%, and 65.4% respectively) was below the metropolitan area’s average (VMVDU 1997, p 125). Conversely, the commercial and service areas (31.1%, 25.8%, and 16.4% respectively) were above the regions’ average (OPAMSS 1995). This is translated into a balanced land use based on the fact that some municipalities of the metropolitan area such as Ilopango, Soyapango, and Antiguo Cuscatlán are predominantly industrial (31.1%, 25.8%, 16.4% of their urbanized areas are designated as industrial) while others such as Cuscatancingo, Mejicanos, and Ayutuxtepeque were considered mostly residential because their total residential use counted above the 90% (92%, 91.45%, 91.0% respectively) (OPAMSS 1995).

With respect to institutional and support uses (open spaces and services), the metropolitan area counted, by 1995, 1497.4 Ha used for these purposes. According to official reports, 70% of institutional land use was public and 421.03 Ha were private. More importantly, 34.70% were used as green spaces and sport installations (VMVDU 1997, p 140). Spatially, 40% of institutional and services uses are concentrated in San Salvador and 17.3% in Santa Tecla and Antiguo Cuscatlán (universities and schools) (OPAMSS 1995). When exploring the amount of the institutional and services uses per inhabitant, the spatial diagnosis of the metropolitan region shows 8.76 square meters per inhabitant, but only 6.11 square meters correspond to public spaces (VMVDU 1997, p 140). More this report informed that the spatial distribution of green spaces and sport installations is approximately three square meters per inhabitant in the metropolitan area.
Considering the population density of the area (2432 people per square kilometer), that is extremely low.

According to the Dirección General de Estadísticas y Censos (General Direction of Statistics and Census) (DIGESTYC) in its V Censo Nacional de Vivienda (V Housing National Census) which took place in 1992, the urbanized area of the metropolitan area had approximately 431,664 houses. This census also reported that only 87% of these houses were inhabited. However, 38,435 of the inhabited houses were considered inadequate, either a room in a meson or an “improvised” house (DIGESTYC 1992). These inadequate houses represented 7.6% of the total and housed 10% of the population in the “big” San Salvador (as the metropolitan area is also known). In other words, 146,658 people lived in houses considered inadequate because they were not formally built or did not provide the minimum spaces and services for which houses or apartments qualify.

The last component of the socio-economic context is the demographic trend of the big San Salvador. In the metropolitan area of San Salvador, the municipalities with higher population densities are San Salvador, Soyapango, Mejicanos, and Cuscatancingo (Figure 10); these municipalities are considered the “first belt” of San Salvador (VMVDU 1997, p 140). This trend may have been the result of the pressure generated by migration to the capital. While between 1971 and 1992, El Salvador’s population grew 42%, the metropolitan area’s population doubled during this period. Thus, in 1992 the big San Salvador reached a population density of 1,668 people per square kilometer.
Figure 10. Population density in the MASS and surrounding municipalities. Source: Mojica 2007.
San Salvador

Urban evolution

Exploring the evolution of San Salvador is, in many ways, exploring the evolution of El Salvador itself. This is especially true due the fact that San Salvador was, during the colonial epoch, the head of the province of San Salvador, which later became El Salvador. Now, the city of San Salvador is not only the capital of the country, but also the administrative capital of the municipality and department of San Salvador. Despite its importance, there is lack of records depicting the urban evolution. A significant source of information comes from Gustavo Herodier’s research on the history of San Salvador and the historical review elaborated for the VMVDU for the Master Plan of Urban Development for the Metropolitan Area of San Salvador. Thus, most of the facts of this description are extracted from the review Herodier presents in his book, *San Salvador: Esplendor de una ciudad 1880-1930*, and the spatial diagnosis of the VMVDU.

Colonial era: 1524-1820

Conversely to other Hispanic-American cities founded during the colonial period, there is no clear agreement among historians (because there is no record to validate it) about the original location and identity of the first officials of San Salvador (Gallardo and Fowler 2002, p 15). Some authors such as Larde y Larín (2000a, p 86) states that Gonzalo de Alvarado founded the villa San Salvador sometime between the end of 1925 and the beginning of 1926. In addition, this author concludes that the city was founded in the old core of the Señorío de Cuzcatlán. Conversely, Baron Castro (1950, p 24) asserts
that the villa was founded by Gonzalo de Alvarado in 1525 in the Valley of La Bermuda a few miles away from its current location.

This marked the beginning of a turbulent process which included a re-foundation and several re-locations and ended with the conferral of the title of city (Figure 11). According to many authors, a year after its foundation, the city was almost abandoned due to an indigenous rebellion (Baron Castro 1950, p 65; Jiménez 1996, p 86; Larde y Larín 2000a, p 93). The Bermuda Valley was the site selected again to be the location of a new village founded this time by Diego de Alvarado in 1528 (Jimenez 1996, p 92; Baron Castro 1950, p 65; Larde y Larín 2000, 106; VMVDU 1997, p 7). In 1530, the city was again relocated, returning to the Bermuda in 1538 (VMVDU 1997, p 7). Finally, the residents of the villa requested the relocation of the city claiming lack of fertile lands and space to growth (Gallardo Fowler 2002, p 16). Thus, in 1545 the city was finally relocated to its current location (Baron Castro 1950, p 182; Baron Castro 1942, p 313; Larde y Larín 2000a, p 257), and received its title of city in 1546 (Baron Castro 1950, p 241; Baron Castro 1942, p 313; Larde y Larín 2000a, p 259, VMVDU 1997, p 7).
San Salvador was located in a valley at the base of a volcano (Cortés y Larraz 2000, p 101), and plotted following the traditional Spanish ordinances (Herodier 1997, p 18). As Figure 12 presents, straight roads forming rectangular blocks defined the public and private spaces (Rodriguez Herrera 2002, p 22). At the center of the grid, there was a square around which were located the political and religious powers as well as the residences of Spaniards, their descendents, and public officials (Rodriguez Herrera 2002, p 23; Kuny Mena 1983, p 6; VMVDU 1997, p 9). Nonetheless, its residents preferred to live outside of the urban areas because of the constant seismic activity (VMVDU 1997, p 7) and other natural disasters.
In spite of these hazards, decades after its designation as city, San Salvador was instrumental in the economic progress of the Kingdom of Guatemala. In 1566, San Salvador economically progressed due to the production of indigo, cacao, and balm (VMVDU 1997, p 7). This progress was hindered by the floods and earthquakes which also continued to control the urban and population growth. As a matter of fact, between 1571 and 1574 the province of San Salvador had 750 residents living in urban areas (Herodier 1997, p 18). By 1575, 130 residents lived in San Salvador city but they left after an earthquake destroyed it in May 23 of the same year (Larde y Larín 2000b, p 84). Despite the fact that in 1581 another earthquake partially ruined the emergent city, in 1586 the population was approximately 150 inhabitants (VMVDU 1997, p 7), growing to
3,500 (Herodier 1997, p 18) then reduced to 60 (VMVDU 1997, p 7) after another earthquake in 1594 (Herodier 1997, p 19, Larde y Larín 2000b, p 88).

The seventeenth century brought many changes to San Salvador, not all of them positive. Herodier reports that in 1625 another earthquake shook the city (Kuny Mena 1983, p 8; Larde y Larín 2000b, p 92). Almost 25 years later, a series of earthquakes produced by the emergence of a secondary volcanic crater in the San Salvador volcano threatened the city (Larde y Larín 2000b, p 91). In spite of this, Herodier (p 20) reports that in 1680 the city had approximately 4500 inhabitants although it still did not have a school.

The next century was not easy as well. The earthquakes of 1707, 1717, 1730, and 1798 (Herodier 1997, p 21; Kuny Mena 1983, p 8; Larde y Larín 2000b, p 108) made the Spanish residents of the city leave their houses for the country (Herodier 1997, p 21). By that time, Herodier comments, San Salvador was the second most important city of the Kingdom of Guatemala, but it did not look sumptuous. He explains that, the city impressed its visitors due to the large group of people going, coming, talking, mingling, and doing business in the central square. According to this historian, 8,804 people lived in houses made with wood and mud instead of brick and rocks. It was not an attractive city to the rural population; it was simply an exchange center for nearly 80% of the indigo production of the region (Herodier, 1997 p 22).
The eighteenth century brought changes not only to the city but also to the province. The city continued to grow, as illustrated in Figure 13, especially to the north-east and south. In this period the city was already divided in neighborhoods in which the grid design could not always be plotted due the topography of the area and the lack of public ordinances to enforce it (VMVDU 1997, p 10). The commercial activities took place in two squares (the central “Plaza de Armas” and the lot of a church (Santo Domingo) destroyed by an earthquake (VMVDU 1997, p 10). The Plaza de Armas remained as the city center surrounded by social, political, and religious powers. In the following ring of blocks were located important commercial buildings such as the post office, the indigo house, and the tobacco house as well as other public buildings such as the Indians hospital, the army headquarters, and the houses of the aqueducts officer and the army commandant (VMVDU 1997, p 10). The water was supplied through clay aqueducts and the sewage was collected in latrines and private pits (VMVDU 1997, p 11).

Figure 13. San Salvador in 1800. Source: Herodier 1997, p
**Independence era: 1820-1935**

In this period, San Salvador was consolidated as city, and the winds of independence were blowing, accentuating the local powers. Herodier describes a province of approximately 32,000 inhabitants. The city was affected again by an earthquake in 1815 (Kuny Mena 1983, p 8); in spite of the destroyed buildings and broken aqueducts, the economic progress and urban growth did not stop, as reflected in the relocation of the center of city from the “Plaza de Armas” to the Plaza of Santo Domingo (VMVDU 1997, p 12). New buildings were added as well as military structures to defend the city, the clay aqueducts are replaced with iron pipes, and San Jacinto (one of the towns surrounding the city) was connected to the city through a bridge (VMVDU 1997, p 12).

Finally, the independence from Spain was declared in 1821. With it, the state of El Salvador, a member of the Federal Republic of Centro America, was born. The old province of San Salvador which also administrated other three departments (Santa Ana, San Vicente, and San Miguel) was expanded with the addition of the province of Sonsonate (Herodier 1997, p 24) which administrated the departments of Sonsonate y Ahuachapán (Rodriguez Herrera 2002, p 30). In 1824, the city of San Salvador, formerly the capital of the province became the administrative capital de El Salvador (Herodier 1997, p 24).

There was little space for urban growth due to the political turmoil in the new country and in the region. Herodier explains that in 1830, the religious properties were...
expropriated; and schools, a pre-university college, and a university were established in
order to solve the lack of superior education. In the early decades after independence, the
expansion of urban centers is limited; thus, the urban population preferred to leave the
cities to pursue a rural life. In 1835, San Salvador was declared the federal capital of
Centro America, affected in 1836 by a pandemic of cholera (Herodier 1997, p 25). In
spite of this, the city saw its main square illuminated with the introduction of street lights
fed with grease (Herodier 1997, p 25).

From its origins as a village San Salvador was relocated several times, and in
1840 the pilgrimage continued. In this year, the capital was moved to the city of
Cojutepeque because of the seismic activity of the valley (Herodier 1997, p; Larde y
Larin 1957, p 265). In 1854, the capital returned to San Salvador, the city which between
1849 and 1853 had approximately 20,000 inhabitants (Herodier 1997, p 26). The same
city, that was visited by a deluge in 1852, and is temporarily relocated in Nueva San
Salvador (now Santa Tecla) in 1854 because of the earthquake of April of that year
(Alcaldia de Santa Tecla 2003). The capital was re-established in San Salvador in 1859
(Alcaldia de Santa Tecla 2003). Then, the progress continued, as the city grew in 1863
with addition of a theater, a court, hospital, and a press (VMVDU 1997, p 12).
Unfortunately, it was devastated again by an earthquake in 1873 (Rodriguez Herrera

In the last decade of the ninetieth century, San Salvador’s urban shape and
economy was transformed. According to the VMVDU’s historical review, between 1881
and 1882, the private property is established through the abolishment of the common
property of lands. Those lands were then used to produce coffee, especially in the surroundings of San Salvador and the western side of the country. This resulted in an increase of the migration of workers and rich families to San Salvador (VMVDU 1997, p 12). Economic consolidation of San Salvador was reflected in the improvement of the economic infrastructure of the city. New commercial establishments, hotels, and warehouses were built, and the transportation and pier system were improved. In terms of urban growth, elites moved from the center to the west side of the city, specifically, to the area of the national hospital (Figure 14).

Figure 14. San Salvador in 1899. Source: Herodier 1997, p
The new century meant to San Salvador its consolidation as the primary city of the country. One of the most important generators of this consolidation was the introduction of the automobile in the early decades of the twentieth century. This progress, though, was hindered again by an earthquake in 1917 (Kuny Mena 1983, p 8). In spite of the fact that this earthquake almost completely destroyed the city, the historic review indicates that the economic consolidation of the capital resulting from coffee exports produced the establishment of other industries such as soap, shoes, cigarettes, and medicines. This also produced the expansion of transportation and improvement of the amenities of the city (VMVDU 1997, p17). Lungo and Baires (1988, p 154) indicate that due to the improvement of the mobilization and the consolidation of the city, by 1930, 71.30 % of the work force in San Salvador came from other places.

The consolidation of the capital meant more than progress. According to the spatial diagnosis, the population was three times bigger (approximately 89,281 inhabitants) in 1930 than in 1890. This represented a big challenge to the city due to the shortage on social housing projects aimed at workers (VMVDU 1997, p 18). The result was a new type of house which took advantage of houses left behind by the elites. This “houses” were a group of single rooms where families (one per room) lived, sharing bathrooms and other amenities. Thus, with the decay of the downtown, the houses of the rich families became “mesones.”
The contemporary era: 1935-2000

This era was characterized by the formation of the metropolitan area of San Salvador. According to the VMVDU in its spatial diagnosis of San Salvador, the urban development of this era was promoted by the stability in the country between 1932 and 1944. After World War II, urban expansion was faster due to the increase in the coffee and manufacturing exports. Indeed, the diagnosis reveals that between 1945 and 1965, San Salvador tripled its extension.

By the 1950s, the city is expanding to the west. At the western side of the city, coffee plantations were being replaced by new residential projects. The public transportation system served all of the metropolitan area and some of the surrounding communities, mobilizing nearly 80% of the inhabitants of the region (VMVDU 1997, p 19). In May 3, 1965, an earthquake left 30,000 inhabitants without a home and many buildings damaged (VMVDU 1997, p 19). As a result, the major housing problem in 1966 was the overcrowding, especially of the oldest areas of the city which had a population density of approximately 400 inhabitants per hectare (VMVDU 1997, p 19).

In spite of the fact that the housing projects for middle and low income families increased, the number of mesones grew. According to the VMVDU (1997, p 20), the number of mesones, extra-legal sub-divisions, and slums (located on the shore of creeks, side of roads, and vacant lots) increased particularly to the south side of San Salvador. The conditions in consolidated neighborhoods and urbanizations were also not standard, lacking supporting infrastructure such as schools, sport installations, and other services.
Most importantly, the supporting infrastructure was concentrated around the city’s core, far from the communities (VMVDU 1997, 20).

The historical review also relates that before the 1960s, the commercial and industrial activity of the emerging metropolitan area is concentrated in San Salvador. From the total commercial activity, 30% was concentrated in the commercial district of the town or downtown. The remaining 70% was distributed in four minor districts (VMVDU 1997, p 21). The industrial activities, on the other hand, were mostly located to the southeast side of the city. The major urban problems were sewage collection and the garbage which littered open spaces (VMVDU 1997, p 21).

Conversely, the population density tended to concentrate in peripheral municipalities. Between 1950 and 1971, the population of San Salvador doubled in its size. Its peripheral communities’ population, on the other hand, grew three, ten, and even fifteen times during this period; especially, the municipalities of Ayutuxtepeque, Cuscatancingo, and Ilopango (VMVDU 1997, p 22). This tendency continued between 1971 and 1992 although new subdivisions were built to the southeast of the city almost completely merging the urbanized area of San Salvador with Antiguo Cuscatlán’s and Santa Tecla’s (VMVDU 1997, p 22) (Figure 15).
Santa Tecla

*Urban evolution*

In contrast to San Salvador, Santa Tecla was purposely founded to be the new capital of the country. On April 16, 1854 an earthquake destroyed the capital (Larde y Larín 2000, p 256), and this strengthened the elites’ idea of moving the city to a safer place (Larde y Larín 1957, p 266). Thus, on December 25, 1854, Santa Tecla was founded as a city capital of El Salvador (Larde y Larín 1957, p 272). Nevertheless, the legal and political functions of the capital were never transferred to Santa Tecla (Contreras Callejas, Alvarado Cea Campo, and Alvarado 2004, p 36). In 1859 the capital formally returned to San Salvador (Larde y Larín 1957, p 272).
Santa Tecla’s location was not fortuitous; it was selected due to several reasons. According to the Alcaldía Municipal (2003), it was strategically located within San Salvador, La Libertad Pier, and Acajutla the major commercial gateways of that time. In addition, the new capital would not lose the centrality of the administrative core of the country because its new site was located just 12 kilometers away from the old capital. As a result, Santa Tecla has been an important hub and trade point due to its location between San Salvador, La Libertad Pier, and the West. The topography and climatic conditions of the valley of Santa Tecla were also favorable (Larde y Larín 1975, p 267).

Also in contrast to San Salvador, Santa Tecla was planned. In the early years, it was mostly a residential city with approximately 92 houses and fourteen huts (Larde y Larín 1957, p 273), distributed in blocks following the traditional grid design of the Spaniard colonial cities (Alcadía Municipal de Santa Tecla). The newly designed city included five neighborhoods (Alcadía Municipal de Santa Tecla) designated for private residents and separated from the peasants’ houses and crop fields by a road called la Ronda (Alcadía Municipal de Santa Tecla).

First urbanization period 1854-1941

According to the Alcaldía Municipal (2003), the period between 1854 and 1884 was characterized by the consolidation of the city as a trade hub, due to developments of the transportation system. In 1870, a road which used to be a shortcut to the western side was finished, and in 1876, a train connected Santa Tecla to San Salvador, replaced in 1920 by a streetcar (Contreras Callejas, Alvarado Cea Campo, and Alvarado 2004, p 62), and discontinued in 1929 when the road Santa Tecla and San Salvador was paved.
(Contreras Callejas, Alvarado Cea Campo, and Alvarado 2004, p 64). Since then, the relationship between San Salvador, Santa Tecla, and the West has been strong. Economically, coffee supplanted indigo as the primary agricultural product (Alcaldía Municipal 2003). In this period, the urban population increased from 2,003 (Larde y Larín 1957, p 273) to nearly 10,000 inhabitants (Alcaldía Municipal de Santa Tecla).

The period between 1854 and 1951 was characterized by the consolidation of the coffee plantations, produced by the abolition of the common lands or “ejidos” where peasants had their houses and crops (Alcaldía Municipal de Santa Tecla 2003). As a result, coffee plantations were consolidated into the main land use as well as the main source of employment (Alcaldía Municipal de Santa Tecla 2003), resulting in a population of approximately 13,715 inhabitants in 1890 (Larde y Larín 1957, p 273; Contreras Callejas, Alvarado Cea Campo, and Alvarado 2004, p 36). This along with the introduction of the automobile in 1903 consolidated the position of Santa Tecla on the national map.

During this period, Santa Tecla also became an important residential pole. The economic development attracted population from other places in the country. In addition, coffee’s decreasing price forced plantations owners to put some of their lands onto the housing market (Alcaldía Municipal de Santa Tecla 2003). Eighty years later, the urban population was approximately 20,000 inhabitants, nearly 69% of the total population of the municipality (Alcaldía Municipal de Santa Tecla).
Second urbanization era: 1942-1952

The next period corresponds to the decade 1942-1952, which was characterized by Santa Tecla’s significant growth towards San Salvador. In this decade, the highly regulated urban form started to reflect the pressure it was facing. Indeed, it experienced growth towards the open lands to the west instead of the earlier pattern of growth to the east, towards San Salvador (Alcaldía Municipal de Santa Tecla). It is important to highlight that even though the growth towards the west was significant, especially because that growth phase included the first subdivision designed for low income buyers (Alcaldía Municipal de Santa Tecla), it was less important than the growth towards San Salvador. Before 1951, the urban density was approximately 35 inhabitants per square kilometer, but after 1951 it grew to approximately 250 inhabitants per square kilometer (Alcaldía Municipal de Santa Tecla).

Contemporary era: 1942-1995

The following 12 years was characterized by the development of low income housing projects. The metropolitan area was engaged with its second regional effort to regulate the growth of the area. This plan considered the timely low-density development of such areas in order to give an alternative to the increasing degradation and saturation of San Salvador (Alcaldía Municipal de Santa Tecla). As a result, the Fundación Salvadoreña de Desarrollo y Vivienda Mínima (FUNDASAL) built the first subdivision for low income families as a means of meeting housing demands due to a population which grew three times in 30 years.
Between 1981 and 1986, Santa Tecla was highly influenced by the political turmoil of the “lost decade” as is popularly known the decade of El Salvador’s bloody war. The direct effects of this conflict were less negative in Santa Tecla than in other urban areas. Nevertheless, due to the deterioration of the quality of life, cities experienced a process of invasion and succession. Santa Tecla’s downtown declined, and lower income and older people came to live in the houses left behind by the elites (Alcadía Municipal de Santa Tecla). Despite the instability, Santa Tecla kept its residential attractiveness.

The last period of analysis corresponds to the years 1987 to 1995. First of all, the war ended and the capital recovered from an earthquake. Santa Tecla was facing the pressure exerted by the migration of upper classes from San Salvador and other cities (Alcadía Municipal de Santa Tecla). Indeed, the city had a population of approximately 98,000 inhabitants, nearly 87% of the total population of the municipality (Alcadía Municipal de Santa Tecla).
Figure 16. Urban evolution of Santa Tecla
CHAPTER 4: ANALYZING URBAN STRUCTURE THROUGH A VISUAL INTERFACE

Methodology

In contrast to a traditional urban structure research, the characterization of the urban evolution of San Salvador and Santa Tecla was the basis for the animated maps of these cities. For this research, the methodology was not limited to collecting land use, urban growth maps, and subdivisions maps, checking archives and reviews, and then analyzing them to draw conclusions. The methodology, in this particular case, involved a conceptual design of the interface and the animated maps, an archival research, a mapping process, an animation process, and finally the analysis of the urban evolutions of San Salvador and Santa Tecla.

The visualization of urban structures using animated cartography, as an analytical tool, demanded a thorough conceptual and theoretical analysis. Both, concepts and theories constitute the framework for the data collection, the mapping process, and the animation process. First, considering the results presented by Acevedo and Masuoka in 1997 and the average speed of nine seconds (Griffin, MacEachren, Hardisty, Steiner, and Li 2006, p 746), data, maps and records, were collected to avoid the creation of intermediate frames using mathematical models. In addition, sound theory helped the identification of data such as earthquake, fires, and other political, economic, and symbolic transformations which, due to their spatial or temporal scale, would not be “visible” in the animations (based on sound’s potential to evoke emotions, establish and
emotional connection, and strengthen the engagement with the phenomena) (Caquard, forthcoming).

With this frame set, the field research took place. The field research was organized in two stages. The first phase consisted of looking, consulting, and collecting books focused on the urban history and evolution of the cities of San Salvador and Santa Tecla. For San Salvador, the starting point was the Museo Nacional de Antropología “David J. Guzman” (MUNA, or National museum of Anthropology). As a part of its regular exhibit, MUNA has a section dedicated to the urban evolution of the city of San Salvador, in which, they present a series of maps portraying the evolution of the city (Figure 17). This section includes maps that could be digitized to produce the frames for the urban growth animation. Some of those maps not only portray the growth of the urban area of the city, they also include representations that can be re-coded to produce generalized portrays of the land uses.

Figure 17. Urban evolution exhibit presented in the Museo Nacional de Antropología “David J. Guzman” de El Salvador. (Photo: Ana Mojica)
In spite of the fact that some of those maps can be viewed at the Archivo General de la Nación, or General Archives of the Nation, their use is limited. As Gallardo and Fowler (2002) commented, many of the records of the city’s transformation are lost (p 15). For this reason, maps and other historical documents that have survived to this day can only be photographed. Although it is a practical way to have a digital reference of the maps, this form of reproduction imposes limitations for their digitalization and encoding. The focus and camera height and angle affect the quality of the pictures; as a result, some of the pictures were blurry and difficult to post-process (Figure 18). To reduce the uncertainty of this process, the alternative was to scan the maps from historical reviews of the cities, most of them guarded by the National Library of El Salvador.

*Figure 18.* Photograph of the map portraying the different locations were the village of San Salvador was settled. (Photo: Ana Mojica)
The second phase of the field research was to collect land use and subdivisions data. The main source for those layers was OPAMSS and the planning offices of each city. Due to the fact that recording land use transformations is relatively a recent subject for their management activities, these offices have not published land use maps in the last ten years. Particularly, the planning office of San Salvador reported that they have decentralized some of their functions; as a result, each office has mapped a section of San Salvador. These partial maps, unfortunately, were not available for this research.

To make up for this lack of maps portraying the land use transformations, private companies have elaborated them for their particular purposes. One of these maps, elaborated in 2000, was available for this research and post-processed during the mapping phase. Land uses were generalized and encoded to portray five categories used for the Salvadoran planning offices: housing, commercial spaces, institutional spaces, industrial parcels, and green areas.

For the case of Santa Tecla, the city planning office has been engaged with different efforts to improve the management of its territory. As a consequence, the city, in cooperation with different universities and researchers, created a database and some reviews which have described and analyzed the urban evolution of the city. For this research, some of those documents and a digital map of the illegal settlements were available through the unit in charge of Sistema Municipal de Información Geográfica (or Municipal System of Geographic Information Systems). As part of the mapping process,
the maps included in the reviews and the digital maps were digitized and encoded respectively.

The next step in the process was to produce static maps to be converted to frames during the animation stages. Maps, events, and relevant facts described in the reviews were used to produce three base maps: urban expansion, land use, and illegal settlements. These base maps were elaborated in three steps: digitalization, post-processing, and mapping. To represent the urban expansion, using Autocad®, a digital parcels layer, and the maps extracted from the historical reviews; polygons portraying the expansion of the urban areas were digitized. For San Salvador, these border lines corresponded to the years of 1594, 1700, 1800, 1850, 1865, 1880, 1895, 1905, 1965, and 2000. For Santa Tecla, the expansion polygons were drawn for the years of 1859, 1884, 1941, 1967, 1980, 1986, and 1995. Finally, to complete the representation of the urbanization process, the subdivisions’ border lines were also digitized using this computer-assisted drawing software.

The creation of the land use layers for both cities followed a similar procedure to the digitalization of urban areas and subdivisions. However, in contrast to the generation of the urbanization layers, the land use digitalization included the identification of each polygon with a label. Those labels correspond to the five urban land use general categories used for the planning offices of these cities: housing, green spaces, industrial spaces, commercial parcels, and institutional uses. In the post-processing phase, these labels were converted in the attributes of the data polygons.
Finally, the illegal settlements layer was produced. The planning office of the city of San Salvador provided a printed map of the subdivisions including the illegal settlements or “developing communities” as they identified them. As in the case of urban expansion layers, the boundaries of these communities were drawn. The GIS unit of the city of Santa Tecla, on the other hand, provided a digital parcels map depicting some of those corresponding to the illegal settlements. Due to the fact that not all the illegal settlement parcels have been surveyed or digitized, its digitalization for this research was limited to create a single polygon for each community. In the case of San Salvador, the subdivisions map provided by the central city planning office depicted only the settlements boundaries. Thus, their digitalization was limited to create that polygon using the digital parcels layer.

Once the polygons were created, the next step was their post processing. Using the Arctools® module of ArcGIS® ArcInfo® workstation, the Autocad files were converted into shapefiles from which the animations’ data layers were extracted. With this application, an error test was implemented to verify that all lines formed closed polygons and that each area had a attribute label. Then, the shapefiles were loaded in ArcView® to create for each year a single layer per each land use category and urban expansion. In other words, after the separation process there were approximately 119 layers (five land use layers, one urban expansion layer, and illegal settlement layer per year), 70 layers for San Salvador and 49 layers for San Tecla. These layers were mapped, using a reference scale of 1: 34,000 for San Salvador and 1: 32,500 for Santa Tecla, to
form the land use, urban expansion, and illegal settlements base maps. Finally, those layers were exported to Adobe Illustrator® to continue with their mapping process.

Adobe Illustrator® was the intermediary application between the GIS database and Macromedia Flash 8® where the animations were constructed. In Illustrator®, the polygons were prepared to be animated. Land use layers as well as the illegal settlements layers were color-coded based on their type of use. In addition, the subdivisions polygons were separated based on their intersection with the urban expansion layers. In doing so, the expansion polygons went from being defined by one single polygon to being formed by subdivisions areas. Basically, the urban space was subdivided based on those development projects forming them. Finally, a street layer was overlaid to work as a reference in the animation.

With these components ready, the creation of the interface and the animated evolution models began. Both interface and animated evolutions needed to ensure an appropriate exploration of the urban evolution. For this reason, special attention was paid not only to how data were introduced and presented but also to the tools assisting the data exploration. Thus, the interface was designed to have three components: an introductory module and the animated maps nest. The introductory module precedes the main map, and it was designed and built to welcome and present to the viewer a brief description of the project as well as Borsdorf, Bähr, and Janoschka’s model and the cities being explored. In spite of the fact that this module can be skipped, the main map (or the nest of the animated maps) was equipped with links to review those descriptions and open the animated evolutions.
In order to enhance the viewer’s control, the animated evolutions are presented in independent windows that can be resized, moved, or closed. In doing so, the viewer is able to open and see one or the other city and thoroughly analyze its evolution. Through this and with the assistance of the set of buttons controlling the animations, the viewer can simultaneously explore and compare the evolution of both cities.

The windows’ design uses the conceptual framework developed by Harrower (2003, 2004), Krygier (1994), Edsall (2008), Caquard (forthcoming), Tufte (1998,2001), Harrower, Griffin, and MacEachren (1999), Harrower and Sheesley (2005), and Acevedo and Masuoka (1997). In order to reduce the readers’ workload, the windows have interactive buttons, which allowed them to interact with the data. Thus they can play, pause, stop, rewind and forward the animations. These tools help to overcome the dramatic changes of an animated map that can lead to a viewer to miss important information, a problem that Harrower identifies as the disappearance of the data (2004).

The confidence of the user (Harrower, 2004) has been helped through the use of simple data exploration. The data layers are directly listed in the window and they can be turned off and on when desired. In addition to this data brushing method, the temporal variable can also be brushed by clicking the markers of the timeline. Through these tools, then, the users may explore each land use transition, their influence or relationship with other land use, and their transformations at specific periods of time or moments.
The data exploration could not be complete without providing a flexible environment ensuring viewers’ orientation. In order to avoid the frustration of the viewers produced by a fixed viewpoint (Harrower and Sheesley 2005, p 78), the windows have tools which assist them to change scale, orientation, and center of the view. A vertical slide bar was added to change the scale at which the animations are displayed; thus, the viewers can zoom in and out at specific areas or features. To keep the spatial navigation simple, the viewer have two options to re-locate the center of the view: click and drag directly in the inside of the window frame, or, click the buttons incorporated in the window frame as the cardinal point arrows: North, South, East, and West. Finally, the spatial exploration is completed through the addition of a rotation button which allows the viewer to change and reset the orientation of the view. As a result, the viewers’ exploration is enhanced by the flexible and simple manipulation of the animations viewpoint.

After the animation environment was built, the data layers were animated. First, context or ground over which the layers would be animated was created. Using ArcView® and Natural Scene Designer®, a digital elevation model, which works as a reference and may provide clues about the agents or processes affecting the evolution of the cities (Tufte 1998, p 34), was created. Then, each land use was animated as a separate layer. Considering the “common fate principle” and the average speed of nine seconds to ensure identification of clusters (Griffin, MacEachren, Hardisty, Steiner, and Li highlight 2006, p 746), the speed of the animated layers is ten seconds.
Sound (Krygier, 1994) was used to add a fourth dimension to the animation. An evocative sound was added to the housing and transportation layers. Instead of using sounds that would could be recognized and learned, sounds for these animations were chosen based on their realistic, emotional, and cultural meaning. This decision was made based on the fact that sounds would not only represent features that due to their spatial and temporal scale would not be visible in the animation, but also they would convey the tension of the urbanization process. The soundscape, then, would recreate the destabilizing environment in which San Salvador and Santa Tecla grows.

The process of producing the interface was labor intensive. In spite of the fact that the number of data layers is relatively small, building the animation nest, the windows, and the animation took approximately eight weeks. Three of those weeks were dedicated to building the introductory module and the animations’ environments. In the remaining five weeks the layers were animated. In spite of the fact that the animation of most land use layers was reduced to defining the span between frames, the animation of the urbanization process took approximately two weeks.

One of the major limitations of traditional expansion representation is the spatial texture used to portray the urbanization process. Urban expansion is depicted only by the variation of the total urban area (see Figures 15 and 16). In spite of the fact that this form of representation provides insights about the direction and tendency of growth, it does not provide clues about how the actual urbanization takes place. As a result, this research explores the urban expansion reducing the spatial and temporal texture of the
representation. The spatial texture is defined as the distance between the centers of the polygons compared to a unit of distance, and temporal texture refers to time between frame to frame divided by a unit of time (MacEachren 1995, p 285). Thus, instead of showing the transitions of the total variation of the urban areas, the urbanization process was represented using the appearance of the subdivisions. This resulted in a smooth animation produced by animating every subdivision in a separate layer. In the case of Santa Tecla, its urban expansion was composed of approximately 295 layers; San Salvador’s, on the other hand, was composed of approximately 575 layers. As a consequence, the representation of the urban expansion of these cities was completed in approximately 140 hours, equivalent to fourteen days.

Analysis

Exploring the structural development of San Salvador and Santa Tecla was based on the review of the general aspects of their urbanization process, and particularly, in the review of the transformations of their land uses. Using the development phases, used by Borsdorf, Bähr, and Janoschka in their model, as temporal frame, the geovisualizations were explored in order to characterize and synthesize the spatial distribution of uses and clusters, to identify patterns, and to compare those elements to Borsdorf, Bähr, and Janoschka’s model.

As a result, for both cities the analysis was developed in two parts: transitions for each land use and transitions for all of them together. Thus, applying Borsdorf, Bähr, and Janoschka’s time frame, the analysis for each city have four phases (depending on its foundation date): 1525-1820, 1820-1935, 1935-1970-2005; and for these periods, land
use analyses, each land use and all together through time. Finally, the findings from these explorations are examined in order to assess the relevance of Borsdorf, Bähr, and Janoschka’s model, and to highlight aspects of their urban evolution that may be significant for the management of the cities’ growth and planning.

The structural development of San Salvador

The colonial phase

San Salvador was originally founded to conquer the rebellious people of Cuscatlán. For this reason before becoming a city, San Salvador was relocated several times. In spite of the instability that marked its foundation, it was the settlement of the groups of major political and economic power of that period (Fernandez and Lungo 1988, p 99). Nevertheless, the consolidation of the city is relatively slow, indeed during this phase, San Salvador was the capital of the country but it was eclipsed by the more densely populated city of Santa Ana (Fernandez and Lungo 1988, p150).

The housing evolution during the colonial period of the city shows the consolidation of the Spanish domination and settlement. The cities, depending on their relevance and role, had a small concentration of people and the living conditions were modest. According to Baron Castro (1942, p 320), San Salvador had in 1551 approximately 500 people living within its limits: 200 Spanish residents in addition to the Indians, blacks, and mestizos. In 1601, the city had evolved, but the forces of nature hindered its development. Baron Castro estimates that the number of Spanish residents dropped from 150 in 1586 to 70 after an earthquake demolished the city. This and the
dependency of the residents in the administrative functions of the city are reflected in figure 19.

In spite of the fact that there are not demographic figures to map the spatial distribution of social classes as Borsdorf, Bähr, and Janoschka did, the city’s housing areas, depicted in figure 19, corresponds to those of a compact town. Many authors as Baron Castro (1942) and Herodier (1997) describe a city of Spanish residents surrounded by Indians settlements which may suggest, or confirm, a core-skirt slope. Nevertheless, considering the Spanish policies with respect of the colonization, single Spanish women were not allowed to migrate to new world (Baron Castro 1942, p150), and the concentration of political and economic powers in Spanish hands, it is difficult to delimit the spatial distributions of classes. Indeed, those authors describe settlements, which could had been more like Indian hamlets, located relatively close to the city limits, but not part of it. However, the extension and shape of the housing zones seems to exemplify the compact ring described by Borsdorf, Bähr, and Janoschka, although the cause(s) of this structural development seems to be different to those assessed by these German geographers.

In addition to the natural process of consolidation of the Spanish settlement, the forces of nature play a central role in the structural development of San Salvador. Historians report that city was ruined several times during that period due to massive earthquakes and volcanic eruptions. For Example, Baron Castro (1942) reports that the city authorities needed to ask for royal help to rebuild the major administrative and religious buildings at least twice between the foundation of the city and 1660. This
“slow” growth, in fact it was more a re-establishment of the city is show in two upper images of the sequence presented in Figure 19. Thus, in addition to an economy based on the exploitation of the resources, transportation through animal traction, and the colonial political administration or domination, San Salvador development was also controlled by the geological activity of its location.

Figure 19. Sequence of the evolution of San Salvador’s housing during the colonial phase.
The visual analysis of the development of San Salvador’s institutional space reports interesting findings. As presented in Figure 20, in the first 150 years the institutional activities were concentrated in the core of the city. Most of the institutional functions of the city were found around the core of San Salvador; nevertheless with its natural expansion, those functions and spaces started to spread throughout the urban area. In addition to administrate the province and its resources, the institutional activities were in charge of conquering and dominating Indians. Then, in addition to the administrative buildings, the landscape started to allocate more religious congregations and churches which were in charge of evangelizing and administrating the "spiritual" resources of the city. As a result, the institutional activities started to be segregated throughout the city, but due to its extension (0.67 square kilometers in 1820), such segregation may have not represented the formation of new administrative or institutional poles.
In contrast with the evolution of urban spaces, the commercial activities went from being a secondary activity to a central activity. According to historians, the commercial activities of the city during this period were limited to the exchange of locally produced consuming products (Herodier 1997, p). As a result, after this exchanges took place in open peripheral areas. As the city consolidated, these activities started to involve more formal establishments such as hostels and stores. Due to the fact that these were mostly dedicated to serve the Spanish residents, they were located close to the core of the city (Figure 21). As a result, the city’s center started to consolidate its center.
In relation to the industrial spaces of San Salvador, the chronicles of this time period reported a modest industrial development. Due to the role and characteristics of the economy of that period, the industrial activities were limited to printing activities and handcrafting. Maps depicting colonial San Salvador only identify a printing company located to the east of the city. Handcrafters, on the other hand, did not have a production large enough to have a significant impact in the structure of the city. As a result, they are only mentioned but not mapped in the representations of the city.

Figure 21. San Salvador’s commercial evolution during the colonial phase.
Green Spaces, on the other hand, have a complex role during this period. In addition to function as open spaces where the citizens and visitors went to rest and socialize, open areas were also used for commercial activities. Herodier (1997, p 21) describes how the exchange activities took place first in a small plaza built over the ruins of a church, and then in the central plaza. Thus, instead of just being commemorative and leisure areas, they provided a space to informal, and small scale, business.

The analysis of the land uses together reports the development of a compact town. Figure 22 illustrates the slow development of San Salvador during the colonial phase. The sequence shows the relatively slow development of the city; San Salvador had approximately 0.31 square kilometers in 1594 and grew to 0.67 square kilometers. This may have been the result of nine earthquakes (1594, 1650, 1671, 1707, 1717, 1730, 1776, 1806, and 1815) and two volcanic eruptions of the Quezaltepeque volcano (1650 and 1671) that damaged the city during that period. In addition, San Salvador was the core of the administrative activities of the territory as part of the colony.
According to Fernández (1988) most of the economic activities took place in other cities which were bigger in terms of population and economic power. The administrative centrality of San Salvador is more evident when the evolution of the city presents all the land uses together. The consolidating core of the city is almost completely dedicated to administrative or institutional activities. In fact, the administrative activities in 1800 constituted 0.1 square kilometer, 0.04 square kilometers were dedicated to commercial activities, and 0.52 square kilometers were used for housing. Thus, it is

*Figure 22. Sequence of the evolution of San Salvador during the colonial phase.*
evident that San Salvador was an administrative city where the Spanish controlling the relationships with the rest of the colony might have had their residences.

In the animation, during this period the shape of the city remains relatively compact and the city center was being consolidated. At the end of this period, the urban landscape exemplifies the colonial town described by Borsdorf, Bähr, and Janoschka in the sense that it had a relatively compact and clear center surrounded by housing areas. In their model they present a spatial distribution of classes with the elites located around the core of the center, but San Salvador seemed to be different. Lungo and Baires (1988) report that the middle class appeared later in the early decades of the twentieth century (p 158). Herodier also explains that, in 1594, San Salvador is mostly inhabited by Spanish, their descendents and some Indians and Blacks who served them (p 19). In terms of shape, San Salvador started to develop an irregular form that differs from the regular shape described by Borsdorf, Bähr, and Janoschka. Thus, in spite of the similarities, San Salvador did not clearly describe the landscape conceptualized in Borsdorf, Bähr, and Janoschka’s.

In summary, San Salvador is not an example of the compact town described by Borsdorf, Bähr, and Janoschka. Such assertion is based in two facts: the spatial distribution of classes, and the shape of the town. In contrast to the German geographer’s model, San Salvador did not have a core-outskirt slope defining the spatial distribution of classes or incomes. None of the historical sources cited in this research describe such distribution. Indeed, the references report that low classes (mostly Indians, blacks, and mulatos) were the working force for the Indigo production which took place in farms
outside of the urban limits. (Lungo and Baires, 1988). Based on the maps a chronicle consulted, then, San Salvador housing areas formed rather a single ring around the city’s core (Figure 23).

The urban shape also reports evidence to sustain that San Salvador does not exemplify the studied model. In spite of the fact that the institutional and commercial activities at the end of the colonial time were concentrated, and formed core, the urban structure started to be segregated. The shape of the city is compact, but irregular, portraying the deep transformations of the period. This may have been the result of the consolidation of the elites administrating the province and royal assets.

![Figure 23. San Salvador’s landscape at the end of the colonial period compared to Borsdorf, Bähr, and Janoschka representation of the Latin American cities structures at the end of the same period.](image)
The first urbanization phase

The analysis of the evolution of the housing areas presents some interesting findings. This period was marked by the deep transformation of the country: its independence from Spain, then, coffee production replacing Indigo as basis of the economy, foundation of a new city to relocate the capital, and expropriation of the common lands. As a result, rural population started to migrate to urban areas, and the elites started to leave the center of the cities. The spatial growth of the housing areas seems, in general terms, to be reflecting the internal consolidation of the different powers of the emerging capital.

As figure 24 presents, San Salvador housing distribution was, visually, exemplifying the forms described by Borsdorf, Bähr, and Janoschka. Following a migration-succession process, elites moved to the west side of the city, and low and middle classes moved to their houses. In spite of the fact that these elements appeared to be the evidence to conclude that structural development of San Salvador is, for this period, exemplifying Borsdorf, Bähr, and Janoschka’s first urbanization period, a deeper analysis proves the contrary. Similarly to the previous period, the historical references do not provide evidences of the existence of a core-outskirt slope as the model presents. Moreover, such reviews describe a heterogeneous landscape in which the elites are located to the west and the center was shared by lower income classes and some rich families. Thus, in contrast to Borsdorf, Bähr, and Janoschka’s, San Salvador began its polarization process.
Second, historians did not describe the existence of marginal quarters. With the migration of the elites along the new paseos of the city, their old houses were subdivided to host several residents. This new typological housing “unit” called mesones started to spread throughout and characterized the center of San Salvador. As people migrated to the city more mesones appeared and the more crowded they became. This was a common pattern between Latin American cities, and it was perceived as a “social problem” (Lungo 2000, p 230). Nevertheless, it was not the same as the marginal settlements which appeared in the 1950s. Thus in my opinion, mesones cannot be completely considered as the marginal quarters that are described in Borsdorf, Bähr, and Janoschka’s model.

Figure 24. Sequence of the evolution of San Salvador’s housing during the first urbanization phase.
With respect to the institutional spaces in this period, the analysis provides more evidences of the beginning of the segregation of San Salvador. In spite of the fact that at the end of this period San Salvador’s institutional uses are mostly concentrated around of its core, it is evident that emergence of a new centroid (Figure 25). It is clear that due to the migration of the elites to the west, the decay of the city’s core was not limited to the decay of the housing areas, but it also included the emergence of new centers of power. This result contrast with Borsdorf, Bähr, and Janoschka’s model which only identifies one city center.

*Figure 25. Sequence of the evolution of San Salvador’s institutional areas during the first urbanization phase.*
The result of the analysis of the commercial evolution shows similar results than those of the institutional evolution. San Salvador went from having most of its commercial activity in the center to develop a secondary nucleus (Figure 26). This trend could have been the result of the migration of the elites to west, the foundation of Santa Tecla or due to the assets (higher elevations, isolation from crowded city, more space to grow, etc) of the this side. In any case, this growth pattern contrasts with the German geographer’s model.

Figure 26. San Salvador’s commercial evolution areas during the first urbanization phase.

The industrial development remains relatively modest. Due to the consolidation of the city as a capital and the coffee production as basis of the economy, the industrial development was relegated. Indeed, the industrial space at the beginning of the twentieth century was of approximately 0.2 square meters. The visual analysis of the animation shows the emergence of an industrial sector to the south of the city (Figure 27). This sector apparently forms a longitudinal polygon similar to the one described by Borsdorf,
Bähr, and Janoschka’s model. Nevertheless, city’s maps from that period did not provided enough evidence to represent other “industrial” areas where handcrafters were located. Thus, due to the little visual evidence, it is not possible to conclude that the industrial development of the city was exemplifying the pattern described by the German geographers.

*Figure 27.* San Salvador’s industrial development at the end of the first urbanization phase.
The analysis of all the land uses together for the case of the town of the first urbanization phase (1820-1920), an analysis of the animation shows mixed result when compared to Borsdorf, Bähr, and Janoschka’s. There are differences rather than similarities between the structure synthesized by the German geographers and the one in the San Salvador animation. For example, there is little evidence of the existence of a longitudinal traditional industrial sector. Flora (2004) and Rodriguez (2002) report that some city neighborhoods were identified based on the economic activity of their inhabitants such as the “handcrafters”. Nevertheless, maps of that time did not depict the location of those “factories”. More importantly, those maps portray a city mostly dedicated to institutional and commercial activities.

In addition, the available data and the chronicles did not describe the spatial distribution of the social classes or the location of the marginal neighborhoods. In fact, San Salvador did not have an evident spatial segregation of social groups (Rodriguez 2002, p 60). From the sequence presented in Figure 28, there is only one evident tendency: the city is growing to the west. This is the result of the beginning of the migration of the elites from the center of the city. That migration could have been the result of the foundation of Santa Tecla, located to the West, to replace the capital destroyed in 1854 by a powerful earthquake. As a result, mesones, resulting from a succession process, started to characterize the housing areas surrounding the center. Thus, to a lesser scale, San Salvador describes some of the tendencies synthesized in Borsdorf, Bähr, and Janoschka’s, although; this is not completely evident from the animation.
In summary, Borsdorf, Bähr, and Janoschka’s model is not relevant for the structural development of San Salvador. In spite of the fact that the shape of the city follows the longitudinal pattern described by the German geographers in their model, a detailed analysis reveal that San Salvador’s development does not exemplifies the structural development on the analyzed phase. At the end of this period, the city’s landscape began to segregate due to the migration of the elites from the center. With this migration, a new centroid emerged. Although there is a clear city center, as they described, the city started to have another pole (Figure 29), one closer to the social groups exerting more power in the city. As a result, San Salvador’s landscape at the end of the first urbanization period does not exemplify Borsdorf, Bähr, and Janoschka’s model.
In the second urbanization period, elites’ migration to the west continued. Due to the steady migration of rural population to the cities, especially San Salvador, the city center became more crowded and the rich families completely abandoned the center. Thus the housing areas became segregated as Borsdorf, Bähr, and Janoschka describe. In this period, Figure 30 shows the presence of extralegal subdivisions (or marginal quarters) which formed a belt around the city center. This resembles the marginal quarter ring include in Borsdorf, Bähr, and Janoschka’s model for this period. In general terms, the housing areas seem to be exemplifying the German’s model; although the visual analysis of the animation does not show the spatial distribution of classes (Figure 30) as described in that model.
Figure 30. San Salvador’s housing in 1965.

The major institutional activities during this period were consolidated in two spaces, close to the old city center and one to its north. The animation’s visual analysis shows the emergence of another pole of activities in the city (Figure 31). Thus, only considering the institutional development of the city, San Salvador was not exemplifying the structural development described by Borsdorf, Bähr, and Janoschka for the second urbanization period. What it is clear, though, it is the polarization of the city.
With respect of the commercial evolution of the city, San Salvador had two poles. The analysis of the animation show that the commercial activities in the city were taken place in two centers: the old center and one located to the west (Figure 32). Considering that elites started to move to the west in nineteenth century, this “secondary” pole seems to be the place where those elites had their business. Thus due to the economic development of the city, San Salvador’s structure for this period did not exemplify the structure described by Borsdorf, Bähr, and Janoschka for this period.
The industrial development of the city shows in a lesser scale, the development described by the German geographers for the second urbanization period. The analysis of the animation shows that there is an industrial strip connected to the old city center (Figure 33). Thus, San Salvador, in this period, followed the structural development described in the model under examination. Nevertheless, this evidence is not enough to conclude that the urban structure of the city exemplified Borsdorf, Bähr, and Janoschka’s.
Figure 33. San Salvador’s industrial spaces in 1965.

The exploration of the geovisualization, considering all the land uses, reports contrasting results. Due to the limited resources dedicated to map and record the changes of the explosive growth of the city during the twentieth century, San Salvador was incompletely recorded through schematic and partial diagrams. However, from those schemes and diagrams, it is possible to identify some tendencies. Figure 34 evidences that the growth to the West continued, but also that the city also grew to the East.

According to Lungo and Baires (1988) several are the factors that generated this growth (p 134). First of all, San Salvador is finally consolidated as core of the political
and economic activities of the country. The traditional capital has expanded its commercial and financial activities, and with them manufacturing companies started to appear. As portrayed in Figure 34, San Salvador’s landscape started to be a polycentric city. The old center has changed from an administrative center to a mostly commercial one, and there is a new pole of economic activities emerging. Considering that elites continued migrating to the west, this new center seemed to be the place where those elites started to exert their economic power. The third area is dedicated to industrial activities, and a third pole started to emerge to the north of the city.

In addition, the liberalization of agricultural labor force, formerly dedicated to Indigo production, resulted in San Salvador becoming the most populated city of the country (Lungo and Baires 1988, p 149). The consolidation of the city as economic and manufacturing center together with an explosive population growth, contributed, Lungo and Baires explain, to the spatial segregation of classes. In the early decades of this century, a middle class started to emerge. Spatially, elites keep migrating to the west; middle and lower income classes started to coexist surrounding the center, and illegal settlements appeared in the outskirts of the city. This is a landscape completely different from the one described by Borsdorf, Bähr, and Janoschka for that phase.

In spite of the fact that this landscape is not completely evident in the animation, it is only helpful to identify certain growth patterns and tendencies such as the polarization and the fragmentation of the landscape. In this sense, the animation is instrumental to a comparison of the shape of the theoretical and “actual” cities. Borsdorf, Bähr, and Janoschka describe a city which started to be characterized by residential
islands, mostly marginal and poor, located outside of the consolidated urban area. San Salvador presents, on the other hand, a segregated, but continuous, area. In spite of the lack of maps to provide more detailed evidence, this certainly contrasts to the urban environment described by the German geographers in their model. However, this assertion is not conclusive due to the schematic map from which is derived.

Figure 34. San Salvador’s urban landscape in 1965 compared to the generalization presented in Borsdorf, Bähr, and Janoschka’s

In summary, Borsdorf, Bähr, and Janoschka’s is not relevant for the structural development of San Salvador in its second urbanization period. In contrast to the model, San Salvador developed in this period different concentrations points or poles (Figure 34). The visual identification of these poles demonstrates that the processes and events affecting this city resulted in a different structure that the one described Borsdorf, Bähr,
and Janoschka’s. Then, this model may be relevant for other Latin American cities, but not to San Salvador in this period.

**The contemporary city**

The analysis of the housing transformations for this period reported interesting results. At the end of the second urbanization period, San Salvador had a belt of extralegal subdivisions around its center. At the beginning of the twenty first century, such belt started to disappear and the extralegal subdivisions spread out the city. Those pockets of poverty have changed; they came from improvised settlements to formalized subdivisions that the city administration now calls developing communities. In the contemporary phase, they are not improved but they are mostly located in the perimeter of the city (Figure 35). Then, they are now forming an outer ring to the city.

This outer ring can be misleading. In spite of the fact that this could be considered as the lower class zone described in the theoretical model, the type of use is different and corresponds to marginal quarters or areas that may include pockets of extreme poverty and areas of in situ accretion. In addition, this new ring is located within other residential areas, to the west within rich neighborhoods and to the east close to the decaying center and other traditional neighborhoods. In order to have a better image of this spatial distribution, it is necessary further research. Nevertheless, this analysis provides the evidence necessary for this research to assert that, based on the data consulted, San Salvador is not exemplifying the spatial distribution of classes and marginal quarters as presented in the theoretical model.
In this period, the institutional spaces spread throughout the city, but there are still some areas where institutional areas are concentrated. As presented in Figure 36, there is an identifiable area close to the old city center. Nevertheless, there are some significant areas concentrated to the east, west, and south to the center. In this respect, exploring the which kind of institutional activity is taking place in those areas would assist in the identification of those areas as new structural centroids. This is due to the fact that these concentrations could be attracting (or depending on) other land uses. Then, they could be forming other city centroids.
In contrast to the institutional spaces pattern, the commercial spaces in the contemporary San Salvador are concentrated in several areas. From the animation’s analysis, it is clear that there are various interconnected poles in which commercial transactions take place. In Figure 37, there are three poles that can be identified: the old center, the north center, and the west one. In addition there are axes connecting those poles and indicating the commercial growth tendency. Considering that the richer neighborhoods are located to the west, this analysis demonstrates the gravitational force of these areas with respect to the rest of the structural elements of San Salvador’s
landscape. More importantly, this analysis demonstrates that San Salvador is not exemplifying the theoretical model.

Figure 37. San Salvador’s commercial spaces in the contemporary city.

The analysis of the industrial spaces of San Salvador shows little industrial activity of the city. Figure 38 shows that San Salvador does not relevant industrial sectors. This is possibly one of the reasons for the differences between Borsdorf, Bähr, and Janoschka’s structural model and the structure of San Salvador. Besides all those processes, catastrophes, and political events which have marked the city’s development,
San Salvador did not consolidate its role until the twentieth century. This may suggest that the industrial activity did not boomed as in other Latin American cities. Then, it has had the influence that these activities over the urban structure of other Latin cities. A detail analysis of the industrial development of the country may provide the evidence to prove this assertion. However, that is beyond the scope of the present research.

*Figure 38. San Salvador’s industrial spaces in the contemporary city*
The analysis of the animation reports similar results to those of the previous period. San Salvador’s urban landscape for this period is visibly polarized, continuous but visibly polarized. Commercial spaces are not longer confined to particular neighborhoods or sectors, similar to what Borsdorf, Bähr, and Janoschka describe in their model. However, the model does not differentiate them based on their importance or nature. In spite of the fact that San Salvador’s old core has remained as a relatively important commercial spot, it has decayed. Currently, it is characterized by consumer oriented small and medium businesses, while the large businesses, banks, and other financial institutions migrated west (Lungo 200, 228), to the richer areas. As a result, San Salvador has an economic center for the middle and lower income classes and one for the elites.

The geovisualization is instrumental to the identification of tendencies such as the polarization and the fragmentation of the landscape. However, a detailed (block by block) and property record analysis may help to draw more conclusive assertions about other elements that may exemplify those described in Borsdorf, Bähr, and Janoschka’s. Until those elements are added, this analysis only reports that San Salvador’s current landscape only partially exemplify the structure corresponding to the contemporary phase of development, as depicted in Figure 39.
Similarly to San Salvador, housing areas were concentrated around the center of the city (Figure 40). Considering that initially the city would allocate the capital of the country, it is possible to assert that the elites settled around the central plaza. In addition, the Indians or servants’ houses were located outside of the city limits. Indeed, after its foundation, Indians common lands and hamlets were separated from the city by a street called the Ronda (Alcaldía Municipal de Santa Tecla 2003). From this, it is possible to infer that within the city limits there were not poor neighborhoods. As a result, the center-outskirt slope represented could not be mapped as represented in the theoretical model.

In contrast to San Salvador, Santa Tecla’s center in its first period of development was used for commercial activities. As Figure 40 presents, the center of the city was surrounded by commercial spaces. The institutional spaces on the other hand were
located around the central commercial area. This may suggest the beginning of the
segregation of the city.

Figure 40: Land uses in Santa Tecla in 1920.
Exploring the land uses together suggest that the case of Santa Tecla is different to San Salvador’s. In spite of the fact that the city was founded in the independence epoch, the first stage of the city’s structural evolution emulates the compact town period presented in Borsdorf, Bähr, and Janoschka’s. Figure 41 presents how the city has a clear core where institutional and economic activities take place. The city presents a clear center surrounded mostly by housing sectors. In spite of the fact that the housing area is not differentiated based on the income or their residents, the basic characteristics and the regular shape of the city seems to exemplify the compact town phase described by Borsdorf, Bähr, and Janoschka, as can be seen in Figure 40.

*Figure 41.* Santa Tecla in 1920, the end of the first urbanization period of a city founded in the colonial period.
The first urbanization phase

As Figure 42 presents, the fragmentation of the city began in this period. The housing areas started to spread out and new subdivisions appeared. These subdivisions turned the shape of the city into an irregular form, and marginal settlements appeared around the city center and in its outskirts. Nevertheless, the city center expanded and consolidated its commercial nature. The institutional spaces, on the other hand moved out of the center, although due to the scale nature of the city, it is possible to infer whether this represents the emergence of a new pole. However, from this figure is clear that the city is residential in nature, probably due to the proximity to the capital of the city.
Figure 42: Land uses in Santa Tecla in 1970.
Due to the proximity to San Salvador and that the city economy was based on coffee production, Santa Tecla did not develop a first urbanization period similar to the one described by Borsdorf, Bähr, and Janoschka. Such a development phase is characterized by a longitudinal traditional industrial sectors and marginal settlements surrounding the city core. As Figure 43 presents, the landscape at the end of the period 1920-1970 is as fragmented as the one described for the second urbanization period. Indeed, Santa Tecla seemed to have the marginal settlements located close to the center of city, as presented in Borsdorf, Bähr, and Janoschka’s. In addition, the city center has expanded and changed its shape.

**Figure 43.** Santa Tecla in 1970, the end of the second urbanization period of a city founded in the colonial period.
Nevertheless, this assessment cannot be considered conclusive because most maps of the city are focused on portray ing generalizations of the land uses and landmarks. Thus mapping land use transitions based on property records may reveal the existence of a first urbanization period similar to that described in Borsdorf, Bähr, and Janoschka’s, or more differences with respect to the second urbanization period.

The contemporary city

The land use analysis shows interesting results for this period. The housing areas have expanded especially to the north of the center (Figure 44). In addition, the extralegal settlements have spread and are not limited to the city limits, a phenomenon described in the theoretical model. Unfortunately, the spatial distribution of classes would have been critical to determine whether the city exemplifies the theoretical model or not. With respect of the institutional land use, the influence of the nearest cities seems to be attracting it, and with it expanding the center to the city to the east. The commercial spaces spread throughout the city and a new commercial pole emerged to the east of the city. The industrial spaces, on the other hand, seem to be forming a spine which run across the urban area, similarly to the industrial strip portrayed in Borsdorf, Bähr, and Janoschka’s.
In spite of the fact that Santa Tecla was founded almost at the end of the independence period, its evolution has followed the structural development of a colonial city. As Figure 44 depicts, the contemporary urban landscape of Santa Tecla describes the fragmentation of contemporary cities. From that image, it is clear that the commercial activities have escaped the central district and the rich neighborhoods. In addition, this city has an industrial sector located inside and in the periphery of the city, an aspect
which is not identifiable in San Salvador. Finally, illegal settlements are located throughout the urban area. In other words, Santa Tecla, besides displaying a compact town period and an urbanization period, emulates the contemporary city similar to the one described in Borsdorf, Bähr, and Janoschka’s model, as can be seen in Figure 45.

These findings are intriguing. The main difference between the hypothetical model and Santa Tecla seems to be the span of each phase. Thus, Santa Tecla clearly presents three evolution periods: a compact phase, a rapid urbanization phase, and a contemporary phase. However, the geovisualization analysis shows that this city has evolved more rapidly than a colonial city may have evolved. This evolution may have been the result of its proximity to San Salvador and the centrality of its location with respect of the rest of the country.

Figure 45. Santa Tecla in 1995.
Envisioning structural evolution: using geovisualizations for exploring urban transformations

Geovisualization tools built for this research were instrumental to the analysis of the urban evolution and the structural development. The role of these animations was not limited to production of the images to illustrate the findings of the analysis; they also assisted with the creation and presentation of a contextualized vision of the evolution, and more importantly, in the identification of the elements of the structure of both cities.

In the analysis of the urban evolutions, Harrower (2003, 2004), Tufte (1998, 2001), Harrower, Griffin, and MacEachren (1999), Harrower and Sheesley (2005), Griffin, MacEachren, Hardisty, Steiner, and Li (2006), Krygier (1994), Edsall (2008), and Caquad (forthcoming) were critical to identification of the structural elements. Following Tufte’s layering concept, land uses were separated and controlled by on/off buttons. These allowed a simple selection (Harrower, Griffin, and MacEachren, 1999) of the land use(s) displayed in the visualizations, and combined with the timeline that allowed focusing (Harrower and Sheesley, 2005) in a particular time period. The navigation (panning, zooming, and re-orientation (Harrower and Sheesley, 2005)) and interactive tools (Harrower, 2003) assisted in micro/macro analysis of the urban landscapes. The application of these concepts helped to identify the emergence and consolidation of “secondary” centers formed by either a migration/succession process or by the gravitational force exerted by surrounding cities.

Although these transformations were noticeable while the animations were in motion, the number of frames used to create the animations disabled the activation of the
“common fate” principle. In the creation of the animations, attention was paid to the speed at which the frames were presented. The lack of data to generate intermediate frames, however, resulted in “incomplete” transitions (time intervals of approximately 50 years without intermediate frames). In other words, the appropriate speed has to be coupled with an appropriate number of data frames (this may vary depending on the period of analysis) to ensure the activation of the “common fate” principle. Thus, it was more effective to pause the animation at a particular moment and compare it with the previous and next frames in order to assess the land uses transitions.

Sound was used to represent variables which have a different temporal and spatial scale that the phenomenon under evaluation (earthquakes, battles, etc), to represent processes whose duration was unknown (reconstruction after an earthquake), to create an emotional and cultural connection between the viewer and the cities, and as a transition indication. Particularly useful was the use of sound for the creation of a landscape that emotionally connected the viewer with the cities and their context and as a cue to indicate that an event was taking place. Thus, the sounds representing earthquakes helped to focus the attention on the evolution process (total area variations) rather than in preventing the appearance or disappearance of the affected zones after an earthquake. To give them greater analytical strength, earthquake sounds were synchronized with written references to synchronous historical events in order to help viewers unfamiliar with the local and national history of El Salvador.
CHAPTER 5: CONCLUSIONS

The exploration of urban structure development using dynamic maps has been instrumental to illustrate the development of the structure of both cities. The following section summarizes the main findings regarding the relevance of Borsdorf, Bähr, and Janoschka’s model and the use of visualizations as analytical tool, and the contribution of visualizations to urban expansion policies.

**Borsdorf, Bähr, and Janoschka’s model and its relevance to San Salvador and Santa Tecla.**

In general, San Salvador and Santa Tecla exemplify some of the elements and phases presented in Borsdorf, Bähr, and Janoschka’s model. In spite of the fact that both urban structures seem to be developing in similar phases to those defined by the German geographers, major differences were found. In the case of San Salvador, the urban landscape started early on to show the existences of various relevant centers. This clearly contrasts with the single center portrayed in the four phases of the analyzed model. In spite of the fact that those centers have been the result of a similar process as the ones described by the German geographers (elite migration, rural migration), their consequences in the urban structure of San Salvador are different. For example, with the migration of the elites to the western side of city, new commercial centers started to appear. In the model, the elites remain connected to the center of the city which coincides with the geographic center of the city.

In addition, Borsdorf, Bähr, and Janoschka described the existence of traditional industrial centers at the end of the first urbanization period. In San Salvador, such a
sector did not clearly appear until the city consolidated its role as the political and economic center of the city. Even in the contemporary period, the industrial sector is not as visible as in Borsdorf, Bähr, and Janoschka’s model. This may result from the fact that the industrial functions of the metropolitan city are located in peripheral cities rather than in San Salvador, its core.

Another element ignored by the German geographers and include in this research is the consideration of environmental events such as earthquakes. In spite of the fact that the temporal scale of these events (minutes or seconds) is different to that used to explore the urban evolution (years), their inclusion in the geovisualization help to recognized that earthquakes slowed the evolution of the city especially in the first and second period of evolution. Their effects in the city, though, did not depend only in their magnitude and the location of their epicenter, which was not included in this analysis, but in the construction system used in those periods. For this reason, the influence of earthquakes in the development of the urban structure cannot be generalized by saying that earthquakes slow the structural development. Indeed, it may result in the permanent abandonment of some urban areas as the city continues to growth in other areas.

Aspects such as these are ignored in Borsdorf, Bähr, and Janoschka’s model. The fact that this model does not considered the influences or relationships with other cities hindered its relevance. This limitation is evident in the analysis of the development of the structure of Santa Tecla. In spite of the fact that this city was founded almost at the end of the independence period of the country, the influence of other urban centers exerted enough pressure to make it develop its structure in less time. As a result, in 1995 the city
presents a fragmented landscape similar to the one described in Borsdorf, Bähr, and Janoschka’s model.

The use of geovisualizations in urban structure analysis.

One of the most important findings in this respect is the potential of animations to assist in the analysis of urban structure at two levels: the individual level, to investigate how urban structure changes specifically for each city, and the general level, to investigate how those structures relate to existing models. In other words, geovisualizations simultaneously provide insights about the actual structure of the cities and about its relation to conceptual ones. More importantly, the insights are not limited to structural development models. Indeed, the animations revealed the consolidation of the city center and other relevant sectors whose further analysis may assist in gentrification projects.

In addition to this, using a geovisualization has been critical for the individual analysis of the land uses. The separation of the land uses in layers was instrumental to focus the attention to the transformations of each land use. For example, the individual analysis of the land uses help to identify the emergence of other hotspots. These elements were not clear, when the land uses were explored all together, because of the size of some of the polygons and the difficulty to differentiate them among polygons.

In spite of this, the data layering also resulted in a larger file size which hinders the performance of the geovisualization. As a result of the file size, the geovisualization interfaces may perform poorly depending on the Internet connection and the system characteristic of the computer terminal where the animations are viewed. This limitation
may have significant effects on the viewer experience because it may limit the data manipulation and exploration.

Another significant element is that the creation of multiple intermediate and detailed frames is still labor intensive. In the production of the animation of both urban evolution most of the time was spent in the creation of the multiple frames and polygons which would smooth out the representation of change through time. Even though this can be solve by using automatic models, this can produce frames which do not considered important political events economic.

The unavailability of data hindered the analysis of the urban expansion. The limited access to the records of the subdivision archives did not allow an accurate representation of the urbanization process. In fact for both animations, this process was hypothetically created based on the maps which registered the urban expansion for particular time instances. As in the case of the land use transition, the incorporation of more elements may lead to identification of more features of urban structure.

This limitation has also significant implications in the use of visualizations in the delineation of urban expansion. Due to the fact that subdivisions were not animated based on their year of construction, these animations do not contribute to the exploration of alternatives to manage and control the growth pattern that these cities are following. For this reason, it is fundamental to incorporate in the database created for this research the temporal dimension of the subdivisions. Then, the urbanization process can be appropriately portrayed and the potential policies can be envisioned.
Finally, the use of sound for this type of analysis requires further consideration. Due to the fact that each land use has a different soundtrack, the exploration of all of them together with all the sounds playing can be confusing and misleading. In addition, the speed of the animation limits the use of sounds when these are synchronized with the events and changes being animated. Thus, more research has to be done to find a frame speed that preserves the common fate principle and allow the creation of an appropriate soundscape.

Implications of the Research

This thesis is a response to the relatively extensive use of automatic models for exploring urban transformations. Almost forty years after the first dynamic visualization of urban growth, the use of animations for exploring urban processes remains relatively low. This research contributes to the visual exploration of urban processes through dynamic visualizations which use envisioning, animation, and visualization techniques. It exemplifies the use of dynamic visualizations for exploring, understanding, and synthesizing urban structures, considering innovative approaches including the potential to use sound as a representation variable.

With respect to urban structure models, the proposed research is not only limited to exemplify existing urban structure models for Latin American cities. This research also provide evidences for Crowley’s criticisms of previous models their limited use of graphic values (point, lines, and areas). Sound not only trascends “traditional” graphic variables, it may also enhances the viewer’s understanding of the urban landscape of Latin American cities. Crowley also criticizes that the cultural background of the model
makers affects their representation of the Latin American urban landscape; if so, my cultural background will improve the analysis and visualization of the urban structures studied in this project. Thus, this thesis will provide some insights about the understanding and representation of unregulated and unplanned urban landscapes.

Finally, this research represents the development of the first urban structure analysis for any city in El Salvador. It also contributes to existing studies to understand and improve the urban expansion management of the metropolitan area of San Salvador. By analyzing the transformation of the urban landscape of San Salvador and Santa Tecla due to the political and economic changes, this thesis may provide some recommendations for improving the city’s urban expansion management.

Further considerations

This research constitutes a challenge to continue in the investigation of the urban structure or less developing countries through geovisualizations. In spite of the potential demonstrated for this analysis, additional elements could be incorporated. For example the animations did not include insets that could have presented more details, or even animations at different spatial and temporal scales. In addition, these animations did not include important elements such as reconstruction and gentrifications projects. These elements may provide insights to how the urban structure is transformed by these projects. And finally, what will the next phase the structural development be for San Salvador and Santa Tecla? This research is the starting point for exploring the relevance of geovisualizations in the prediction and management of urban growth.
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