Four Dimensional Approach to Center City Transformation: A case study of Knoxville, TN: 1884—1950

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DEDICATION

This thesis is dedicated to my mother, father, and grandmother. Without you love and guidance, I wouldn't be the man I am today

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ABSTRACT

Urban morphological models were created to enhance our understanding of urban growth and form. Prior to Geographical Information Systems (GIS), these models were supplementary products of ideas and concepts that set out to explain the spatial configuration of the urban landscape. While these models are of great importance to the field, they are mostly two-dimensional (2D) and static. Three-dimensional (3D) modeling has strengths in landscape visualization, manipulation, and planning, where analyses of historical urban landscapes may be carried out efficiently and thoroughly. A method that utilizes 3D modeling through time or four-dimensional (4D) modeling will enhance our understanding of transformation of a city's center. Consequently, the primary objective of this study is to demonstrate how 4d modeling may enhance our understanding of the changes in urban structure and form, i.e., morphology, of Knoxville, Tennessee from 1884 to 1950. This period from 1884 to 1950 captures Knoxville's early metropolitan era, in which technological innovations such as the steel frame building and the automobile arrived, dramatically influencing Knoxville's urban landscape. A time series of five Sanborn Fire Insurance Maps from between 1884 to 1950 of Knoxville's central business district (CBD) were digitized into five 3D models. Through the results and discussion of this thesis, I found that the general forces that influence center city transformation in most American cites between 1884 and 1950 are definitely prevalent in Knoxville's urban morphological story. With this in mind, it is safe to assume that this method could be utilized for observing the vertical change of all American CBD's.

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CHAPTER 1: INTRODUCTION

The Central Business District (CBD) has come to be known as the heart of the American city. It is often characterized by its tall buildings, high population concentration and diverse services; all working together to make the center of the city an economically efficient engine (Murphy, Vance, and Epstein 1955). With the primary objective of the CBD being to generate and maintain wealth, the spatial configuration of buildings and services reflects its urban morphological story. This is a story that changes and transforms as more economically efficient innovations are added to it. While there has been an abundance of urban morphological research on the spatial configuration of building and services within the entire city (Burgess 1928; Hoyt 1939; Harris and Ullman 1945), there has been less research done on the spatial arrangement of these elements in the center of the city. Some of the blame can be attributed to the lack of technological and methodological capabilities. For example, two-dimensional maps were utilized to carry out the initial studies in urban morphological research. While the concepts are set it in stone, we are able to address the models that are in dire need of an update utilizing modern geographical technology such as Geographic Information Systems (GIS) and three-dimensional modeling (3D).

Understanding the complexity of urban morphological theories, urban investigators often created visual supplements to assist in the comprehension of their ideas. Dating back to the late 19th century (Von Thunen 1825), these visual supplements, or models, were by-products of ideas and concepts set out to explain the spatial configuration of major aspects of the urban landscape (Knox 1993). America's most prominent urban morphological models all tend to focus on land use. During the mid-20th century, American urban sociologist, geographers and planners set out to explain what had become our American urban landscape (Harris and Ullman 1945). The strength of these models lie in their ability to generalize urban structure as well as contribute insight on future growth and structure within most American Cities.

While these models have a great amount of utility in understanding urban morphology, they have visual shortcomings that have yet to be addressed. The first shortcoming of these models is their static nature. With the CBD being one of the most dynamic environments within the American urban landscape, a single snapshot in time of a city only tells a miniscule portion of the entire morphological story. The second shortcoming of these models is that they are primarily two-dimensional. The most distinguishing characteristic of the CBD is its tall buildings. These massive structures provide diversity and uniqueness in the look of the American urban landscape. However, this distinguishing aspect is negated by geographer's overutilization of maps (Smailes 1955). While these models have been scrutinized for many years, their visual shortcomings have yet to be addressed.

In this thesis, I will address the visual shortcomings of these city models utilizing a four-dimensional approach to urban morphology. A four-dimensional approach consists of three geometric dimensions with time being the fourth. Geographic technology such as GIS and 3D modeling give us the ability to go back in time and address the issues that past visualization technologies could not. 3D models are able to simplify complicated concepts and convey complex relationships that are difficult to visualize from two-dimensional illustrations. Concepts and ideas, which cannot easily be represented through two dimensional city illustrations, can be easily created and viewed from different angles providing a host of different perspectives and insights in the CBD. These abilities combined with time offer the ability to observe the transformation of the spatial relationships and structures of the CBD.

Knoxville's central business district in the time span of 1884 to 1950 serves as a legitimate study area and era for my four-dimensional approach to depicting CBD transformation. Knoxville's downtown area has a rich history and has undergone dynamic changes throughout its existence. These changes have led to an interesting urban morphological story. The time span of 1884 to 1950 captures the waning of Knoxville's preindustrial era and the dawning of its metropolitan era, which indicates its transformation from a town to a city (MacArthur, 1976). A major catalyst to this transformation was the very impactful technological innovations that arrived in the southern city during this era. Innovations including the steel frame building and the automobile, both of which heavily impacted the structure and function of the city. Fortunately, most of these urban morphological transformations have been captured in Knoxville's historical Sanborn Insurance Map collection. These maps will serve as my historical data source, as well as the foundation of this thesis.

The primary objective of this thesis is to tell the urban morphological story of Knoxville's CBD utilizing GIS and 3D modeling as my primary tools. This leads us to ask the question, "*How might 3D modeling through time or 4D modeling enhance our understanding of CBD transformation?*" I will address this question through a comparative time series analysis focused on the amount of change that has occurred within the center of the city. To gauge this change, I will be observing volume and area as my primary determinates. Firstly, I will provide a literature review focused on the drivers behind CBD transformation. Secondly, I will explain the methods and analyses used to reconstruct Knoxville's CBD in 3D. Lastly, I will present the results from the analyses and discuss Knoxville's historical influences that shaped the presented Sanborn model.

CHAPTER 2: LITERATURE REVIEW

2.1 Shaping and Modeling of the American CBD

Many sociologists, geographers, and other urban researchers have tried to develop a general list of spatial characteristics that define the CBD, but this has proven to be a very difficult task. The complication lies in the CBD's fragile urban fabric, dynamic land use patterns, and the constant construction and destruction of buildings, all driven by a host of centripetal and centrifugal forces. However, there are some common influences emphasized throughout CBD literature that provide some explanation to the transformation of the American urban landscape. This literature review discusses how high land values and transportation innovation influence center city transformation in respects to the spatial configuration of services, as well as the volume of the buildings and land use of Knoxville's CBD.

High Land Values

In American cities during the early 19th and late 20th century, centrality was valued for a multitude of reasons with the most obvious being accessibility. The center of the city provides land renters with the ability to serve the entire city. This acts as a centripetal force attracting the most lucrative and vital services that thrive of the need for centrality. Besides this key aspect of the CBD, other price determinants of land include size and potential utilization. However, Vance and Murphy found that there was another driver that was contributing to land value in the center. (1954). They called it the *front-foot value, which is* an appraisal method that bases the price of a commercial property on the commercial importance of the road that the front of the building is facing. For this reason, the relative values of lots are more dependent upon their business street frontage, than upon their size (Murphy and Vance 1954).

With a centripetal mechanism of change now put in place, I will now review the two physical aspects upon which high land values had the greatest influence, i.e., land use and building height.

Land Use

In 1964, William Alonso developed a theory that explains how the supply and demand for real estate changes as one increases their distance away from the CBD in his famous book titled "Location and Land Use" (Alonso 1964). While his theory is based off the previous work of von Thunen's theoretical attempt to understanding the relationship between location and land uses within geographic space, his work distinguishes itself by focusing on the location of land uses within the urban landscape (Von Thunen 1825). Alonso's theory begins with the projected amount a renter will pay. This is called the *bid rent*. The bid rent theory implies that as businesses increase their distance from the CBD, the amount in which the business will pay for the land will decrease depending on the service (Alonso 1964). For example, he found that most industry and manufacturing businesses were found in the periphery of the CBD. The CBD core was occupied by retail and highly lucrative occupations that thrive off the need for centrality and could operate efficiently with a small portion of land. However, by surrounding the CBD, these industries and manufacturing businesses are still able to reap the benefits of centrality. While Alonso's theory has many critics, that will be discussed in deeper detail later, this theory exemplified the economic stratification that land values imposed on land use. Additionally, Alonso (1964) provided a clear and concise model of this relationship as depicted in Figure 2.1.

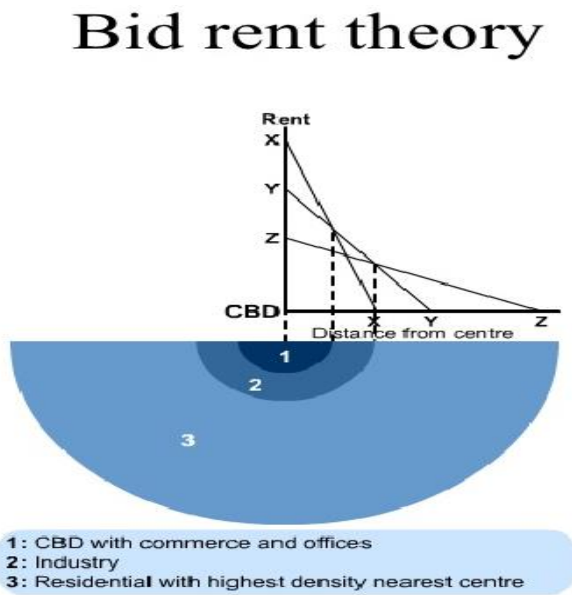

Figure 2.1: William Alonso's bid rent curve model (Yater, 2013)

While the concept of Alonso's (1964) work is very meaningful at the city scale, it can also be applied to the internal structure of the CBD. Prior to the publication of "Location and Land Use, two scientists by the name of James Vance and Raymond Murphy set out to explain the internal structure of the CBD (Vance and Murphy, 1954). By comparing the internal structure of nine CBDs, they were able to derive the general characteristics and spatial arrangement of land uses within the American CBD.

Vance and Murphy's research led to the realization that the spatial structure of the American CBD functions like bid rent theory, but at a smaller scale. In the center of the CBD lies the peak land value intersection (PLVI), where land prices are the most expensive. By placing four concentric zones around the PLVI, each increasing by 100-yard increments, Vance and Murphy were able to identify the most common land uses within each zone, as well as delimit the boundaries of the CBD. What they discovered was the same economic stratification of land uses based on the distance from the center as found in Alonso's model. (Murphy, Vance, and

Epstein 1955). Moreover, they were also able to calculate the rate at which the land value decreased from zone to zone (Murphy and Vance 1954). Their observations of these general spatial characteristics of the CBD led to the creation of the core frame model of the general structure of the CBD as seen in Figure 2.2 (Murphy and Vance, 1954).

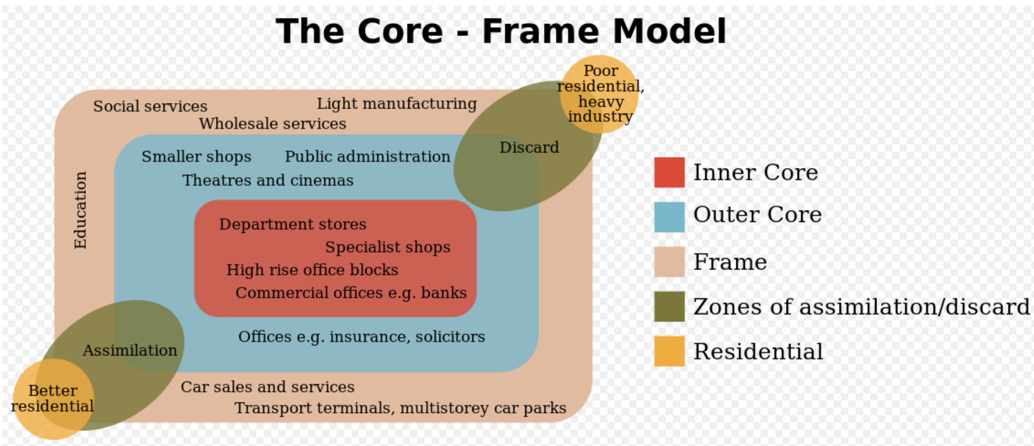

Figure 2.2: Vance and Murphy's Core Frame Model (Yater, 2013)

Even though these models provide a coherent logic behind the spatial structure of land use within the CBD, they come with some very critical assumptions that challenge the legitimacy of the underlying theory. It important to understand the assumptions of these theories so one may understand some of the real world aspects that were not taken into consideration. The first assumption of these models is economic competition for the center of the city. This competition is driven by the supposition that all land bidders are motivated by profit. The second assumption of these models is that the city of interest is isolated. This means that there is no external trade coming in or out the city. The third and final assumption is that the land is on an isotropic plain or perfectly flat land. This assumption negates the influence of geography in the choice of service location.

Building Height

Tall buildings are one of the most distinguishing characteristics of the American CBD, as well as high land values. With the increase of white collar jobs in the early 20th century, the need for business and office space increased as cities became more business oriented (Fogelson 2003). Early solutions to this problem included the expansion of cities through the zone of discard but this resulted in rapid sprawl throughout many American cities. Taller buildings seemed to solve all problems related to the need of space. Building vertically allowed property owners to create space while also increasing the rental value and profit potential of their land. Even though building vertically seemed to solve all of the problems of the spatial scarcity within the CBD, there were also some disadvantages: such as an abundance of space and depreciation of peripheral land values that were not taken into consideration. (Fogelson 2003; Tunnard 1956). This leads us to understand the history of building construction and its effects on the utilization of space within the central business district.

Building construction technology is a key element in understanding how the spatial scarcity problem of the CBD was solved. Prior to the 1885, building height was limited. This restriction was caused by the slow technological advancement of masonry techniques. To construct new heights with brick or concrete, the foundational walls of the building had to be extremely thick in order to support the massive amount of weight and materials that were at its base (Tunnard 1956; Fogelson 2003). The instability of these materials led to many of the buildings first floor space to be substantially smaller than the rest of the buildings floors.

Utilizing these techniques and materials, buildings were limited to up to only four to five stories. This building height sufficed until American cities began to encounter economic booms after WWI, increasing the importance and function of the CBD and requiring more space (Knox 1993). In 1885, William Le Baron Jenney responded to this need for space in the CBD with his design of the metal frame building (Tunnard 1956; Swenson 2014). The frame was comprised of cast iron columns supporting wrought iron beams, together with two floors of rolled steel beams that were substituted during construction (Swenson 2014). The steel frame made buildings much lighter and gave builders the ability to build much higher, creating an abundance of space within the CBD.

The introduction of the "skyscraper" brought many benefits to the American CBD. First and most importantly, they created an abundance of space within the center of the city to supply the growing need. With buildings shooting upwards of ten to twelve stories and the capacity to house thousands of tenants, skyscrapers were able to centralize office work and slow down sprawl by the turn of the century. Skyscrapers also had the ability to consolidate a host of different utilizations under one roof (Tunnard 1956; Fogelson 2003; Knox 1993). In his novel, *Cliff-Dwellers*, Henry Fuller explains how skyscrapers had become "cities in themselves", addressing the diverse array of utilizations within some of these massive buildings in Chicago. "A tenant could eat, drink, have a haircut, obtain legal advice or consult a real estate broker without leaving the building" (Fuller, 1891). Lastly, skyscrapers increased the ability to capitalize on a relatively small plot of land. This increase in rent often raised the rent for the surrounding buildings as well causing them to either compete by also building vertically or close their business.

While skyscrapers solved the spatial scarcity issue of the CBD, they also presented problems within it as well. Once the constructions of the skyscraper was mastered, they were rapidly produced in larger cities; often resulting in a surplus of space. This surplus of space created in the inner core of the CBD resulted in many of these building losing millions of dollars in their massive investment (Fogelson 2003). Once the buildings were filled, they created a very high concentration of business in a very small place. As a result of this phenomenon, the land values of the outer CBD were greatly devalued (Fogelson 2003; Knox 1993; Tunnard 1956).

Transportation

The second most prominent CBD-shaping influence is transportation. Prior to introduction of transportation innovation, the compact monocentric city was almost a necessity. With walking being the most common way of travel, most transportation of goods and services were transported by hand or horse cart (Knox 1993; Yeates 1989). This lack of efficient and faster transportation led to the geographic extent of most American cities being controlled primarily by the distance people could walk to their services. However, with the arrival of the railroad in the mid-19th century, the internal structure and overall environment of the CBD changed drastically. As most of the literature discusses, the arrival of the railroad increased interurban connections, causing economic booms for many cities (citations?). However, along with these obvious benefits came population booms that the compact urban fabric was not ready to handle causing many problems ranging from epidemics to extremely high crime rates. With this influx of undesirable characteristics in the downtown area being caused by rapid urbanization, the central business district needed what Adna Weber called a "decongestion" (Weber 1899). This part of the literature review focuses on how innovation of transportation acts as a centrifugal force upon the American CBD, as well as how it shapes the city around it.

Street Car

The idea for an efficient intra-urban transportation system began with the streetcar's predecessor, the omnibus. The omnibus was a stagecoach on rail that was pulled by a horse or mule. The omnibus first emerged in the 1830's but wasn't widely implemented in cities until the 1860's (Fogelson 2003). Knoxville's first omnibus was built along Gay Street in 1876 (Gray and Adams 1976). With transportation being based on animal labor, omnibuses tended to be extremely slow and unreliable. Fortunately, this was an innovative era in which gaslight, steel frame construction, elevators and most importantly electrification, all were adopted into the American urban scene (Knox 1993). The first electrified omnibus system emerged in Richmond, Virginia in 1888 under Frank Sprague, who once worked under Thomas Edison (Knox 1993). To put in perspective how innovative the electrification of the streetcar was, in only three years, over 200 streetcar systems that were managed by approximately 800 companies operated 32,000 streetcars along almost 6000 miles of rail in different cities (Knox 1993; Yeates 1989; Fogelson 2003).

With the mass consumption of these streetcars in the American urban landscape, cities began to annex surrounding lands at an astounding rate (Yeates 1989). These streetcar systems tended to extend from the center of the city in a hub and spoke pattern, often surrounded by commercial development. The abundance of residential land within these newly annexed neighborhoods combined with Henry Whitney's nickel fare approach guaranteed residential decentralization of the middle class to what came to be known as the streetcar suburbs

(Warner 1978). These streetcar suburbs were created by developers who were able to capitalize on the plethora of cheap land that lay between the radial patterns of the streetcar rail system (Knox 1993; Warner 1978). It is important to realize that streetcar suburbs did not increase the population, but restructured it based on socioeconomic status.

With this mass movement of middle class residents to the peripheral areas of the city, there was an abundance of space and infrastructure available in the center of the city. This led to the reassignment of many structures within the CBD, along with the specialization of the high order offices and shops that hadn't left for a less competitive area along the railway system. In most cases, residential buildings were often transformed into a more commercial use such as retail or a service (Knox 1993). This reassignment of buildings provided CBDs with the opportunity to diversify by providing smaller shops and businesses with space, which made the CBD more appealing to the general public. Also, the street car also increased the importance of CBD due to the fact that all the streetcar rails were extensions of the central business district. To go anywhere, you had to go the center of the city.

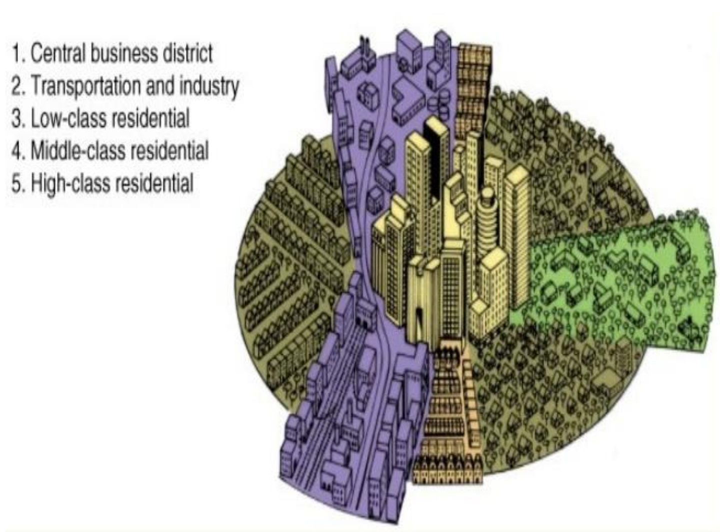

Figure 2.3: Homer Hoyt Sectorial Land Use model (Yater, 2013)

With the impact of the streetcar being so prominent, it changed the way many urban geographers looked at the structure of the American city. With a change in perspective, comes a change in models. To take into account the major influence in which the streetcar had on the structure of the city, there was the arrival of Homer Hoyt's Sectorial model seen in Figure 2.3 (Hoyt, 1939). The model was derived from an assignment that Homer Hoyt received on behalf of the Federal Housing Administration in 1939. Based on his observations and a comparative analysis of 142 cities, he created this model (Hoyt, 1939). As one can see in this model, economic sectors of the city are still stratified. However, the stratification of the city is now guided by what Hoyt calls the "communication routes" of the city (Hoyt, 1939).

Automobile

At its peak, the streetcar dominated intra-urban transportation as well as guided suburban growth away from the CBD for much of the 30 years after its emergence. However, during the 1920's, riding alongside it in the streets of many cities was a technological innovation that would eventually lead to the streetcars extinction in the mid-20th century. This technological innovation was the automobile. Like the streetcar, the automobile was slowly adopted in the American urban scene because of its unreliability in its early innovative period, but once it became efficient, mass produced and affordable to the middle class, it was consumed at a rapid rate. According to Paul Knox, "there were four motor vehicles in use in the United States in 1894, 16 in 1896, 8000 in 1900, 9.24 million in 1920 and nearly 27 million in 1930. (Knox 1993)

Now that the middle class had the ability to travel freely throughout the city, American CBDs began to experience rapid decentralization of services in the early 1920's. The automobile dominated the streets of the CBD because many had stopped utilizing public transit by the 1920s, even though they were a very inefficient mode of travel within the CBD. Automobiles consumed more space than the walking pedestrian and carried less than the street car. These characteristics, combined with the slower modes of transportation that also occupied the road, caused horrendous gridlock traffic in the CBD during the 1920s. This aspect alone made the CBD very unappealing to consumers and hurt businesses within the CBD. However, as the economist Ernest M. Fisher stated during this time: “There is no valid reason for the concentration of a large portion of the economic function now focused at the center of urban areas” (Fogelson, 2003). Businesses had figured out that they could be just as efficient and profitable by placing their services near their consumers now that the automobile was an unrestricted mode of transportation. This rapid decentralization of services caused land values to plummet within the CBD, causing city governments to panic. To slow the rapid decentralization, they responded with new infrastructure in the form of the parking garage. The parking garage was created based off the notion that the more accessible the CBD, the more people would come. However, the parking garage only solved one of many problems that occurred in the CBD caused by the automobile.

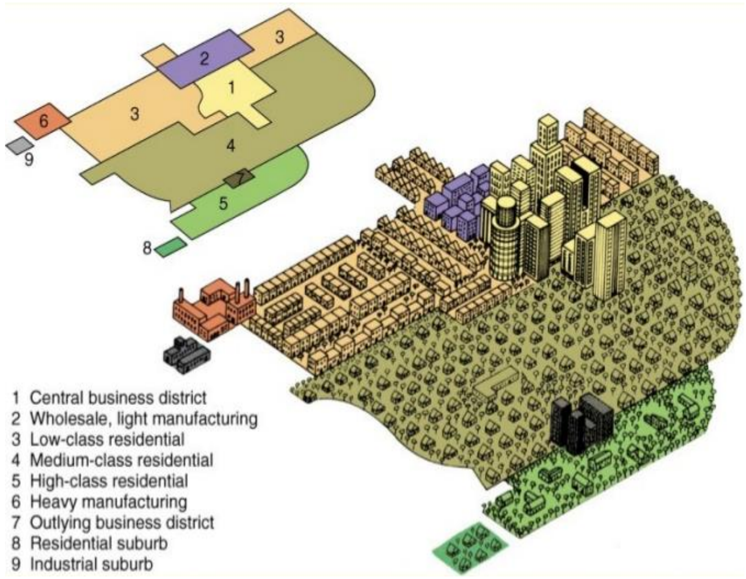

Figure 2.4: Ullman and Harris Land Use Model (Yater, 2013)

Like the streetcar, the automobile also had a major impact on the way urban researchers thought about the city. With the center of the city being stripped of most of its services, many American CBD's responded by specializing in a particular function or services, thus broadening already immense amount of diversity within the American urban landscape. Despite this diversity, in 1945, Dr. Chauncey Harris and Edward Ullman devised a general theory that observed the spatial arrangement of land uses throughout the city. In their paper, "The Nature of Cities", Ullman and Harris explain that the CBD was still the center of the city. However, through the innovation of transportation, function-based nodes form in the city based on the needs of that function (Harris and Ullman 1945). Certain functions attract particular uses while repelling others.

2.2 Solutions to the Shortcomings of Urban Morphologic models

Static Nature

Understanding the complexity of urban morphological theories, urban investigators often created visual supplements to assist in the comprehension of their ideas. Urban morphologic models date back to the late 19th century and are utilized in all disciplines that study the urban realm. These two dimensional representations of urban space are products of theories in ideas that set out to explain the spatial configuration of space while also “freezing time” or negating the dynamics of change. With this vast variety of urban components, came a vast variety in urban morphologic models based on the urban aspect of focus, as well as the expertise of the respective disciplines. For example, geographers and sociologist tended to refer to models that set out to explain the utilization of space, while foundational architects tended to produce models that focused on the more tangible aspects of the urban landscape, such as buildings, plots and streets.

In spite of these attempts to generalize a very diverse urban realm, there are some shortcomings that recent technology and new analysis techniques have the ability to address.

One shortcoming of urban land use models is their static nature. These models display a city at a particular time that only tells a miniscule portion or snapshot of the entire morphological story. Even though these models were derived from an abundance of observations through time, they attempt to generalize their observations in a single illustration that may leave out key elements to that cities story. With urban morphology’s prime objective being to understand the form and structure of the city, it only seems legitimate to understand the entire story, rather than a single portion (Marshall and Çalişkan 2011). This leads us to propose a historical time series analysis on the city of Knoxville.

Time series analyses are the foundation of historical GIS research. These analyses are most efficient when researching very dynamic aspects of the historical environments, such as urban morphologic change. To conduct these types of analyses, the integration of history and GIS is a necessity. Historical GIS is an emerging field birthed from the quantitative and visual needs of historians to support their contextual inferences. GIS provides historians with the ability to “re-examine historical interpretations as well as illuminate historical events that I could not otherwise grasp so well” (Knowles 2005). With the many benefits that GIS provides to historical research, GIS enhances time series analysis in many ways. The first being that it gives historians the ability to revisit accepted knowledge with statistical backing as I will be revisiting the generalization of models (Gregory and Healey 2007). GIS also enhances time series analyses by providing historians with the ability to answer unresolved questions about geographical change over time. This aspect opens the door for historians to go back and observe aspects that they couldn’t due to technological limitations. This door is slightly closed by the fact that historical data sources are hard to come by depending on the research (Gregory and Healey 2007). With these benefits in mind, I wish to conduct a time series analysis on the central business district of Knoxville, TN from 1884-1950.

Two Dimensional

Another shortcoming of urban land use models is that they are two-dimensional (2D). Dr. A.E. Smailes recognized that most models that were being created were contemporary. Dr. Smailes felt geographers were becoming too consumed with 2D maps, that they limited the potential of geographical research, and that geographers would rather study a map of an area instead of the actual area itself (Smailes 1955). Dr. Smailes suggested "Urban morphology, however, is not merely two-dimensional in scope. On the contrary, it is through the special importance which the third dimension assumes in the urban scene that much of its distinctiveness" (Smailes 1955). During Smailes' time, 3D modeling had not fully evolved and there were few attempts at it. 3D modeling emerged in the 1960s in attempts to find a theoretical ground to address the conjectures of the urban environment. Photomontages, architectural parse drafting, and conventional wood block models were the first endeavors into 3d modeling, but these methods were extremely time consuming and labor intensive (Shiode 2000). It wasn't until the emergence of GIS that 3D modeling became increasingly more time efficient and powerful in functionality (Shiode 2000).

To address the two-dimensional shortcoming of these current models, I look to the strengths of 3D modeling. The urban environment is undoubtedly 3-dimensional and it seems only right to study it in that fashion. The strength in 3D models lies in their ability to simplify complicated concepts and convey complex relationships that are difficult to visualize from 2-dimensional illustrations by providing a virtual environment that users can interact with. While most of these models are utilized for planning purposes, they have the potential to be of great utility to urban morphology, as suggested by successes in historic preservation studies (e.g., Pavelka 2002; Edwards 1998) and urban growth/change analyses (Decker 1993; Holmgren, Rüdiger, and Tournay 2001). In this thesis, I have developed a time series of 3D models (or 4D models) to display the change and growth within Knoxville, Tennessee's CBD

The CBD is one of the few places within the American landscape where the third-dimension is essential to understanding the dynamics of its growth. Because space is at a premium in this area, building volume is very important. This leads to not only a focus on the 2D or areal growth of the landscape, but also on its 3D or volumetric growth. Now that we have the 3D technology to do this, it is necessary to revisit these past concepts and strengthen them by providing quantitative support.

CHAPTER 3: GIS RECONSTRUCTION OF KNOXVILLE

3.1 Sanborn Maps

An integration of historical data and modern geographic technology requires a legitimate and reliable data source. The data source is of great importance in this type of research due to the subject of the analysis. Therefore, it is safe to say that a historical GIS database is only as good as the data source. Taking this heavy reliance on a trustworthy source into consideration, the historical Sanborn Fire Insurance maps serve as a legitimate source for urban morphological analysis. The historic Sanborn maps are some of Americas oldest and detailed historical urban representations as well as the foundation of this thesis.

Dating back to the 1860s, the Sanborn Fire Insurance Map collection extends to over 12,000 U.S. towns and cities containing over 660,000 maps (Proquest, 2014). These hand drawn fire insurance maps were originally compiled to help insurers assess the value of property, highlight potential risk factors, and underwrite losses. They also proved to be of great value to government agencies, commercial utility companies and banks due to their unprecedented detailed portrayal of street patterns, lot shapes and sizes, and individual building information (Lamb 1961; Ross 1971; Sauder 1980). Adding to their commercial and business fame, the Sanborn Maps have also gained a great amount of academic prominence from urban researchers who seek a better understanding of urban processes and transformations. These maps have been utilized in many urban studies ranging from population calculations to historical reconstruction (Applebaum 1952; Lamb 1961; Ross 1971). In this thesis, they are the foundation for the geographical database that will be utilized to recreate the historical urban landscapes of Knoxville's CBD.

It is clear to see that the Sanborn maps are a legitimate data source for historical urban morphologic research, however, these maps still have their analytical limitations. In his critical review of the maps, Dr. Robert B. Lamb addressed four shortcomings that researchers should take into consideration before setting up their analysis (Lamb 1961). The first involves non-existent distinction between vacant land and non-structural land use. The issue is very prevalent within the earlier years of Knoxville's Sanborn collection. However, large parcels of land that contain no structures, such as parking lots, parks, and vacant land are labeled in the 1903, 1924 and 1950 maps, specifying it's use or potential use. The second limitation and most relevant to this thesis, is the difficulty in distinguishing the multiple uses of multistory buildings. In Knoxville, multistory buildings often contained multiple uses. Along Gay Street, where most of the multistory buildings were located, retail would occupy the first story while the remaining stories were occupied by businesses that could afford the expensive space. There are some cases where each story is appointed a use, but unfortunately, this is only true when a fire hazard exists. The third shortcoming is the fact that the Sanborn maps do not cover sparsely settled areas. In the 1884 Knoxville Sanborn collection, only the eastern half of Knoxville's CBD is mapped due to this issue, thus this map series was omitted from volumetric and land area comparative analyses. The last shortcoming involves the Sanborn's inconsistency to provide building ages. Unfortunately, only buildings that were fireproofed or buildings that held considerable historical value were dated in the margins of the maps. Despite these four limitations, these maps still are the most accurate and detailed portrayal of Knoxville, Tennessee in the time period of interest.

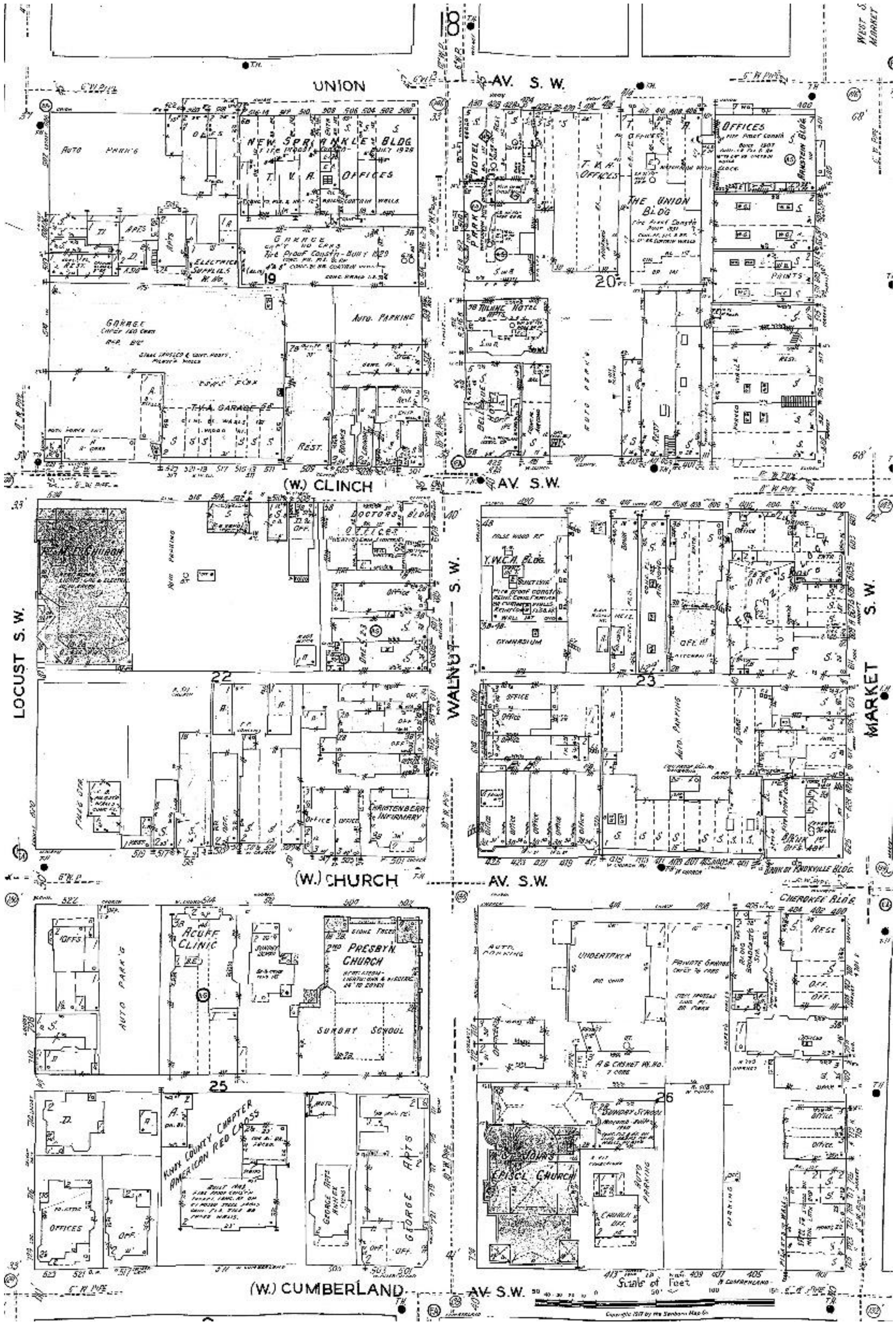

Figure 3.1: ***Example of a typical Sanborn Map Sheet. These maps are extremely cluttered with information about each building ranging from construction material to fire alarm systems.***

Map Processing

The University of Tennessee-Knoxville's digital library holds a vast majority of the historical Sanborn maps for the state of Tennessee. Organized by city and year, Knoxville's archive consists of five volumes; 1884, 1890, 1903, 1924 and 1950. These years serve as historical urban "screenshots" of Knoxville's central business district. Depending on the year, approximately 8 to 12 maps were downloaded in portable document format (PDF) from the Proquest server to cover the entire central business district of Knoxville. The number of sheets required to cover the study area varied seeing as the Sanborn Maps came in different sizes based on the amount of development in a given area. Maps with dense land parcels tended to cover smaller areas (a single block), while sparse land parcels tended to cover entire sub regions of the CBD.

In order to be imported into the ArcGIS software, these PDF images first had to be transformed into geo-tiffs. The PDF's were transformed in GIMP, a free image-processing program. To keep the print legible, the TIFF resolution had to be increased to 1000 dpi. This increase in DPI made the file size large but was necessary to preserve the legibility. Before any information was extracted from any of these maps, the maps were first registered to ESRI's world imagery base map. This imagery served as a legitimate reference map due to Knoxville's CBD having an unchanging grid reference. With the street patterns being the most enduring and resilient aspects to urban transformation, street intersections were used as geo-referencing points. Close attention was paid to street names and widths (which is documented within the Sanborns) to ensure that the points were located to the corresponding street corner. The root mean square error (RMSE) under was kept under ±2 (units) to uphold the integrity of the map and thus make the area calculations as accurate as possible.

3.2 Data Creation

In order to perform the proposed analysis, two shapefiles were created for each Sanborn year for each analysis. A major drawback to historical GIS research is the amount of time required to create or collect archival and other non-digital data that may be integrated within a GIS (Hunter 2014; Knowles 2000). Tools that may accelerate the integration process, such as the raster-to-polygon tool and other conversion tools within the ArcGIS toolbox were attempted but all proved to be incapable of transforming the rasterized images into shapefiles. Therefore, each building had to be tediously digitized within an ArcMap editor session. ArcMap editor session provides users with the ability to create their own vector coverages, as well as assign the attributes to them (ESRI, 2014). In efforts to accelerate the digitization process, a top down approach was utilized. The 1950 Sanborn shapefiles were created first. After completion, a copy of the shapefile was generated and labeled as the 1924 Sanborn shapefile. Next, the shapes and attributes were changed to reflect what the 1924 Sanborn displayed and the process was repeated until all shapefiles for each year were completed. Although lengthy and tedious, this method ensures precise digitization and attribution.

Building Footprint

The first shapefile created was Knoxville's building footprint for each Sanborn year. Every building within the study area was precisely digitized according to the Sanborn. Precise digitization of the buildings footprint is especially important seeing as building area calculations will be based solely on the accuracy of my digitization. Six attributes were assigned to each digitized building polygon. The building name (if one is provided), height, number of stories and utilization were derived straight from the Sanborn. However, Building footprint and volume were calculated using two basic tools within ArcScene's toolbox: Calculate Geometry and Field Calculator. Concerning building use, the 1950 Integrated Public Use Microdata Series or IPUMS classification scheme was used. The IPUMS classification scheme provides a list of building utilizations broken down by function or the services that they provide. However, I was not able to classify all multiuse buildings, the fourth issue of Sanborn Maps (Lamb 1961). As Lamb (1961) states in his critique of the Sanborn maps, "multiple use of large buildings is not easy to determine unless a fire hazard exists." With this taken into account, we are unfortunately unable to answer the question: "what building utilization occupies the most volume?"

Land Use Map

The second shapefile consisted of a parcel map for each Sanborn year. With these parcel maps, I was able to calculate land area consumption by utilization through each Sanborn year. To create the parcel shapefiles, I began by digitizing the blocks of each map. Fortunately, with Knoxville's CBD being in a grid format, the blocks maintained the same structure and shape for the most of the time period of interest. The only major structural block change was due to the widening of Henley Street in 1932. After each block was digitized and numbered, according to the Sanborn block numbering system, a copy of this layer was generated. I needed two copies of this layer because one of the analyses require the parcels at a block scale while the other requires the layer at a parcel scale. Once the copy was created, it was partitioned into parcels according to the Sanborn maps depiction. With land being at a premium within the CBD, dense urban parcels were very common. Dense urban parcels were troublesome to delineate and classify because real estate depictions were not required as seen in Figure 3.2 (Sanborn Surveyor manual). In these cases, the building was taken as the parcel. Each parcel was assigned three attributes: the land use, the number of functional buildings and the number of supplementary buildings (garages, outhouses, sheds). A total of seven land use classes were used to classify the parcels. The land use was classified by the building within the parcel that covered the most land area. Lastly, like the building footprint, the area at the parcel scale, as well at the block scale was calculated utilizing the ArcGIS's "Calculate Geometry" tool.

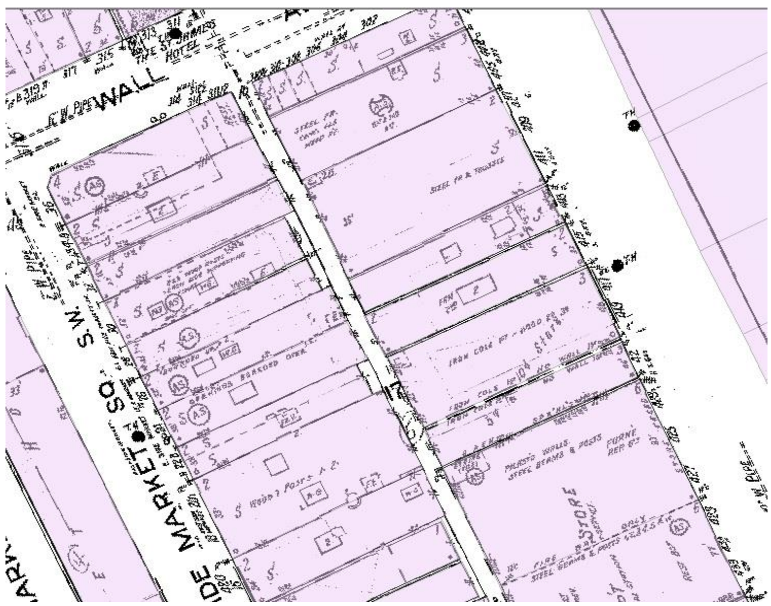

Figure 3.2: Example of dense urban parcel in Knoxville's 1950 Sanborn volume, which has no clear distinction of parcel boundary

3D Models

Because the Sanborn maps provide a height attribute, we are able to create 3D models that allow us to view the urban landscapes of the available Sanborn years. Before creating any 3D models, there are three considerations that must of be taken into consideration so that your model portrays your findings clearly. The first factor is the degree of reality. This aspect of a 3D model addresses the amount of details that will be incorporated into your model. Degrees of reality range from 2D digital orthography to fully detailed volumetric, textured CAD models. For this particular project simple volumetric block extrusion models were enough to display area and height change between the available Sanborn years. The second consideration is the type of data you have. This aspect of 3D modeling is key to processing time and the software that would be needed. Since I was only dealing with digitized shapefiles, I chose to utilize ESRI's ArcScene for my 3D rendering. ArcScene is one of ESRI's two 3D extensions besides the Spatial Analyst. The last consideration is functionality. Functionality is the most important of the three considerations because it pertains to the amount of analytical power a 3D model has (Shiode 2000). For example, CAD type models with high geometric content tend to have little analytical power due to the fact that their main function is to portray the buildings in the most realistic fashion, whereas GIS based models are generally supported by attribute data and are essential to some type of analysis.

All 3D modeling was done in ESRI ArcScene. ArcScene's power lies in raster terrain analysis, but it has polygon manipulation capabilities that makes it a suitable program for 3D vector analysis of urban footprints. Once the buildings were imported into ArcScene, the polygons were extruded by the height attribute. This block extrusion provides a volumetric 3D urban landscape that portrays Knoxville's CBD within that particular Sanborn year.

3.3 Analysis

The objective of my thesis is to enhance the understanding of urban morphological models through the observation and analysis of 3D models through time. To accomplish this, three urban-based analyses were conducted. Using Knoxville's most dynamic era as the model time frame, each analysis provides specificity to general concepts of center city transformation. The first two analyses utilize quantitative techniques that focus on how much space is being added or deleted from the CBD, along with how it is being used. The final analysis focuses on the spatial arrangement of services within the CBD. This allows me to observe spatial configuration of major services, as well as how they transform as time progress

Volumetric Analysis

The primary objective of this analysis is to calculate the amount of space that has been added within Knoxville's central business district between the given Sanborn years. With a total of four different years of 3D models of CBD, we are able to capture the urban landscape to quantify the total volume of the building footprint at the block level. Only 4 years were used, because the 1884 Sanborn 3D model was removed from the analysis as only half of the study area was mapped. Sparsely populated, underutilized, or forested areas were not mapped in any of the Sanborn maps, while those residential parcels close to economic functions were (Sanborn Surveyors Manual).

Finding an application that could replicate workflows in a fast and efficient manner was a must for this analysis. Fortunately, ArcGIS's Modelbuilder is able string together sequences of geoprocessing tools to accelerate and replicate workflows. Therefore, a model was created to obtain the total volume of the buildings in each block. As shown in Figure 3.3, the model begins with the building and block shapefiles. The first geoprocessing executed was a Union. Union is an ArcGIS overlay tool that is able to merge two shapefiles together based on geometric intersections. By doing this, each building is assigned to a block within the attribute table. The output layer from the union process (1st green circle) was copied so the original is preserved.

Next, the dissolve tool was executed. This tool allows the user to aggregate features based on a specific attribute. To calculate the total volume of the building for each block, all of the building features were aggregated into their particular block by adding the volume. This model was run on each Sanborn year. Once the total volumes were collected, the attribute table was then exported into an excel sheet. Along with the volume attribute, the block features were attributed with other supplementary attributes as well. These attributes included the number of buildings, the total area coverage of the buildings in that block, the area of the block and the amount of free space within the block.

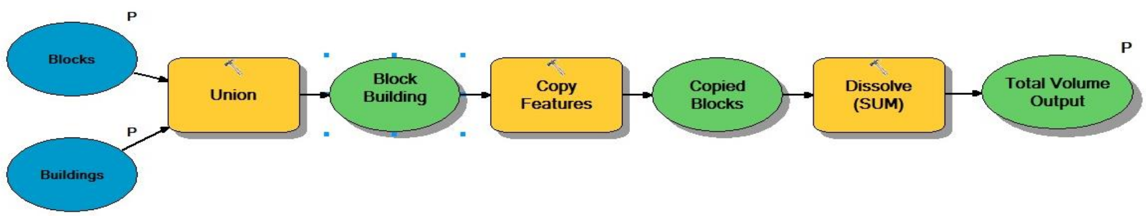

Figure 3.3: Model created within ArcGIS Modelbuilder to obtain total volume of buildings within each block

Once the volumes were exported into a excel spreadsheet, the annual volumetric growth rate was calculated utilizing the equation below.

$$\frac{\textbf{Year2 Volume} - \textbf{Year1 Volume}}{\textbf{Year2 Volume}} / \textbf{Difference in years between Year 2 and Year 1}$$

Equation 1: Equation utilized to calculate per annual growth rate

Land Area Analysis

Land Use maps are essential to any urban morphological study. They are able to capture how parcels of land are being utilized within the urban landscape at a given time, while also displaying distinct patterns of agglomeration. However, with the CBD being the most dynamic region of any large city, observing a single land use maps only provides a partial display of the story. Therefore, this analysis observes all of the Sanborn maps available within the time period of interest to obtain a more vivid understanding of how much land is being utilized for a particular utilization within Knoxville CBD is being used. With that being said, the primary objective of this analysis is to quantify the total amount of land that is being consumed for each utilization in each Sanborn year. By comparing the amount of land that is being utilized for a particular utilization though time, we are able to decipher what the most prominent land use was within the CBD during this era as well as observe how these land use patterns change.

This analysis began with the classification of the land use parcel shapefile. The classification scheme was based off the Sanborn building occupation classification scheme documented within the Sanborn Surveyor's manual. It consists of the following six land uses: residential, institutional, commercial, industrial, recreational, transportation. "Vacant" was added as the 7th land use to accommodate unused or unspecified land. Unfortunately, the parcels had to be manually classified being that the land parcels were classified by the building that occupied the most area. After every parcel was classified, each utilization was isolated utilizing the select by attribute tool. After the utilization of interest was selected, the total amount of area that that particular utilization occupied was obtained from the field statistics table and entered into a excel spreadsheet for comparison. This process was replicated for each utilization in each Sanborn year.

Description of Land Use Pattern

Each one of these 3D models provides a "snapshot" of Knoxville's urban landscape at a particular time; meaning that we capture all of the attributes of the city as well. When I began to look at these attributes throughout time, I discovered that Knoxville's urban landscape is a very dynamic case. While the building footprint changes in a geometric sense, this leads to change in a building's utilization as well. Change in building utilization acts as a passive defense against building destruction. Building utilization assists in identifying a sector of a city, as well as suggest future direction and patterns of the urban landscape.

For this analysis, I focused on the spatial arrangement of two of the most prominent building utilizations that exist in the urban realm: retail and residential. Retail services are a distinguishing characteristic of the CBD and serve as a very strong thread within the CBD's urban fabric. The residential sector is often the first to display influence of urban change due to its close ties to anthropogenic influences and low commercial value within the central business district. Business and office buildings were considered for this analysis, however, due to the Sanborn's inability to display multi-use buildings efficiently, they were removed from this analysis. To identify these building utilizations within the urban landscape, I queried these utilizations within the attribute table utilizing ArcGIS's select by attribute tool. The residential query included apartments and single-family units, while the retail query was nothing but retail services. Once the two building utilization queries were run and the selected buildings were returned, they were color coded to display the pattern of each utilization. By isolating a building utilization individually, I was able to focus on the spatial pattern and transformation of a particular utilization within the CBD through time. The patterns were then compared to Vance and Murphy's core frame model for similarities and anomalies.

CHAPTER 4: RESULTS

4.1 Time Series 3D Models

Upon observation of Figures 4.1-4.4, there is obvious vertical growth between the 3D Sanborn models. These extrusions of the Sanborn heights present a clear and concise visual representation of Knoxville's historical urban landscape. By combining these visuals with quantitative results derived from Sanborn maps, Knoxville's history, and literary concepts, we are able present the urban morphological story of Knoxville's CBD from 1884 to 1950

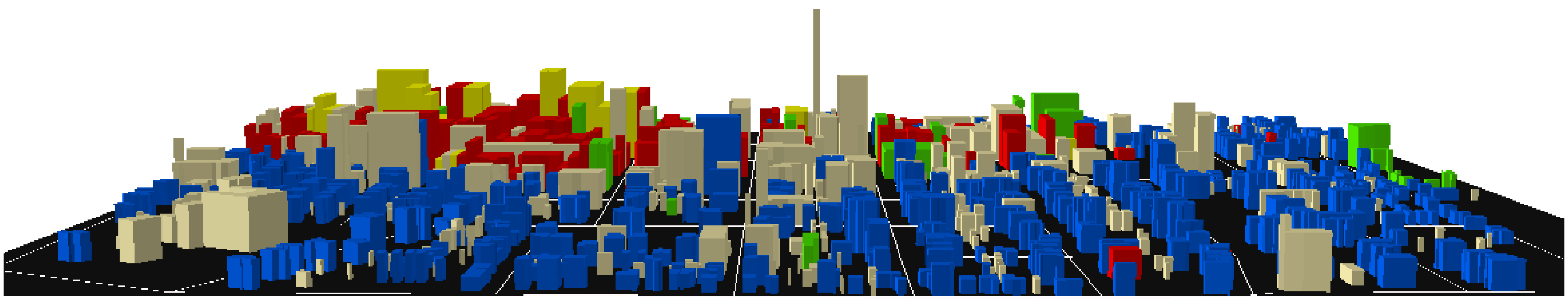

Figure 4.1: Knoxville's urban landscape according to 1890 Sanborn

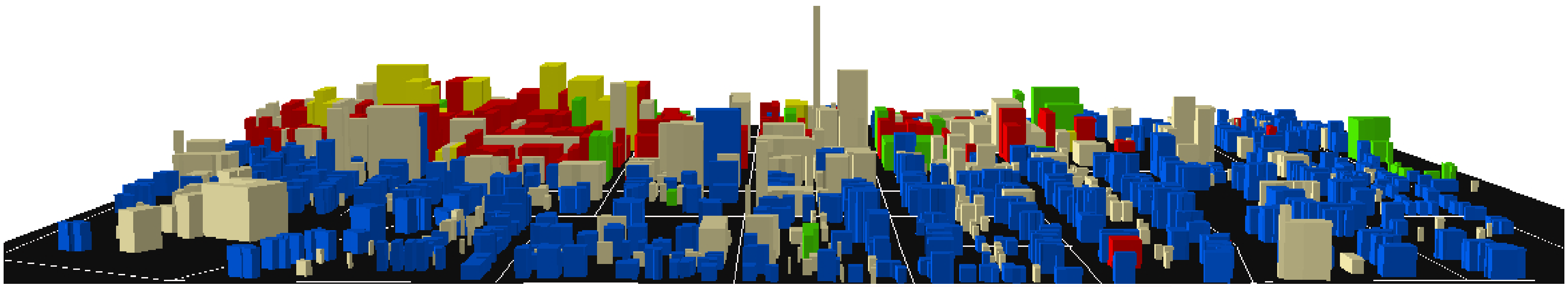

Figure 4.2: Knoxville's urban landscape according to 1903 Sanborn

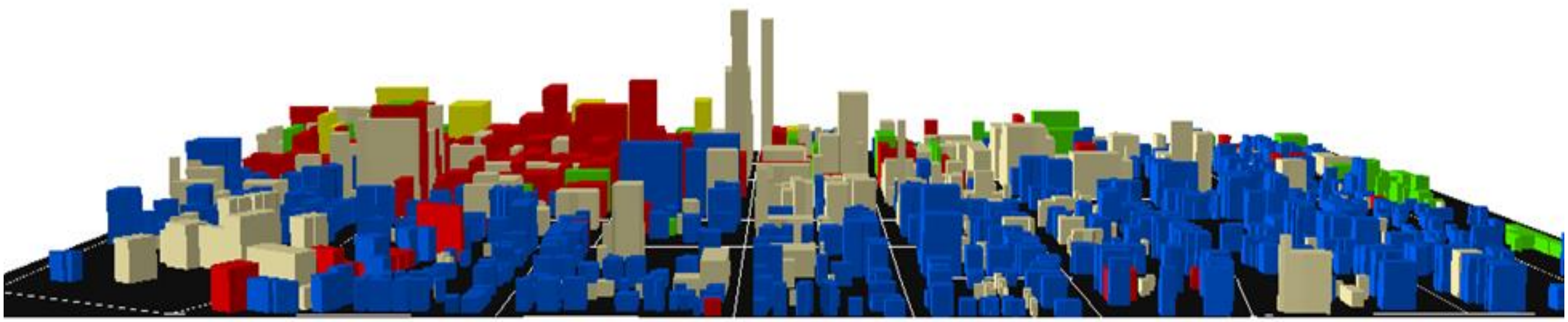

Figure 4.3: Knoxville's urban landscape according to 1924 Sanborn

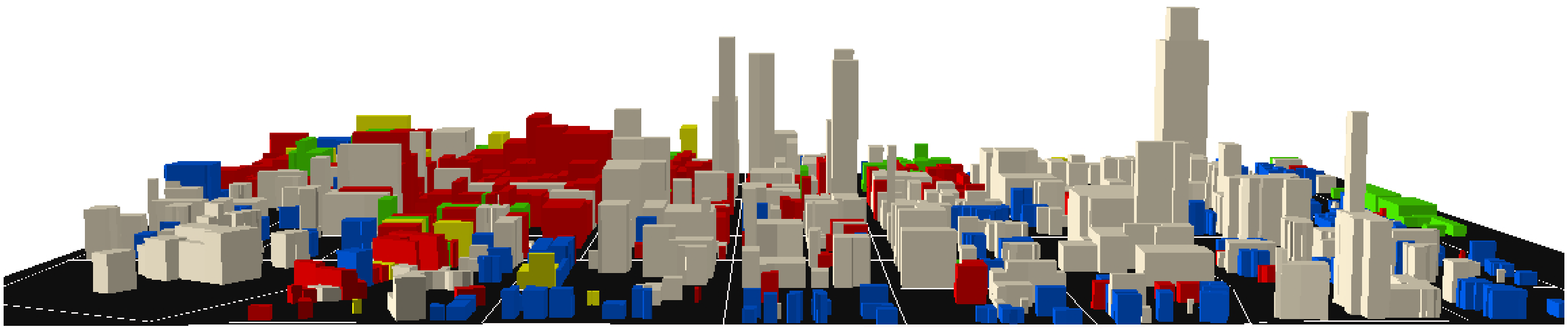

Figure 4.4: Knoxville's urban landscape according to 1950 Sanborn

4.2 Volumetric Growth

As we can see in Figure 4.5, Knoxville's building footprint is obviously growing as time progresses. However, it is safe to assume that these numbers are underestimates of the actual volume for each year. Unfortunately, with the inability to obtain and model roof top geometries due to data limitations, all buildings had flat tops. As we know, this is very untrue within all American CBDs. In addition, if a building did not state a specific building height, the building height was calculated by multiplying the number of stories by 10, the average story height. This was done for majority of the residential buildings within the study area.

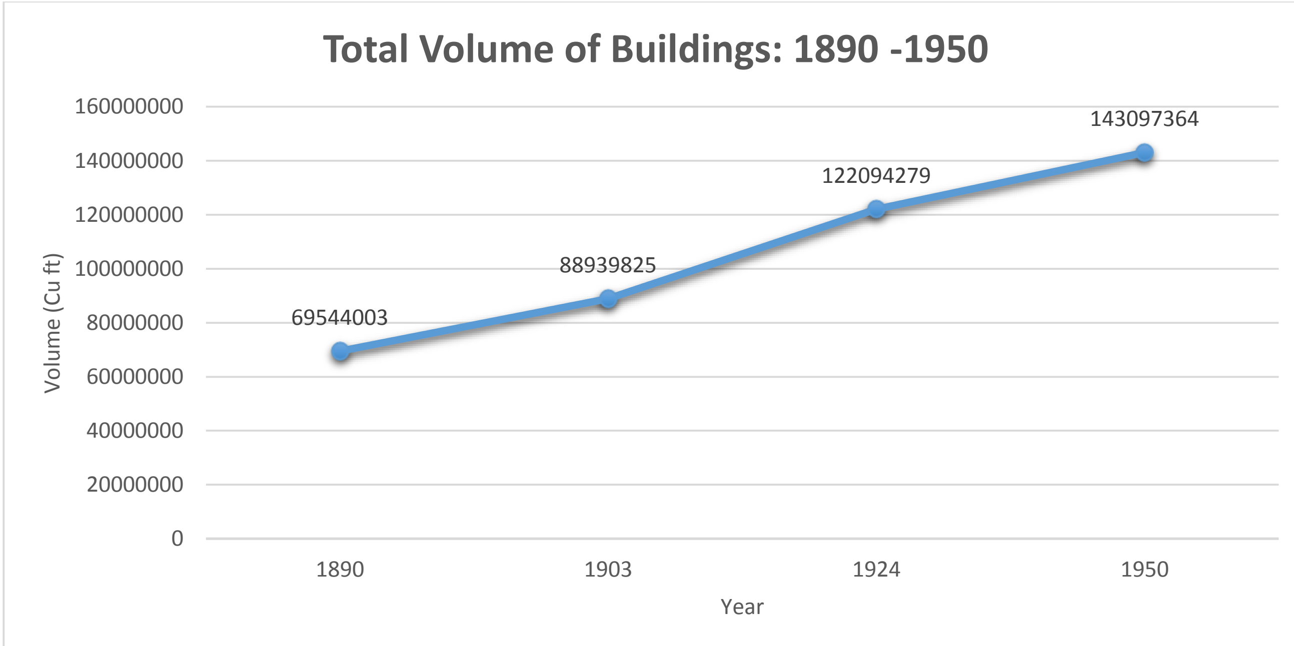

Figure 4.5: When observing the total volume of all the buildings within each Sanborn year, we are provided with the expected outcomes. The total volume increases as time progresses.

Table 1: Table showing the annual growth rate between Sanborn years. As shown, the span between 1890 and 1903 exhibited the highest annual growth. However, this calculation could be highly due to the short time span

Years	Differences (ft^3)	Growth (ft^3)	Annual Growth Rate	Percent of Annual Growth
1890-1903	19,395,822	0.218	0.0168	1.68%
1903-1924	33,154,454	0.272	0.0129	1.29%
1924-1950	21,003,085	0.147	0.0056	0.56%

I then observed how different sectors of the city were growing. By attaching a spatial reference to the volumetric growth, we are able to make inference about why specific areas of the city are more dynamic than others. Following the footsteps of the Vance and Murphy's CBD delimiting study, which sought to identify the general characteristics of the American CBD, I decided to divide Knoxville's CBD based on proximity to the PLVI in order to look at the growth trends of different sectors of the city. As one can see in Figure 4.6, Knoxville's CBD was divided into four tiers: the inner core, outer core, 2^{nd} outer core and frame. The expectations of each tier, displayed in Figures 4.7 through 4.10, were based on Vance and Murphy's findings leading up the creation of the core frame model.

There are some things that one must keep in mind when looking at these graphs. The first and most important aspect is that different services require different amounts of space. While some services require minimal amount of space to operate efficiently in the CBD, there are other services that require massive amount of space, which dictates where they can be located within the center of the city. Also, keep in mind that we are looking at Knoxville, TN. Knoxville's CBD during this time is relatively small compared to its northern counterparts that inspired the core frame model. With this in mind, a large volumetric addition could skew our results quite a bit.

Figure 4.6: The results of the volumetric growth were graphed according to proximity to the peak land value intersection. Agglomerating the graphs like this allows us to observe the growth trends of each section

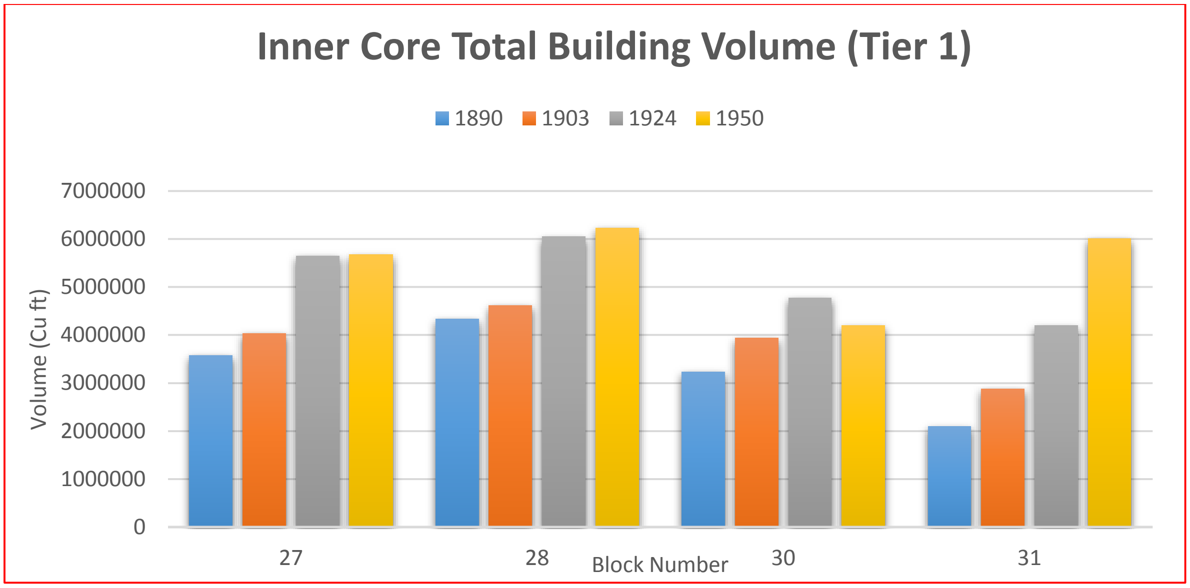

Figure 4.7: Volumetric Growth of Knoxville's inner core. These blocks are expected to be filled with the tallest buildings occupied by the most lucrative businesses dealing with finance, insurance and real estate. As shown, three out of the four blocks closet to the PLVI display volumetric growth every year. However, block 30 experiences a decrease between the years of 1924 to 1950 due to the destruction of buildings for parking lots

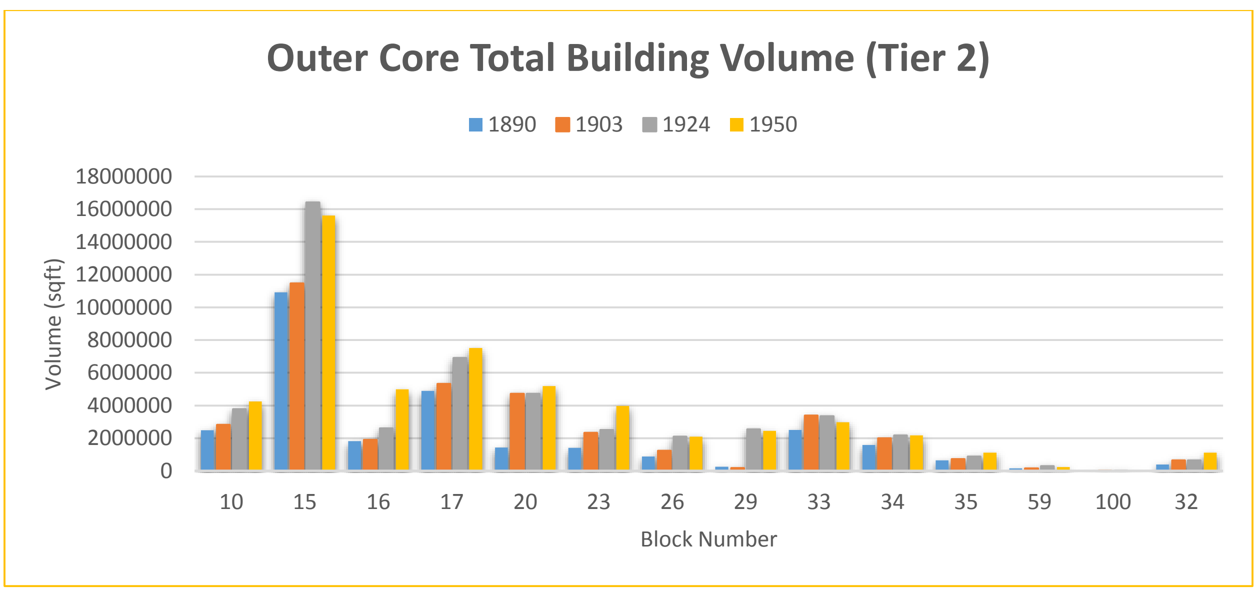

Figure 4.8: The outer core is usually filled with services such as retail and other personal services that thrive off centrality but cannot afford the expensive price tag around the PLVI. In Knoxville's case, Knoxville's wholesale district takes full advantage of the slightly less expensive land (block 15). This block also was the largest in land area contributing to its volume.

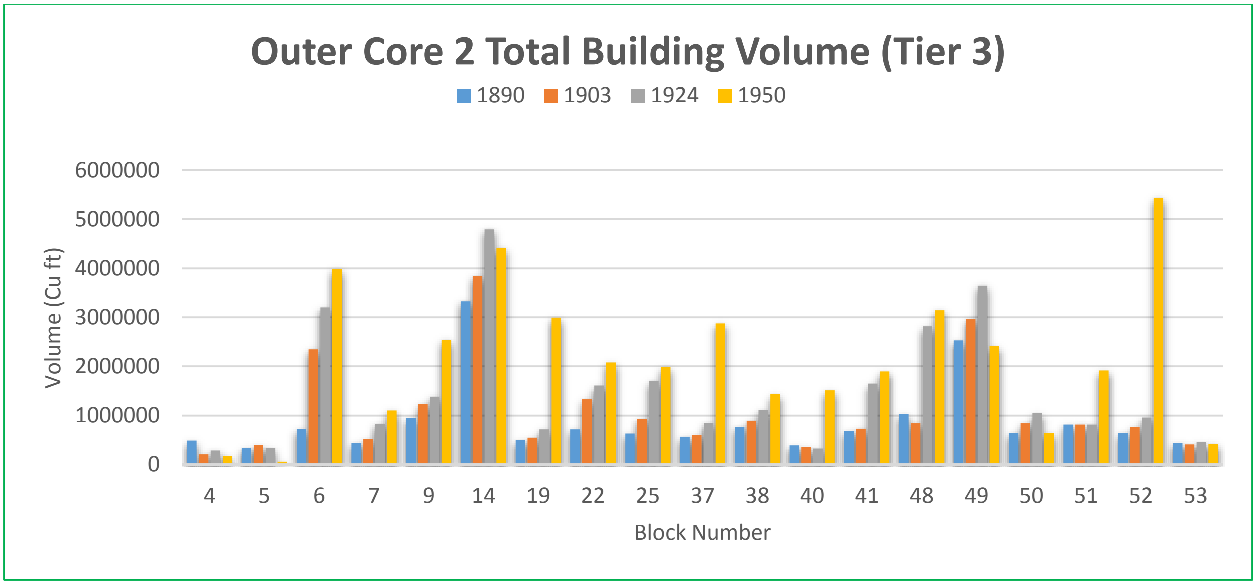

Figure 4.9: Knoxville's outer core consisted of an abundance of blocks that displayed characteristics of the outer core. Therefore, it was split in two to somewhat even out the results. As one decreases the distance from the PLVI, land become cheaper and you begin to observe diversity within the utilizations. With diversity in utilization comes diversity in buildings. In the figure above, we begin to see huge volumetric growth spikes in between 1924 and 1924 in the outer core two blocks caused by the decentralization of services and new building technology

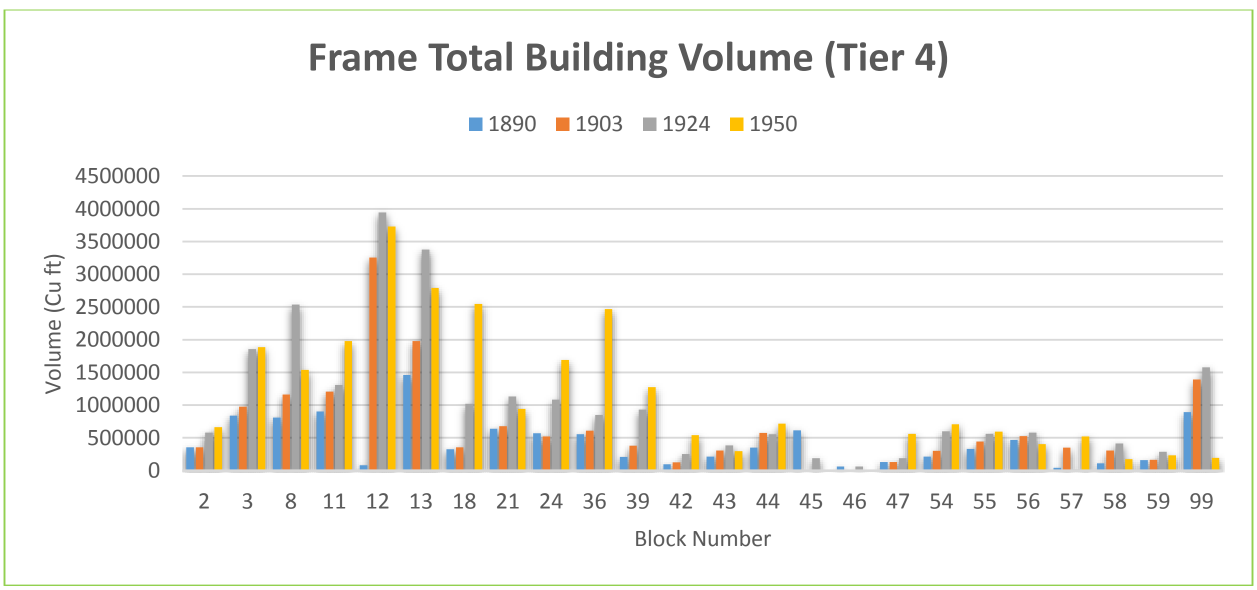

Figure 4.10: Frame blocks are the outer most blocks of the CBD. They tend to be the most dynamic in terms of volume due to the fact they could contain a variety of services.

Upon visual perception, I recognized that the first half of the graph always seemed to be taller than the rest of the second half. This was because the first half of the graph was displaying the northern half of the PLVI, while the second half displayed the southern half of the PLVI. Therefore, I isolated the blocks adjacent to Gay Street and compared the northern half to the southern half in Figures 4.11 and 4.12 in order to observe the nature of the volumetric growth along Gay Street. Church Street was used as the dividing street due it being the bottom of the inner core.

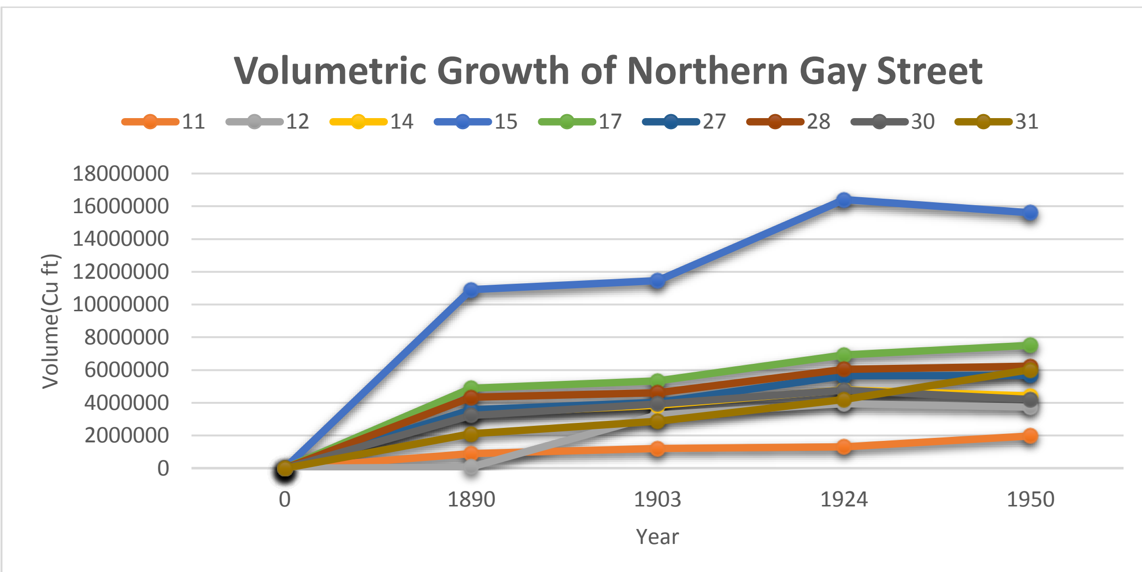

Figure 4.11: Volumetric Growth of Northern Gay Street. Northern Gay Street presents a very gradual growth. This trend tends to be an example of gradual building addition. As you can see, there are no decreases in volume signifying that there were no volumetric losses presented in the Sanborns. This does not mean that there were no buildings torn down between the years. This just means that we did not have the temporal resolution to capture it.

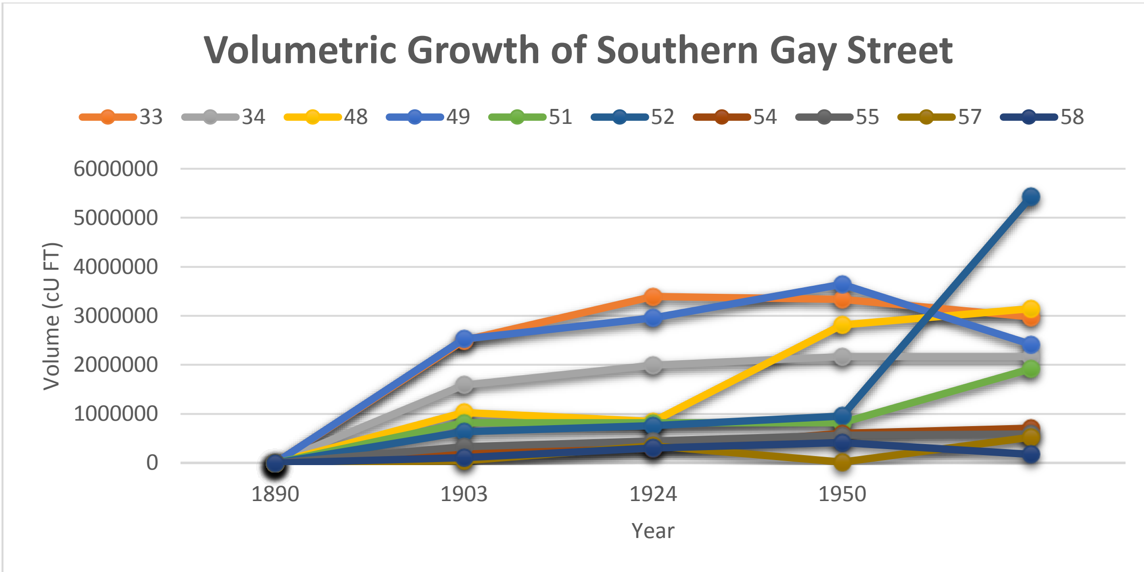

Figure 4.12: Volumetric Growth of Southern Gay Street.   As one can, see Southern Gay Streets volumetric growth is much more chaotic than the North; mainly being that the Southern Gay was filled with residential buildings for most of the study era.

4.3 Land Use Area

Unfortunately, with the Sanborn's inability to provide all of the utilizations within a multi-story building, I was unable to answer the question, "Which utilization occupied the most building volume?" To compensate for this Sanborn shortcoming, a time series land use area analysis was conducted to obtain the total amount of land being utilized for each land use within Knoxville's CBD. The results are displayed in Figures 4.13 and 4.14. Land use area and volumetric growth are closely related on the ground that different services require different amounts of space. With space being at a premium within the Knoxville's CBD, the size of a building is based upon how much land is available to build on.

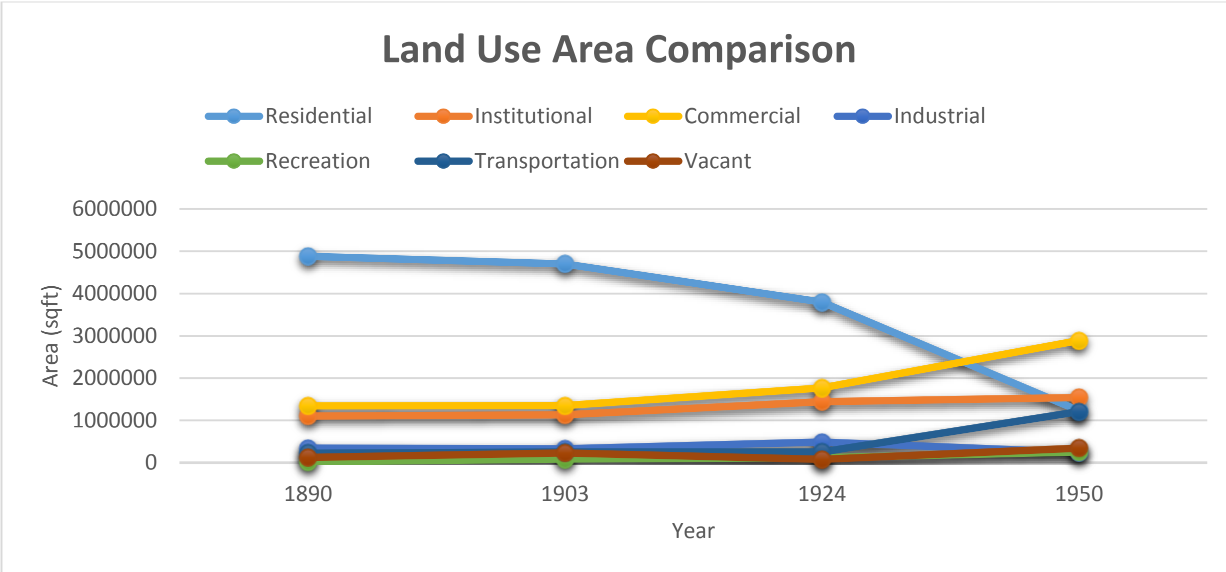

Figure 4.13: Land Area comparison based on utilization: There is a major switch between residential area and commercial area between 1924 and 1950. This is a result of the economic specialization of land use that occurred within the CBD after mass decentralization caused by the automobile

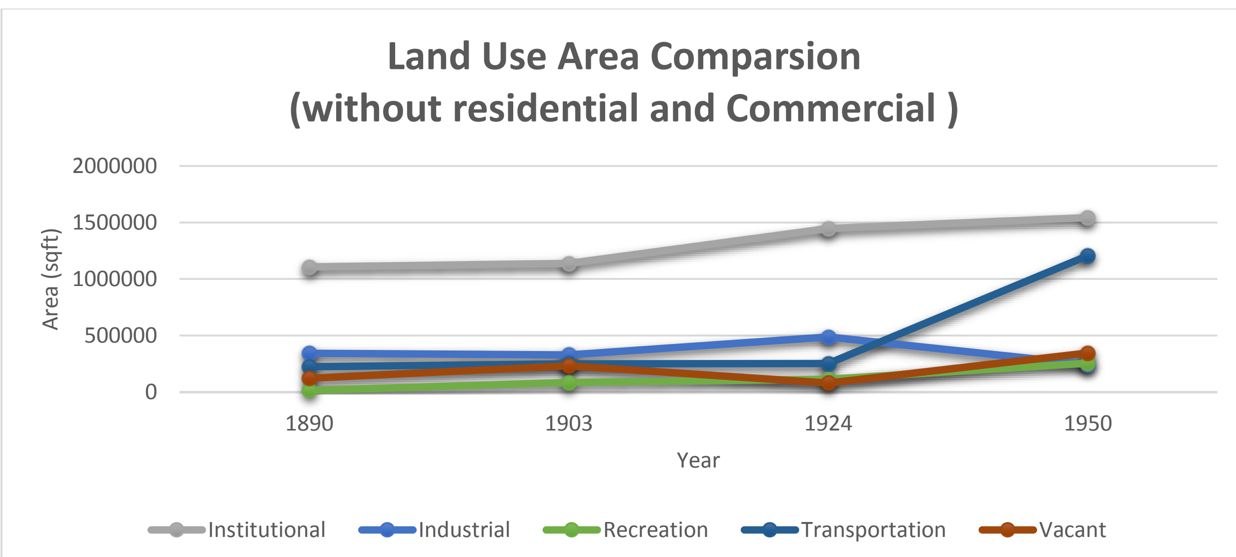

Figure 4.14: Land Area Comparison based on utilization. There was an increase in transportation land use between 1924 and 1950 caused by infrastructure built to support the mass consumption of the automobile. Institutional land use is skewed due to the immense amount of land that the Star Tech High School occupied in block 99.

CHAPTER 5: DISCUSSION

5.1 Knoxville's Economic Boom

As mentioned in Chapter 2, Knoxville's 1884 Sanborns only covered half of Knoxville's CBD due to sparse development. For this reason, the 1884 Sanborn model was removed from calculations given that it does not present the entire landscape of the CBD as seen in Figure 5.1. However, even with its partial display, the Sanborn was still modeled simply because it sets the foundation for Knoxville's urban morphological story.

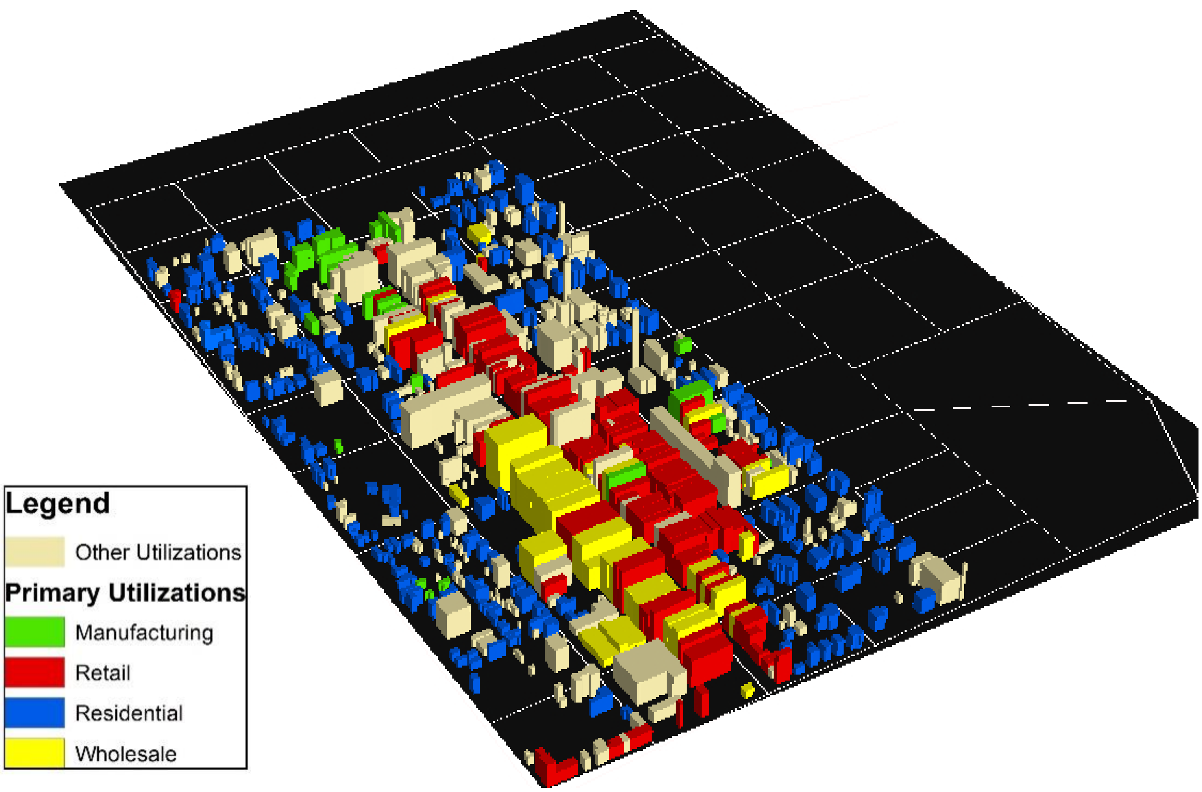

Figure 5.1: Knoxville 1884 Sanborn Model. Unfortunately, the Sanborn maps were unable to cover the entire CBD

After the end of American Civil War in 1865, Knoxville experienced an economic boom that made it one of the largest cities in the south. Knoxville became what historian Bruce Wheeler calls the "new jewel in the crown of the South," by exploiting its distributive strengths in support of the booming cotton industry of the South (Wheeler 2005). Northern investors teamed with wealthy Knoxville elites to bring the city an abundance of wealth that lead to the rebuilding of the city (Krafft 1993;Wheeler 2005). The railroad was a major component of these reconstructive efforts. Prior to the introduction of the railroad, Knoxville experienced a period of economic stagnation due to its geographic location. With Knoxville being located in the treacherous Appalachian Mountains, transporting through the city was limited to what be moved on boat (MacArthur 1978; Deaderick 1976). This changed once Charles McClung along with several other investors purchased two major railroads and merged them into Eastern TN-VA-GA railroad system expanding Knoxville's already strong market (Neely 2008). With this reconstruction of the railroad, Knoxville's wholesale and textile market skyrocketed. According to William McArthur, Knoxville's wholesale jumped from a dozen firms to 50 by 1896; making Knoxville the third largest wholesale market in the American South behind only Nashville and New Orleans.

With an idea of Knoxville's economic status and urban structure during the late 19th century, we now observe how both of these aspects change and how these changes are reflected upon Knoxville's urban structure.

5.2 Knoxville's Age of Expansion: 1890 & 1903

With the reconstruction of the railroad finished in the 1870's, Knoxville's markets could now reach five surrounding states. This facilitated Knoxville's transformation from a town to a city. With all of the new industrial growth, Knoxville's population grew rapidly. According to Robbie D. Jones, Knoxville's population had grew by 113% from a modest 3704 to an impressive 32637 by 1900 (Jones 2006; Krafft 1993). With Knoxville's abundance of wealth and rapid population growth, the center of the city became a breeding ground for urban problems which

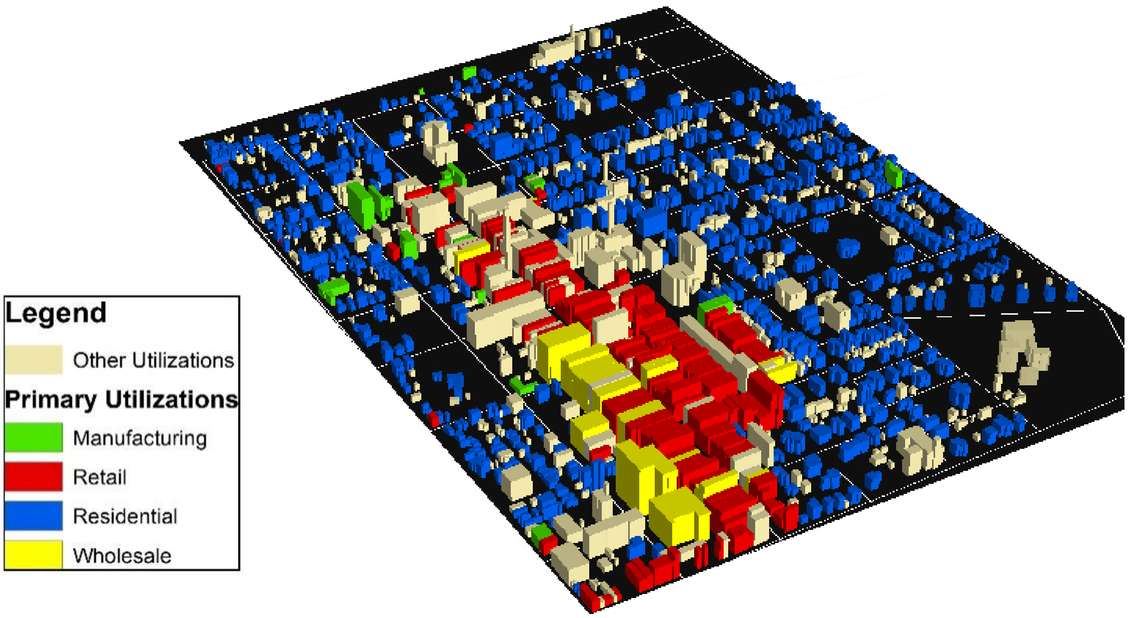

Figure 5.2: Knoxville 1890 Sanborn Model.

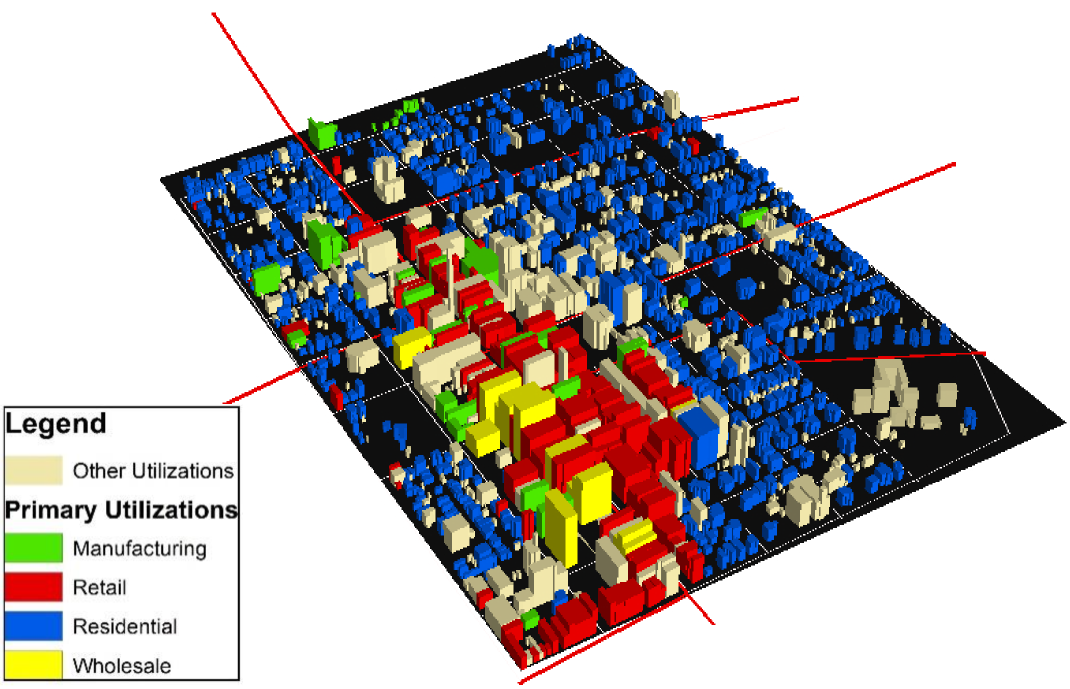

Figure 5.3: Knoxville 1903 Sanborn Model

required an abundance amount of residential space added to the CBD which can be seen in Figure 5.2 and 5.3.

Due to this abundance of wealth being accumulated in the center of the city by the wholesale industry along with the population continuously increasing, Knoxville’s CBD became extremely crowded and congested; resulting in a host of unfortunate consequences for city. Epidemics and crime plagued the streets of Knoxville during the late 19th century. "Saloons, whorehouses, cocaine parlors, gambling dens, and poolrooms" lined Central Street from the railroad tracks to the river” during the 1890s (Neely 2008; Gray and Adams 1976). Along with these undesirable social characteristics, the urban fabric of Knoxville’s CBD became increasingly dense. This was due to relatively small lot sizes. Lot owners figured that by partitioning their large parcels of land into smaller parcels, they would be able to increase profitability of their lots. According the Sanborn maps, in 1903, 66% of the parcels along Gay Street were under 2800sqft^2. With the Knoxville’s most prominent thoroughfare this densely developed, Knoxville’s CBD was in need of a decongestion. This decongestion came in the form of the streetcar.

With a streetcar system in place since the 1870s, Knoxville had already had the infrastructure. However, it was very inefficient and slow considering it was powered by horses. Fortunately, under the construction of Williams Gibb Aldo, Knoxville’s omnibus system was electrified in 1890 (Deaderick 1976). With an efficient streetcar system now in place, Knoxville rapidly expanded towards the city’s peripheral neighborhoods in all directions as seen in Figure 5.2 and 5.3. Starting in 1897, Knoxville annexed the city of west Knoxville that included Fort Sanders and the campus of the University of Tennessee. That same year, Fourth and Gill, the primary neighborhood of the city of North Knoxville was annexed as well(Gray and Adams

1976).In 1907, the expansion continued back eastward picking up Parkridge and Chilhowee Park, in which would become a symbol of economic achievement. Lastly, the affluent neighborhood of Sequoyah Hills and parts of south Knoxville were the last to be annexed. At the end of this period, Knoxville's territorial area dramatically increased from 4 square miles to 26 square miles a doubling of the population (Gray and Adams 1976).

As the 1890 and 1903 Sanborn models exhibit, Knoxville's CBD answered this demand for space with rapid construction of residential buildings. With the introduction to Knoxville's first street car system in 1880, Knoxville was able to annex an abundance of space to the west of the study area to be utilized for residential purposes as seen in Figure 5.2 and 5.3. With urban to rural migration at an all-time high in the city due to the abundance of job opportunities created by the manufacturing and wholesale boom, you begin to see Knoxville's first suburbs(Krafft 1993). This type of suburbanization was a result of mass-market rental housing created factory owners in order to increase the size of their workforce. The quality of the housing tended to be dictated by the wages of the workers(Knox 1993). As one can see, residential buildings surround all of the green manufacturing buildings. These primal suburbs also attracted white-collar workers and some retail attendants who wanted to be away from the bustling and noisy inner core. Between 1885 and 1904, Knoxville is suspected to have built 5000 new homes(Jones 2006). According to the Sanborns, there was a total of 545 buildings being utilized for residential purposes alone, adding an astonishing 17,896,501ft^3 of residential space to the study area.

Upon visual perception of the 1890 and 1903 Sanborn models, volumetric growth is difficult to observe. However, even though this span had the smallest amount of volumetric growth totally, it had the highest building growth rate of 2.14% per year. This can be attributed to Knoxville's booming wholesale market. During this time, the largest buildings were wholesale houses that consumed massive amounts of areal space in the northern half of Gay Street. While these buildings do not contribute obvious visual change in Knoxville's urban landscape, the do contribute to the quantitative analyses. Most of the houses were concentrated in Knoxville's 400 block where the infamous "Million Dollar Fire" of 1897, which slowed down Knoxville's economic growth dramatically.

5.3 Knoxville's Vertical Expansion: 1924

The economic depression of 1893, caused by over building of railroads, and infamous the Million Dollar Fire temporarily slowed down Knoxville's economic growth. (Jones 2006). Despite these economic deterrents, Knoxville's CBD urban landscape experience substantial vertical growth spurt as seen in Figure 5.4. Prior to the turn of the century, building height was limited by its lack of building construction technology and materials that had already taken the northern U.S. by storm. Nevertheless, once the innovation of the steel frame building arrived in Knoxville, the CBD's landscape changed dramatically in respects to visualization as well as volume.

Tall buildings were a way to display a city's wealth and progressiveness. They exhibited prestige and a form of advertisement that awed visiting investors. By 1900, Knoxville had only four buildings that stood over 80ft. Unfortunately, as mentioned in Chapter 1, these building were extremely heavy given that they were constructed with brick. It is through technological innovation of the steel frame building that this weight problem was resolved, giving developers the ability to build even higher. This innovation arrived in Knoxville in 1907 in the form of the Arnstein building. The Arnstein building consisted of seven stories on the corner Market and

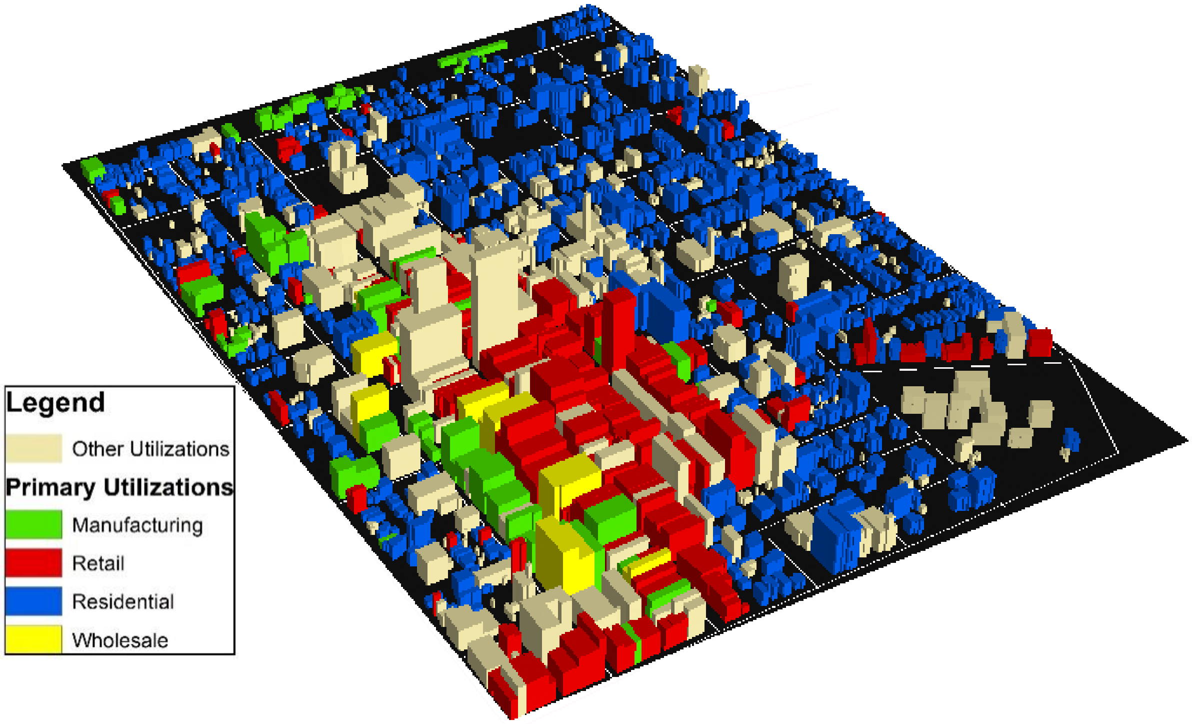

Figure 5.4: Knoxville 1924 Sanborn Model

Union Street. It reached a height of 100ft, adding 971300 ft^3 of volume to Knoxville's urban landscape to be utilized as seen in Figure 4.8 in block 20.

The introduction of the steel frame building had the most influence on the volumetric growth of Knoxville's inner core. With this construction innovation, land owners could now capitalize on their land by building vertically; creating more utilizable space. Due to this phenomenon, between 1903 and 1924, three of Knoxville's most prominent skyscrapers were erected on three of four corners of Knoxville's PLVI; adding an immense amount of volume to the landscape. The first volumetric addition was the Burwell building (836,160ft^3) constructed in 1907. The Burwell building was originally constructed as "Knoxville Banking and Trust" but received a name change once C.B. Atkins Realty Company took over (Knox Heritage, 2014). The second skyscraper added to the PLVI was the Holston Bank building (1630087ft^3). The Holston

National Bank building surpassed the height of the Burwell standing at 167ft. Two more stories were added in 1931 once it was forces to with Union National bank adding an additional 78,000 ft^3 to its volume (Knox Heritage, 2014). The last addition was the Farragut Hotel constructed in 1919 (2,248,575 ft^3). It stood 105ft and served as Knoxville's premier hotel until the building of the Andrew Johnson hotel in 1930 (Knox Heritage, 2014). These three massive volumetric additions alone constituted for 14% of the volumetric growth alone. These three buildings certainly distinguished and validated Knoxville's PLVI.

Knoxville's skyline was not the only changing element of the time. The 1924 Sanborn model also begins to display the beginning phases of decentralization. As one can see in Figure 5.4, retail begins to disengage from Knoxville's commercial core. This disengagement is a repercussion of the next major technological innovation to arrive in Knoxville; the automobile.

The arrival of the automobile had a tremendous impact on the spatial configuration of the city as seen in Figure 5.5. Like the streetcar, early consumption was slow due to inefficiency. Many thought that the future of the automobile would be limited given the intra-urban transportation had seemed to be mastered by the streetcar (Yeates and Garner 1997). However, the automobile became increasingly efficient with the integration of the single combustion engine. Along with the lifesaving engine, these automobiles were being mass produced with the introduction of assembly line production; decreasing the cost of them and making them affordable for the middle class in many American cities(Yeates and Garner 1997). Knoxville being one of those cities. According to Harland and Bartholomew and Associates (1930), a prominent American urban planning firm, there were only 102 registered automobiles Knox County in 1910.

In only a fifteen year span, the number of automobiles exploded by 118% to an astonishing 18,600 registered automobile in 1925 (Bartholomew and Associates 1930).

5.4 Decentralization: 1950

The span between 1924 and 1950 marks Knoxville's decentralization period. With the middle class being able to move freely throughout Knoxville via automobile, centrality lost its value causing a massive flee of services in Knoxville's CBD which is displayed in Figure 5.5. Upon visual observation of the 1950 Sanborn model, one can recognize three major alterations from the previous model. The first and most obvious being the massive depletion of residential buildings. The next major visual change is the sporadic arrangement of retail services throughout the study area. The last being the addition of 1950's Sanborn models tallest building also known as the Andrew Johnson Hotel on the southern half of Gay Street.

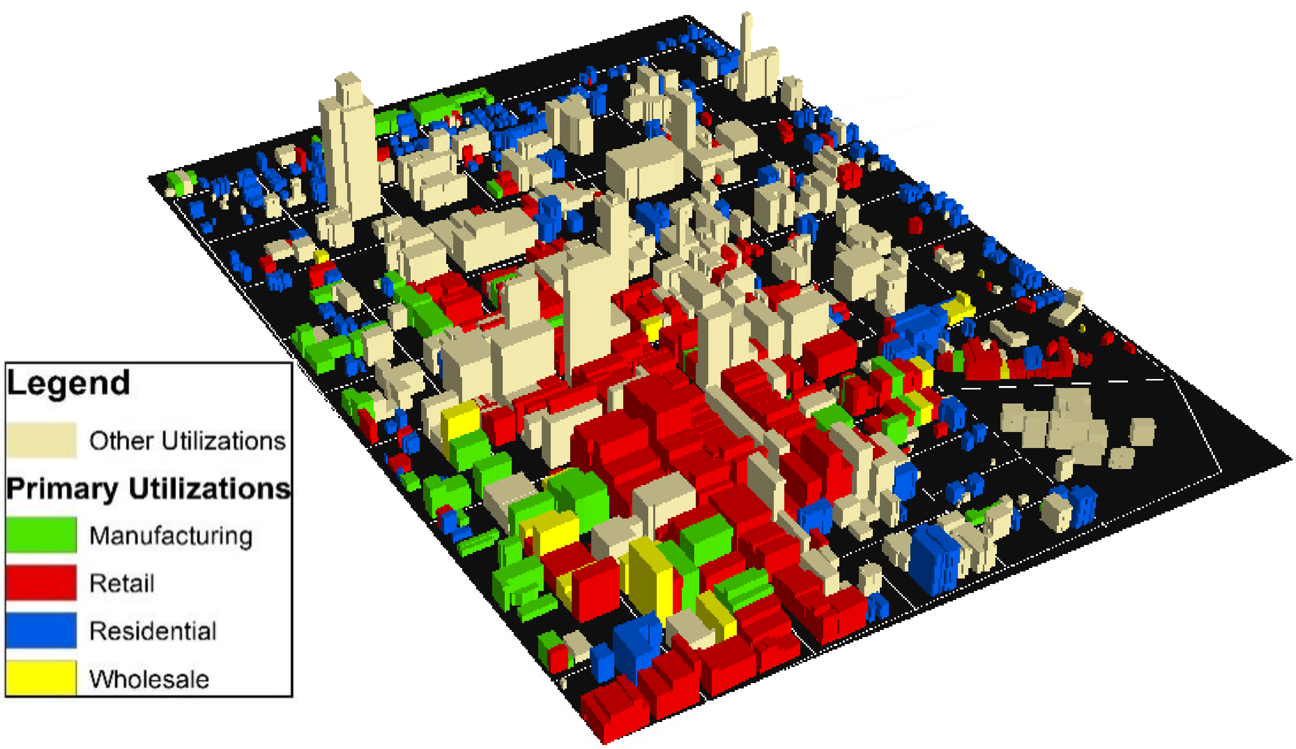

Figure 5.5: Knoxville 1950 Sanborn Model

With the arrival of the automobile to Knoxville, the residential sector was the first to leave Knoxville's CBD. As portrayed in Figure 4.13, the study area lost a total of 2,564,836 ft^2 of residential land between 1924 and 1950. This phenomenon lead to what Paul Knox calls "Automobile suburbs" (Knox 1993). Much like the streetcar suburbs, automobile suburbs were an escape from the congested, overpriced CBD. These automobile suburbs tended to fill in the vast amount of cheap and available land that lay in between the street car lines; acting as a type of suburban infill(Knox 1993; Yeates 1989). Two of these automobile suburbs were created in Knoxville. They were Lindbergh Forrest and Forrest Heights; both established in the mid 1920's (Knox Heritage, 2014 Back in the CBD, the only residential buildings left in the 1950 Sanborn model are at the fringe of the city insinuating that the commercial value of residential land has been surpassed by other services.

With majority of the consumers now outside of the downtown area, retail followed. This left the center of the city in an economic slump. Knoxville's CBD became increasingly unappealing commuting consumers for two reasons. First, the growing number of automobiles in the 1930s, created an immense amount of traffic. Close to 25,000 cars fought for space in the CBD (Jones 2006), making trips to or near the CBD extremely long. Knoxville's urban planning committee recognized this problem and attempted to fix it by creating parking garages and lots. This caused an increase in the transportation land use area in Figure 4.14. Although this alleviated the problem the unappealing aspect, it could not solve the second issue of massive retail decentralization. Knoxville business owners figured that by placing their businesses within or near automobile suburbs, they could run their businesses just as efficient while also dodging the expensive land rent of the CBD. In respects to the CBD, retail sector was still greatly concentrated in the northern half of Gay Street. However, the commercial core was not the only place a retail business could flourish as seen in Figure 5.5.

The massive amount of decentralization caused by the automobile resulted in an economic specialization of land use within Knoxville CBD. This specialization can be seen in Figure 4.13 with the increase in commercial land use from 1924 to 1950, insinuating that the role of the CBD has changed. Leading the way of the specialization was the influx finance, insurance and real estate jobs in the mid 1920's. However, this commercial growth was stunted by the Great Depression that put Knoxville, as well almost all American cities in a terrible economic position. During the depression, six of Knoxville's largest banks failed and were forced to merger. On top of Knoxville's financial failure, construction fell by 70% and unemployment tripled(Wheeler 2005). Fortunately, Knoxville was able was relived of the Depression due to a massive amount of federal investment including the opening of the Great Smokey Mountains National Park, the establishment of the Tennessee Valley Authorities within the city(Wheeler 2005).

Lastly, during this era, the Knoxville's CBD received a decent amount of volume; especially in the southern half. While the northern half of the CBD received a good amount of growth with the addition of numerous flats and hotels as seen in Figure 4.11, none of them compared to the massive constructions that were built in southern half (Figure 4.12). The most prominent of these constructions was the Andrew Johnson Hotel. Construction of the Andrew Johnson Hotel began in 1918 but the 205ft hotel was not completed until 1928. It consisted of 18 stories and stood as Knoxville's tallest building for 50 years strong. It added astonishing 4,853,220 ft^3 to Knoxville's CBD. The massive impact of its amount of volume can be seen in Figure 4.12 and Figure 4.9, in block 52. The remaining major volumetric additions to southern half of Knoxville's CBD came after the escape from the Depression. This included Knoxville's Medical Arts Building (1,652,489 ft^3) and the U.S. Post Office and Court House 2,875,400 ft^3.

CHAPTER 6: SUMMARY AND CONCLUSION

By integrating these historical maps with our modern technology, I was able to revisit the landscape of Knoxville's CBD between 1884 and 1950. Utilizing the strengths of 3D modeling and GIS, I visually displayed and quantified the impact of CBD-shaping technology of the era, providing a different perspective to center city transformation and thus enhancing our understanding of it. This research also breathes new life into the historical Sanborn maps. As mentioned earlier, these maps have been utilized in a host of different studies in the past relating to different aspects of the urban realm. However, there is little to no research that utilizes our modern technology to exploit the information within held within these maps.

I presented a methodology that has the ability to shine light on matters that urban researchers in the past were unable to answer due to technological limitations. One of these matters being the initial impact of the skyscraper on the American CBD. With a massive amount of space being added in such a compact area, Knoxville experienced a recentralization of services that diminished the price of land in the outer cores. With the price of land decreased in the outer cores, you begin to see more diversity of services, influencing the spatial configuration of Knoxville's most prominent sectors. The most dramatic change being Knoxville's residential sector being pushed to the periphery of the city. Another aspect this research shines light on is the relationship between services and volume. Even though I am unable to say what service specifically obtained the most volume, I am able to make inferences based on volumetric growth trends.

Through the results and discussion of this thesis, we can see that the general forces that influence center city transformation in most American cites between 1884 and 1950 are definitely prevalent in Knoxville's urban morphological story. With this in mind, it is safe to assume that this method could be utilized for observing the vertical change of all American CBD's. I was able to provide a more complete urban morphological story of Knoxville's CBD utilizing a four dimensional approach. This integration of 3D time series model provides several benefits to our perception of center city transformation. First, I was able to visualize the vertical change that had occurred in the city and it explain it utilizing Knoxville's construction history. The visualization benefits of this approach made it easier to observe growth and identify anomalies of landscape, which facilitated what questions to ask and what buildings to focus on. Second, I was able to quantify this change utilizing the benefits of modern GIS tools. By quantifying this change, I was able to identify the magnitude of a certain innovation on the landscape.

There are definitely some limitations in this type of analysis. My biggest limitation was my foundational data. While the Sanborn maps provide an abundance of meaningful urban information on an historical landscape at a given time, their imbedded weaknesses definitely are brought forth when integrated into a geographic information system. Due to its dense amount of information, I was unable to map as much as wanted; thus shrinking my study area. Also, the time spans were a bit long. A historical data source with a higher temporal record will definitely yield better and more descriptive quantitative results, as well as more detailed visual results.

6.1 Future Research

I have three main goals for continuing 4D research:

- Extend the footprint of the 4D study to the entire city
- Extend the time series to the present

- Link contemporaneous socioeconomic data to the 4D volumetric data to understand and explain urban morphological change.

The first goal of continuing my research would be to 4D model the entire city. This would be done by mapping all of the Sanborn Fire Insurance maps that the University of Tennessee's Libraries have in their collections. However, I would need a rapid and efficient way to digitally transform the Sanborn maps into vector coverages. This would allow me to spend more time on the analyses and 4D modeling of the Knoxville's landscape, rather than digitizing.

My second goal would be simultaneously accomplished, that by digitizing the entire collection of Sanborn maps I would also extend the time series analysis to the present. By doing this I would be able to describe the current urban morphological story of Knoxville, as well as display and quantify how much Knoxville's urban landscape has changed from 1884.

My final goal would be to find more historical and contemporary time series of social and demographic data to apply to these models. By doing this I would be able to make more contextual inferences about why a certain area of the city is structured the way it is; giving urban demographers the ability to go back in time and populate the historical urban environment. I would also be able to compare Knoxville's landscape to the projected land use models to see how well they correlate with each other.

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