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Made in the Shade: Using GIS to Model Pedestrian Shade in Austin, Texas

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Made in the Shade: Using GIS to Model Pedestrian Shade in Austin, Texas

by

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Report

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Dedication

I would like to dedicate this to my beautiful wife, Kim. Jane Jacobs might have her eyes on the street, but I’ve only got eyes for you.

Acknowledgements

I would like to thank my readers, Dr. Sletto and Dr. Spelman, for their thoughtful advice, generous feedback, and time. I would also like to thank Matt and Big Man for allowing me to use their wonderful photographs throughout the report. A picture is worth 10,470 words.

Abstract

Made in the Shade: Using GIS to Model Pedestrian Shade in Austin, Texas

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There are many benefits to living in a walkable city, and just as many barriers to making a city truly pedestrian-friendly. In hot climates such as Austin, Texas, high temperatures are a principal challenge to walkability and also a safety concern when temperatures rise above 100°F. Although city planning came about largely to protect the streetscape from unbridled, sunlight-blocking development, too much sunshine can be just harmful and therefore shade provision merits the attention of urban planners. One useful tool for shade analysis and planning for shade provision is Geographic Information Systems (GIS). However, GIS has typically been limited to tree cover analysis, leaving out the significant contributions of the built environment for shade provision. This report examines recent applications of GIS for walkability analysis and planning efforts to enhance pedestrian comfort in Austin, and then presents an analysis of shade provision in East Sixth Street, Austin, Texas, focusing on 3D modeling of the built environment. It is the hope that this study will inform future shade research and analysis for improved walkability, particularly in cities located in hot climates.

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Chapter 1: Introduction

Cities in America are currently undergoing a fundamental shift. Two of the most rapidly growing sectors of the population, young professionals and retired baby boomers, want to live in places where they can get around without the need for a car. They want to live close to services and be able to get to those services on foot, in both a safe and comfortable manner. In other words, they want to live in walkable places.

There are many economic, environmental, and social benefits to walkable places, and cities should work to improve their walkability for both their own good and for the good of their residents. However, in communities with hot climates such as the American South and Southwest, a particularly important factor that influences walkability is the level of plentiful and continuous shade. Especially during summer months, being protected from the heat of the sun while outdoors is not just about comfort; it is about safety. In order to foster a pedestrian-friendly city, therefore, it is vital that cities located in hot climates, such as Austin, Texas, incorporate shade analysis into their decision making process in order to develop walkable urban environments.

Increasingly, research to document levels of walkability in order to inform planning processes draws on Geographic Information Systems (henceforth referred to as "GIS"), which allows a variety of spatial factors to be comprehensively analyzed. Investigators using GIS analysis to assess and plan for walkability typically incorporate physical features such as sidewalk and street width, traffic volume, tree canopy, building heights, and population as common variables in their spatial analysis. A comprehensive walkability analysis tries to capture as many of these features as possible. Unfortunately only physical features can be used for GIS analysis, which means that subjective characteristics such as human scale, transparency, a sense of safety, enclosure, or comfort are difficult to measure and include in GIS analysis.

In this report, my goal is to specifically describe the use of GIS for shade analysis, which is a critical component of walkability, and test a model for such shade analysis in a central area in Austin, Texas. I will first present the current experiences of using GIS software to model shade in public spaces, focusing on the cities of Redlands, Buffalo, and Tucson, I will then review how the City of Austin currently incorporates shade analysis and considerations of shade provision through an analysis of planning documents and policies. I focus on three case studies in which shade analysis is incorporated into a walkability metric. Then, I will use two ArcGIS programs (ArcMap and ArcScene), as well as Trimble SketchUp to conduct a shade analysis in downtown Austin. I chose to focus my analysis in this area because downtown, along with the UT campus and adjacent West Campus neighborhood contain the highest amount of pedestrian traffic in the city. My steps included obtained building footprint and height data, creating 3D models, running a sun shadow analysis to determine shade patterns, and finally using this resulting information to draft shade maps over one day. Based on this analysis I provide recommendations to municipalities for best practices in the application of GIS modeling for shade analysis, and ultimately for a more systematic consideration of shade provision in planning, particularly in cities such as Austin, Texas, located in hot climates.

Chapter 2: Walkability and Shade: Benefits and Current Research Approaches

BENEFITS OF WALKABILITY TO CITIES

People benefit from living in walkable cities for many different reasons. Residents of walkable cities live in smaller housing, consume and pollute less, and are healthier. Many people living close to one another allows for chance conversations to take place on the sidewalk and harbors the potential to lead to a the creation of a new idea or product.

Cities should be designed to be as walkable as possible in order to attract the next generation of professionals. Young college-educated professionals overwhelmingly prefer to live in places with an active "street life". Well over half (64%) of college-educated millennials first choose where they want to live, and only then where they want to work, and seventy-seven percent of those want to live in "walkable urbanism" defined by dense urban cores (Doherty and Leinberger 2010). As this population decides where to live (and pay taxes), walkable cities have an advantage in attracting them.

Corporations who want to attract young professionals are also adapting to entice the next cohort of employees. The clothing company Patagonia recently relocated one of its offices from suburban West Michigan to Portland, Oregon based on the urging of its employees, who expressed wanting to live and work in a more urban setting (Johnson 2013). Brand Muscle similarly relocated 150 of its employees from suburban Beachwood, Ohio (Population: 11,844) to downtown Cleveland (Chilcote 2012). Concur, a corporate expense managing company, moved from the exurbs to downtown Bellevue, Washington due to employee demand, paying three times as much for office space (Sokolowsky 2012). In order to attract talent, companies are locating in walkable downtowns.

On the other end of the spectrum, aging baby boomers also desire to live in walkable cities. As they age, the elderly feel less comfortable driving and prefer to get around by public transit or on foot. Living in walkable neighborhoods allows them to remain independent. This is good news to cities: baby-boomers are generally at the top of their income curve and control 70% of the country's disposable income (Institute for the Ages 2010). Many of them are trading their large suburban homes for small apartments in walkable cities, where they can more easily get around without a car and stay active as they age.

Walkability has several environmental advantages over traditional suburban-style development. People who live in walkable places spend 25% less on transportation costs, allowing them to invest that extra income in their local economy (Perks and Raborn 2013). Residents of walkable neighborhoods are more likely to live in housing with shared walls and consume less energy used for heating and cooling (EPA 2013).

In addition to environmental benefits, residents in walkable neighborhoods are also healthier than their suburban and rural counterparts. These residents can forgo vehicular transportation and instead get around on foot, thereby incorporating exercise into their daily routine. People who live in walkable neighborhoods undergo higher levels of physical activity, weigh less, have a lower body mass index (BMI), and are less likely to be obese (Giles-Corti and Donovan 2002, Sallis, et al. 2009, Lopez 2004).

New research into the health benefits of walkability has demonstrated a correlation between WalkScore.com's Walk Score® and public health. Walk Scores are calculated in part by measuring the number nearby amenities such as restaurants, shops, and employment centers. Areas with high Walk Scores have been associated with higher rates of physical activity, lower rates of disease, lower Body Mass Indices (BMIs), lower rates of obesity, and a higher quality of life (Murray 2011, Jones 2010, S. Rogers, et al. 2011, Brewster, et al. 2009). It is clear from the emerging literature that improving a city's walkability has the potential to significantly increase the health of its residents.

CURRENT WALKABILITY-RELATED SHADE RESEARCH

Understanding that walkable cities enjoy many different community benefits, it is up to city planners to assess current walkability based on various characteristics. This in turn allows planners to replicate successful strategies and remove barriers to walkability. Research to document such limitations to walkability and to analyze potential solutions to walkability challenges is often conducted using GIS software, which is useful for plotting physical characteristics on a two-dimensional plane. These different characteristics (referred to as "layers" in the GIS world) can be laid on top of each other, revealing spatial patterns.

Factors most commonly included in GIS walkability analysis include residential density, street connectivity, the number of nearby destinations, the extent of pedestrian infrastructure, safety from automobile traffic, and transit network quality (Cerin 2006, Leslie, et al. 2007, Cutts, et al. 2009). Climate-related factors are less common in GIS analysis but just as important. In hot climates such as Austin, the amount of shade covering the pedestrian network profoundly influences that area's walkability.

There are different ways to measure shade using GIS, the most common being the use of remote sensing analysis to identify the presence of urban trees. Typically, remote sensing data such as LIDAR is used to estimate where trees are located in a given area and to produce geospatial files indicating the location and extent of the tree canopy. Researchers then use this resulting digital tree canopy layer as a proxy for where shade is. In other words, what is mapped is not the shade itself but the trees, with the assumptions that the trees provide shade for those walking underneath them. There are two problems with this methodology, however. First, LIDAR imaging works by illuminating a target on Earth with a laser-equipped satellite and then analyzing the reflected light (NOAA 2014). Vegetation reflects a particular type of light, so it assumed that urban vegetation represents shade-bearing trees. However, this is not always the case. LIDAR images also pick up grass, low-lying shrubbery, and immature trees, and it is often difficult to distinguish between the two. Second, LIDAR images only represent a snapshot in time. Depending on how old the images are, or even what time of year they were taken, the resulting tree canopy layer may misrepresent the actual extent of shade and hence the walkability of the area.

One example of the use of LIDAR imagery for shade analysis comes out of Redlands, California. In an effort to provide more shade for pedestrians on Safe Routes to School routes, a University of Redlands student used GIS to identify shaded and unshaded sidewalks by using LIDAR data to create a tree canopy layer which was then overlaid on the city sidewalks layer (Crowley 2011). This kind of analysis is appropriate when trees cast more shade than nearby buildings, such as in a residential neighborhood. Another study in Orange County, California sought to increase bus ridership by focusing on the walkability of the streets that serve as bus routes (Chen 2012). The criteria used to measure walkability in this case were street connectivity, steepness, and tree canopy. The logic was that that as street connectivity increases, pedestrians have more destinations located near enough to make walking to them convenient. Similarly steepness was included as to indicate the level of pedestrian comfort.

In addition to using tree canopy as a proxy for shade, researchers have also attempted to estimate shade provided by built structures. A 2007 study attempted to identify neighborhoods with low walkability in Buffalo, New York in order to devise strategies to improve their quality of living (Bhattarai 2007). The report found vacant lots and poor street conditions were associated with low walkability, while street furniture, trees, and sidewalks were associated with high walkability. These criteria were then used to create a walkability heat map using GIS, in which areas with high walkability were brightly colored. In 2012, the City of Tucson conducted a shade analysis of their downtown (Tucson Area GIS Cooperative 2012). They acknowledged the difficulty of identifying the complex zones of shadows and sunlight caused by tall, closely spaced buildings at a fine spatial and temporal scale. Their research sought to find out how GIS can be used to model these patterns and what data and methodology could best be used to do so. They created models of their downtown buildings using ArcGIS, a popular GIS software developed by Environmental Systems Research Institute (ESRI), and ran a shadow analysis tool to produce shadow maps. They then added time and date data to their individual maps and created a browser-based viewer allowing the user to track shadows over time using a time slider. They lastly uploaded it to their server and published it for public use.

What the experience of Tucson shows is that while it is common for GIS based walkability analyses to use available tree canopy data, this only represents a part of the shade present in an urban environment. Just as important is the shade produced by tall buildings. The interest in modeling shade is typically greater in the fields of architecture and urban design, yet it is just as important for planners to be able to understand how zoning and other development regulations affect the walkability of public spaces through the presence or lack of shade in hot climates. In the following chapter, the degree to which shade analysis is incorporated into city planning efforts in Austin, Texas is reviewed.

Chapter 3: Shade Provision in Austin Planning

Austin is one of the fastest growing cities in the United States. It is home to 885,400 residents, and 110 move here every day (Census 2014, Pope 2014). It increased from the 13th to the 11th largest city in America in 2012 (Carlyle 2014). The city has doubled in size every 25 years, and in 2013, the city grew at an unparalleled 2.5 percent, more than any other metropolitan area of its size in the country.

The speed at which Austin is growing is putting a real strain on city infrastructure, especially since Austin is overwhelmingly a driving city. Eighty-four percent of workers commute by car, while only 2.4% walk (Census 2013). More people take public transportation than walk (4.2%), but less ride a bicycle (1.4%). The percentage of people who walk as a form of transportation has actually decreased since 2010 when it made up 3% of all trips and is about the same as it was in 2000 (2.5%) (Census 2010, Census 2000). As a result, according to a 2014 study, Austin has the fourth-worst traffic congestion in the country (Inrix 2014). This was based on the difference between trips taken in normal traffic and those taken during peak hours. In Austin, people spend 42 hours in traffic per year in stop-and-go traffic. Driving during rush hour adds 35 minutes to every hour driven (TomTom 2013).

Because of these increases in population and the difficult traffic conditions, the City of Austin is seeking to improve its walkability. However, the hot climate in central Texas is a serious, constraining factor. The average high in Austin summer months is in the high 90s °F (34–36 °C) and temperatures top 100 °F an average of 18 days annually (National Oceanic and Atmospheric Administration 2012). In addition to a natural hot climate, Austin suffers from a phenomenon common to large cities: the urban heat island effect. Cities modify the land by replacing natural vegetation with pervious surfaces such as asphalt, steel, and concrete. These new surfaces reduce the amount of shade and moisture at ground level, evaporate less water, and change how the sun's energy is absorbed and reflected, all raising the ambient temperature (EPA 2013). In Austin, the urban heat island effect accounts for a 14-21 °F temperature increase in the downtown area (Steyn 1982). If the rate of Austin's growth continues, the heat island effect will increase by 2-3 °F over the next century, above and beyond the effects of climate change (Stone 2007), leading to potentially serious public health consequences. Heatstroke can occur when one's body core tops 104 °F (MAYO Clinic 2014), and since heatstroke is most common during daytime temperatures of 100+ °F, strategies that can decrease daytime temperatures in urban locales should be pursued.

However, despite these climatic conditions and the heat island effect, according to a 2007 survey conducted by the Austin Parks and Recreation Department, downtown has a smaller percentage of tree canopies than surrounding neighborhoods (26% compared to an average of 34%) (City of Austin Urban Forestry Board 2013). In order to improve walkability in the central city, it is there important to consider shade provision by the built environment, not merely by tree canopy cover.

SHADE PROVISION IN EXISTING PLANNING EFFORTS

While Austin has incorporated shade provision in several of its plans over the years, it has done so in an ad hoc manner. Rather than singling shade out as an important aspect of walkability, it is only referred to in passing in planning documents. At best, features that improve shade conditions are the indirect result of planning measures and ordinances that are not directly concerned with improving shade provision.

Sidewalk Master Plan

In 1997, the City of Austin conducted a transportation survey that found only 3% of Austinites walk to school or work (City of Austin 1997). In response, the Austin City Council adopted the Pedestrian Master Plan in 2000, the goals of which were to "encourage walking as a viable mode of transportation, improve pedestrian safety, and enable people to walk to and from transit stops" (City of Austin 2000). The plan was meant to help control air pollution and traffic congestion by reducing vehicular miles traveled as well as improving the quality of life in Austin. It focuses on building sidewalks in neighborhoods which have none and includes a Project Selection Matrix, which prioritizes areas for improvement based on their score on several criteria, broken down into five parts:

1. Pedestrian Attractor Score (PAS)
2. Pedestrian Safety Score (PSS)
3. Fiscal Availability Score
4. Neighborhood Plan Score

The Pedestrian Attractor Score is weighted most heavily, accounting for half of the base score. Points are awarded based on the proximity of the proposed sidewalk to particular "attractors". These attractors include schools, transit stops, government offices, and arterial streets. Residential population density, presence of existing facilities on the street, existence of bicycle lanes, and 311 citizen requests for sidewalks are also factored into the PAS. The Pedestrian Safety Score accounts for 40% of the base score. Points are awarded based on street type (local, collector, or arterial), health of the area's residents, and occurrence of automobile/pedestrian collisions in the area. The Fiscal Availability Score makes up the remaining 10% of the base score, and points are awarded based on whether outside funds tied to the improvement have been dedicated. Finally, special consideration is given to areas which have higher pedestrian activity than would be suggested by the other criteria, such as nearby parks, segments of city trails, or routes to schools. Sidewalks are then ranked from very high to very low priority, with projects with highest priority being funded first.

Although the program has proved successful by supplying the city with wide sidewalks complete with many amenities, it does not take shade into account. Arguably streets with continuous shade are better suited for sidewalk construction than similar streets without shade. The amount of shade a street receives should be included as a criterion in the Pedestrian Attractor Score.

Urban Design Guidelines of Austin

The Downtown Austin Design Guidelines were established in 1999 as a component in the city's Smart Growth Matrix, where downtown projects that met the design guidelines would be awarded development incentives. In 2008, this document was revised to encompass any part of the city that chooses to create and shape dense development, and the name was changed to reflect this change: the Urban Design Guidelines of Austin.

The guidelines are divided into four categories: area-wide, streetscape, plazas and open space, and buildings. Streetscape Guideline 5, Enhance Key Transit Stops, notes the following recommendation: "Consider pedestrian comfort and safety and provide adequate space, shade, and trees at transit stops in the development of site plans." One recommendation contained in the Guidelines for Plazas and Open Space calls for plazas that are shaded by vegetation, canopies, and trellises (City of Austin 2009). Others include:

1. Provide filtered shade by means of deciduous trees and vine covered which reduce temperatures in summer, yet allow sun in the winter

2. Provide continuous shade by means of arcades, canopies, and awnings adjacent to buildings

3. Calculate sun-shade patterns as seating locations are developed

4. Place seating in shaded areas as well as in sunny areas. Shade may be created trees, trellises, canopies, umbrellas, or building walls

In the section Use Plants to Enliven Urban Spaces, the document notes how trees offer shade to cool the city. It also recommends considering the eventual height and mass of mature plants in regard to views, shade, and maintenance.

The eighth Streetscape recommendation is installing street trees, and this is the one that most directly affects shade provision in Austin. Here is a little of what the guidelines say of trees:

> Trees improve air quality, reduce storm water runoff, provide cooling effects for the urban heat island, increase property values and create urban wildlife habitat. They can also greatly increase the quality of life in downtown.

This section of the report makes several recommendations regarding street trees, not the least of which include providing them along major pedestrian corridors, providing adequate soil volume to serve mature trees, set tree setbacks so that they have room to mature far enough away from each other and buildings, install irrigation systems to provide adequate water, install tree guards in high pedestrian use areas, and selecting trees which are adapted to the harsh conditions of a dense urban environment.

It is through this means of planning for the urban street tree that Austin has shaped the amount and location of pedestrian shade in Austin. The recommendations found in the design guidelines regarding a continuous shade canopy provided by street trees is most visibly and successfully demonstrated through the city's Great Streets Program. However, there is no requirement that shade be addressed in street improvement plans.

Great Streets Program

Downtown Austin, i.e. the area bounded by Eleventh Street to the north, Cesar Chavez Street to the south, Interstate 35 to the east, and Lamar Boulevard to the west, is home to 124,800 workers and 10,000 residents. This latter figure is set to increase significantly, as 1,330 housing units are currently under construction and another 2,700 units in planning stages. Given all of this growth in downtown Austin, it is imperative that a process be in place to meet that growth. In 2004, the Great Streets Development Program was implemented to cope with this growth, in part by providing a standardized process of improving the quality of Downtown Austin streets for pedestrians and transforming public rights-of-way into vibrant public spaces (City of Austin 2014).

The Great Streets Development Program provides financial assistance to developers who implement particular streetscape improvements above and beyond the minimum required by city code during construction. The program is funded through the Capital Improvements Program and the Great Streets Parking Meter Fund. The latter sets aside 30 percent of the revenue from parking meters located within the program area (City of Austin 2004). Improvements are planned to coincide with utility improvement projects in order to minimize construction time and maximize efficiency.

In order to be eligible for the program, projects must meet several criteria:

1. Locate within the program boundaries
2. Locate along a Capital Metro route
3. Locate along a City of Austin bicycle route
4. Implement underground utility improvements
5. Implement Great Streets Design Standards streetscape improvements
6. Serve a high degree of pedestrian activity
7. Encourage active uses on the ground floor, such as sidewalk cafes
8. Incorporate placemaking features

Developers are reimbursed $10-18 per sidewalk square foot, depending on how well the above criteria are met.

Great Streets Design Standard streetscape improvements include widening the sidewalk to 18 or 32 feet (depending on pedestrian use), installing public benches, bike racks, and trash receptacles (City of Austin 2014). But most importantly, street trees must be planted close enough to each other to create a continuous canopy. This ensures the sidewalks will shade the pedestrians when buildings cannot. The Great Streets Program has standards for tree placement that ensures a continuous shade canopy upon maturity. Other street-focused programs should address shade provision in such a systematic way, yet street trees should not be the only tool for bringing about shade.

Figure 1: View of 2nd Street District, Downtown Austin. Source: City of Austin Economic Development Department.

Austin Walkability Summit

In May 2013, the City of Austin and America Walks, a national walking advocacy organization, co-hosted the Austin Walkability Summit, a two-day workshop focused on "transforming Austin into a nationally recognized leader as a pedestrian friendly city - a city with a safe and pleasant walking environment that encourages all people to walk as an integral part of their daily lives" (City of Austin 2013). It served to identify community-based efforts to increase walkability in Austin and as a way to highlight walkability as an issue within the city, to share experience and expertise among stakeholders, and most importantly to develop a set of projects that could guide efforts to improve walkability. City staff from three departments (Public Works, Urban Design, and Transportation) joined representatives from America Walks and the Center of

Disease Control and Prevention to educate attendees on the benefits of walking on day one. Day two consisted of identifying walking priorities around the city and drafting initiatives. A summary report of the workshop with the projects and proposed action plans were then published online.

While this event fostered the creation of several important walkability initiatives, none of them directly addressed shade provision. Instead, these initiatives include efforts such as educating the public of pedestrian legal rights, prioritizing pedestrian infrastructure near schools, and improving pedestrian wayfinding downtown. It did lead to the formation of the Pedestrian Advisory Council, which is made up of resident volunteers who advise the city on all matters related to walking.

As has been shown above, Austin has not done a good job of systematically analyzing shade conditions and providing rigorous and systematic recommendations and requirements for shade provision. While programs such as the Great Streets Program do set a standard for street trees, tall buildings provide much more shade more consistently along pedestrian corridors. Given this fact, cities such as Austin should have access to technologies that can quickly and accurately show shade conditions in a particular area over time. To this end, the remainder of this report describes such a process in the hopes that it will be systematically integrated into planning for improved walkability.

Chapter 4: Research Design

SELECTING THE STUDY AREA

I chose East Sixth Street as my study area due to the City's recently revealed plans to drastically change the streetscape as a part of an infrastructure improvement project. The $19 million, seven-block plan would widen sidewalks, make them level with the street, and separate pedestrian and car traffic with bollards, short steel and concrete posts which are use to control traffic. These bollards sink at specified times to close the street to car traffic (Wear 2014). The street is currently four lanes wide with parallel parking on either side. The plan would remove the parking on the north side and replace one travel lane with a bike lane. The south lane would only be open during rush hour and would convert to another row of parking the rest of the time.

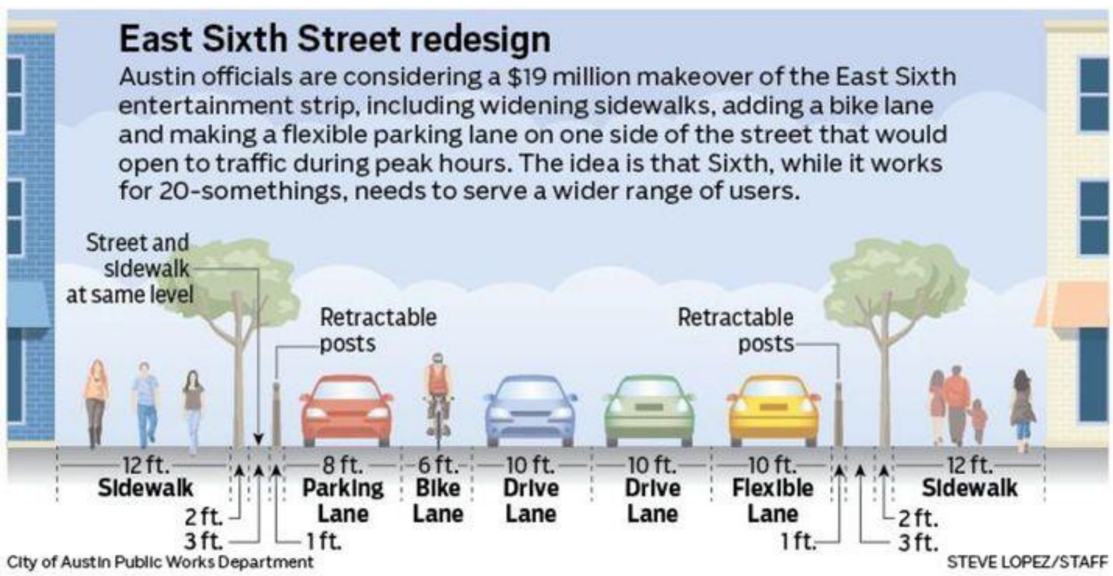


Figure 2: Festival Street Section. Source: Austin American-Statesman.

This plan would work to further enhance the walkability of a part of the city which already has high pedestrian activity. East Sixth Street has served as the city's main trade district since the late nineteenth century, and the predominant architecture is two or three-story masonry Victorian commercial buildings of that era.

Figure 3: Buildings on East Sixth Street. Source: Google Maps.

Since the 1970s, Sixth Street has served as a major entertainment district, and dozens of bars, clubs, music venues, and shopping destinations are located here. The street is closed to car traffic weekend evenings, UT Longhorn football games, holidays, and special events (Downtown Austin Alliance 2014). Sixth Street plays host to a variety of events each year, including the South by Southwest music/film/tech festival, the Republic of Texas Biker Rally, and the Pecan Street Festival.

As far as Austin streets go, East Sixth Street is relatively pleasant for pedestrians and therefore sees more foot traffic than almost all other parts of downtown. There are continuous sidewalks of both sides of the street. Street trees, although not continuous, are present in significant numbers. Buildings are built close to the street and to one another, creating a sense of enclosure that gives pedestrians something to look at, a destination, and importantly for our purposes, shade. However, recent plans to make improvements along the street has the potential to significantly change its form, and it is important to use as many tools as possible to further improve the area's walkability. Identifying the shade provided by the adjacent buildings is merely the first step toward identifying which parts of the street are comfortable for pedestrian in summer months and which are not.

Figure 4: Sixth Street, Austin, Texas. Photo by John Rogers, 2014. Photo is licensed under CC BY-NC-ND 2.0.

In order to create maps that depict the shade on East Sixth Street throughout the course of a day, several steps were taken. The first step was data acquisition, where I secured available data pertaining to building location (footprints) and building height. The next step was data processing, where I fed the building data into the GIS program ArcMap in order to calculate sun position and the resulting shade cast of a particular point in time. This process was replicated on an hourly basis until an entire day's worth of shade is overlaid onto the street map, which made it possible to develop time-lapse shade maps and areas of plentiful versus scarce shade. Finally, I verified the outputs of the GIS analysis with observations in the field through a process called ground-truthing.

Preparing for Analysis

First, it is necessary to prepare the data for analysis by configuring ArcMap's workspace settings. The first step in this process is creating a Home folder to store map documents, save tool results, store new datasets, and access file-based information. After creating a new folder named *GIS* and saving it to the C: drive main directory, I opened a new ArcMap document, clicked the Options button and set *GIS* as the Home location to be used for all new map documents. Within the Home folder, each map document comes with a default geodatabase where the spatial content of the map is stored. When features added to the map or are exported from a layer, the data is saved in the map's default geodatabase. The Scratch Workspace and Current Workspace environments are synchronized by default to the map document's default geodatabase. In order to keep all datasets in one location, a new geodatabase named *Shade_Analysis.gdb* is created within the Home folder and set as the Default Geodatabase.

In order to preserve the portability of the data, I changed ArcMap's settings to reference datasets using relative paths. When layers are added to a map document, the path linking to this data is saved as a layer itself, known as a Data Reference. ArcMap by default references datasets using absolute paths, an example being "C:\GIS\Shade_Analysis\Downtown.shp". Storing data references using absolute paths can potentially cause problems when sharing data, requiring users to replicate the folder structure within their own C: Drive, creating folders and subfolders to match the path. Relative paths, on the other hand, specify the location of the data only relative to the current location of the referenced file. An example of relative paths is "\..\Shade_Analysis\Downtown.shp\". Because relative paths do not contain drive names, the layer can be moved to any disk drive or computer and ArcMap will locate *Downtown.shp* based on where the other layers in *Shade_Analysis.gdp* are located. This saves users time not having to reconnect layer's data links every time it is copied or moved.

To create a basemap over which the relevant data were to be layered, GIS layers representing contour lines, neighborhood boundaries, and building footprints were downloaded from the City of Austin's GIS portal (City of Austin 2014). Contour lines can be used to create three-dimensional terrain on which the building models will be placed. Neighborhood boundaries were used to clip this terrain from the city as a whole to the downtown neighborhood. Building footprints are needed to create 3D models of the buildings, so they were also downloaded.

After downloading the necessary datasets, the next step was to create a 3D scene from my two-dimensional data. I did this by using the Create TIN tool in ArcScene to create a 3D surface, selecting *Downtown_Contours*'s Elevation attribute as the Height Field. The result is a three-dimensional terrain.

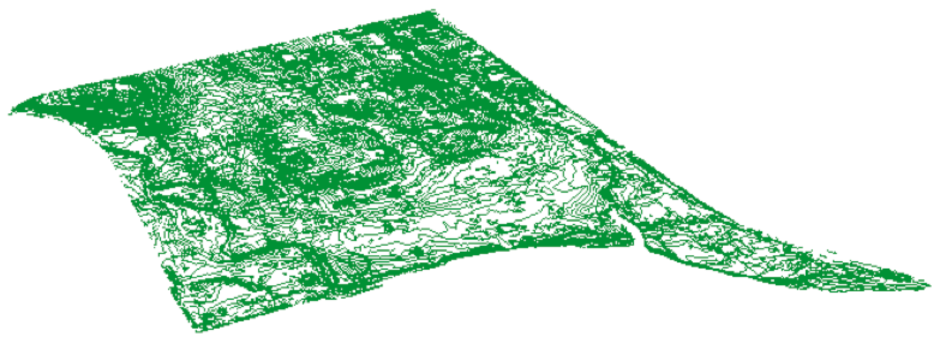


Figure 5: Downtown Austin, Contour Lines.

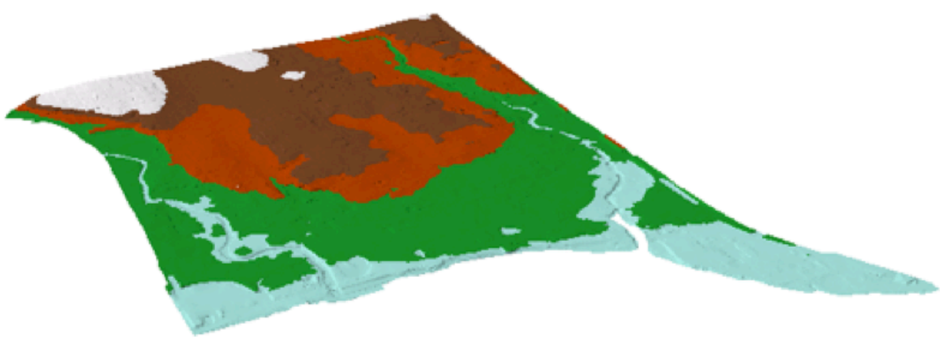


Figure 6: Downtown Austin, 3D Terrain.

After clipping the terrain down to the study area of Sixth Street from Congress Avenue to IH-35, I created 3D buildings from the 2D building footprints dataset. This was accomplished by collecting building height data in the field using a laser distance measurer and extruding the footprints by their height value. While most of the buildings within the study area are rectangular in shape, extruding their height from their footprint produces a fairly accurate representation. Two of the larger high-rises on Fifth Street, however, are more articulated in shape with a narrower top sitting on a wider pedestal. In order to get an accurate shade map, the models had to be refined in SketchUp. Building models were downloaded from the SketchUp 3D Warehouse (Ramirez 2014, Bf2 Austin Assault 2014). Complex 3D analysis such as ArcScene's Sun Shadow Volume tool is highly resource-intensive, becoming exponentially more so when interacting with highly articulated models. In order to achieve a more feasible rendering time, the models were simplified and then imported into ArcScene.

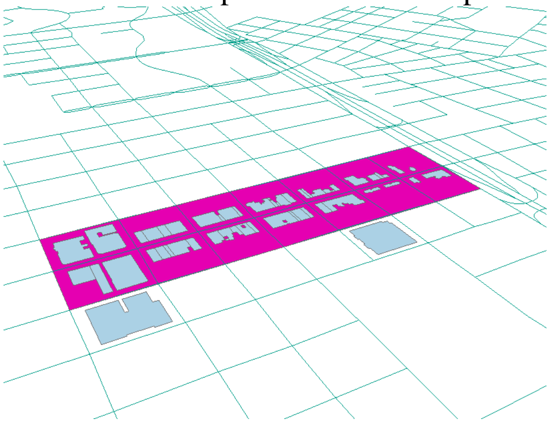


Figure 7: Study Area, 2D Building Footprints (ArcScene 10.2)

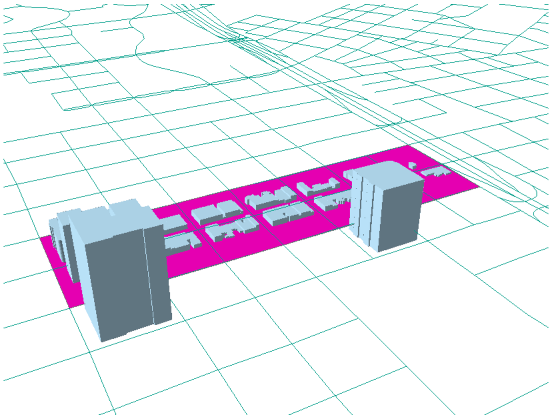


Figure 8: Study Area, 3D Building Models, Unarticulated (ArcScene 10.2)

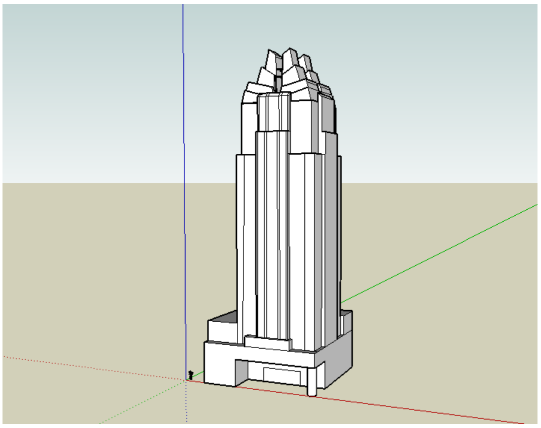


Figure 9: Frost Bank Tower. (SketchUp 14). Source: Anonymous, SketchUp 3D Warehouse.

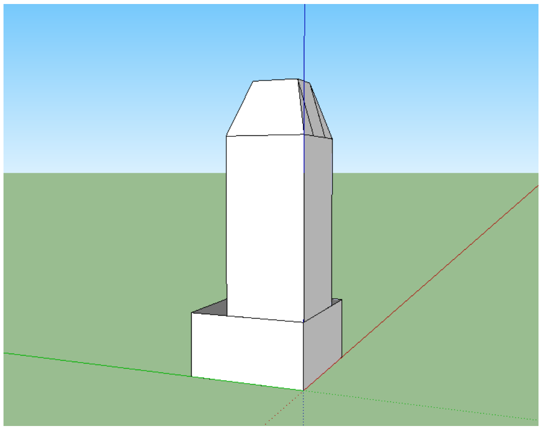


Figure 10: Simplified Frost Bank Tower. (SketchUp 14).

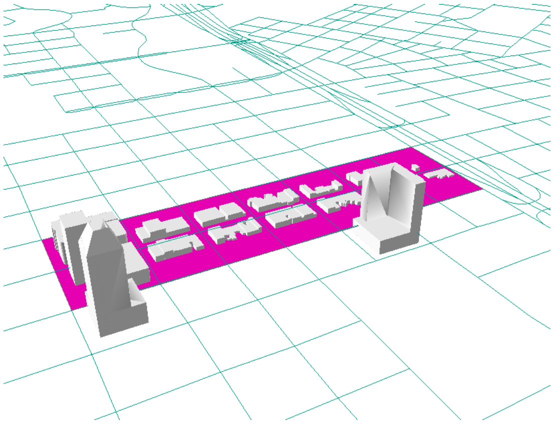


Figure 11: Study Area, 3D Building Models, Unarticulated. (ArcScene 10.2).

Only now are we ready to begin the shadow analysis. I began my modeling by running the Sun Shadow Volume operation, which extends three-dimensional shadows from the buildings toward and through the terrain. The angle of the shadows depends on the position of the sun, which is calculated based on temporal and positional inputs. For this analysis, I chose to look at the shade from sunrise to sunset on June 21, 2014 at one-hour intervals.

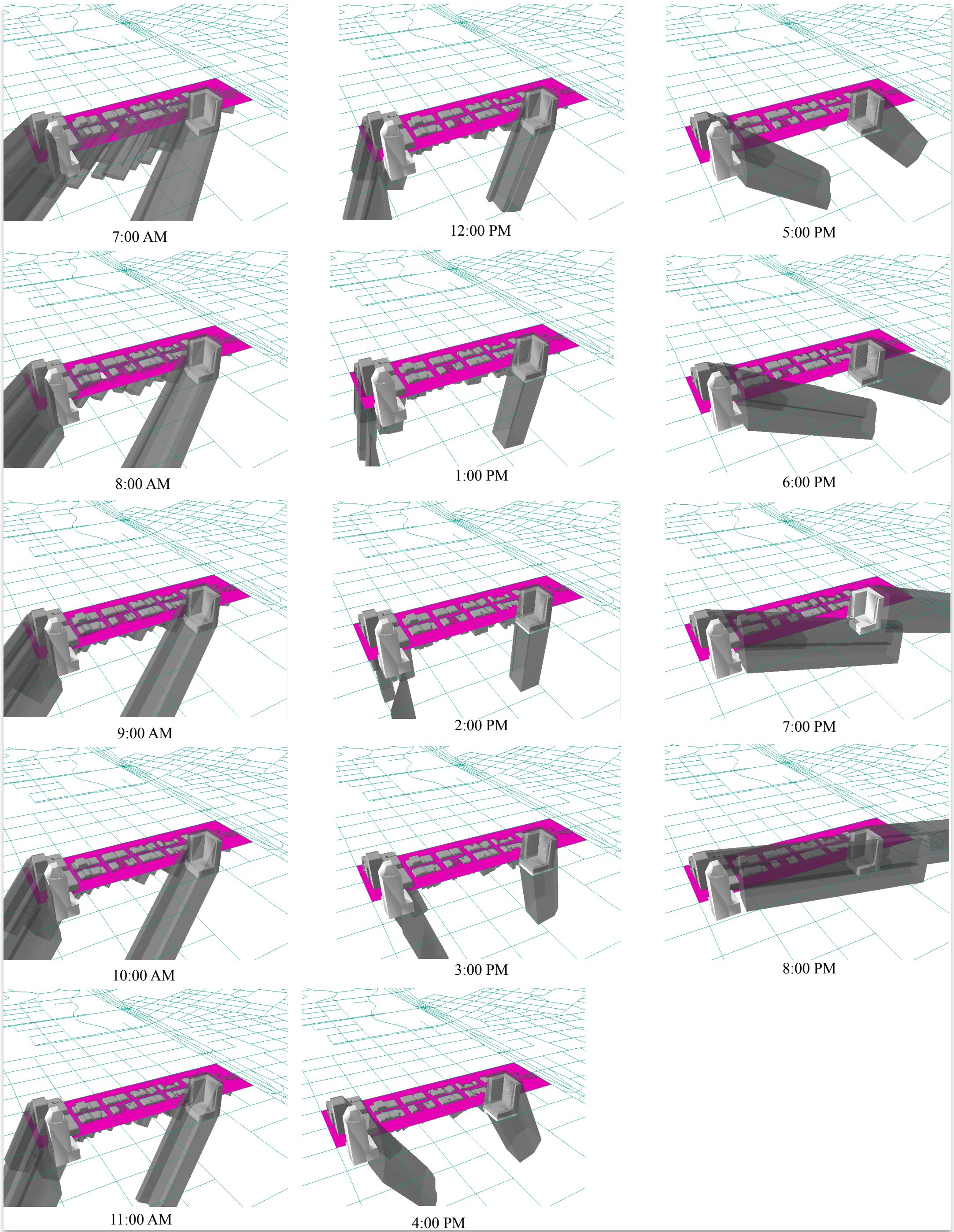


Figure 12: Sun Shadow Volume Output

Once the Sun Shadow Volume operation is complete, it is time to convert the data back into a two-dimensional format for analysis. Since the shadows are represented by solid projections that go through the two-dimensional study area layer, we need to isolate the areas where they intersect. Using the Intersect 3D and Multipatch Footprint tools, the shadow remains only where it should, on the ground. At this point we are left with 14 layers, each depicting where on the street and sidewalk buildings are providing one hour of shade (Figure 13, opposite).

In order to sum up these values and calculate the total length of time an area is shaded over the course of a day, I needed to first convert the features into rasters. This allows for each cell of shade to be valued at one and overlapping layers to be summed up, the value representing the total length of time, in hours, a part of the sidewalk is in shade. The different values are then color-coded to indicate areas enjoying an abundance of shade, those suffering a "shade desert," and everything in between.

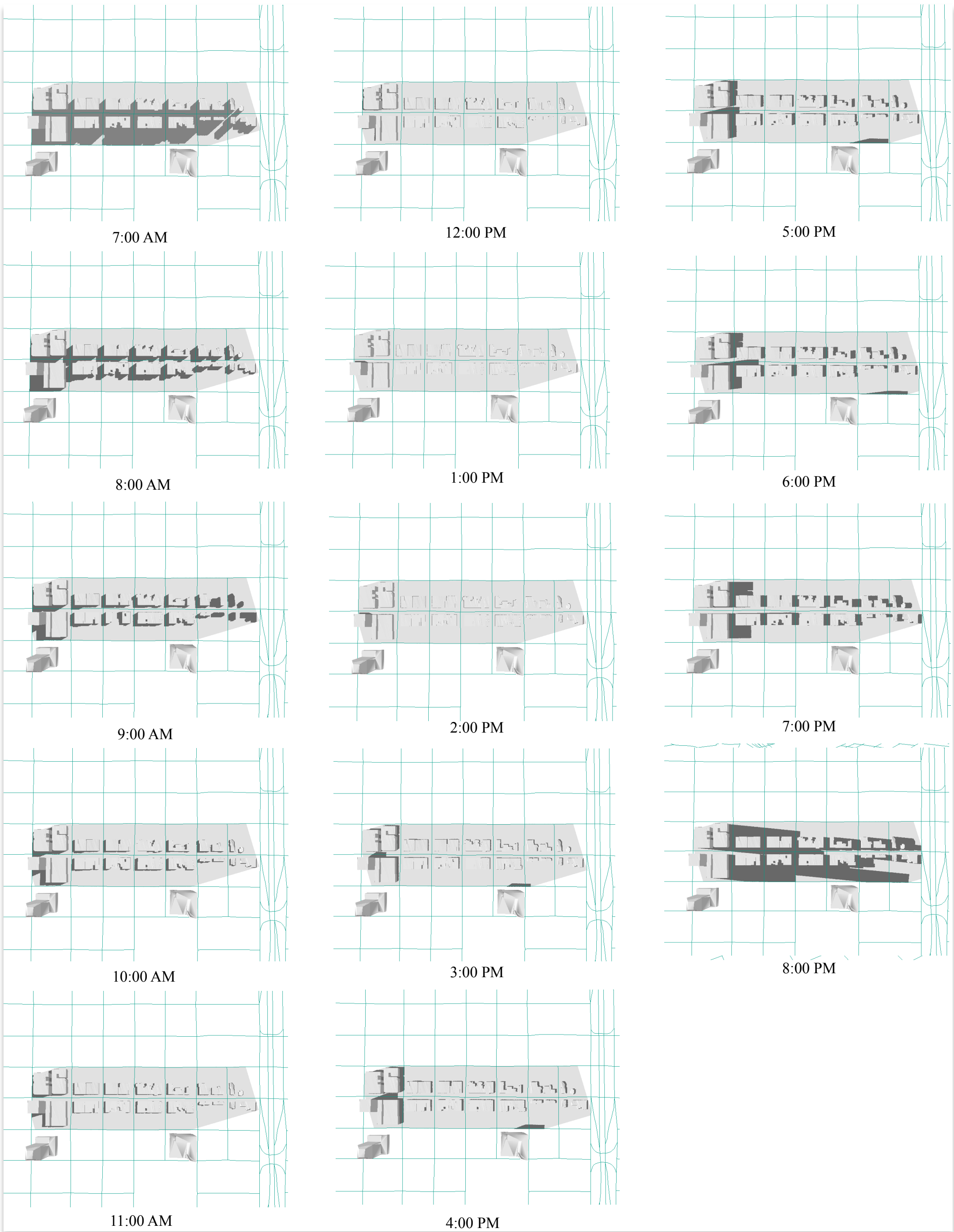


Figure 13: Shadow Maps at One-Hour Intervals

RESULTS FROM ANALYSIS

The followings maps illustrate the impact of buildings on the amount of shade along East Sixth Street throughout the day. The amount of shade produced by buildings varies significantly within the study area, ranging from 0 to 14 hours of shade. Generally, the north side of the street receives more shade than the south side. This is in line with the sun's path across the sky, which is not directly overhead, but to the south, causing shadows from the north side of buildings to be longer overall (UCSB ScienceLine 1999).

The western half of the study area was found to enjoy more shade due to the buildings being relatively taller and more densely placed. Block 1 enjoys the most shade, enjoying on average six hours of shade. East of Neches Street one begins to see block-long stretches of sidewalk that are reached by shade.

By isolating the areas that receive the least amount of shade, two hours or less, I was able to identify the south side of Blocks 4, 5, and 6, as well as both sides of Block 7 as the area most underserved by shade. I would recommend committing resources to look more closely at these areas to see how public space is currently used and what interventions can me made to shade these streets, at least from the hottest afternoon rays of sun.

It should be noted that only buildings adjacent to East Sixth Street were used for analysis, and that while streets to the north and south seem less shaded than they actually are, this is because buildings adjacent to those streets were not analyzed.

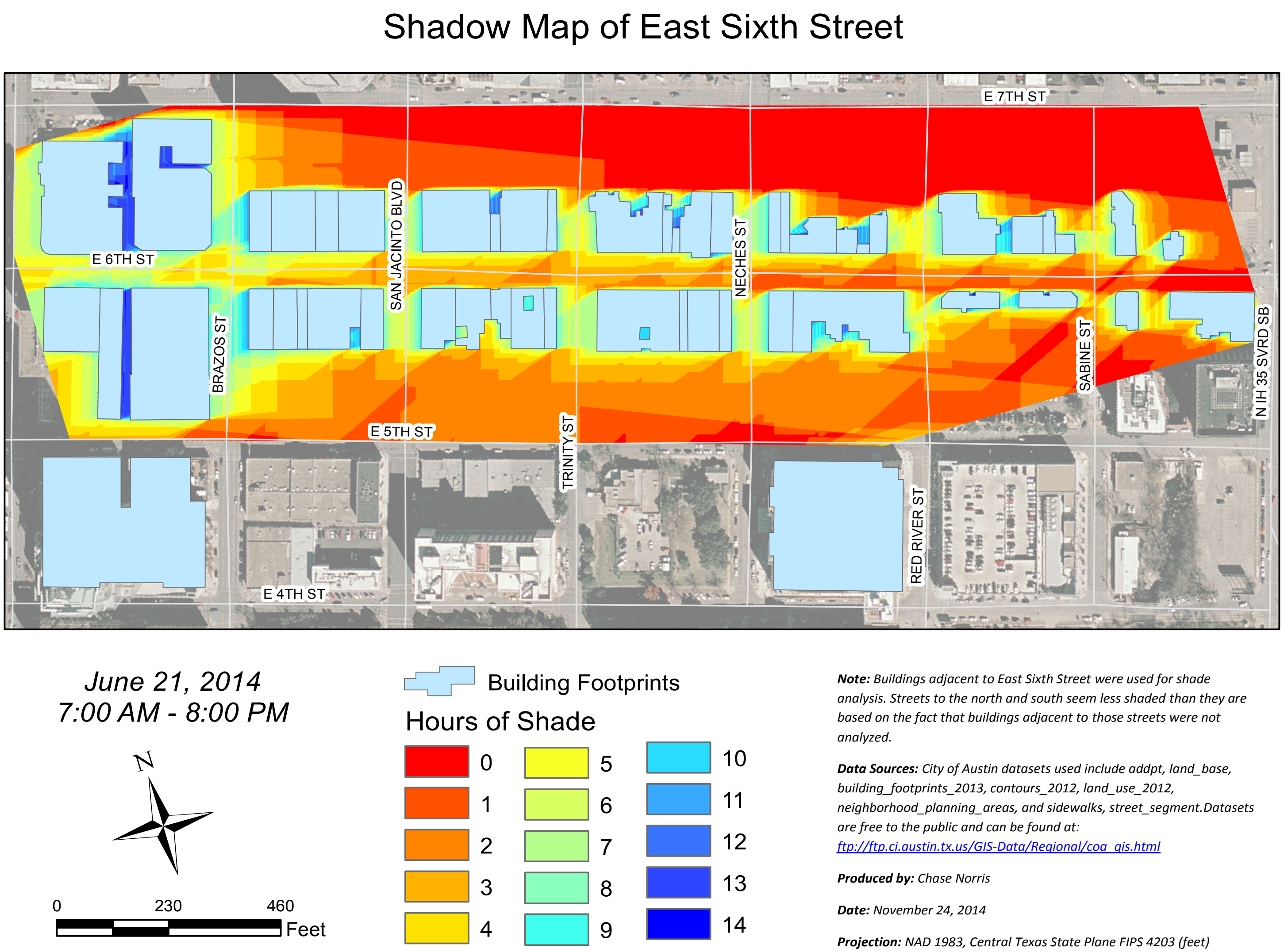


Figure 14: Shadow Map of East Sixth Street

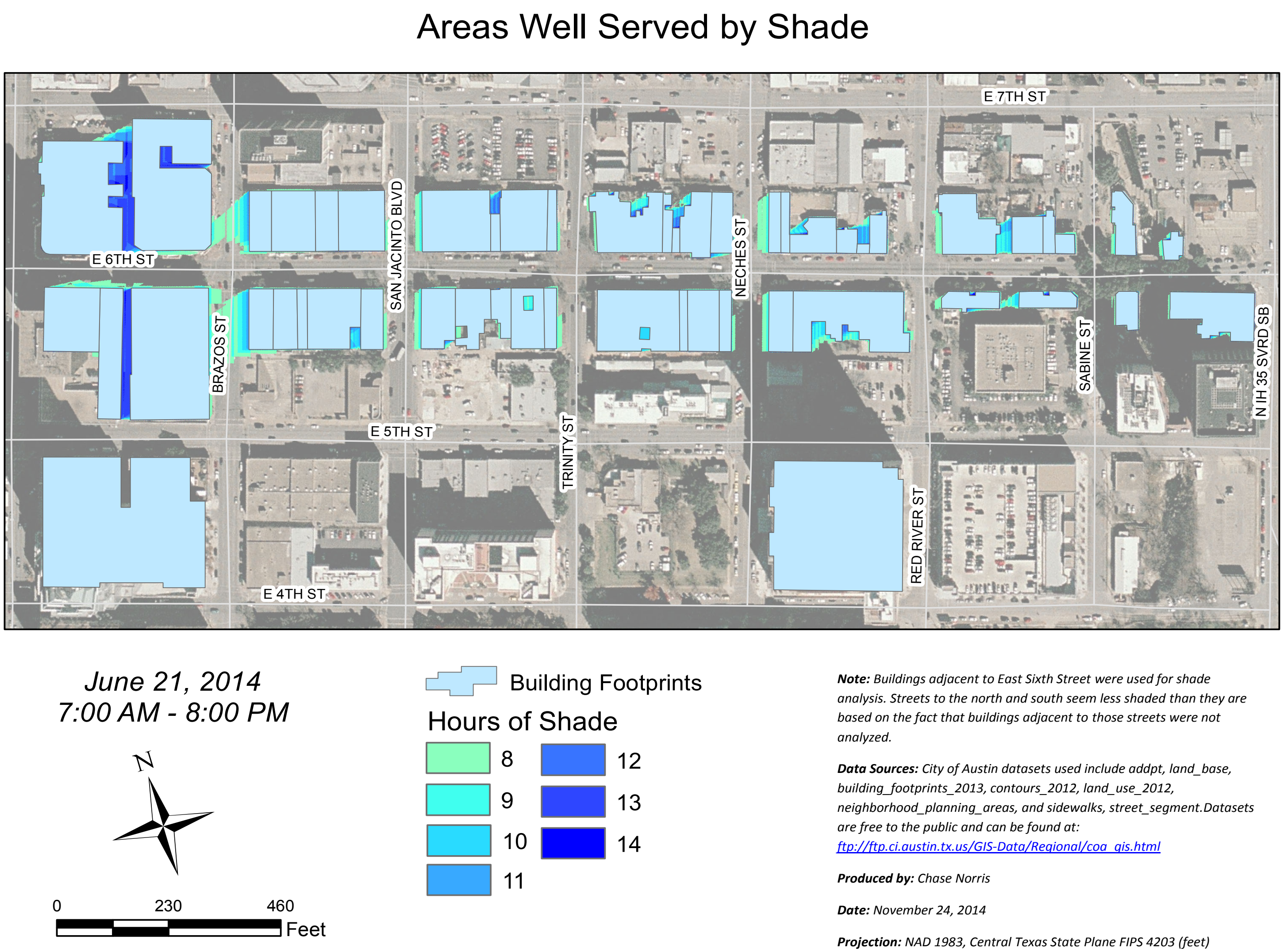
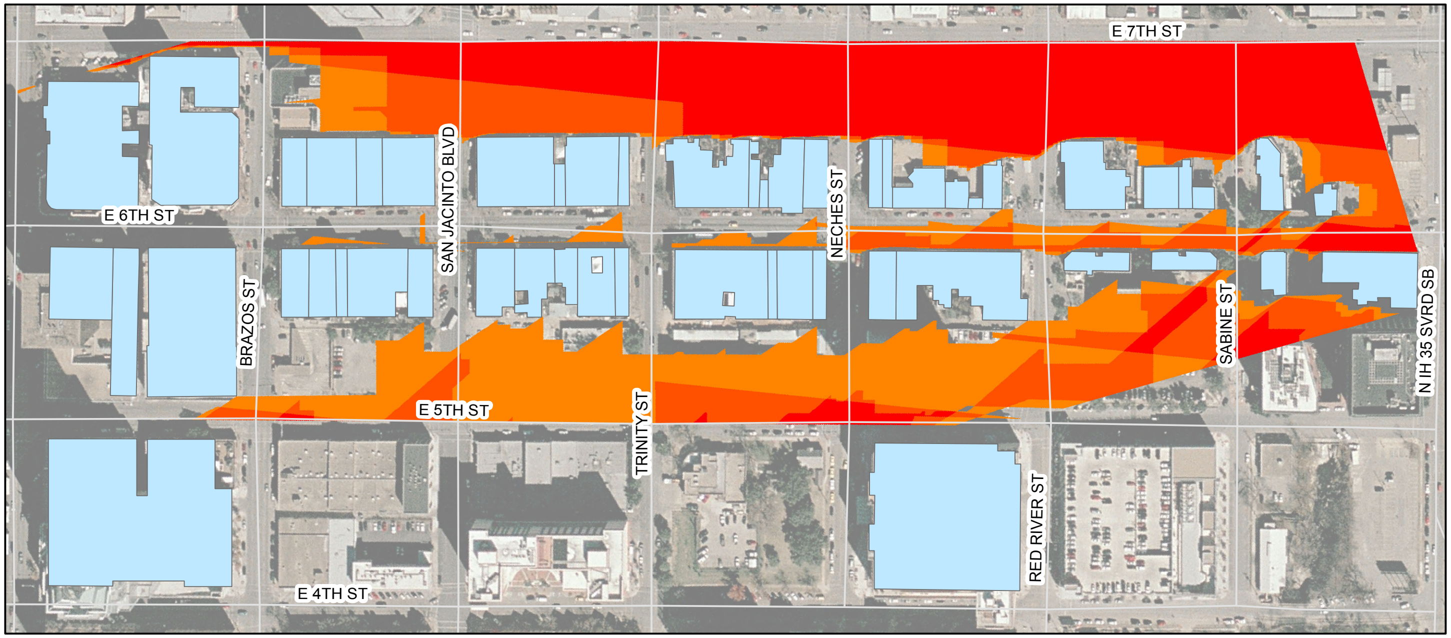


Figure 15: Areas Well Served by Shade

Areas Underserved by Shade



June 21, 2014
7:00 AM - 8:00 PM

N

0 230 460 Feet

Building Footprints

Hours of Shade

- 0
- 1
- 2

Note: *Buildings adjacent to East Sixth Street were used for shade analysis. Streets to the north and south seem less shaded than they are based on the fact that buildings adjacent to those streets were not analyzed.*

Data Sources: *City of Austin datasets used include addpt, land_base, building_footprints_2013, contours_2012, land_use_2012, neighborhood_planning_areas, and sidewalks, street_segment.Datasets are free to the public and can be found at:* *ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html*

Produced by: *Chase Norris*

Date: *November 24, 2014*

Projection: *NAD 1983, Central Texas State Plane FIPS 4203 (feet)*

Figure 16: Areas Underserved by Shade

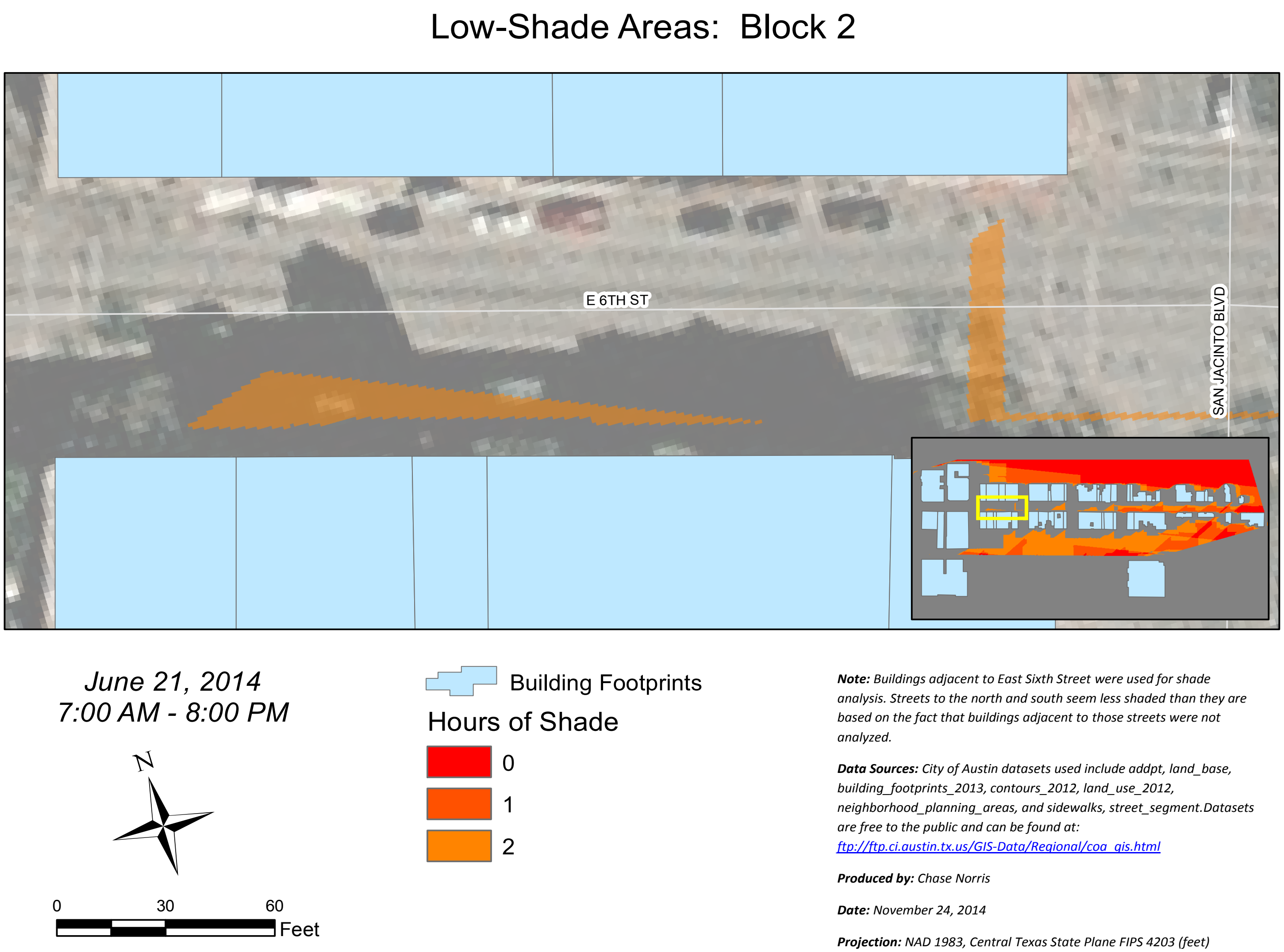


Figure 17: Low-Shade Areas: Block 2

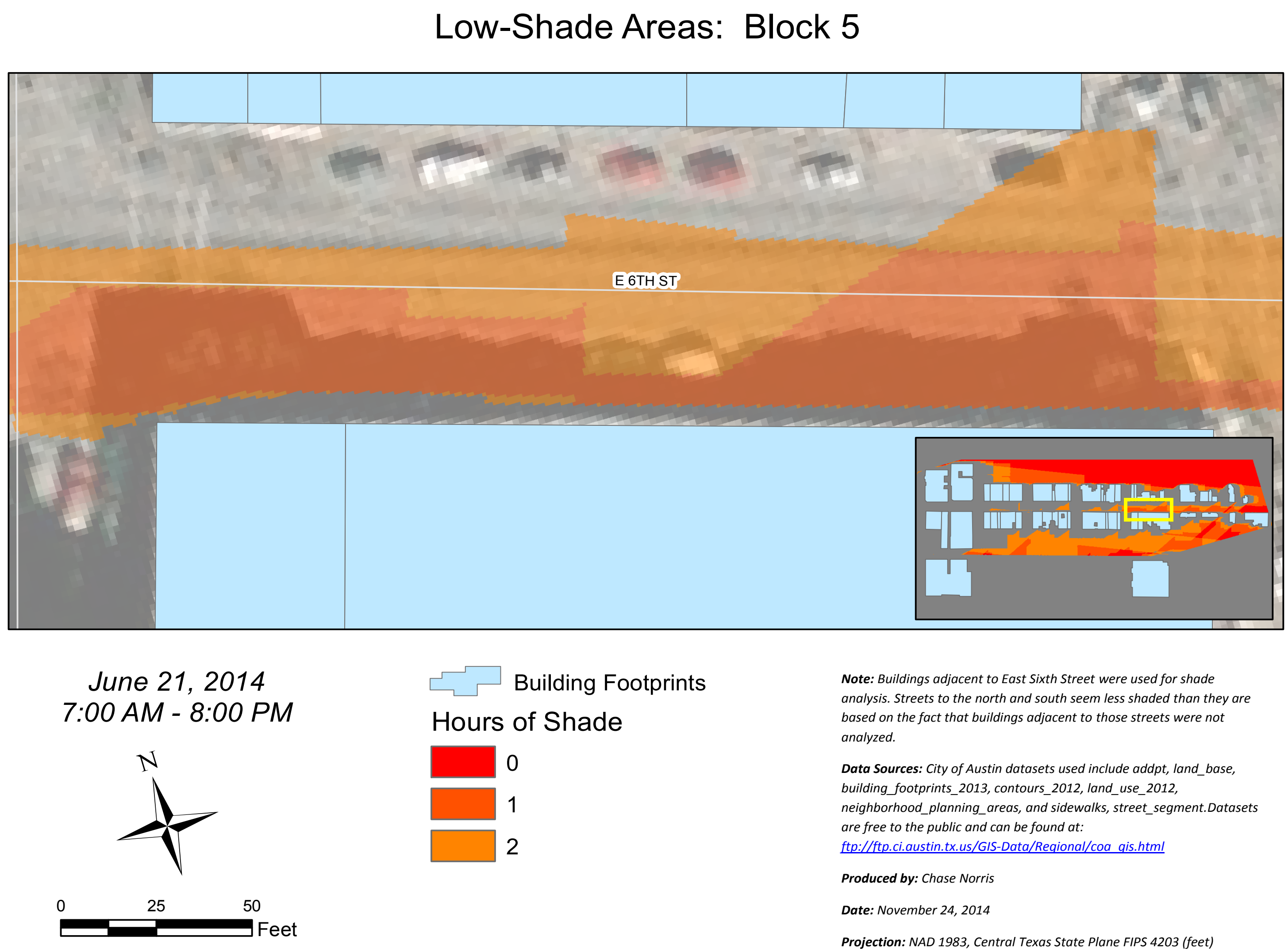


Figure 18: Low-Shade Areas: Block 5

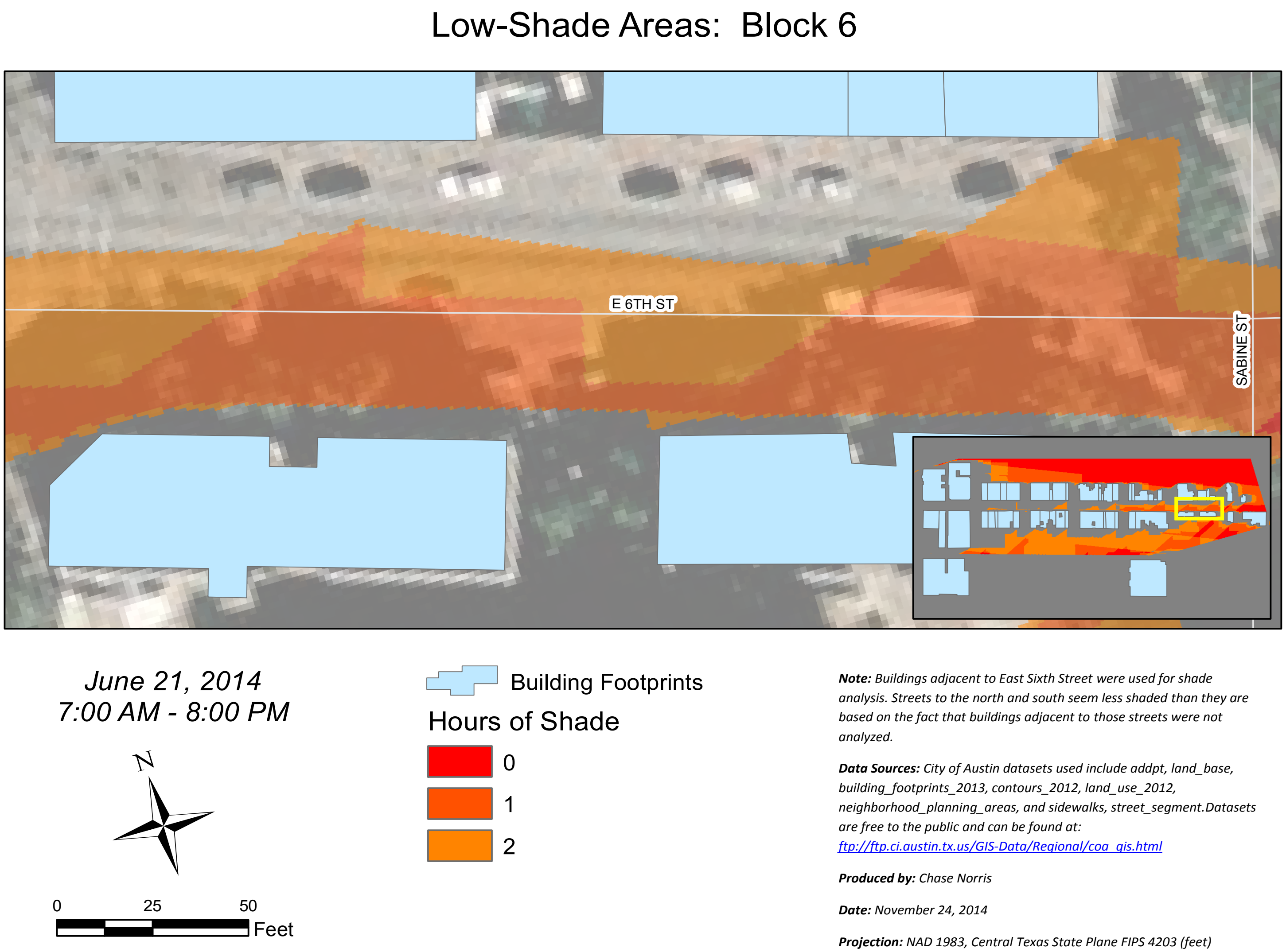


Figure 19: Low-Shade Areas: Block 6

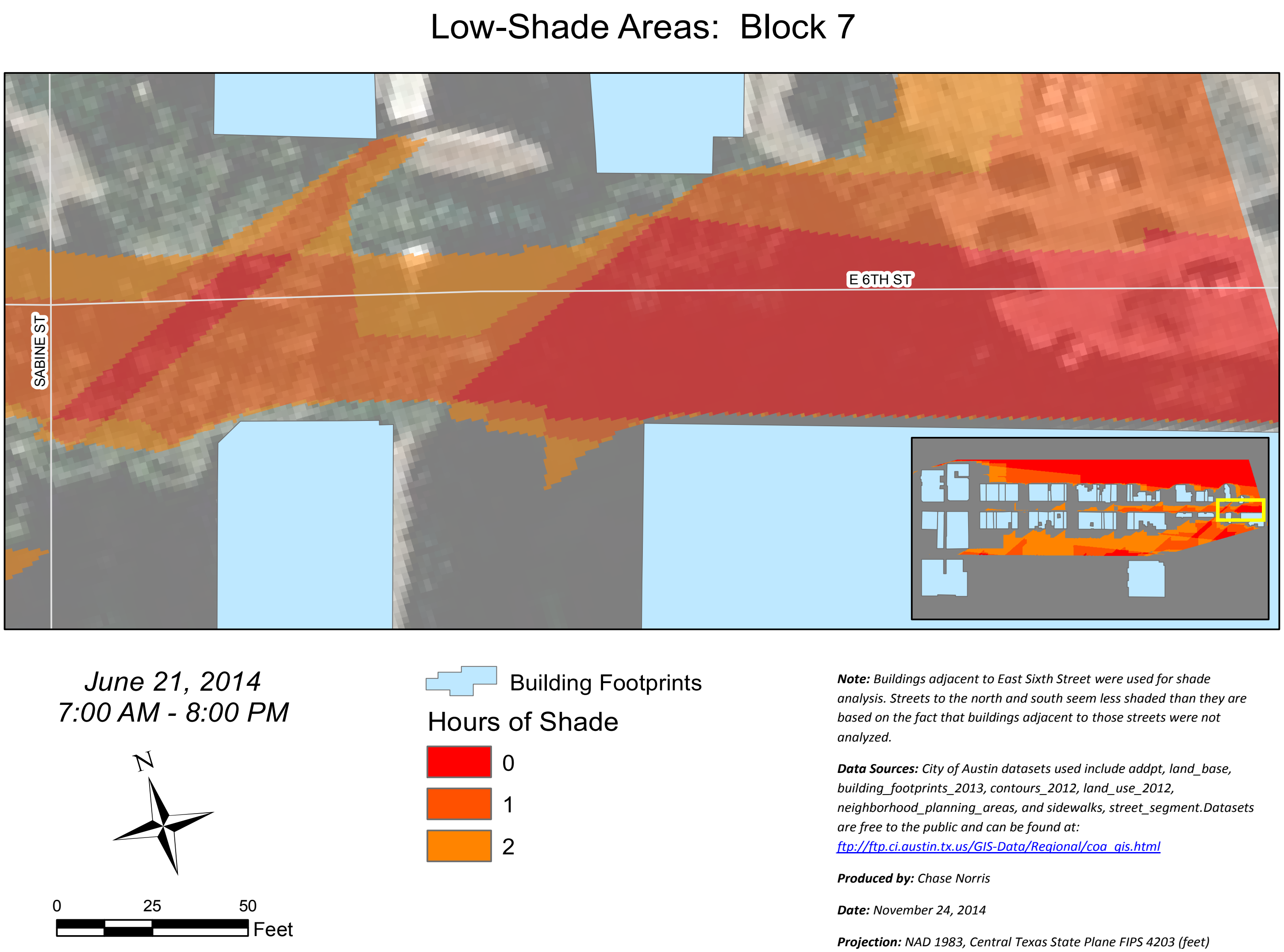


Figure 20: Low-Shade Areas: Block 7

GROUND-TRUTHING THE MODEL

All models should be verified if they can, and GIS analysis is no different. To test its accuracy, I conducted ground-truthing by modeling the shade on 6th Street for a selected future date. On that date—June 21, 2014—I printed and brought the map with me to 6th Street (Figure 21. I then walked the length of the street eastward, starting at Congress Avenue, and compared the shade as I observed it with the way it was modeled on the map. As I walked, I noted that the shadows lined up well with the model estimates. Shadows such as that pictured at 407 East Sixth Street (Figure 22) had been accurately modeled, give or take a foot.

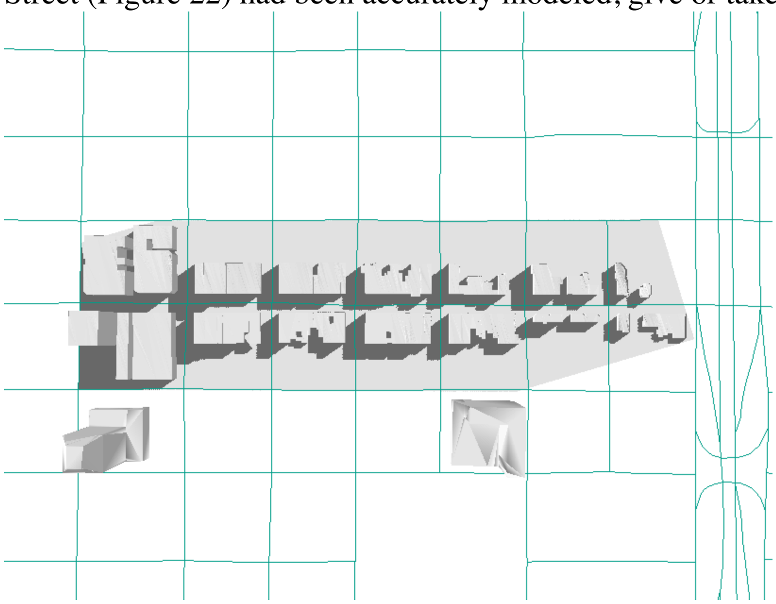


Figure 21: Sample Field Map

Figure 22: 407 East Sixth Street

One limitation of the study turned out to be that it focused only on one type of shade. Shade from street trees and awnings was just as common as that from buildings, and to leave them out of a definitive shade map would be coming up short. Figure 23 shows the sort of shade provided by trees in the study area that was not analyzed in this study. However, this report does not profess to be provide a comprehensive shade map, but instead a thorough and systematic tutorial on how to accurately measure built structures, which is an element that is often missing in walkability research.

Figure 23: 702 East Sixth Street

Given the findings of the shade analysis, along with the insights gained during the ground-truthing exercise, it seems appropriate the next stage in this process would be to collect a dataset representing the tree canopy, subject it to the same verification process we have seen here, and subtract that which is shaded by street trees from the areas known as under-shaded. Additionally, further work in 3D modeling could include awnings into the analysis, as several areas saw many hours of shade thanks to them.

Chapter 5: Conclusion

In cities with hot climates such as Austin, the amount of shade provided by trees and the built environment could make the difference for a person's choice whether to walk or to drive. Performing the sort of shade analysis presented above is useful for planners who wish to look hard at how comfortable a street is for pedestrian use.

It should be noted that while the focus of this analysis is strictly on shade produced by buildings, planners should see this as just one more tool in their ever-expanding toolbox. The purpose of this analysis is to supplement, rather than replace, existing models for tree canopy shade analysis. Trees have often been the only source of data for walkability research and planning efforts oriented towards improving pedestrian quality, and the intent of this study has been to develop a model for incorporating buildings into more comprehensive shade analysis. To that end, an extensive Appendix provides step-by-step instructions for conducting such a building-based shade analysis.

Much urban design praises street trees and their numerous benefits, not the least of which is shade. However, little is said about how building tall buildings close to the street can result in shady sidewalks that are much cooler than that same sidewalk in the sun, or how land use decisions regarding building height and setback requirements can have long-lasting consequences for the walkability of those places.

Appendix

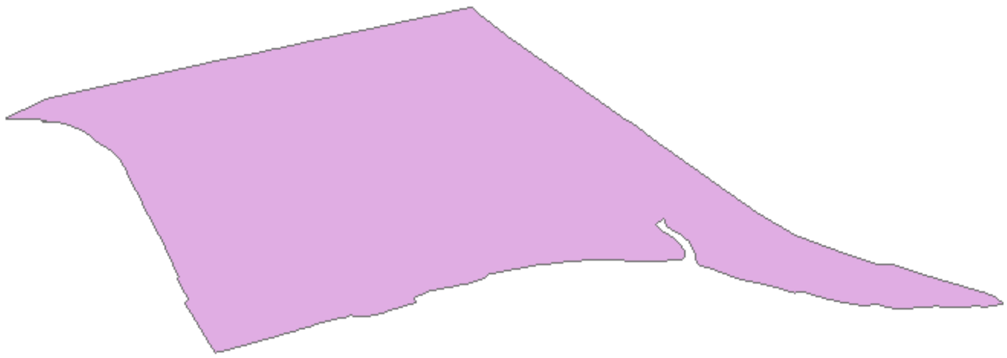
The following steps are intended as a tutorial and include screenshots of the process. ArcCatalog 10.2, ArcMap 10.2, ArcScene 10.2, and Trimble SketchUp 14 were used for this tutorial. Users with earlier versions of the software used in this tutorial might encounter some variation in interface or output. No software packages under the ESRI masthead of ArcGIS is supported by Mac OS X and must be installed on Windows or Linux-based machines.

First, we need to set up our workspace:

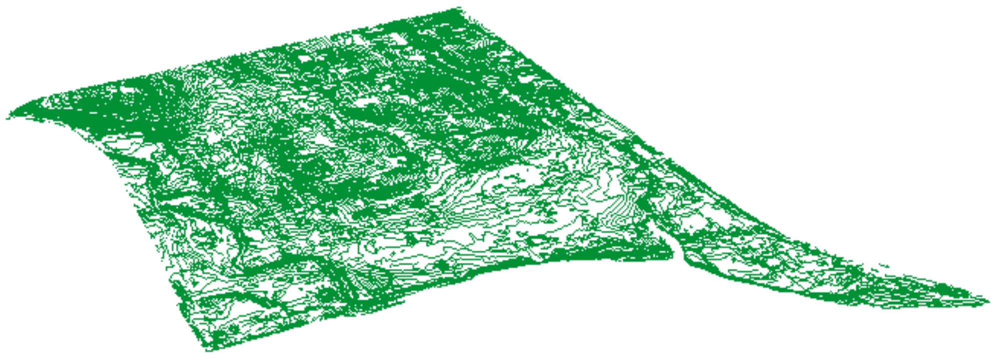
1. Open ArcScene
2. Open ArcCatalog
3. Create Folder in C Drive called "Shade_Analysis"
4. Right click this folder and create a Geodatabase to hold all your features, also called "Shade_Analysis"
5. Right click this Geodatabase and make it default. This will ensure that all new features are automatically stored in the same place.
6. Right click the "Shade_Analysis" folder and select new folder. Name this one "Shapefiles".
7. Go to the City of Austin's GIS database (ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html) and download *neighborhood_planning_areas*, *contours_2012, Street Centerlines,* and *2003 Building Footprints* into the Shapefiles folder.

Next, we will create a 3D scene for our analysis:

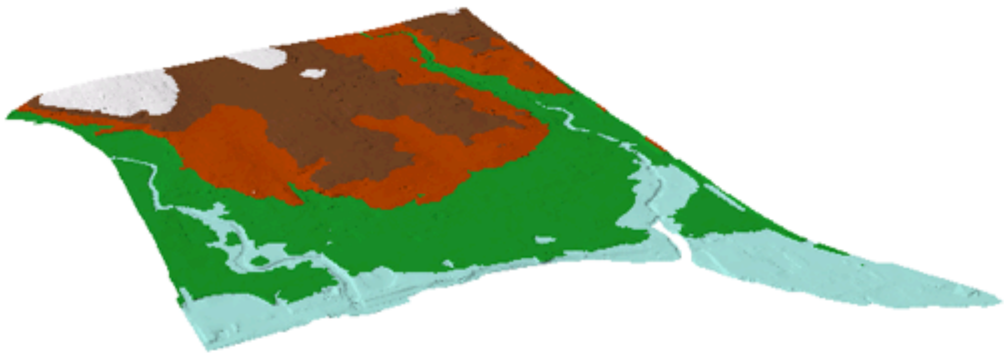
8. In ArcScene, add *neighborhood_planning_areas* to the scene.
9. Use the Select By Attribute tool to select *downtown* from the layer using the SQL expression "PLANNING_A" = 'DOWNTOWN'.
10. Right-click *neighborhood_planning_areas* and select export. Name the selection *downtown* and add the new layer to the current scene.



11. Clip the *contours layer using the downtown* layer as the extent. Name the resulting feature *downtown_contours*.

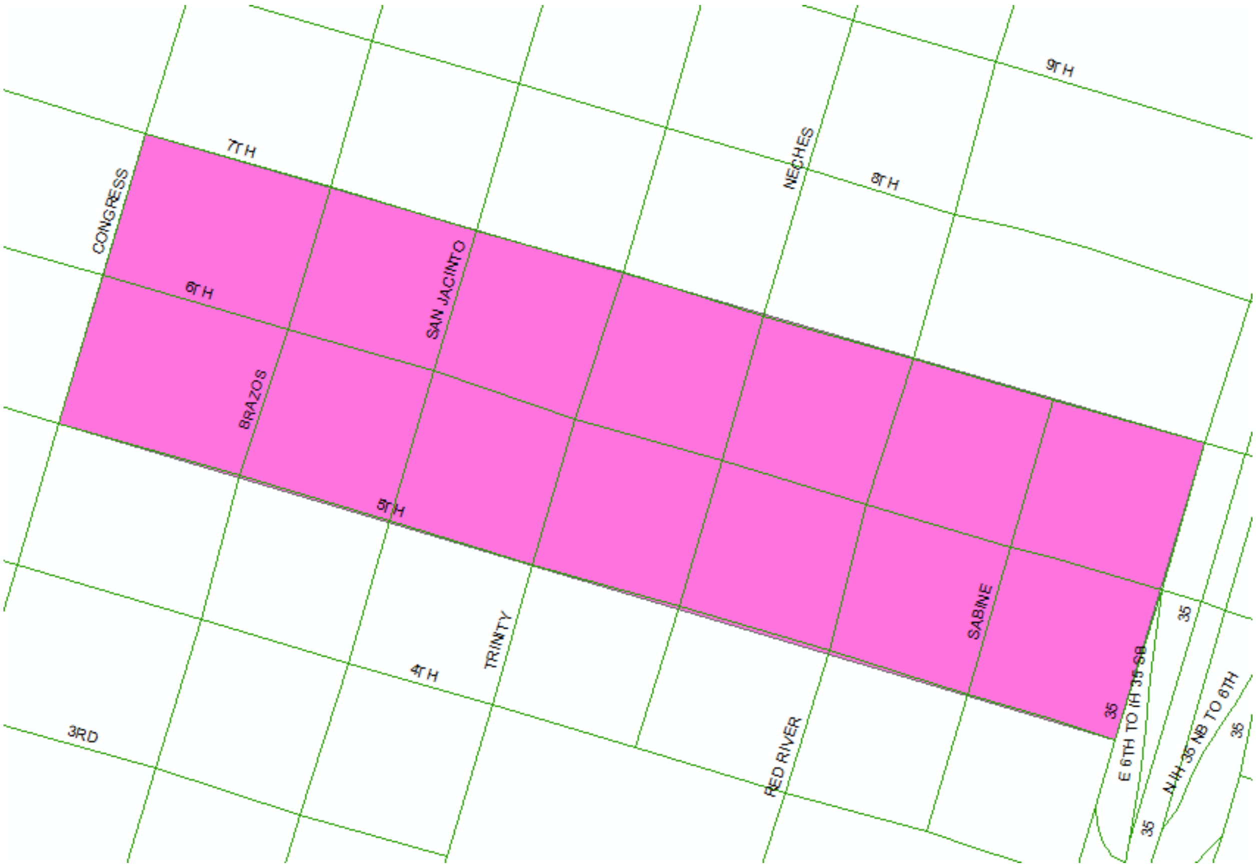


12. Finally, use the Create TIN tool to create a 3D surface, using *downtown_contours* and *downtown* as inputs. For *downtown_contours*, make sure Elevation is selected as the Height Field. Choose Soft_Line as the Surface Feature Type, since the feature edges of the contour lines do not represent distinct breaks but gradual changes in elevation. For downtown, leave the height value blank and select a Hard_Clip Surface Feature Type. This will clip the resulting surface TIN by the extent of downtown. Name the output TIN *Surface* and assign it the "NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet" Coordinate System.
13. Turn off the *Contours* and *Neighborhoods* layers and Zoom To the new *Surface* layer.



The next step is to define our study area:

14. Open ArcMap and add the *Streets* layer.
15. Zoom to Sixth St and Congress Avenue by using the Select By Attribute tool to highlight both streets and find their intersection.
16. Turn on the *Streets* layer's labels.
17. With the catalog window open, create a new polygon feature and name it *Study_Area*.
18. Enable the Editor toolbar and Start Editing the *Study_Area* feature.
19. Create a rectangular feature containing Sixth Street from Congress Avenue to IH 35 and Stop Editing, saving the edit when asked.

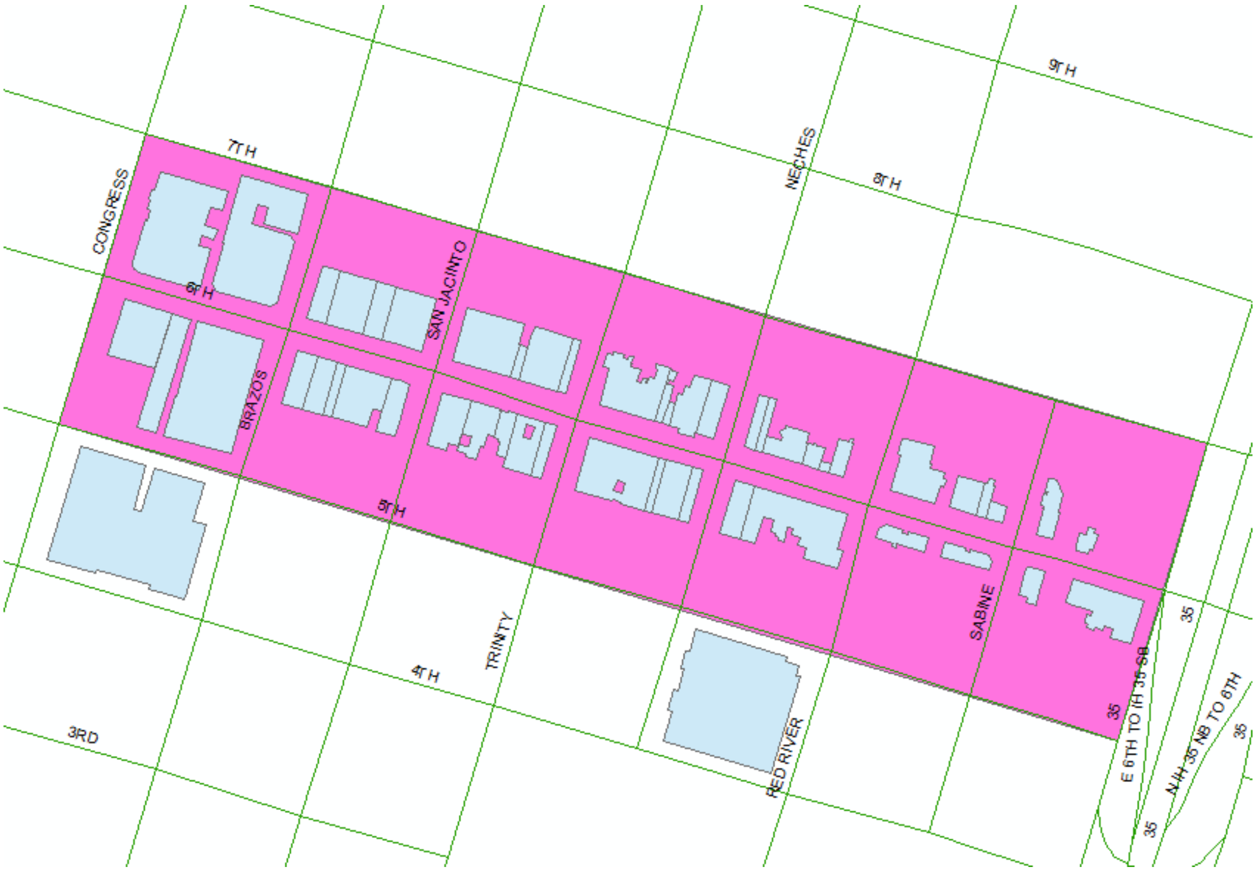


Now, to create the 3D buildings:

20. Add the *Footprints* layer and use the Select by Location tool to select all building footprints which are completely within the study area, as well as Frost Bank Tower and Hilton Downtown on Fourth Street.

21. Export the selection to a feature within the geodatabase named *Footprints_Clip*. Remove the original building footprints layer.

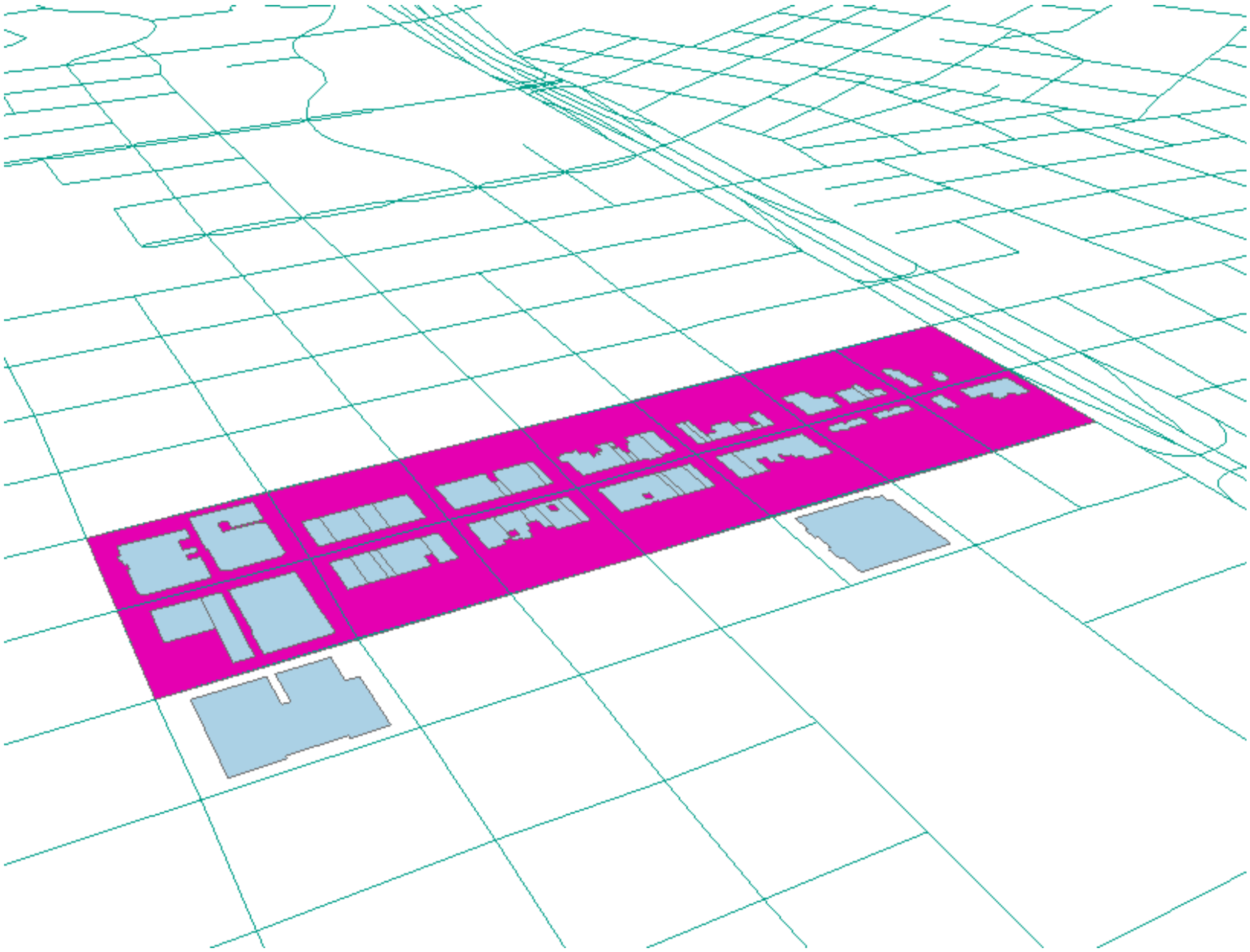
22. Since the footprints sometimes group multiple buildings, we need to cut them into smaller pieces. Do that using the Cut Polygons Tool. (This can be a time intensive process, depending on the frontage and varying heights of the buildings.)
23. Delete all buildings not adjacent to the street.



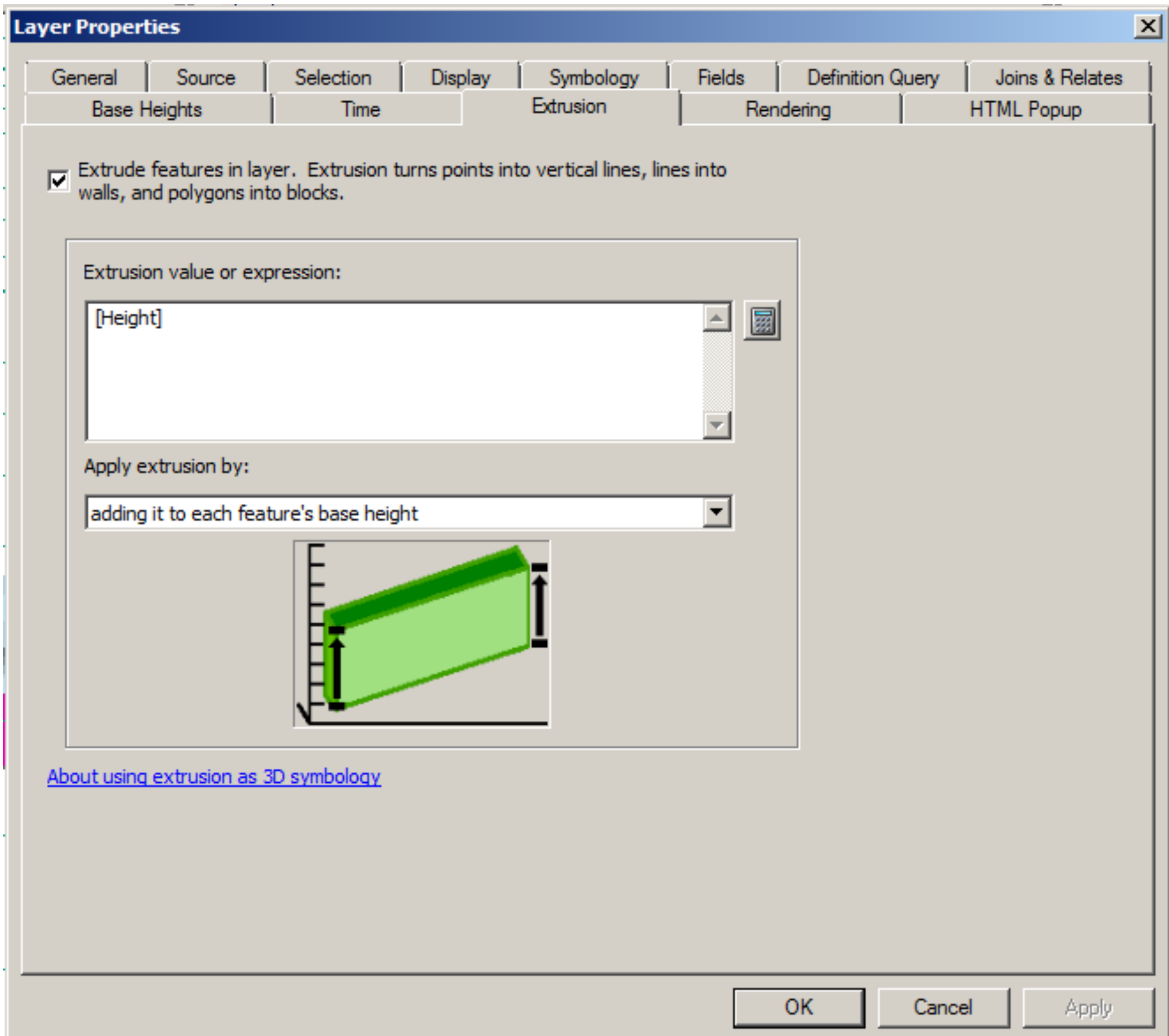
24. Add a Field to the feature named "Height" and populate with building heights in feet. (This was done manually since the City of Austin does not track individual building heights.)

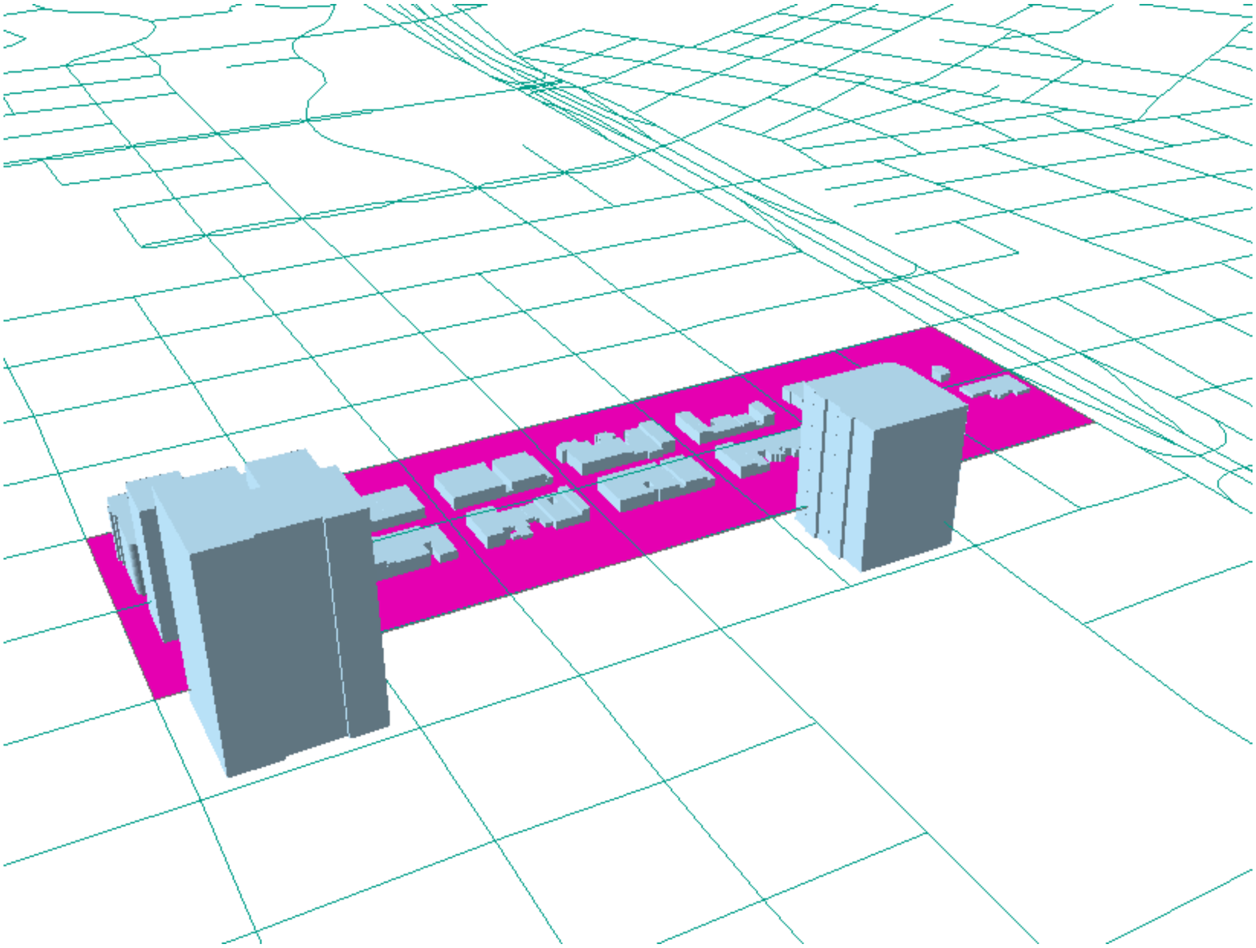
To create 3D buildings:

25. Back in ArcScene, turn off the surface layer.
26. Import the *Study_Area*, *Streets*, and *Footprints_Clip* layers.



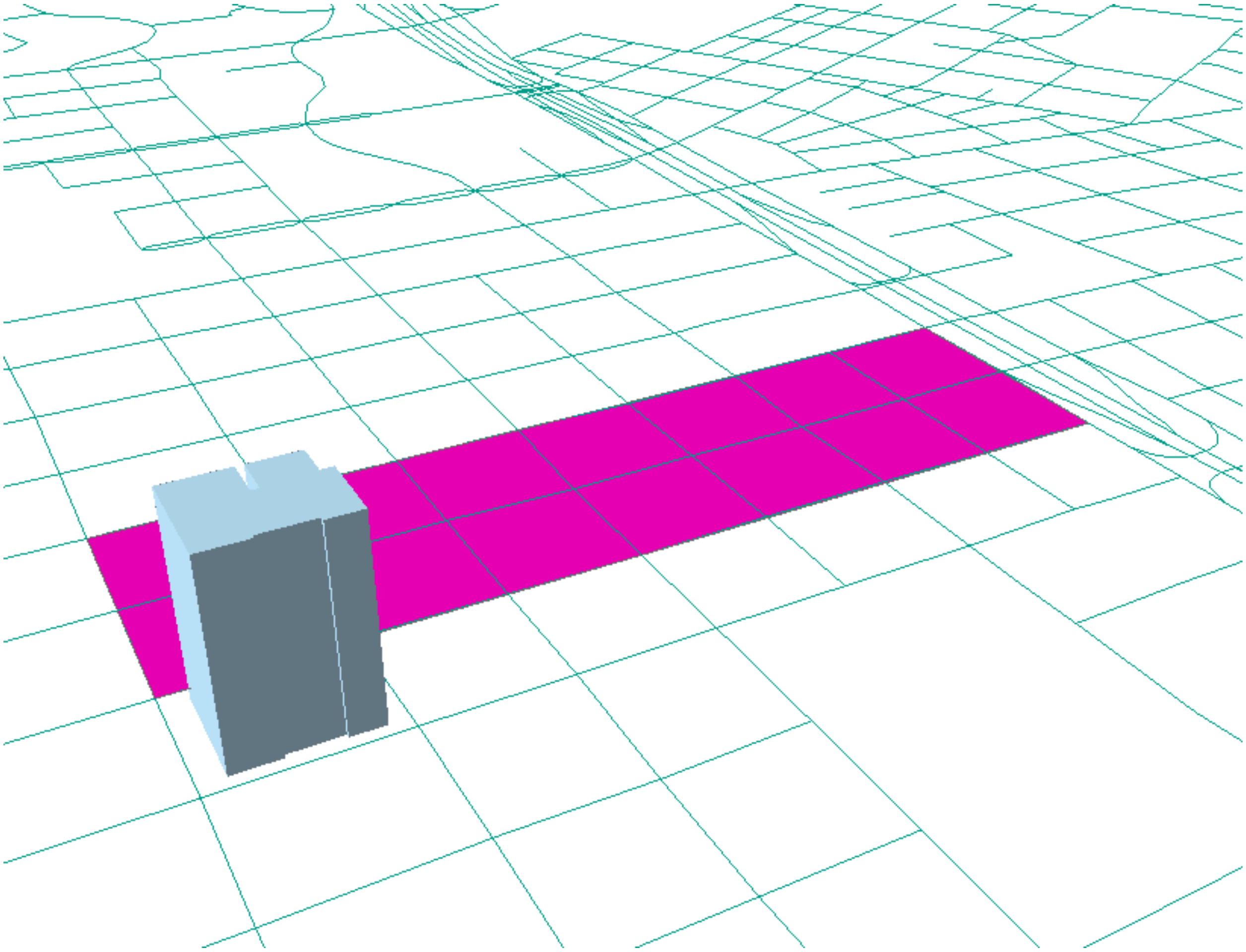
27. In order to bring up the buildings into 3D, we need to extrude the building footprints by their height. Do this by right clicking on *footprints-clipped* and going into properties. Under the Extrusion tab, click the box next to “Extrude features in layer.” Click on the calculator icon next to “Extrusion value or expression” and select the attribute category under which the building heights were assigned, in this case [Height].


Layer Properties
General
Source
Selection
Display
Symbology
Fields
Definition Query
Joins & Relates
Base Heights
Time
Extrusion
Rendering
HTML Popup
Extrude features in layer. Extrusion turns points into vertical lines, lines into walls, and polygons into blocks.
Extrusion value or expression:
[Height]
Apply extrusion by:
adding it to each feature's base height
About using extrusion as 3D symbology
OK
Cancel
Apply

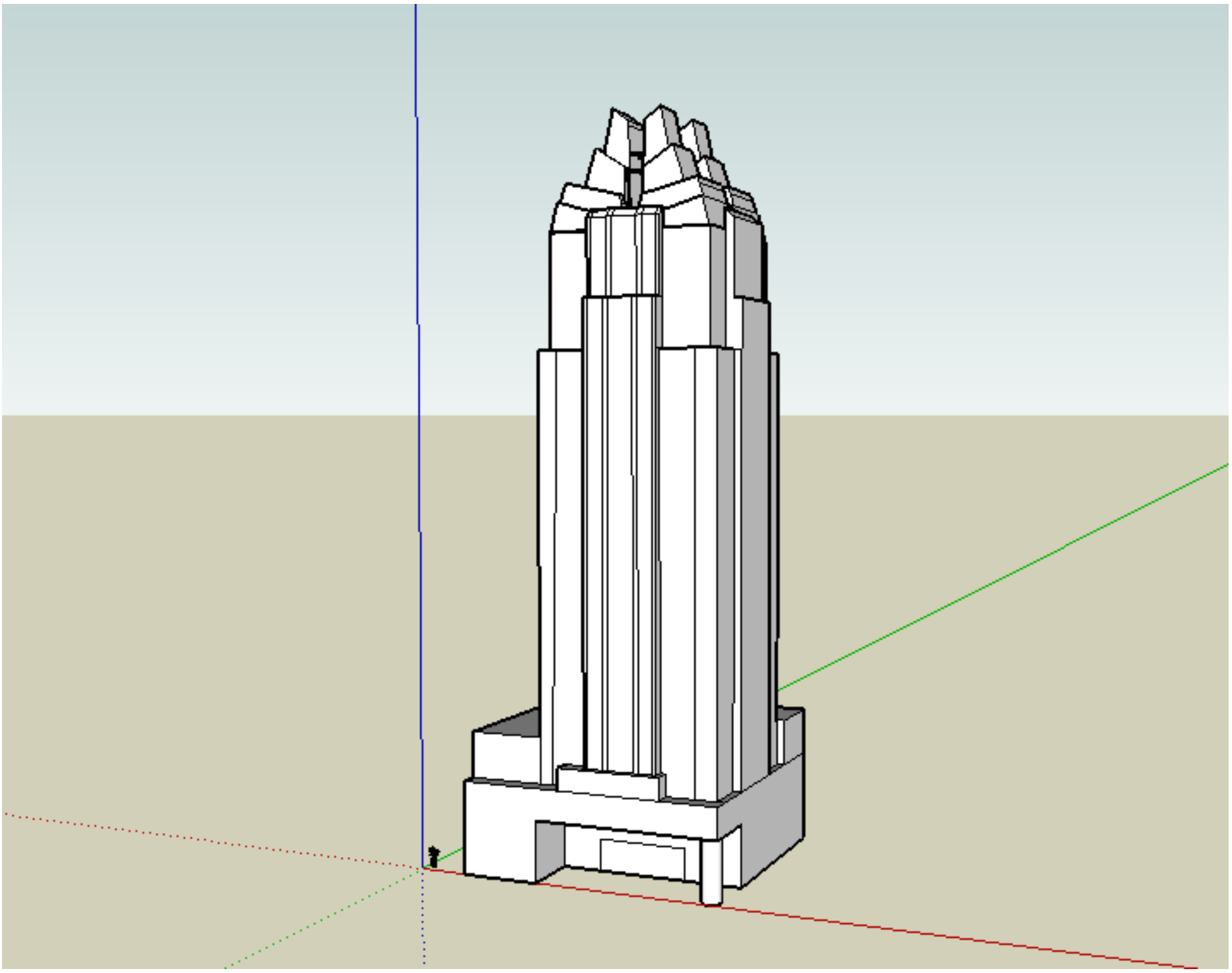


While most of the buildings within the study area have are rectangular in shape, extruding their height from their footprint produces a fairly accurate representation. Two of the larger high-rises on Fifth Street, however, are more articulated in shape with a narrower top sitting on a wider pedestal. In order to get an accurate shade map, the models had to be refined in SketchUp and then imported into ArcScene.

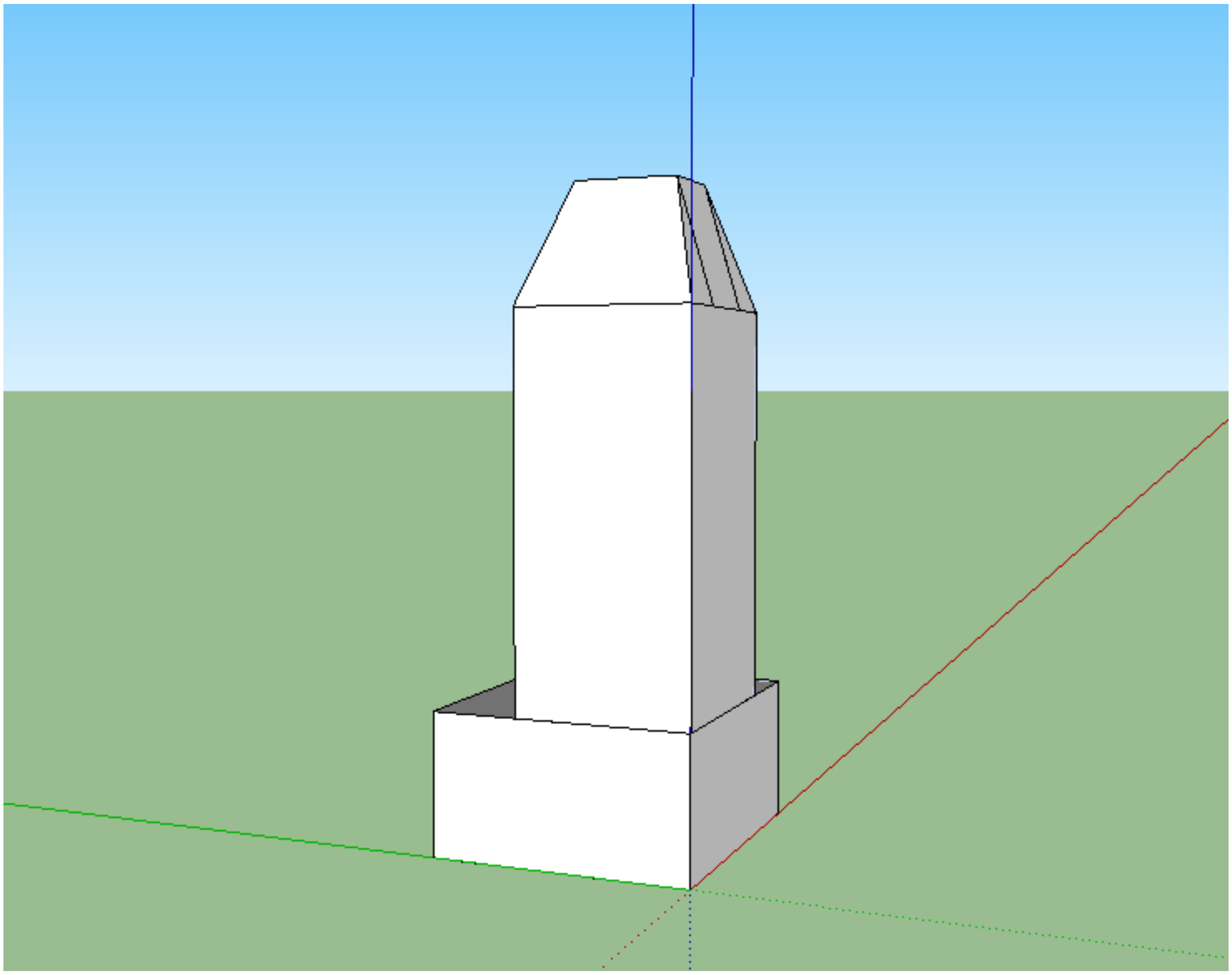
28. Select the Frost Tower footprint and Export Data.
29. Extrude it by the Height Attribute and use the Layer 3D to Feature Class tool to convert into a format that can be replaced with a model.



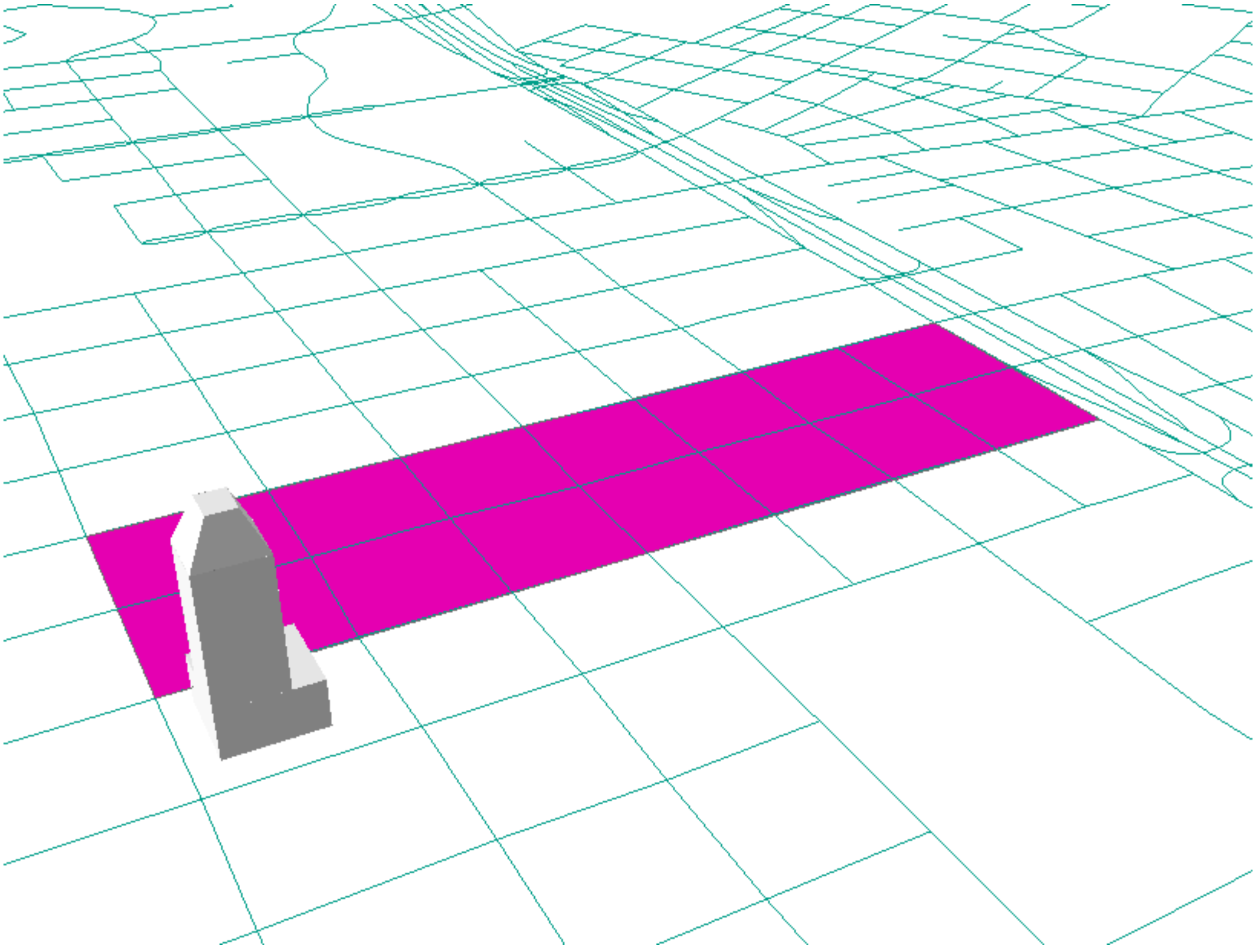
30. Go to the SketchUp 3D warehouse (https://3dwarehouse.sketchup.com/) and download the appropriate models by searching “Frost Bank Tower” and “Hilton Downtown Austin.”
31. Open SketchUp and load the first model.



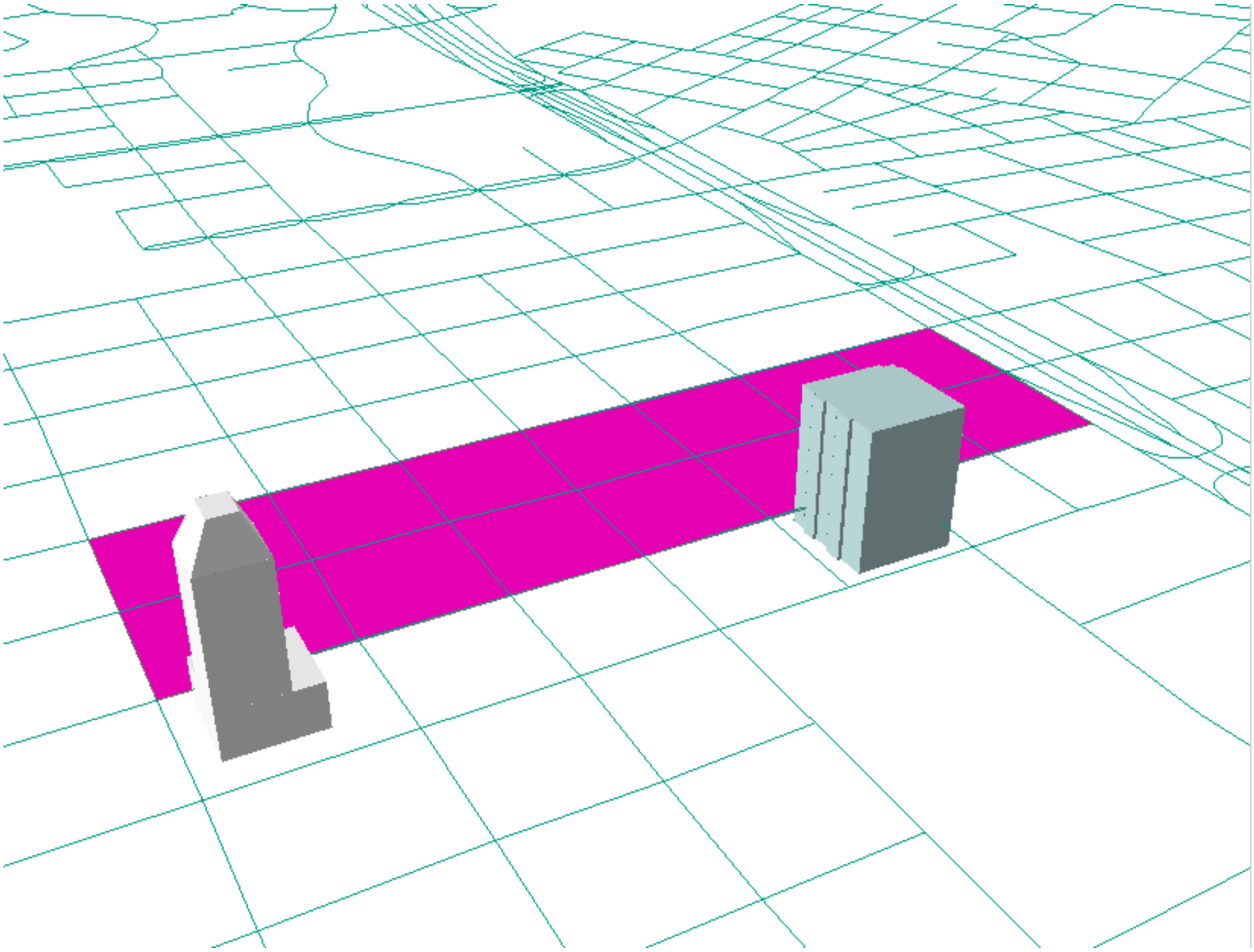
32. Since the amount of detail in a model can significantly increase rendering time in GIS, try to simplify the model as much as possible.

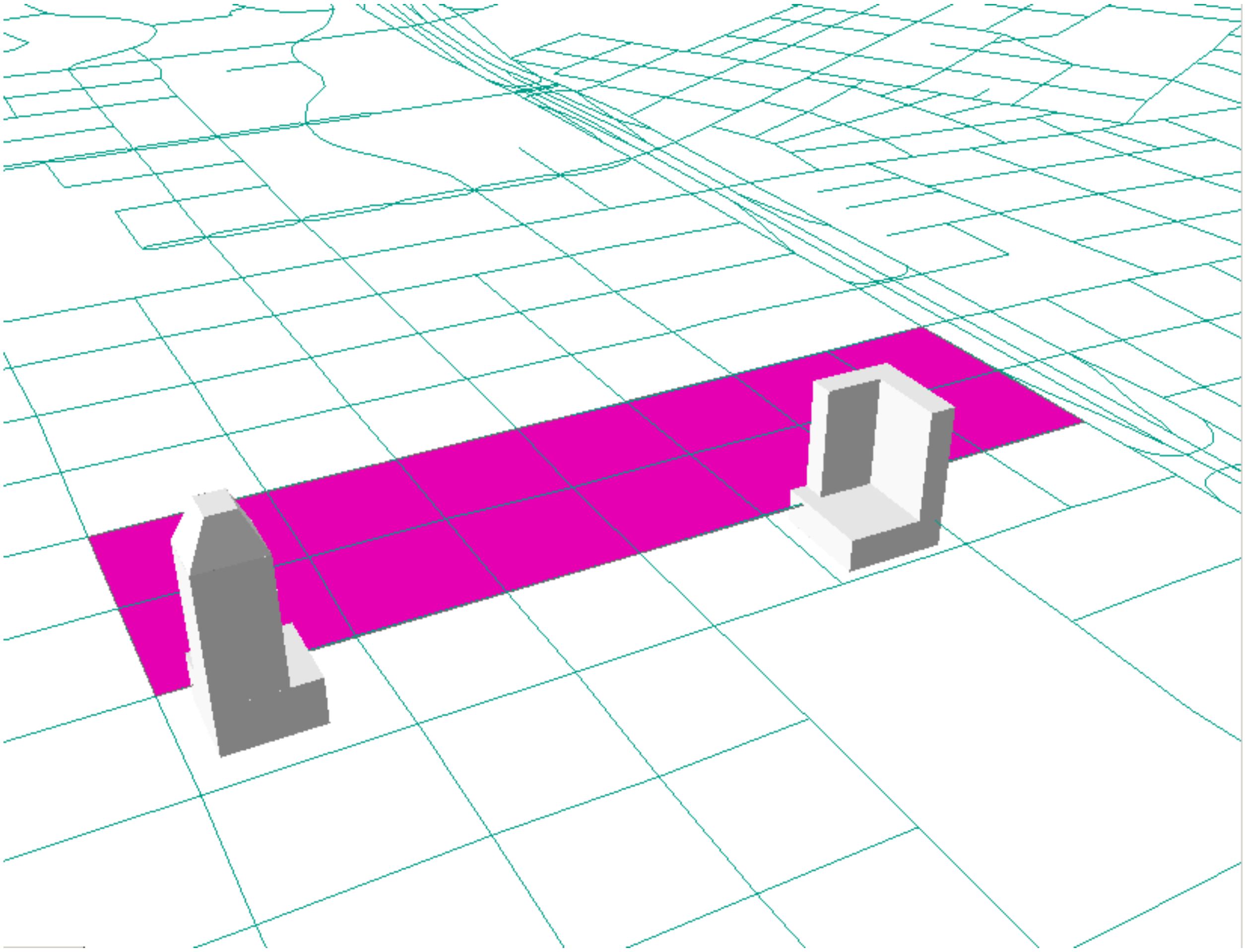


33. Export the model as a Collada file.
34. Back in ArcScene, enable the 3D Editor toolbar if not already enabled.
35. Start Editing the Frost Tower feature.
36. Select the feature and Replace With Model.
37. Select the Collada model created in SketchUp.
38. Scale and Rotate the model until it fits the building footprint.
39. Turn off the model and select and delete the footprint it is replacing.

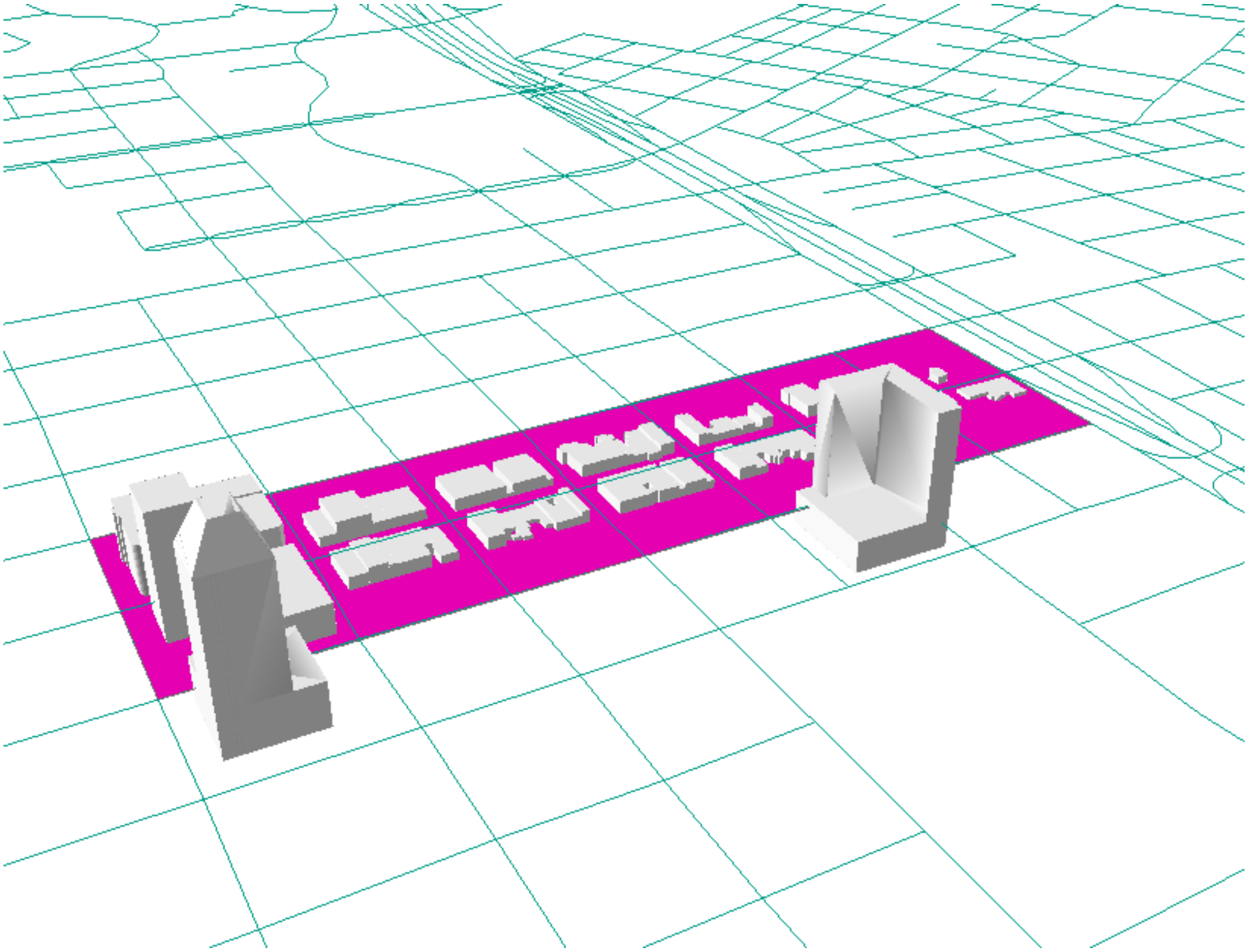


40. Repeats steps for the Hilton model.





41. Use the Layer 3D to Feature Class tool to convert *Footprints_Clip* to a multipatch feature, naming the output *Enclosed_Buildings_Without_Tall_Buildings*.
42. Merge the models with *Enclosed_Buildings_Without_Tall_Buildings* and name the output *Enclosed_Buildings*.

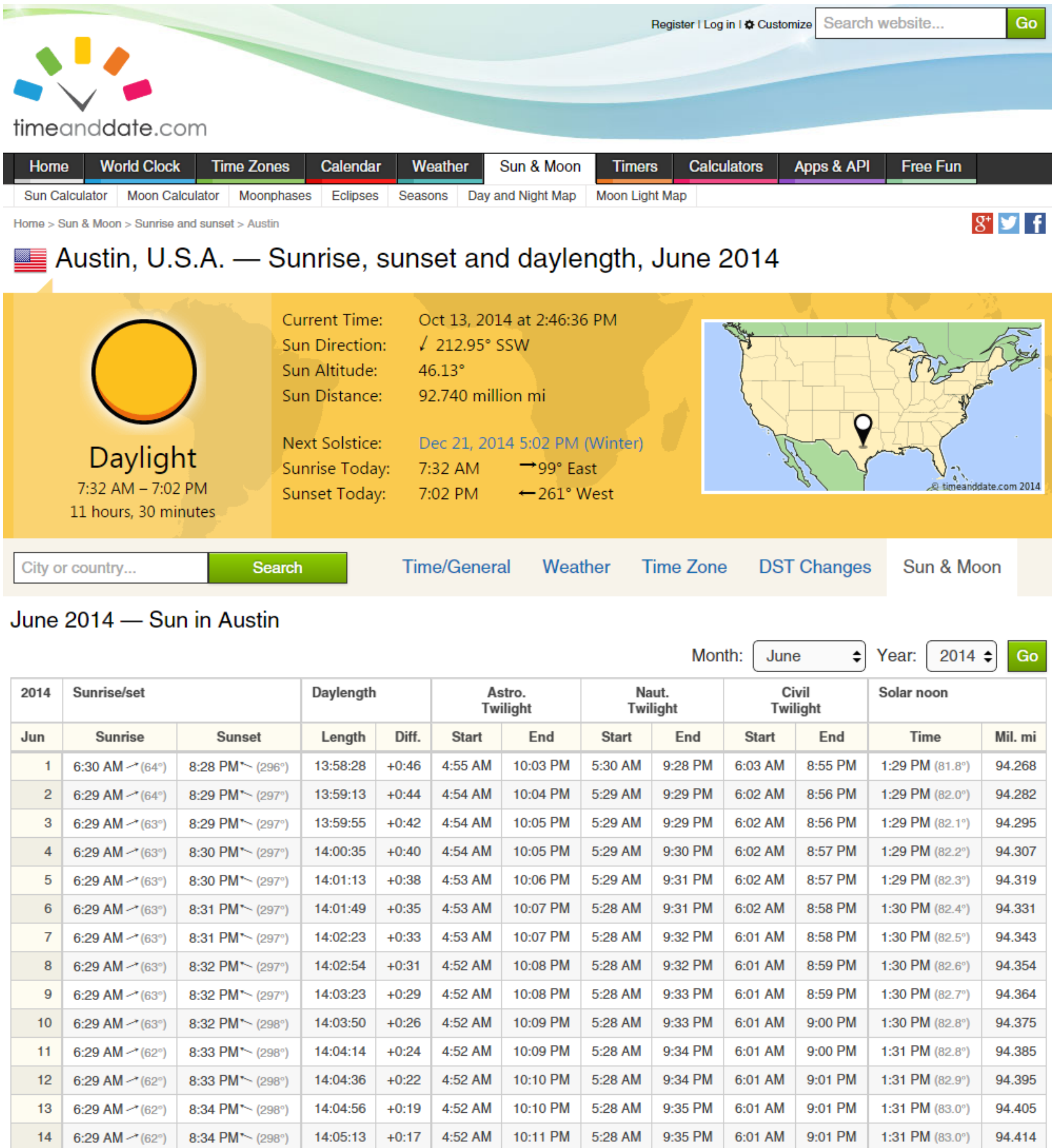


43. Run the Enclose tool to close geometric gaps in 3D Buildings Layer

Only now are we ready to begin the shadow analysis. First, three-dimensional shadows are extended from the buildings toward and throw the terrain. The angle of the shadows depends on the position of the sun, which is calculated based on the time and locational inputs.

To create the shadows:

44. Run the Sun Shadow Volume tool using the *Enclosed_Buildings* feature as the input.
45. Go to http://www.timeanddate.com/sun/usa/austin to find the sunrise and sunset times. For this shadow analysis, (June 21) sunrise is 6:30 AM and sunset is 8:36 PM.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Sun Calculator | Moon Calculator | Moonphases | Eclipses | Seasons | Day and Night Map | Moon Light Map

Home > Sun & Moon > Sunrise and sunset > Austin

Austin, U.S.A. — Sunrise, sunset and daylength, June 2014

Daylight
7:32 AM – 7:02 PM
11 hours, 30 minutes

Current Time: Oct 13, 2014 at 2:46:36 PM
Sun Direction: 212.95° SSW
Sun Altitude: 46.13°
Sun Distance: 92.740 million mi

Next Solstice: Dec 21, 2014 5:02 PM (Winter)
Sunrise Today: 7:32 AM 99° East
Sunset Today: 7:02 PM 261° West

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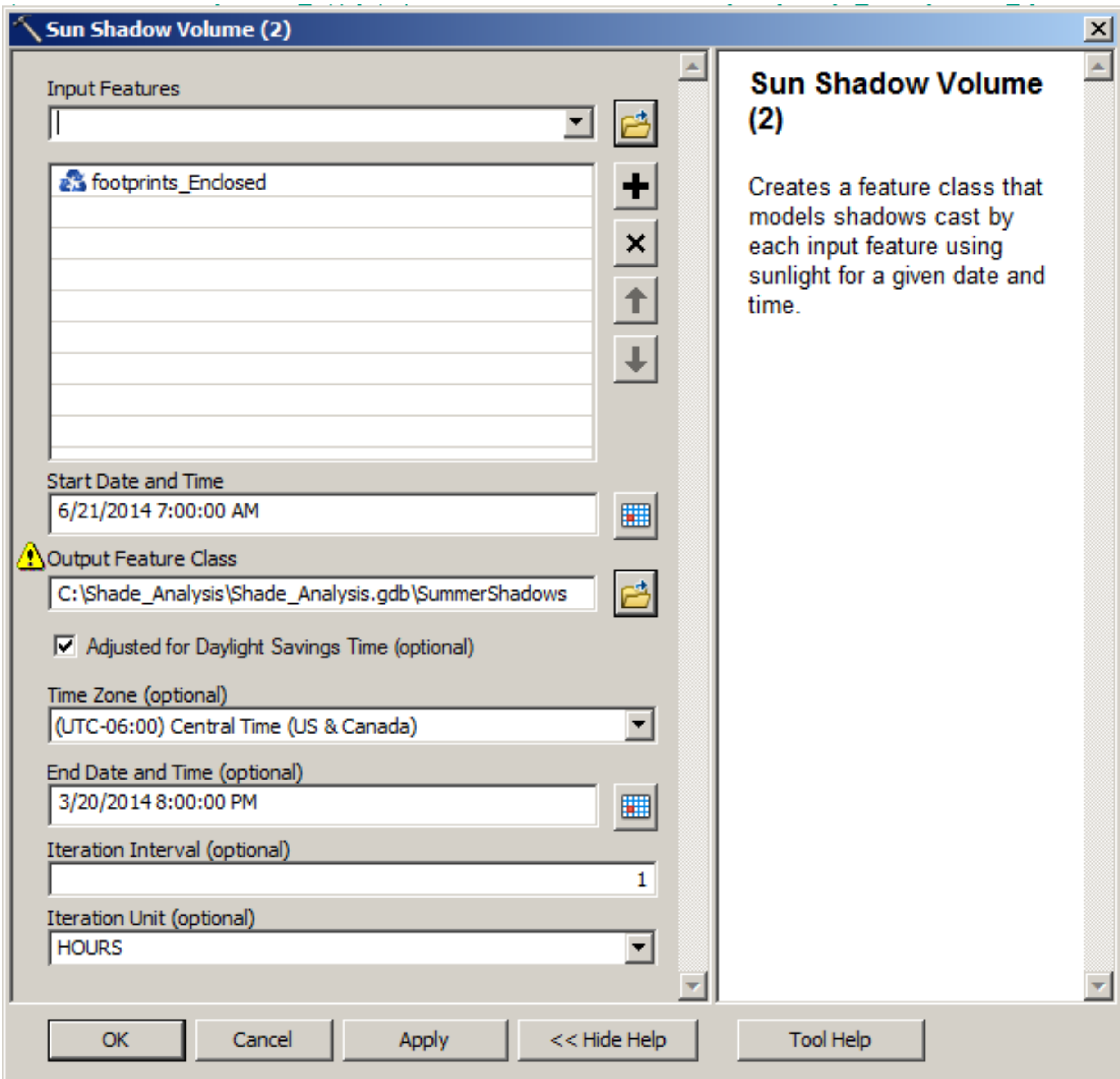
City or country... Search | Time/General | Weather | Time Zone | DST Changes | Sun & Moon

June 2014 — Sun in Austin

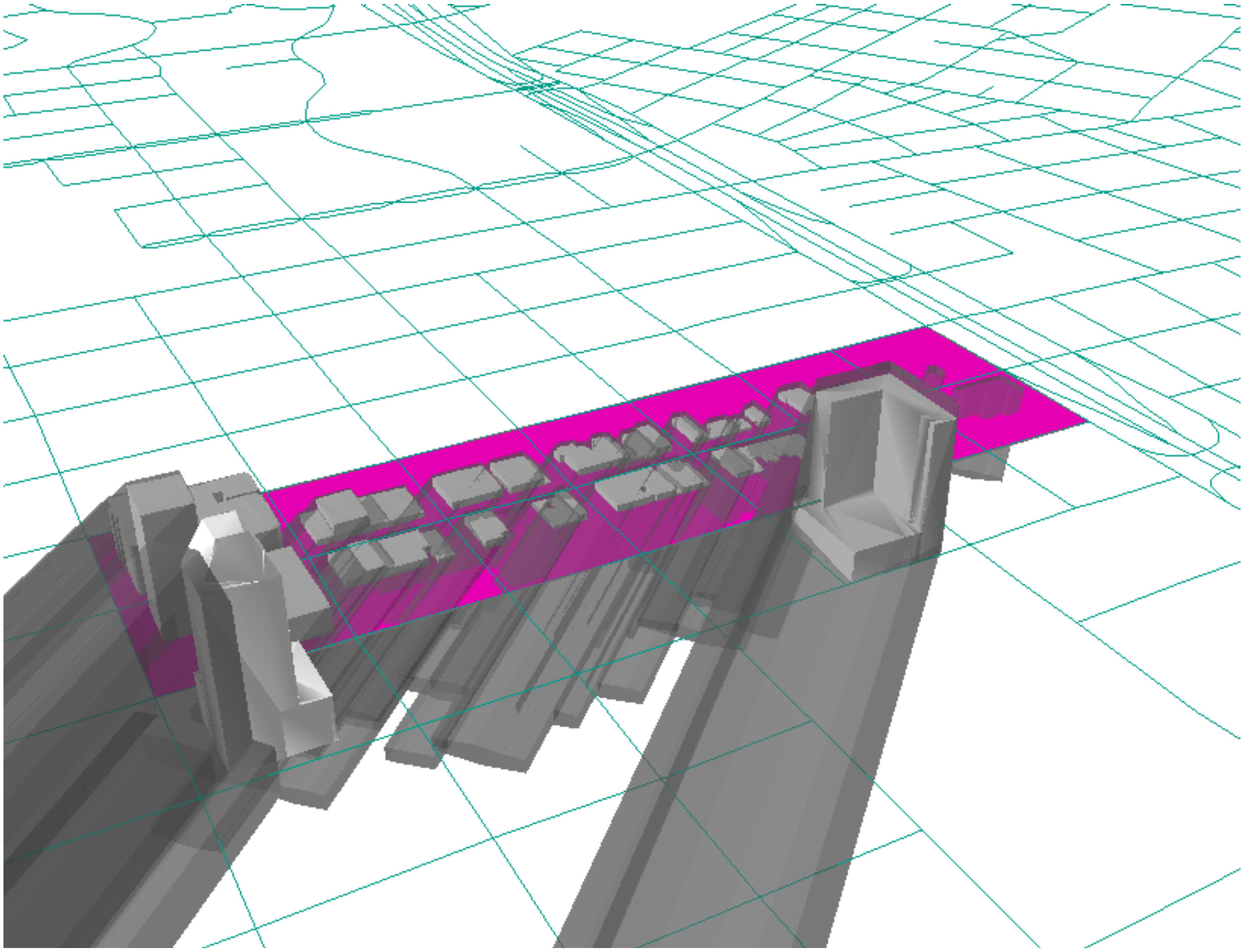
Month: June Year: 2014 Go

2014	Sunrise/set		Daylength		Astro. Twilight		Naut. Twilight		Civil Twilight		Solar noon	
Jun	Sunrise	Sunset	Length	Diff.	Start	End	Start	End	Start	End	Time	Mil. mi
1	6:30 AM (64°)	8:28 PM (296°)	13:58:28	+0:46	4:55 AM	10:03 PM	5:30 AM	9:28 PM	6:03 AM	8:55 PM	1:29 PM (81.8°)	94.268
2	6:29 AM (64°)	8:29 PM (297°)	13:59:13	+0:44	4:54 AM	10:04 PM	5:29 AM	9:29 PM	6:02 AM	8:56 PM	1:29 PM (82.0°)	94.282
3	6:29 AM (63°)	8:29 PM (297°)	13:59:55	+0:42	4:54 AM	10:05 PM	5:29 AM	9:29 PM	6:02 AM	8:56 PM	1:29 PM (82.1°)	94.295
4	6:29 AM (63°)	8:30 PM (297°)	14:00:35	+0:40	4:54 AM	10:05 PM	5:29 AM	9:30 PM	6:02 AM	8:57 PM	1:29 PM (82.2°)	94.307
5	6:29 AM (63°)	8:30 PM (297°)	14:01:13	+0:38	4:53 AM	10:06 PM	5:29 AM	9:31 PM	6:02 AM	8:57 PM	1:29 PM (82.3°)	94.319
6	6:29 AM (63°)	8:31 PM (297°)	14:01:49	+0:35	4:53 AM	10:07 PM	5:28 AM	9:31 PM	6:02 AM	8:58 PM	1:30 PM (82.4°)	94.331
7	6:29 AM (63°)	8:31 PM (297°)	14:02:23	+0:33	4:53 AM	10:07 PM	5:28 AM	9:32 PM	6:01 AM	8:58 PM	1:30 PM (82.5°)	94.343
8	6:29 AM (63°)	8:32 PM (297°)	14:02:54	+0:31	4:52 AM	10:08 PM	5:28 AM	9:32 PM	6:01 AM	8:59 PM	1:30 PM (82.6°)	94.354
9	6:29 AM (63°)	8:32 PM (297°)	14:03:23	+0:29	4:52 AM	10:08 PM	5:28 AM	9:33 PM	6:01 AM	8:59 PM	1:30 PM (82.7°)	94.364
10	6:29 AM (63°)	8:32 PM (298°)	14:03:50	+0:26	4:52 AM	10:09 PM	5:28 AM	9:33 PM	6:01 AM	9:00 PM	1:30 PM (82.8°)	94.375
11	6:29 AM (62°)	8:33 PM (298°)	14:04:14	+0:24	4:52 AM	10:09 PM	5:28 AM	9:34 PM	6:01 AM	9:00 PM	1:31 PM (82.8°)	94.385
12	6:29 AM (62°)	8:33 PM (298°)	14:04:36	+0:22	4:52 AM	10:10 PM	5:28 AM	9:34 PM	6:01 AM	9:01 PM	1:31 PM (82.9°)	94.395
13	6:29 AM (62°)	8:34 PM (298°)	14:04:56	+0:19	4:52 AM	10:10 PM	5:28 AM	9:35 PM	6:01 AM	9:01 PM	1:31 PM (83.0°)	94.405
14	6:29 AM (62°)	8:34 PM (298°)	14:05:13	+0:17	4:52 AM	10:11 PM	5:28 AM	9:35 PM	6:01 AM	9:01 PM	1:31 PM (83.0°)	94.414

46. Using this information I chose the start time as 6/21/2014 7:00:00AM and the end time as 6/21/2014 8:00:00PM to ensure that every hour contain some shade.
47. Choose UTC -6:00 as the time zone and check Adjusted for Daylight Savings Time.
48. Since we want to see how the shade changes from hour to hour, set the Iteration Interval to 1 and the Iteration Unit to Hours.



49. Run tool (It will take approximately 30 minutes).



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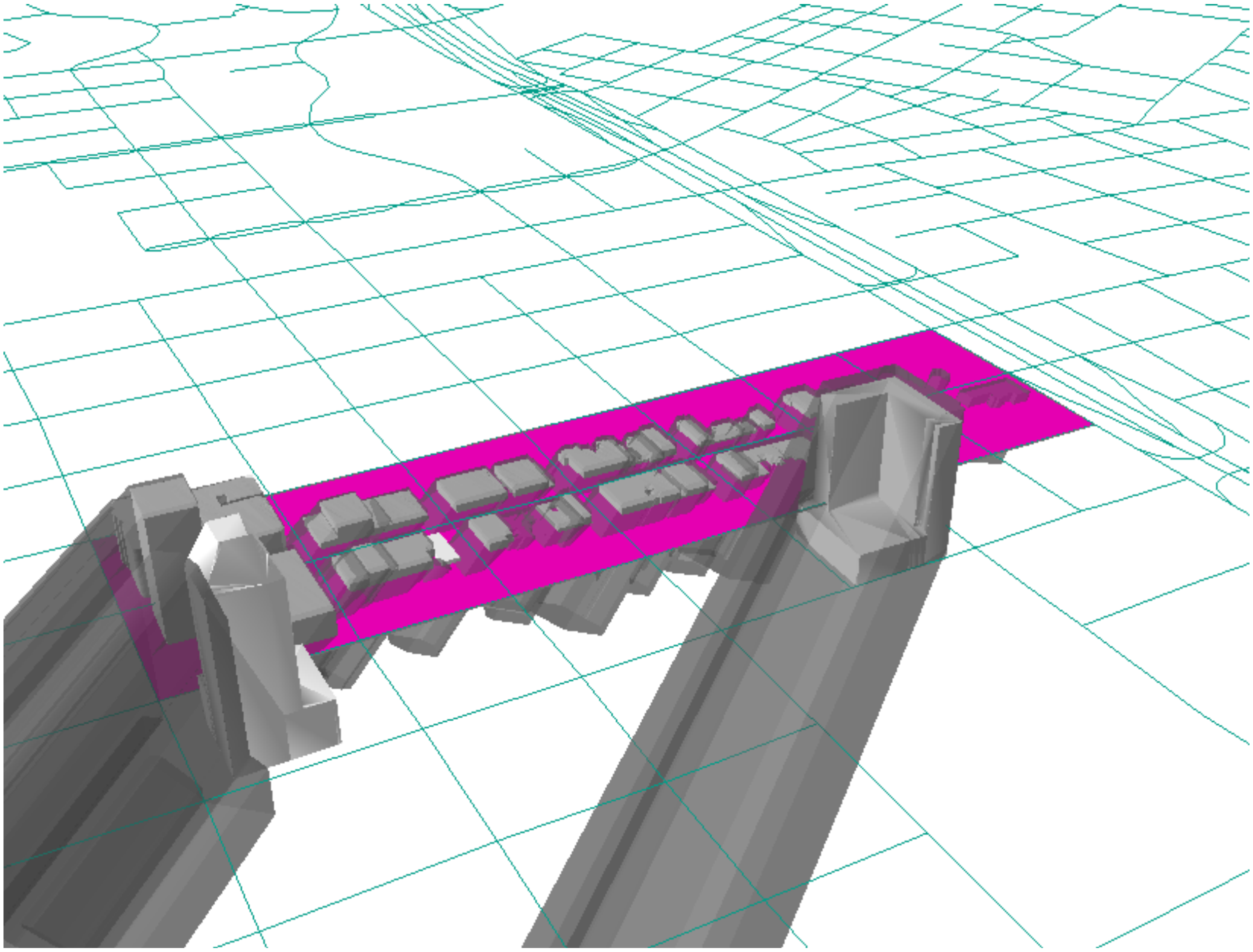

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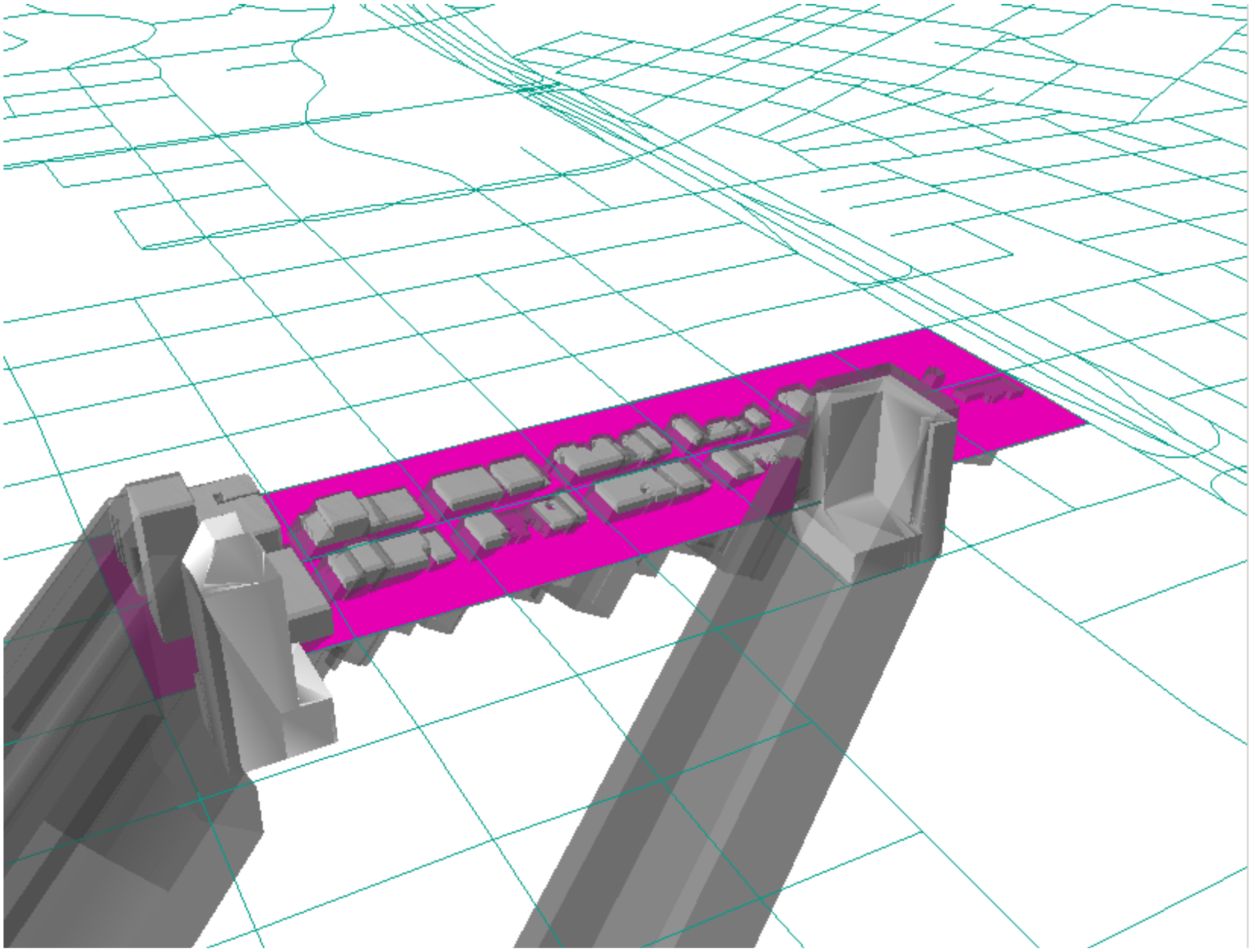
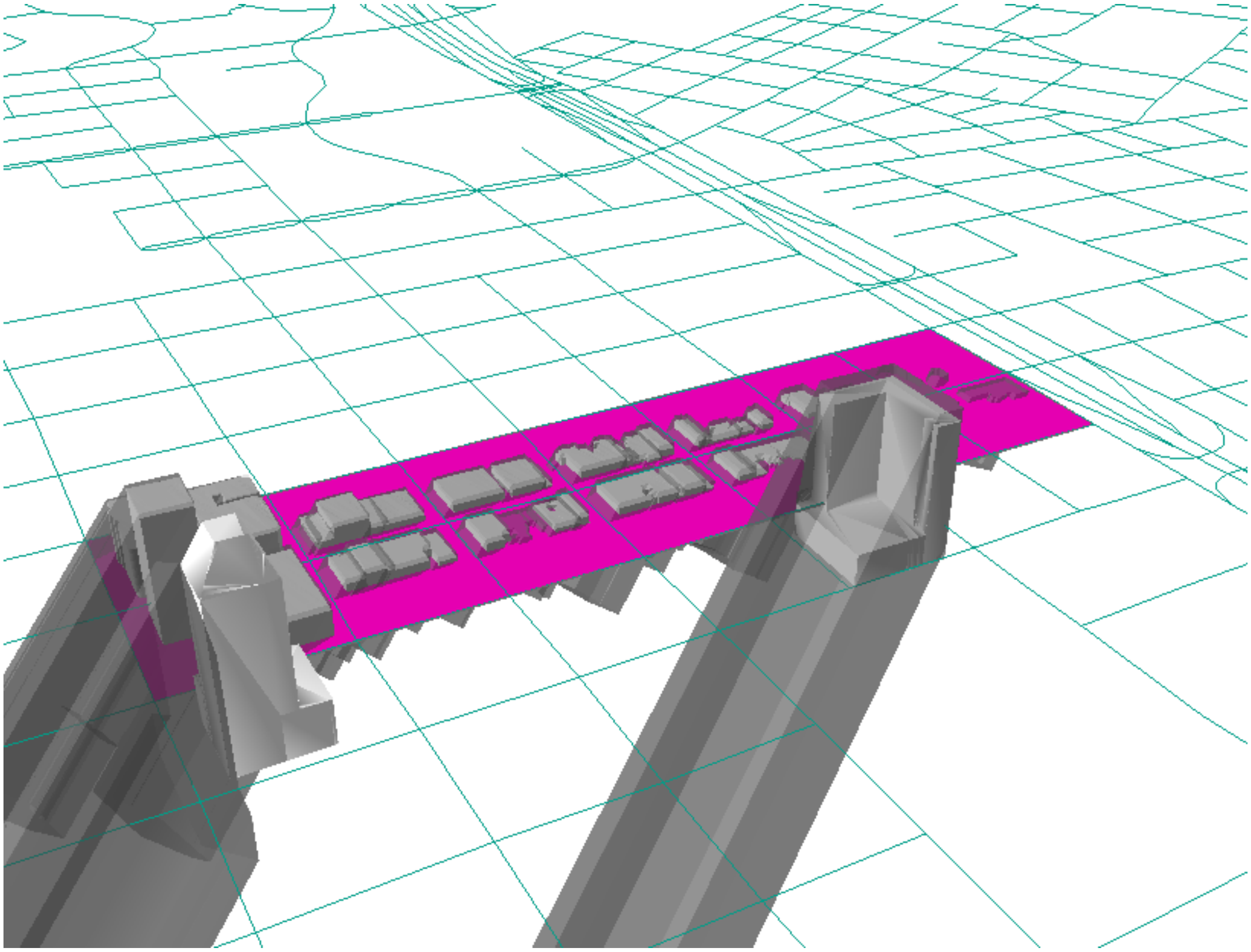
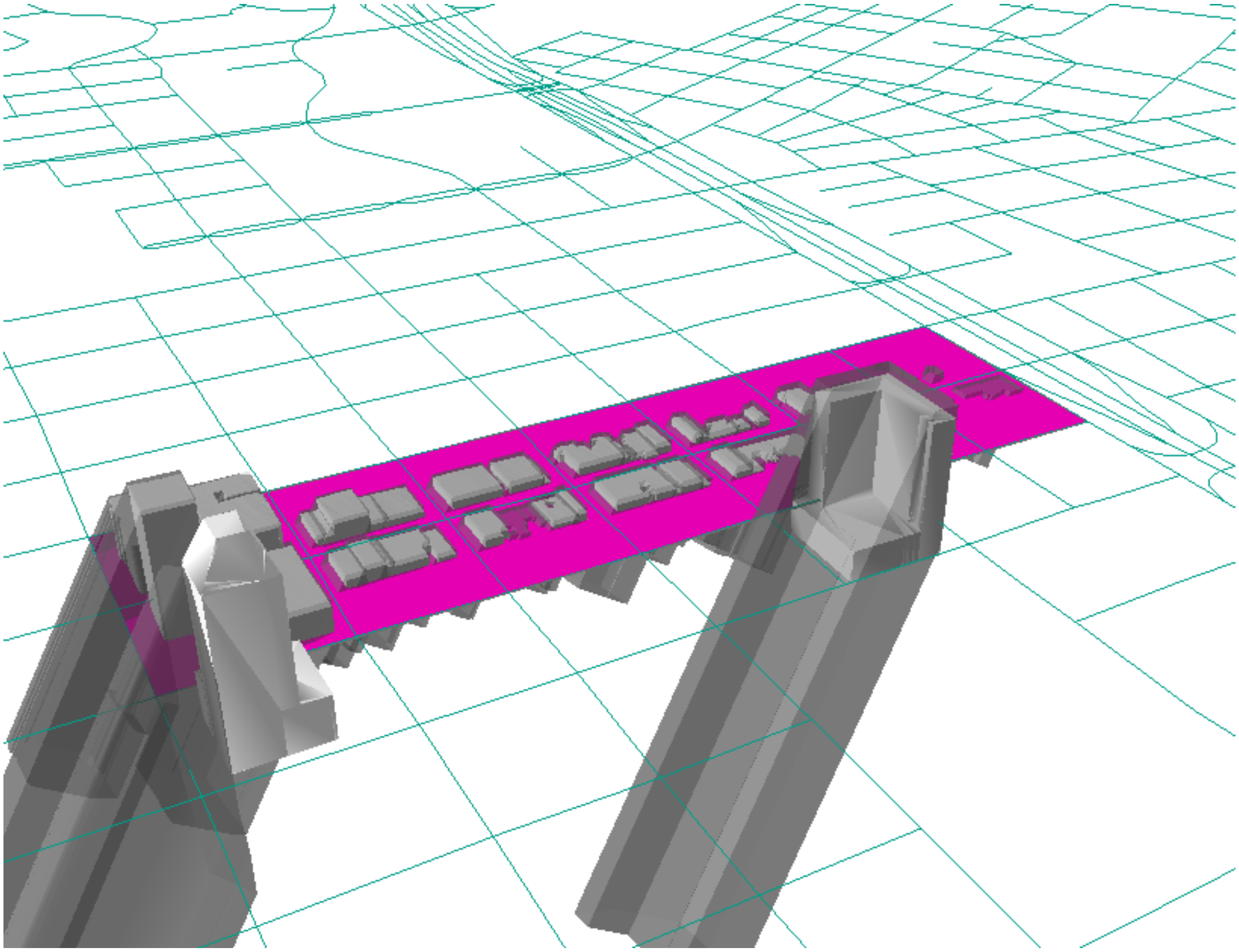
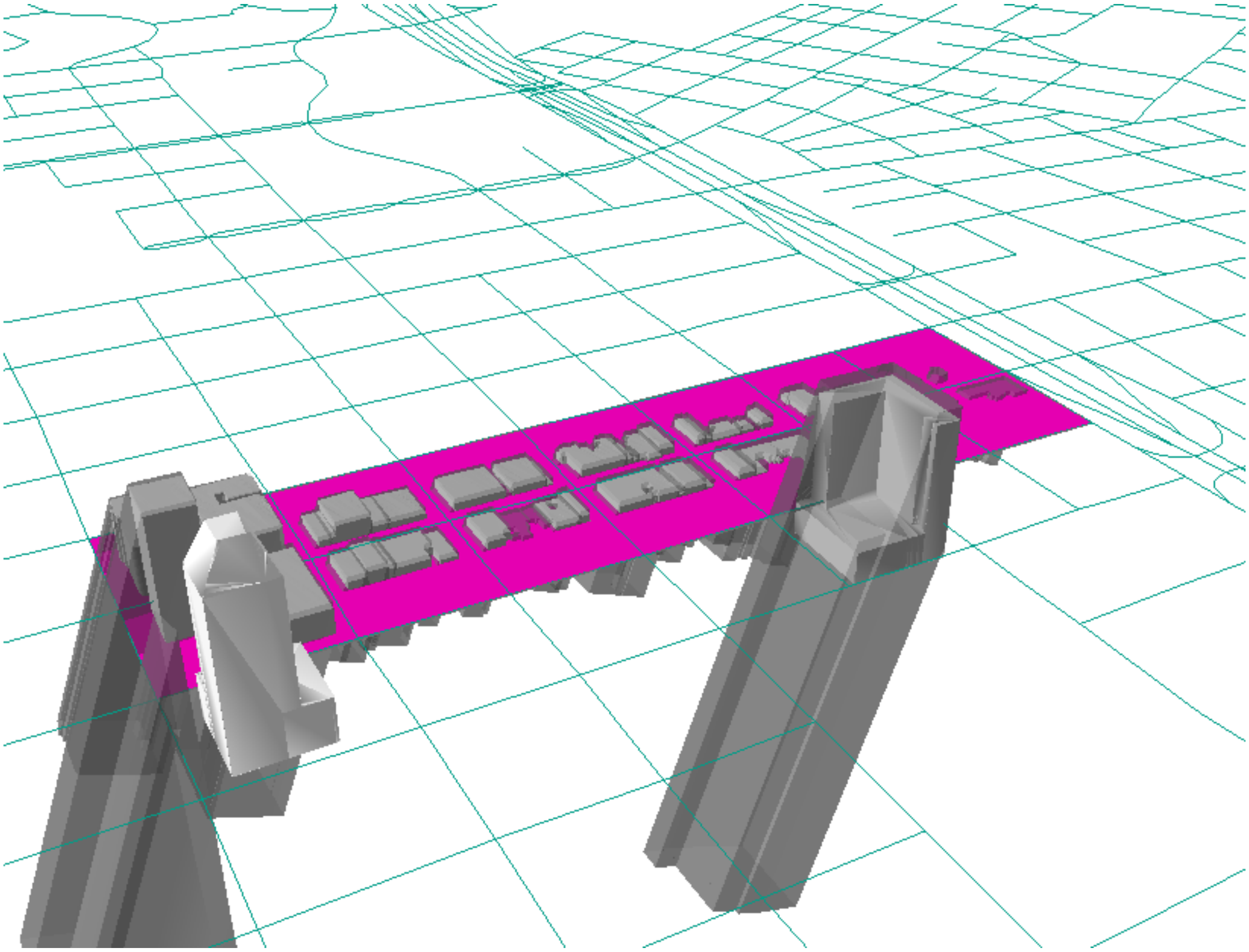

9:00 AM



10:00 AM



11:00 AM



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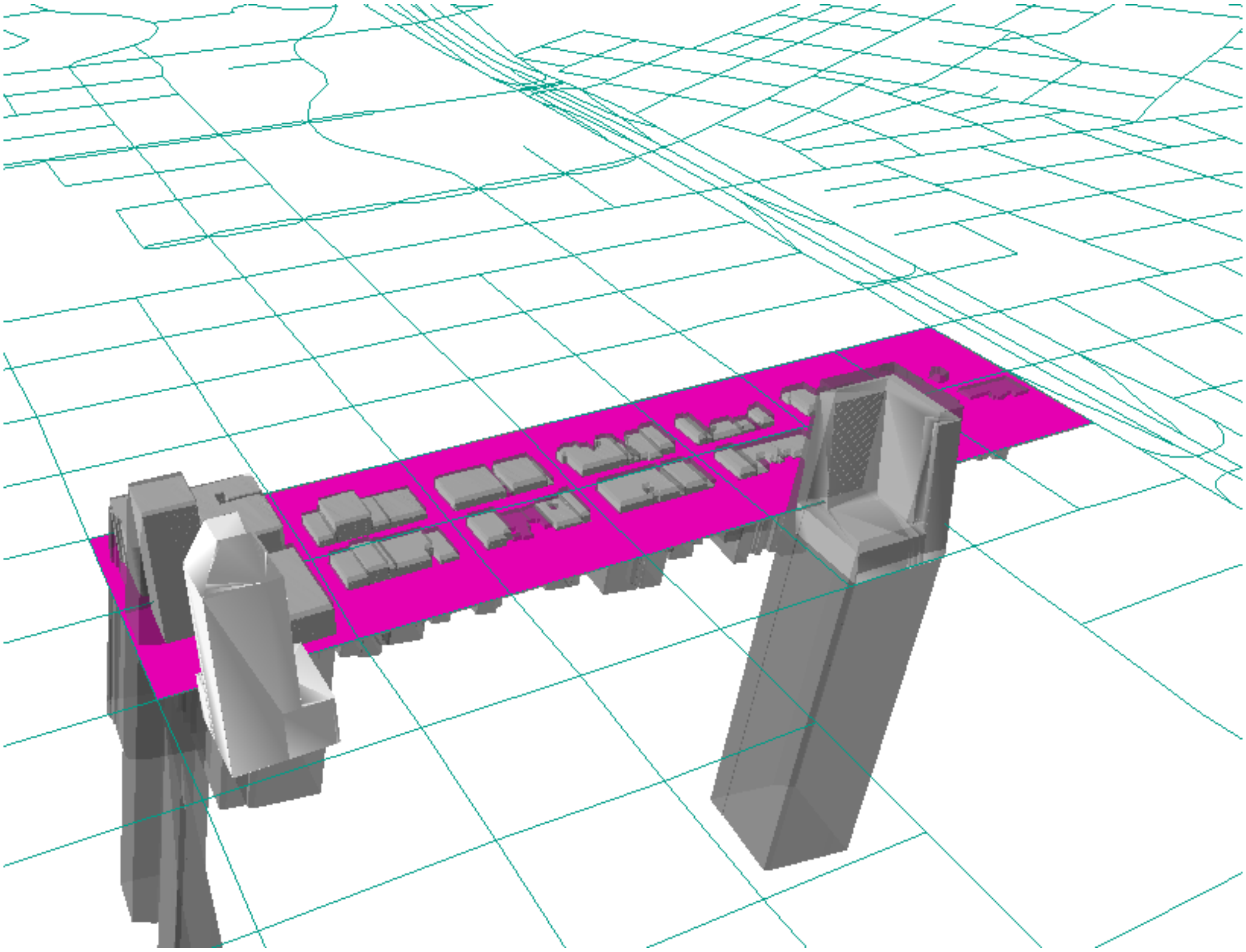
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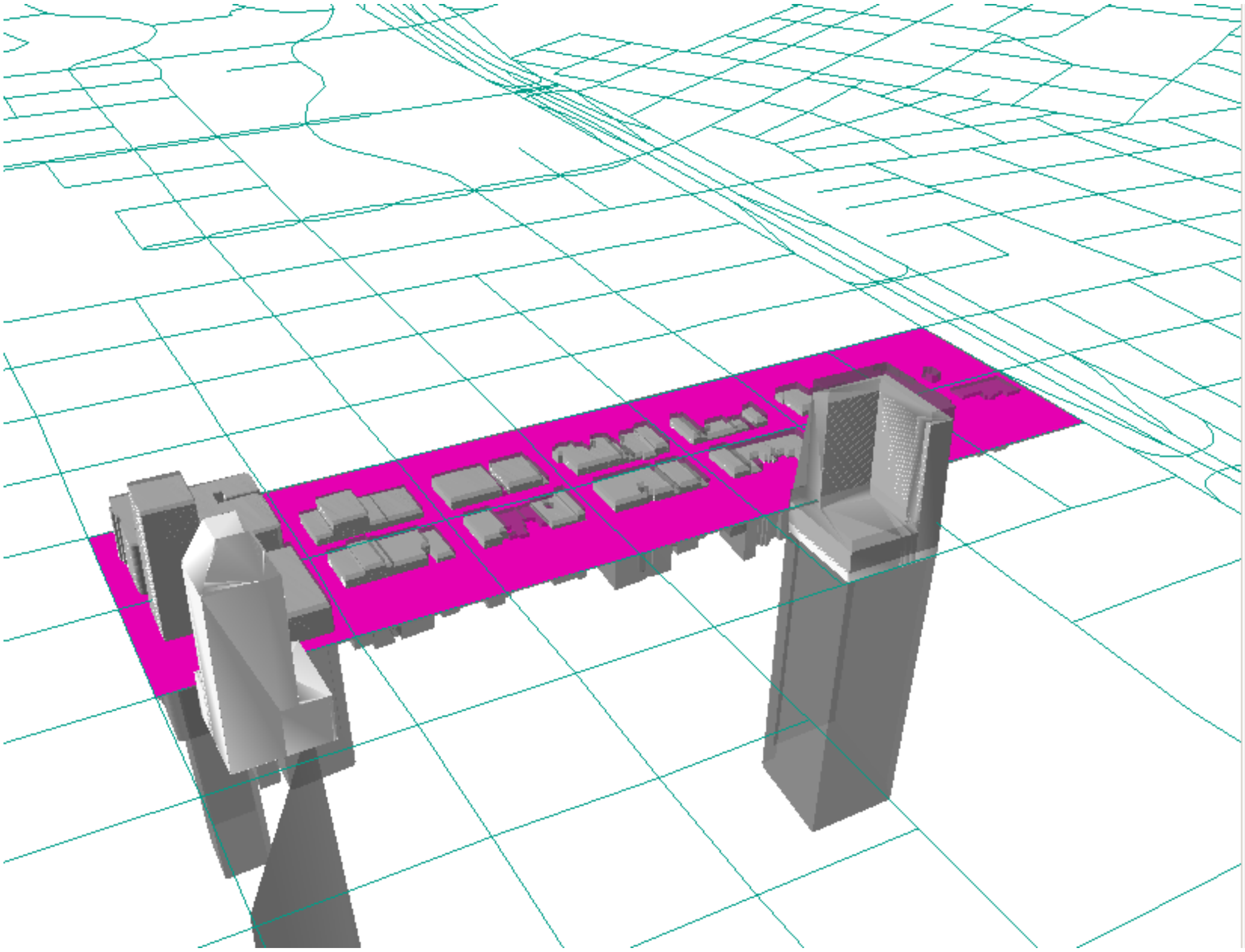
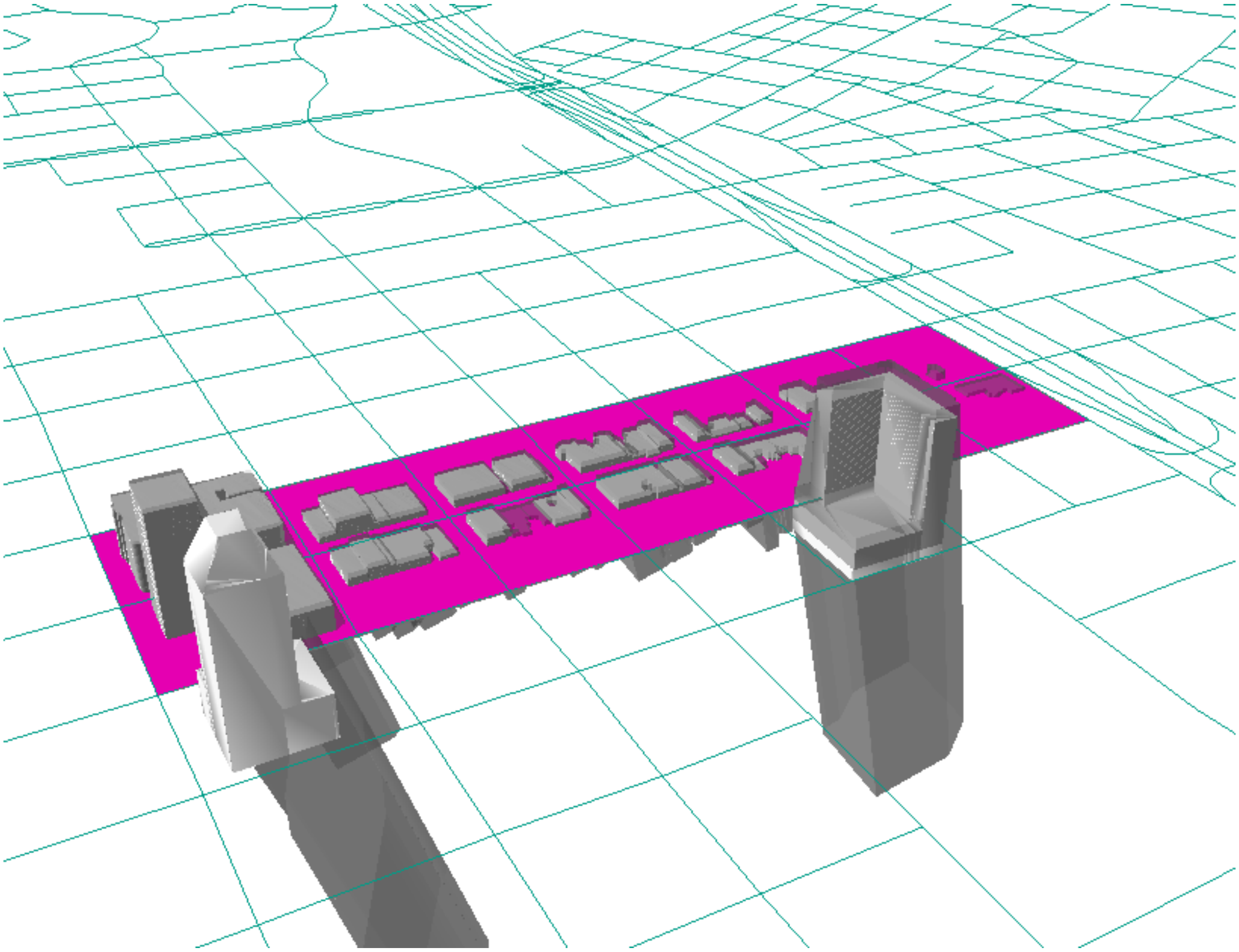
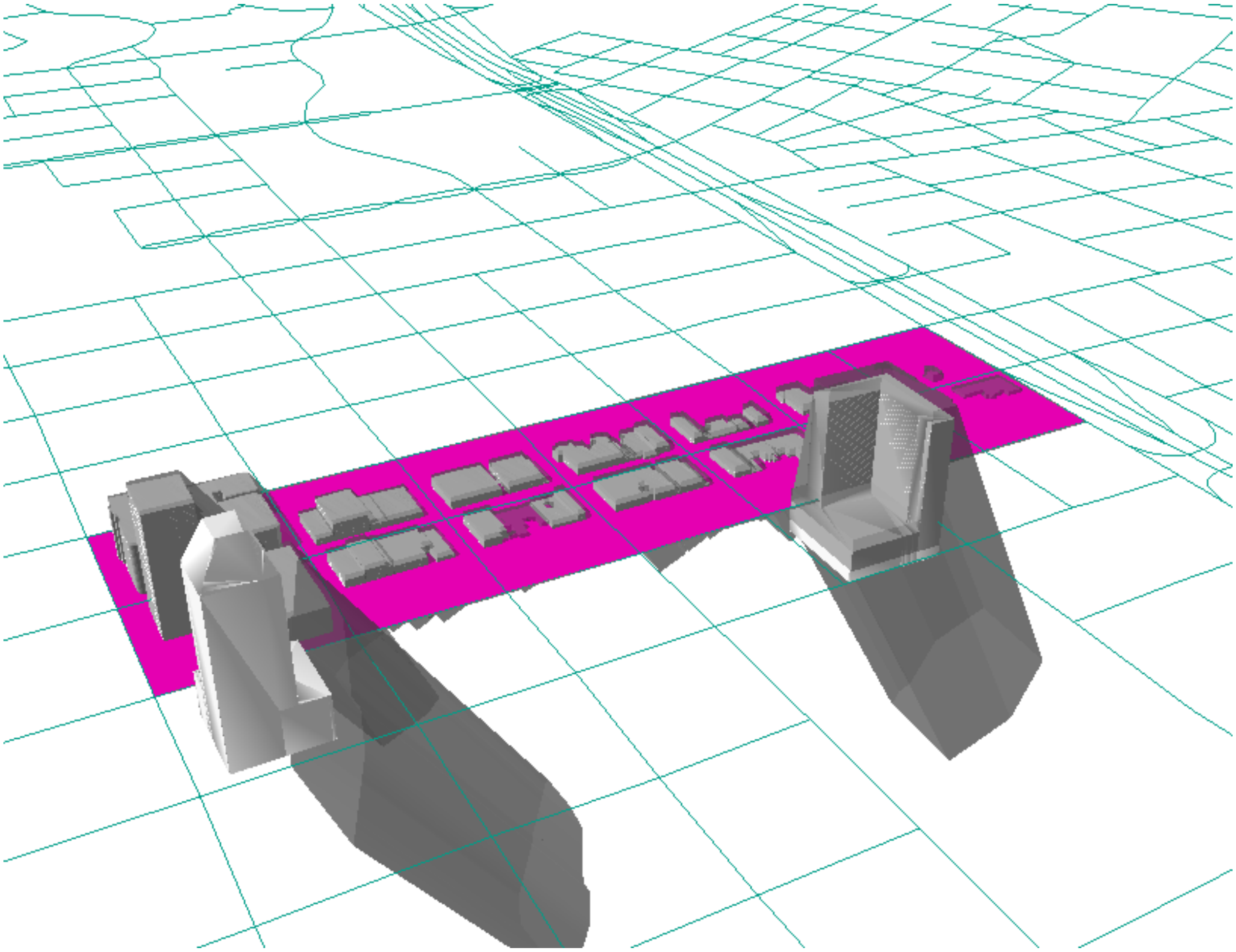
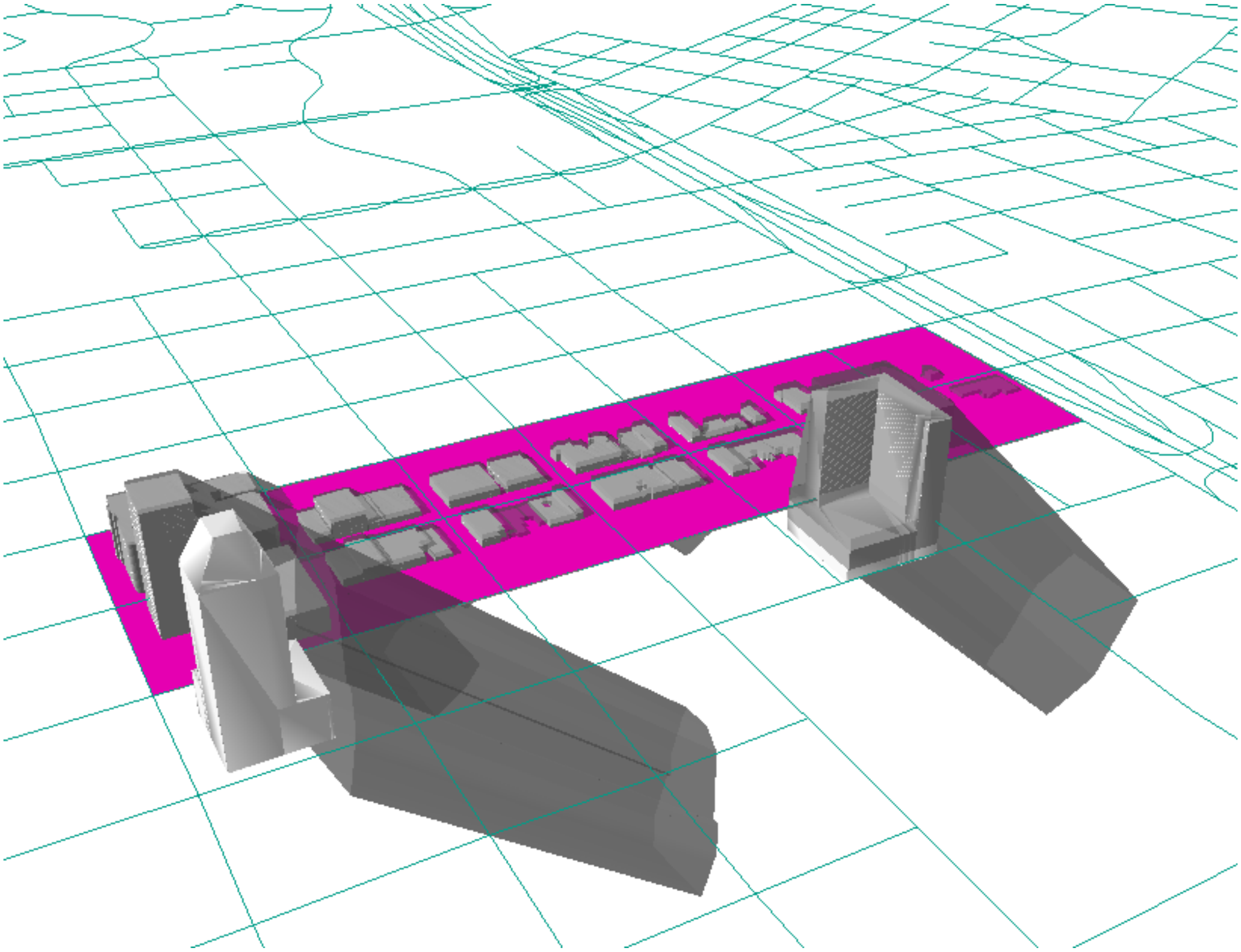

2:00 PM



3:00 PM



4:00 PM



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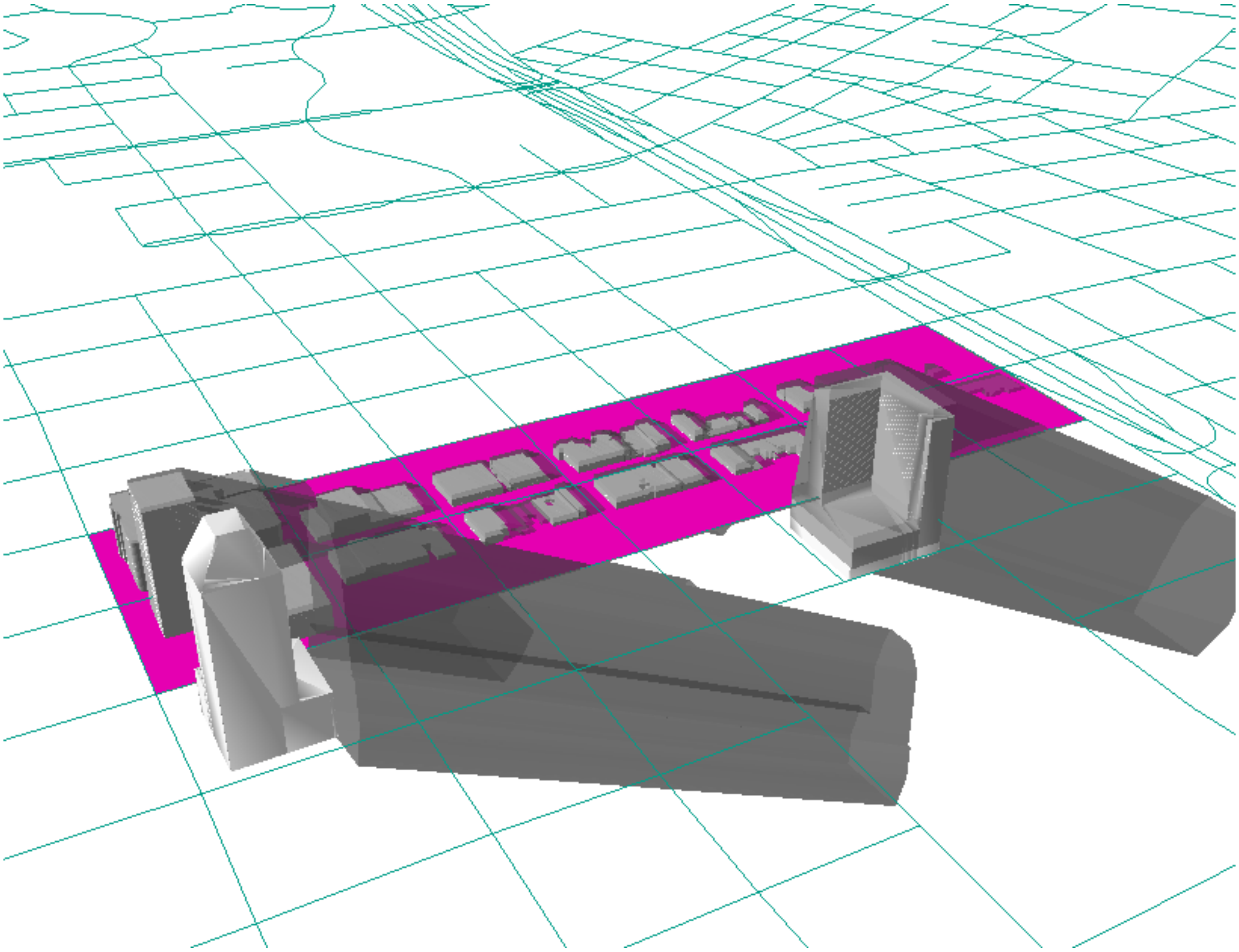
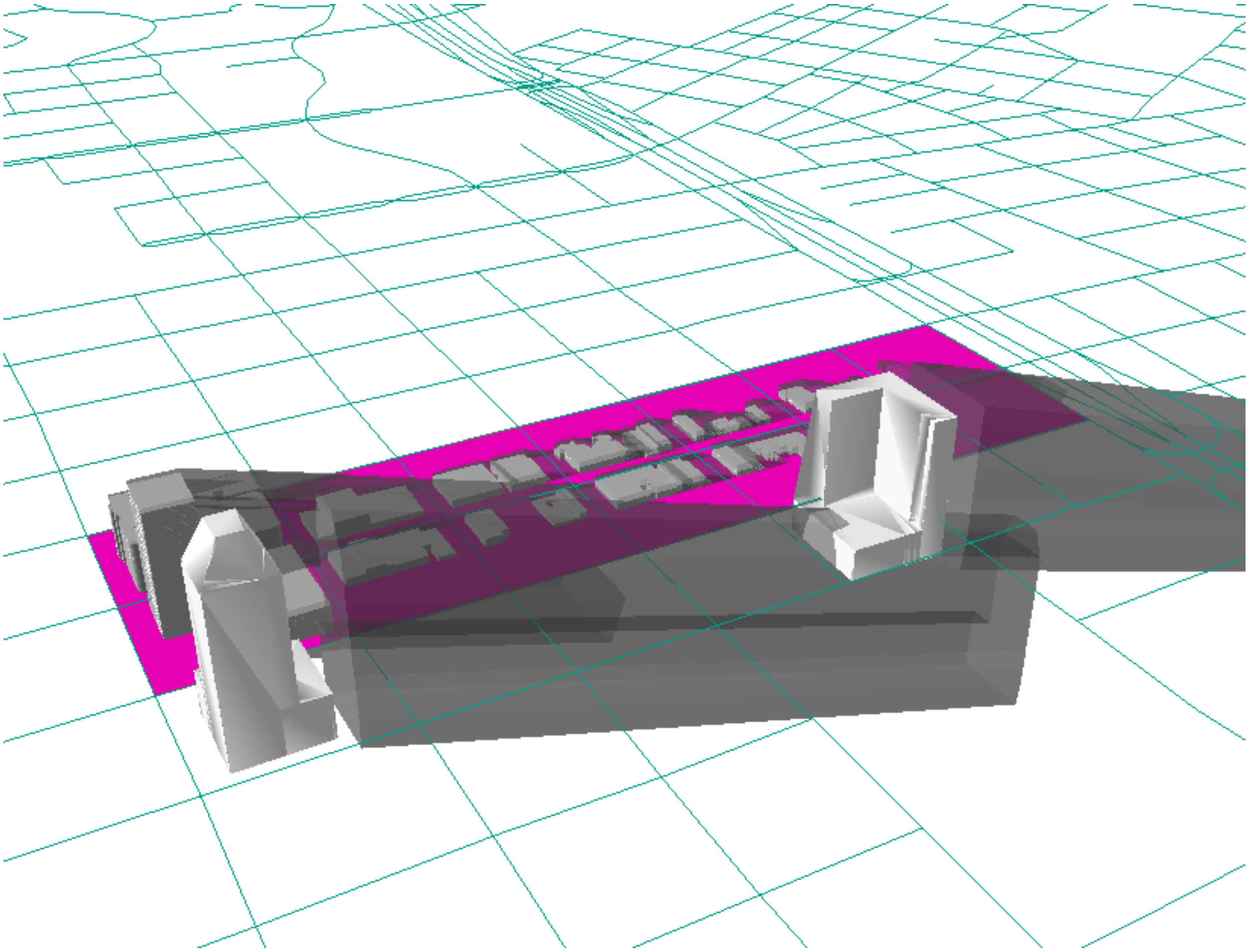
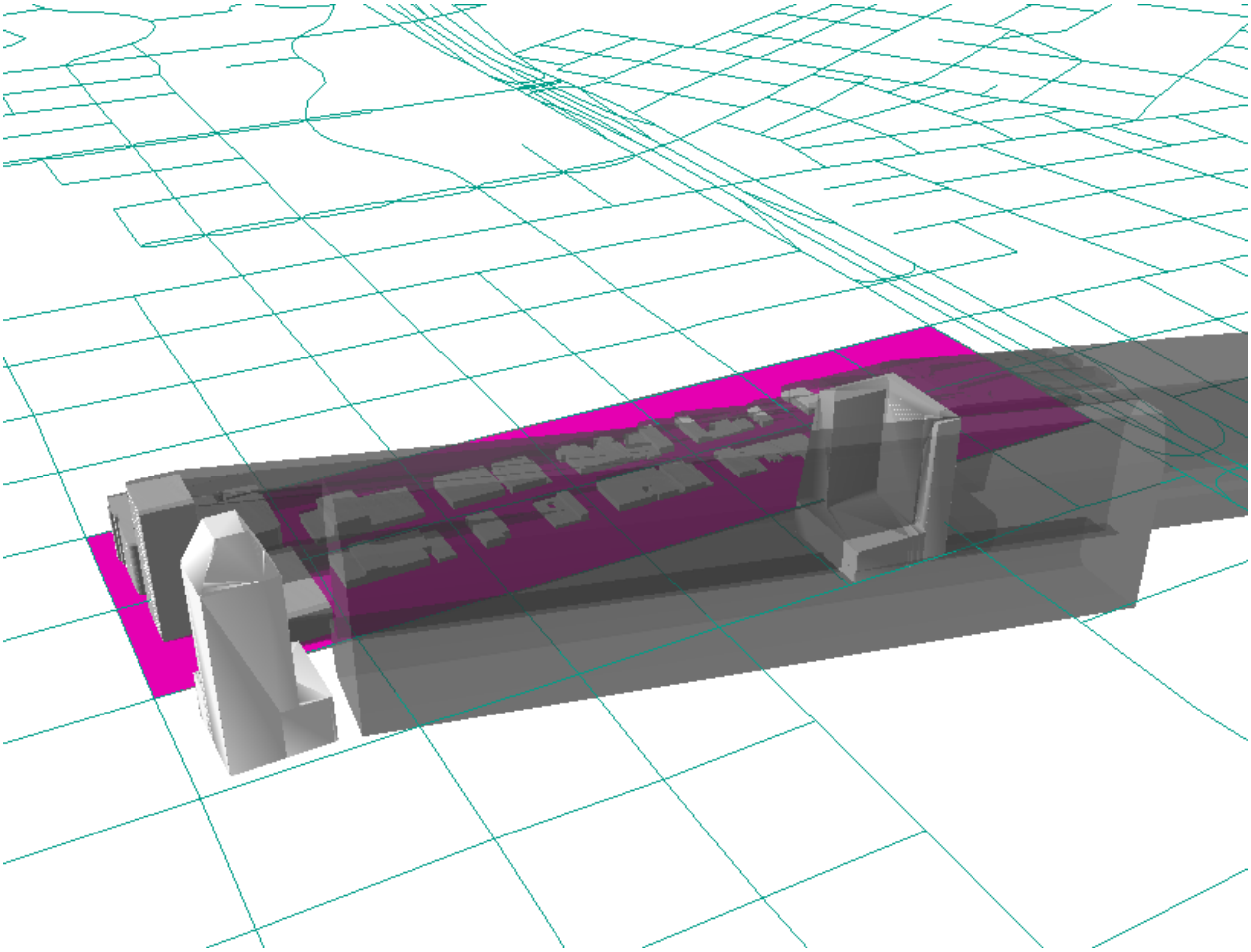


6:00 PM



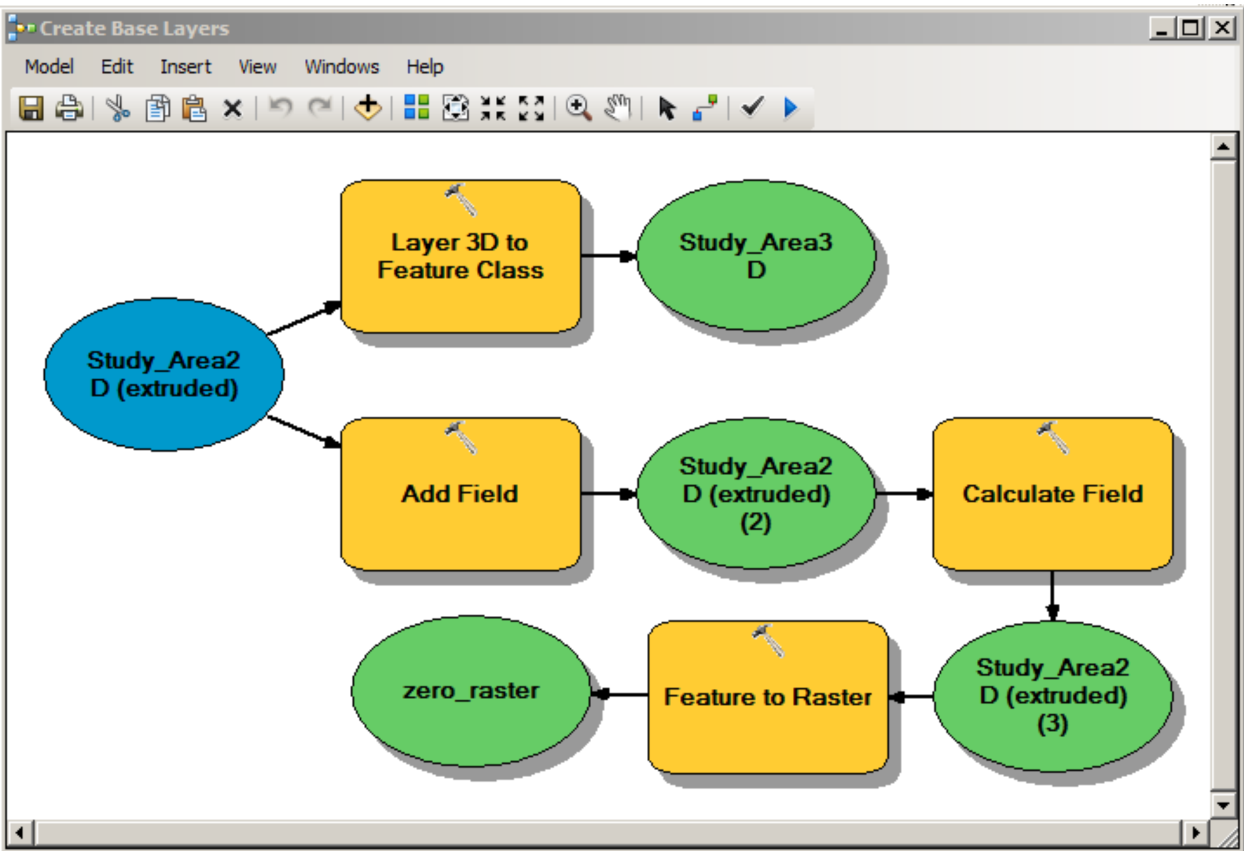
7:00 PM



8:00 PM

To create a base layer on which to sum up shadow values:

50. Extrude *Study_Area* by one foot and convert to a multipatch named *Study_Area3D* using the Layer to 3D Feature Class tool.
51. Add a field to *Study_Area* called shadow and calculate it as zero.
52. Use the Feature to Raster tool to create a raster named *Zero_Raster* on which to sum the shadow values.

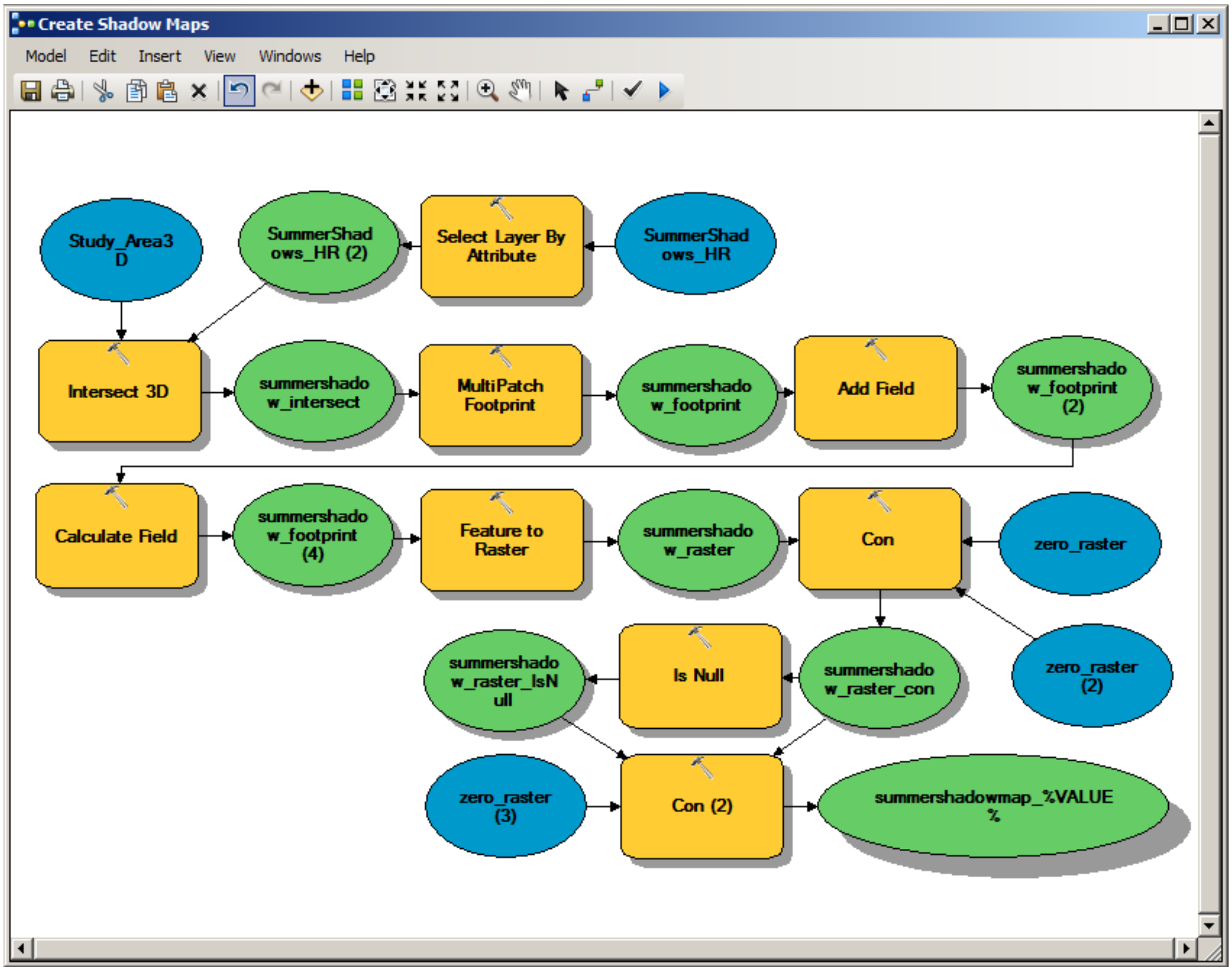


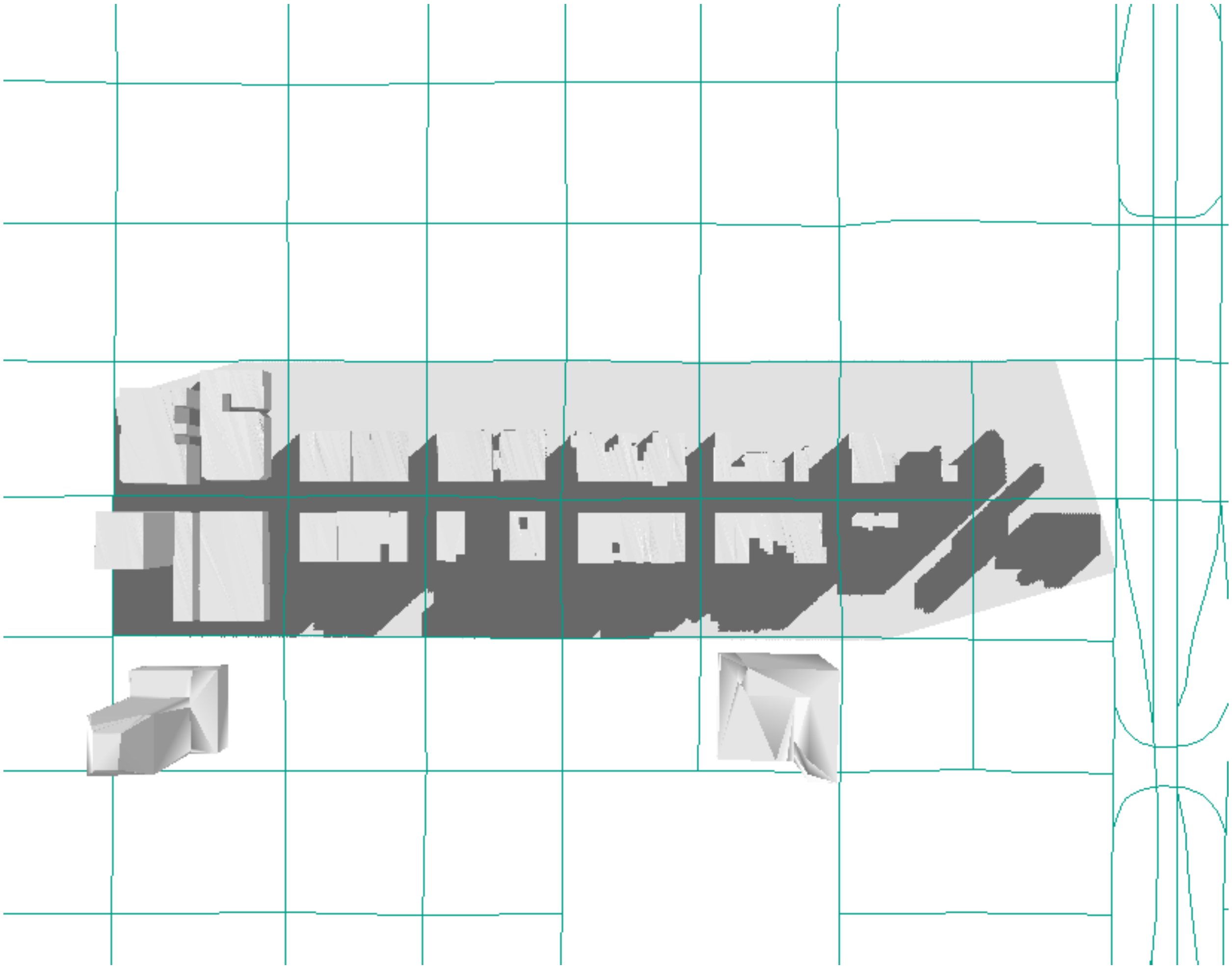
53. Export the *Summer_Shadows* attribute table as a text file and open with Excel.
54. Add a column named "HR" and calculate a number for each set of shadows per hour, 1-10.
55. Save and import table.
56. Join with the *Summer_Shadows* layer using the ID column as a linking column and save as *Summer_Shadows_HR*.

The following steps will create the hourly shadow maps. Repeat these steps for each hour of shadow:

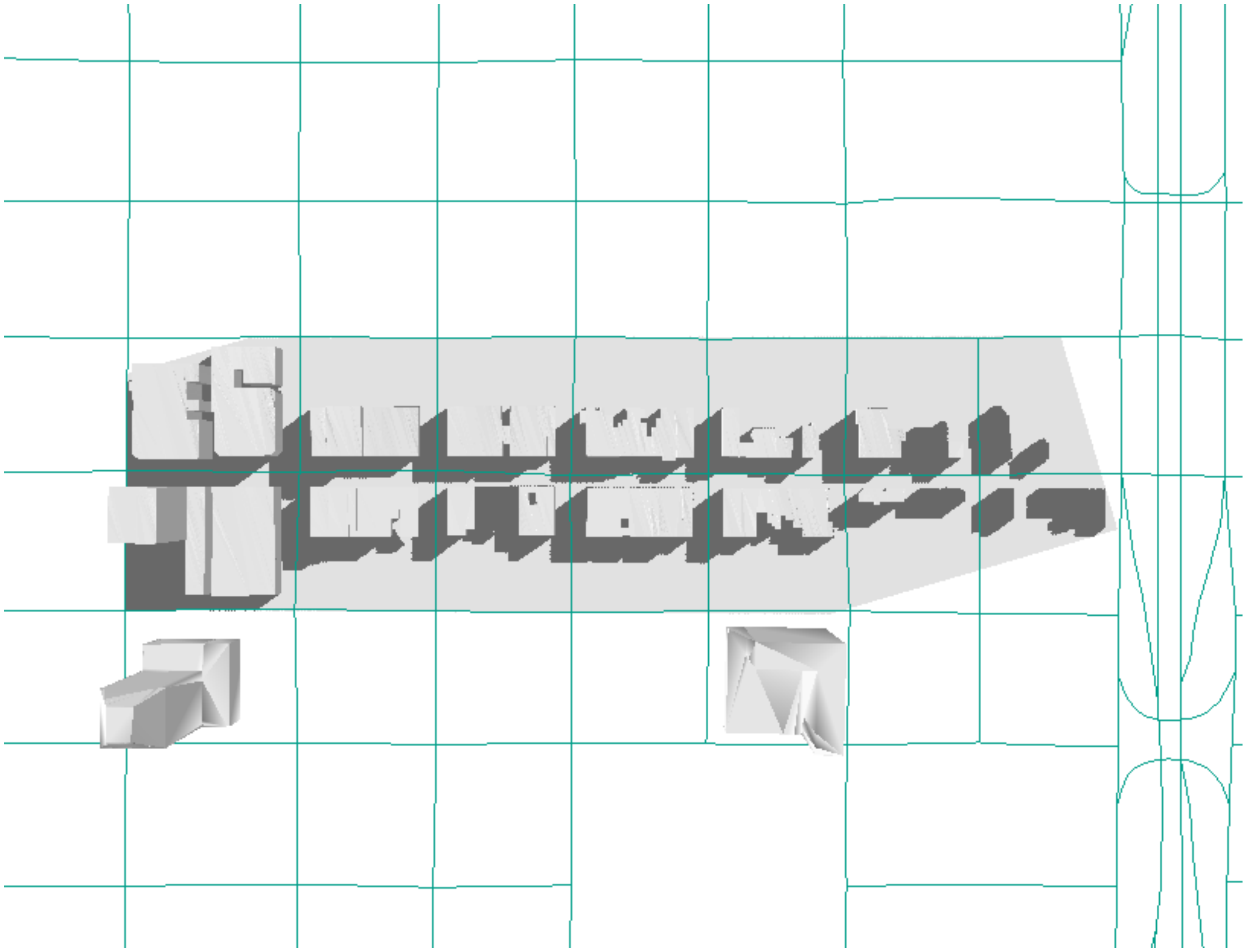
57. Select by Attribute HR = 1.
58. Use the Intersect 3D tool to find the intersection between *Study_Area3D* and *Summer_Shadows_HR*.
59. Use the Multipatch Footprint tool to get a 2D shape of the intersection named *Summer_Shadows_footprint*
60. Use the Add Field to add an attribute called "shadow" and the Calculate Field tool to set it to 1.
61. Use the Feature to Raster to create a raster that returns 1 values for shaded areas and name the output *Summer_Shadow_Raster*.
62. In order to create a common extent on which to layer the shadows, use the Con tool. Set the Input Conditional Raster and Input True Raster to *Zero_Raster* and *Summer_Shadow_Raster* as Input False Raster. Name the output *Summer_Raster_Con*

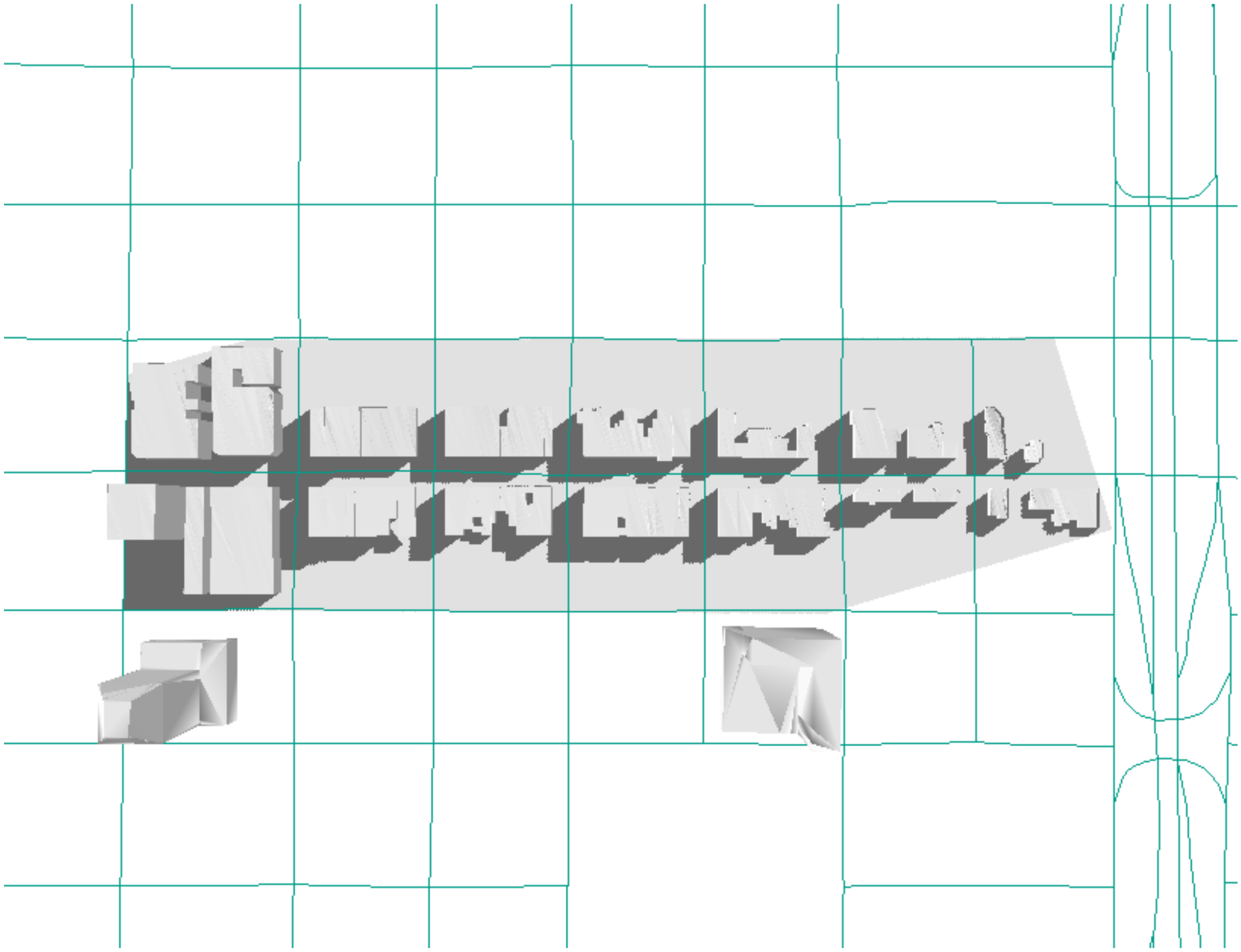
63. Use the Is Null tool to convert all NODATA values to zero and name the output *Summer_Shadow_Raster_IsNull*
64. Finally, use the Con tool again using *Summer_Shadow_Raster_IsNull* as the Input Conditional Raster, *Zero_Raster* as the Input True Raster, and *Summer_Raster_Con* as the Input False Raster. Name the output *Summer_Shadow_Map_1*.



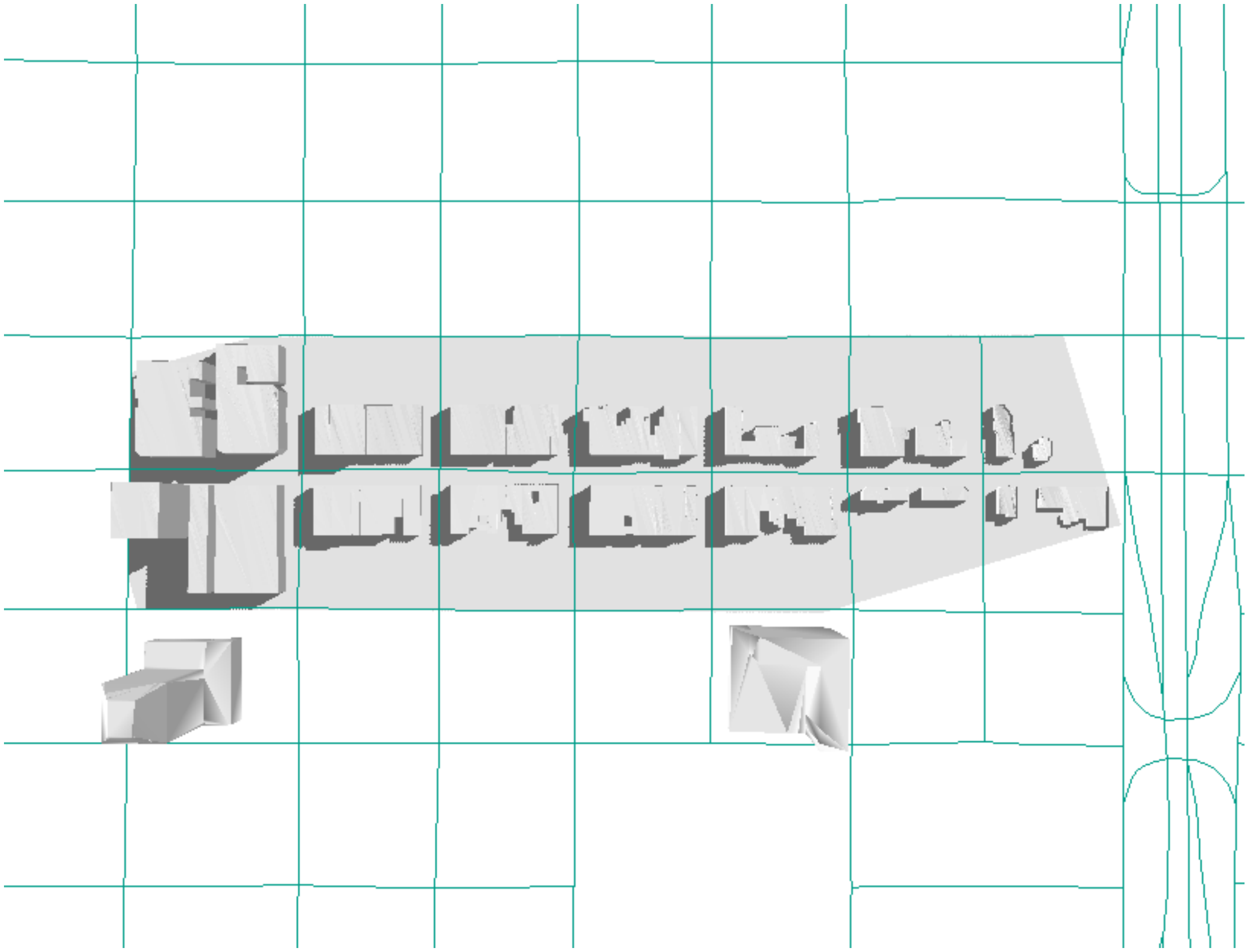


7:00 AM


8:00 AM



9:00 AM



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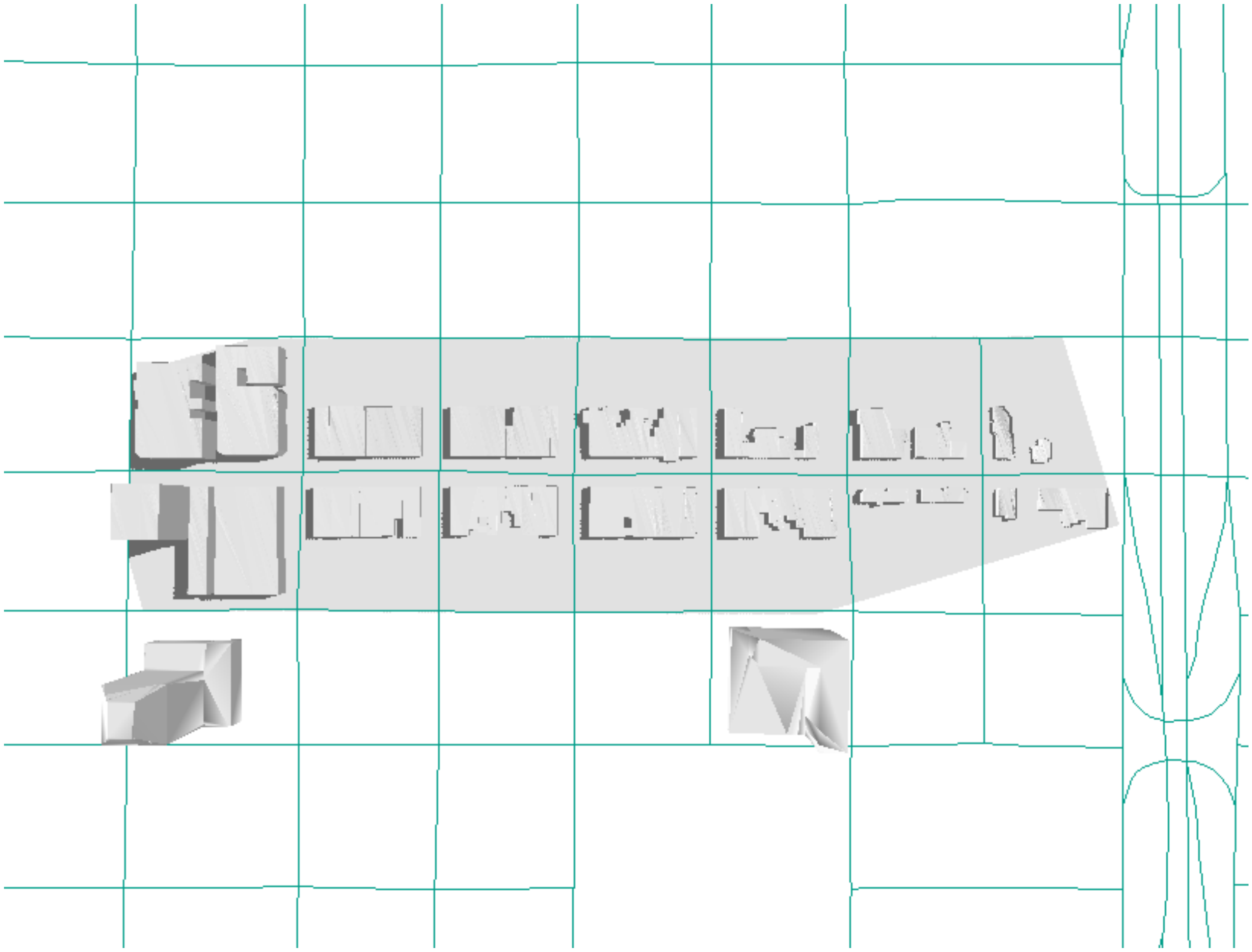
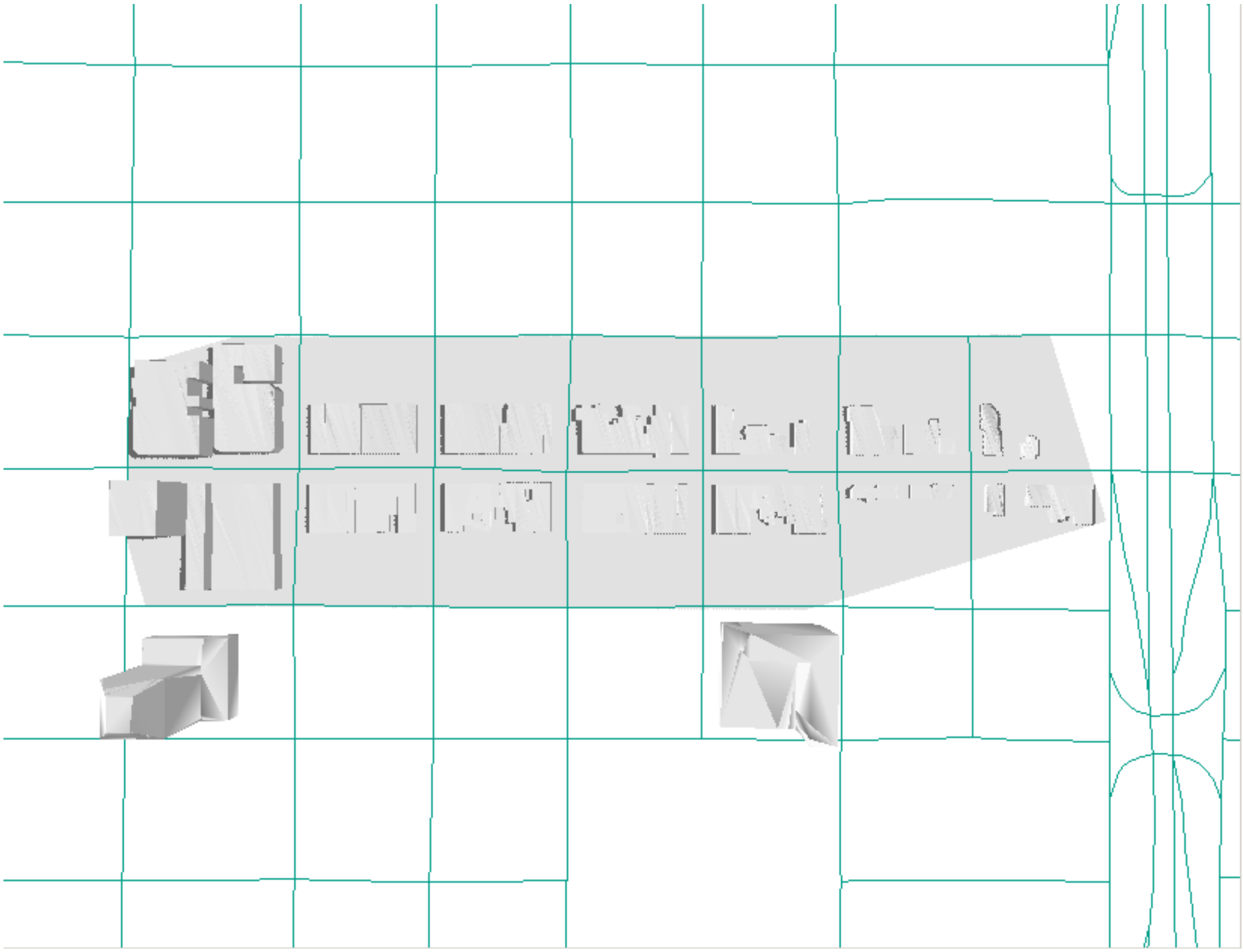


11:00 AM



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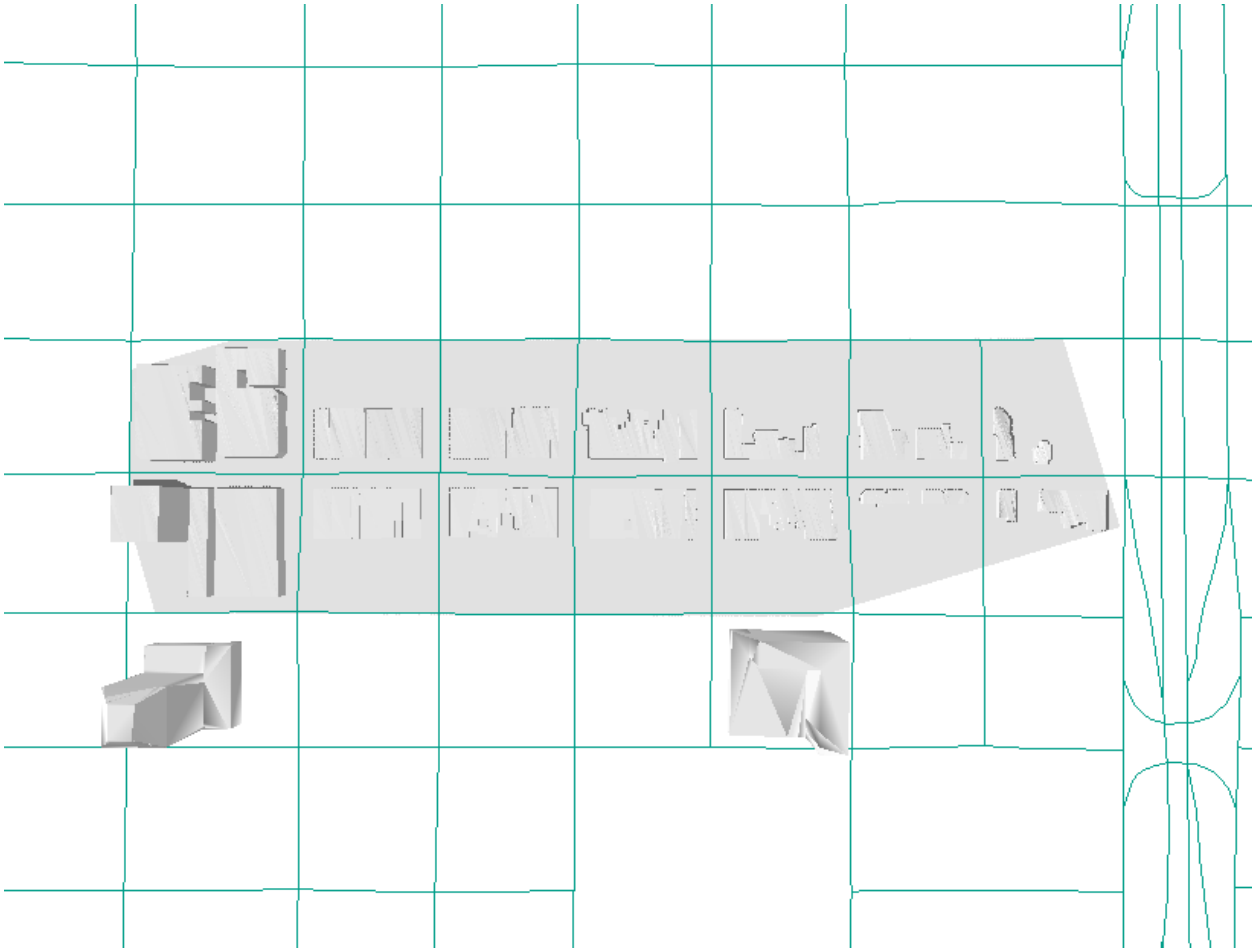
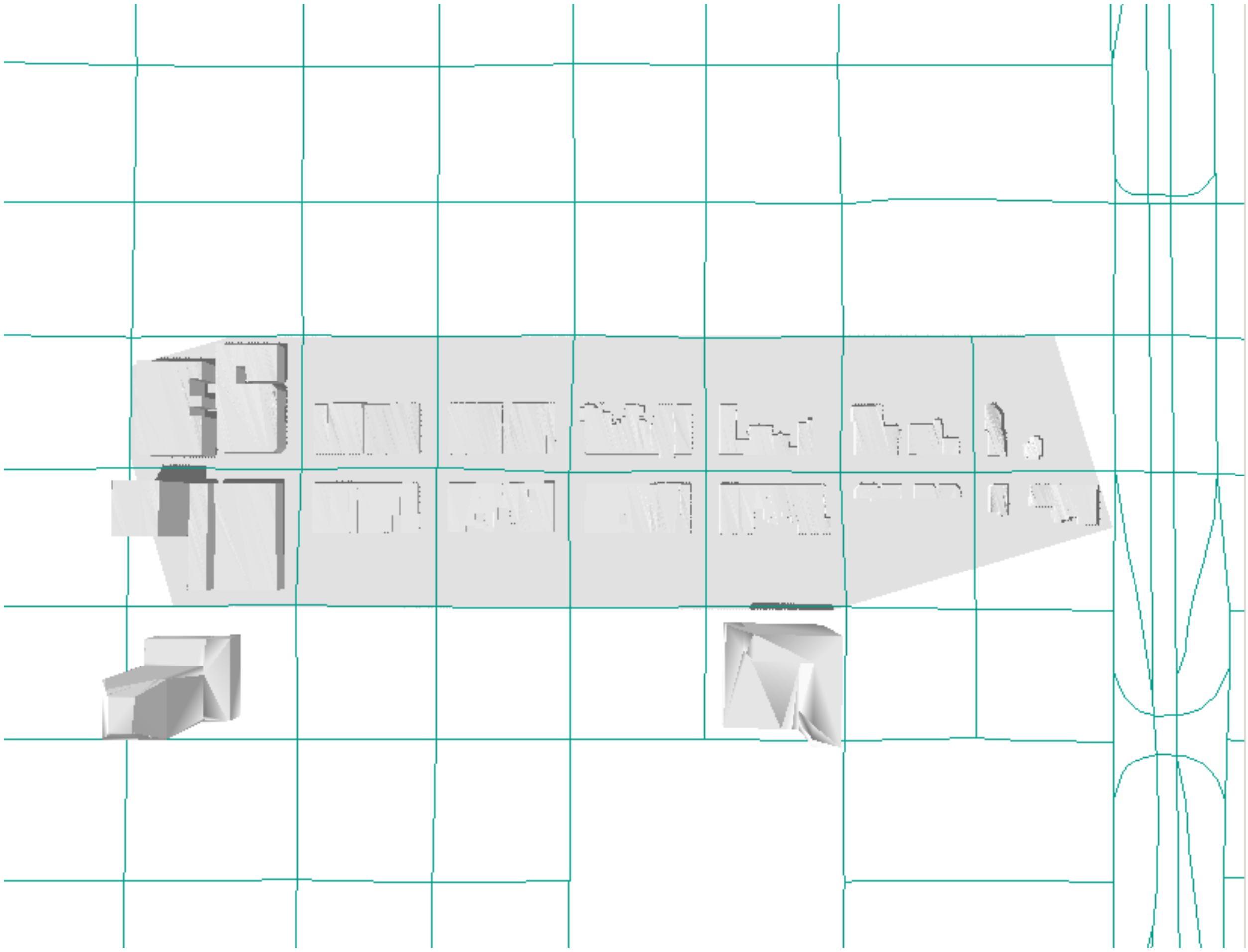
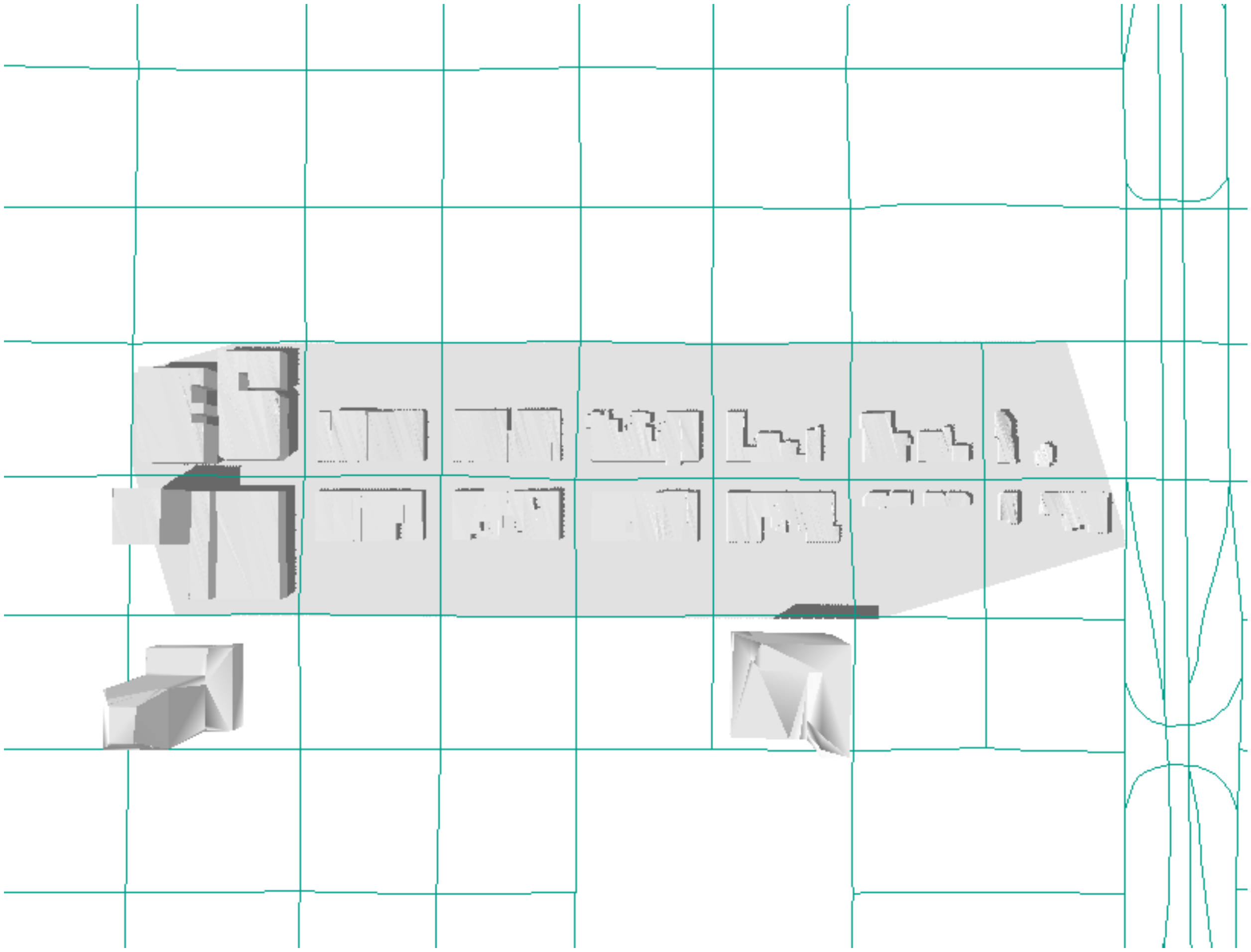


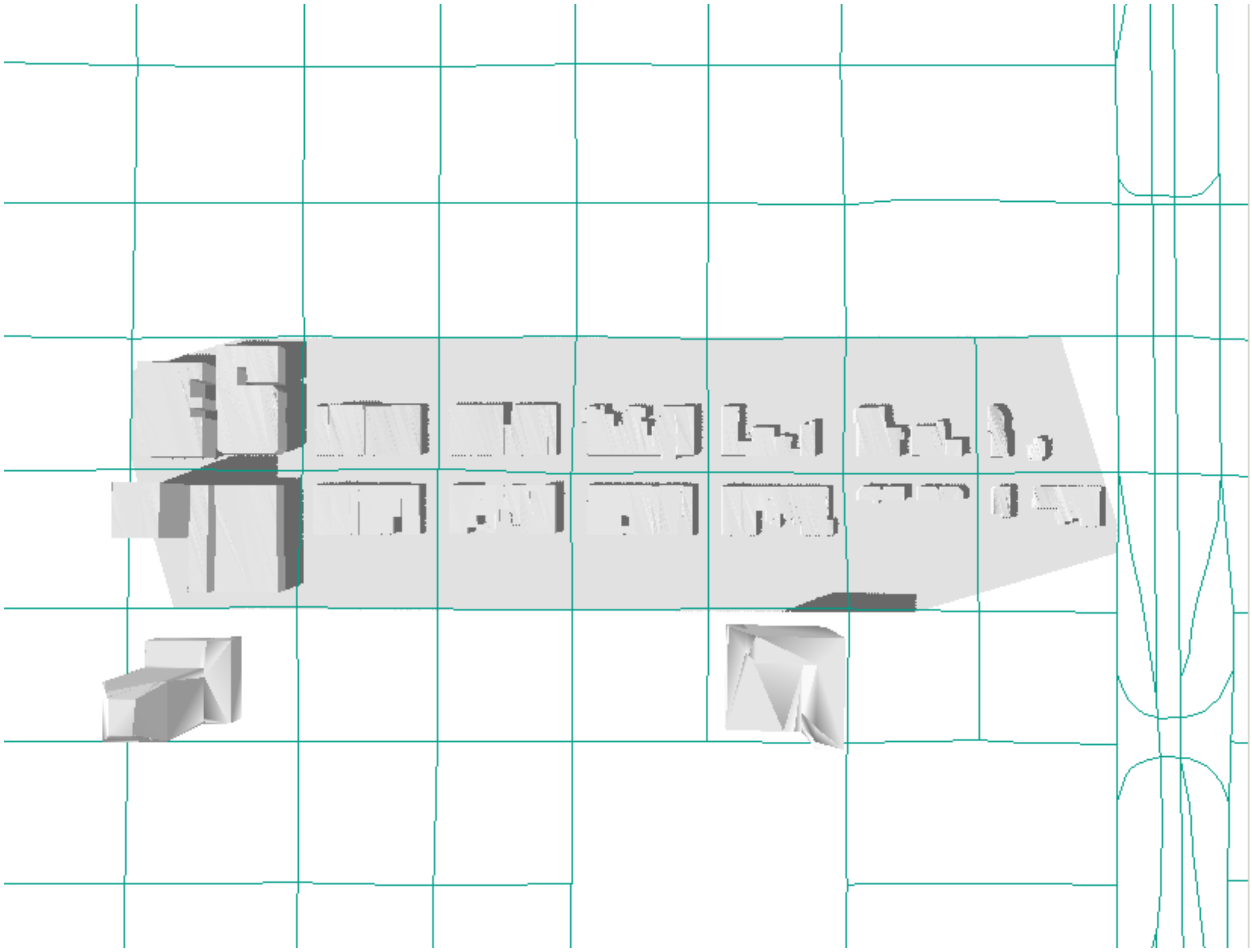
1:00 PM



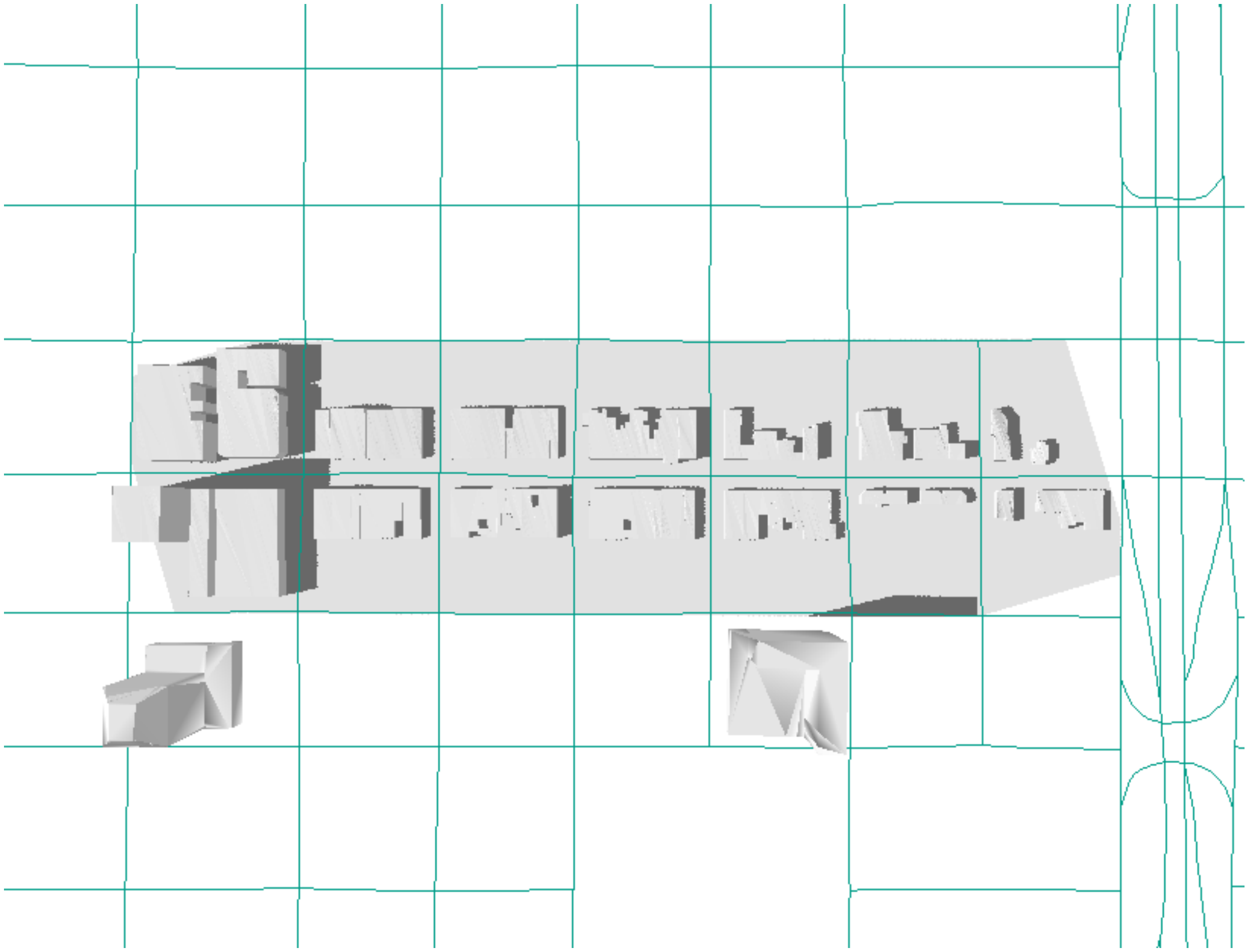
2:00 PM



3:00 PM



4:00 PM



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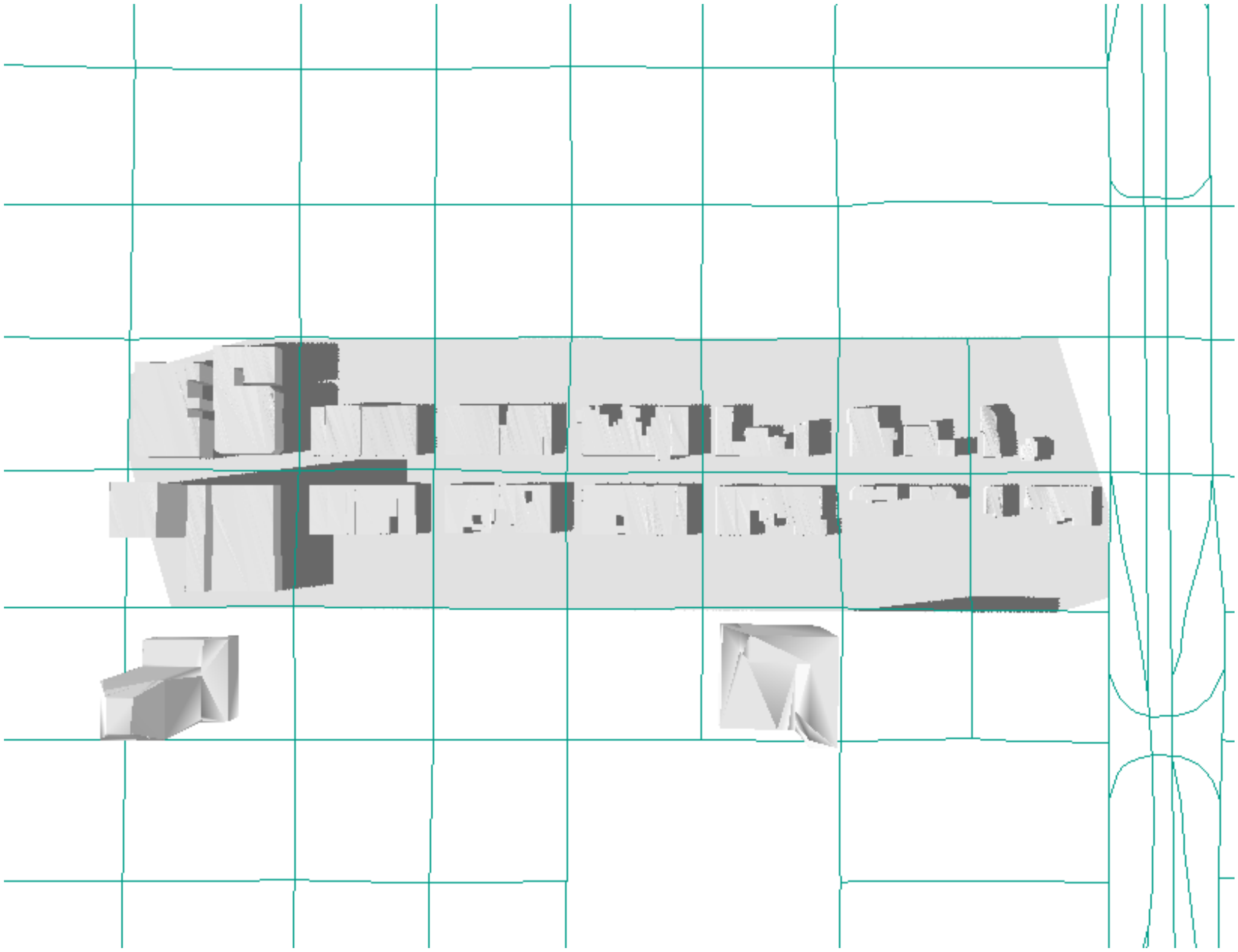
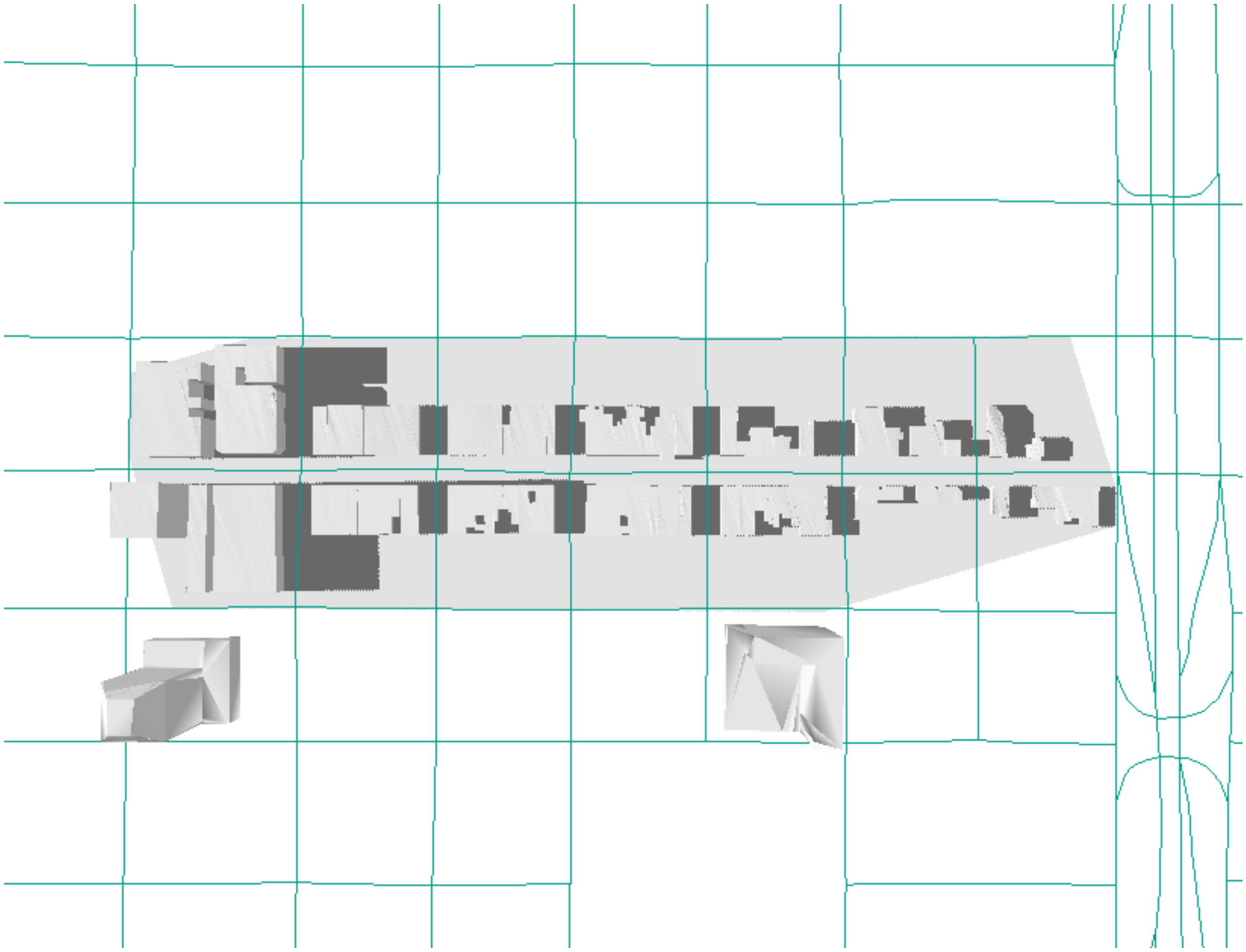
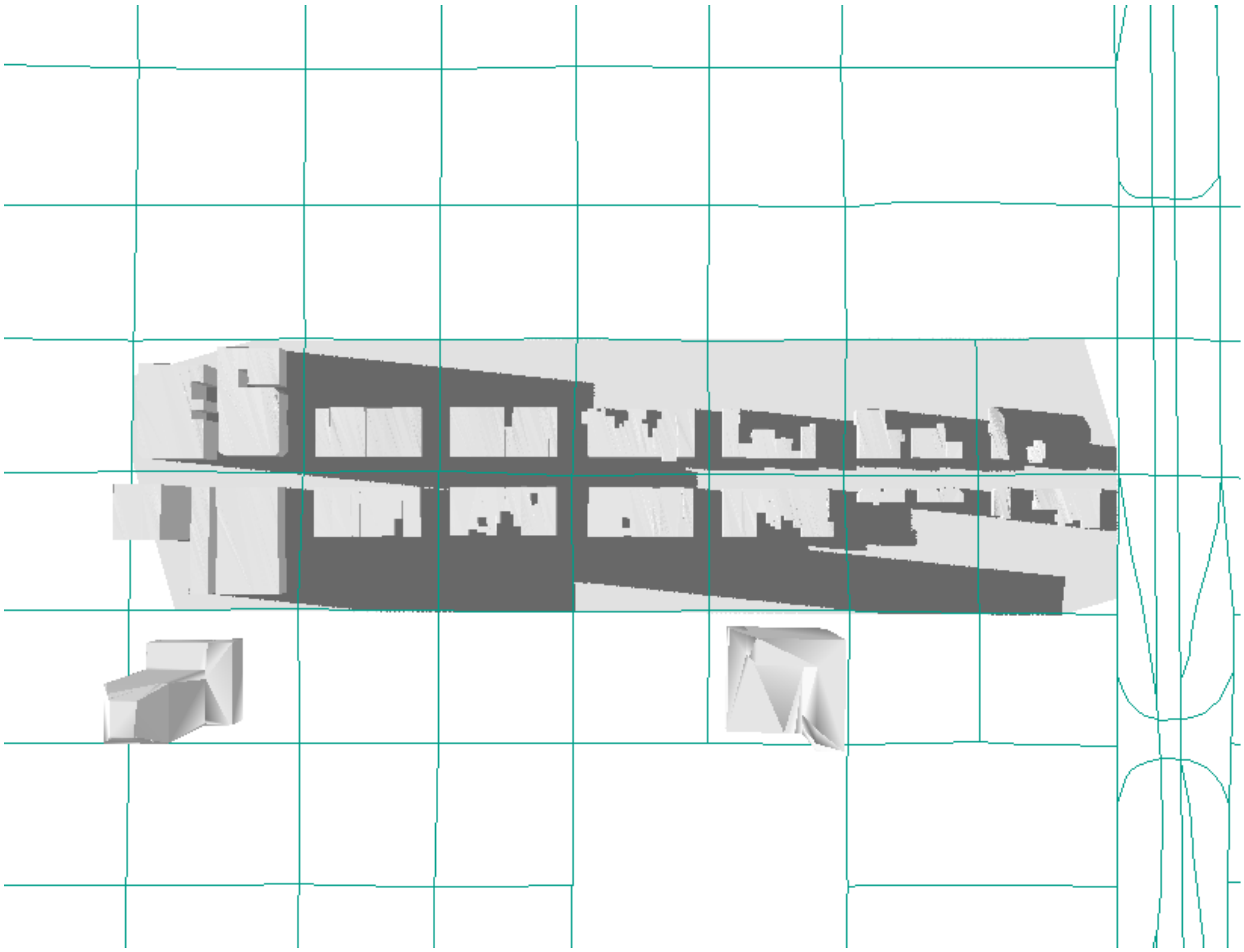


6:00 PM



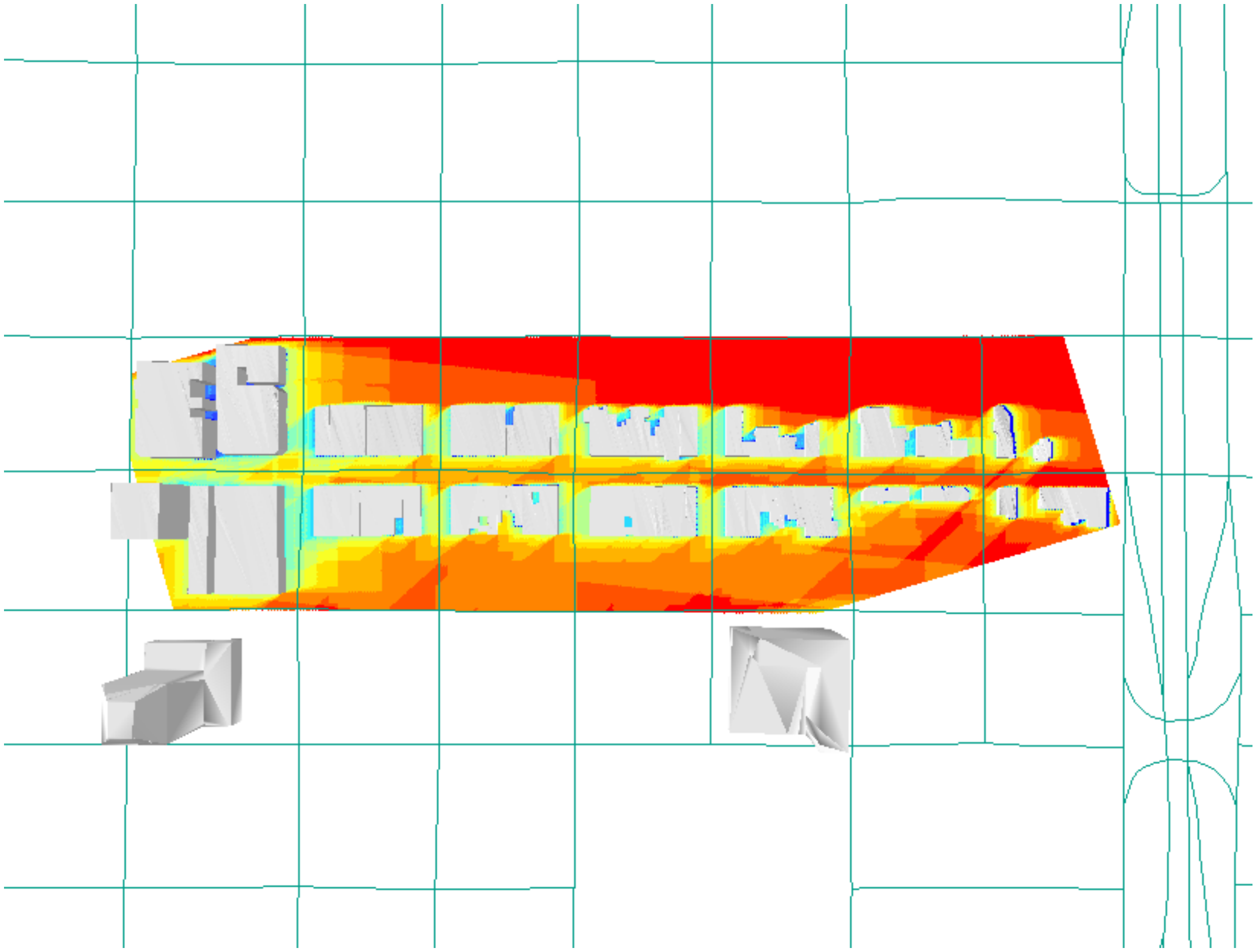
7:00 PM



8:00 PM

The following steps will summarize the individual maps to get a daylong shadow map:

65. Use the Raster Calculator to add all of the *Summer_Shadow_Maps* and name the output *sum_summer_shadow_map*.



Shadow Map for June 21, 2014

66. Copy the *sum_summer_shadow_map* layer and paste it into to the ArcMap document.
67. Finally, delete the *Study_Area* layer and format the map for publication.

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Vita

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