VISUALIZING URBAN DEVELOPMENT:

IMPROVED PLANNING & COMMUNICATION WITH 3D INTERACTIVE VISUALIZATIONS

by

RYAN ALBRACHT

A REPORT

submitted in partial fulfillment of the requirements for the degree

MASTER OF LANDSCAPE ARCHITECTURE

Department of Landscape Architecture and Regional & Community Planning
College of Architecture, Planning and Design

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2016

Approved by:

Major Professor
Brent Chamberlain

ABSTRACT

3D interactive visualizations can communicate complex urban design ideas to communities to improve planning (Bertol & Foell, 1997; Bishop et al., 2008; Griffon et al., 2011; Lange & Bishop, 2005). Unfortunately, many landscape architects, urban designers, and city planners currently re-frame from using such gaming technology capable of creating 3D interactive visualizations (Deane, 2015a). Many firms use verbal descriptions with images. This method is insufficient for facilitating feedback (Bratteteig & Wagner, 2010; Gordon, et al, 2010; Stakeholder Engagement, 2009; Zhang, 2004). According to Lange and Bishop (2005) there is no reason why real-time visualizations should not be used in urban design. Design fields will be moving toward procedural modeling software that is code-based to quickly model urban development (Flachbart & Weibel, 2005). However, this type of software, i.e., ESRI CityEngine, is only being used by approximately 10% of firms (Deane, 2015a).

This paper is one of the first to analyze how ESRI CityEngine can be used and improved to support the workflow of landscape architects, urban designers, and planners for urban development projects. The project explored ESRI CityEngine's procedural modeling and metric capabilities, and how it could be used to visualize a proposed Urban Core Residential District in Manhattan, Kansas. This process involved applying CGA (computer generated architecture) rules to GIS data, to model trees, streetscapes, landscapes, and buildings. Visuals that were produced include a CityEngine Web Scene and a Unity game.

VISUALIZING URBAN DEVELOPMENT

IMPROVED PLANNING & COMMUNICATION WITH 3D INTERACTIVE VISUALIZATIONS

BY RYAN ALBRACHT

Master of Landscape Architecture | Kansas State University | 2016

VISUALIZING URBAN DEVELOPMENT

IMPROVED PLANNING & COMMUNICATION WITH 3D INTERACTIVE VISUALIZATIONS

BY RYAN ALBRACHT

Master of Landscape Architecture| Kansas State University | 2016

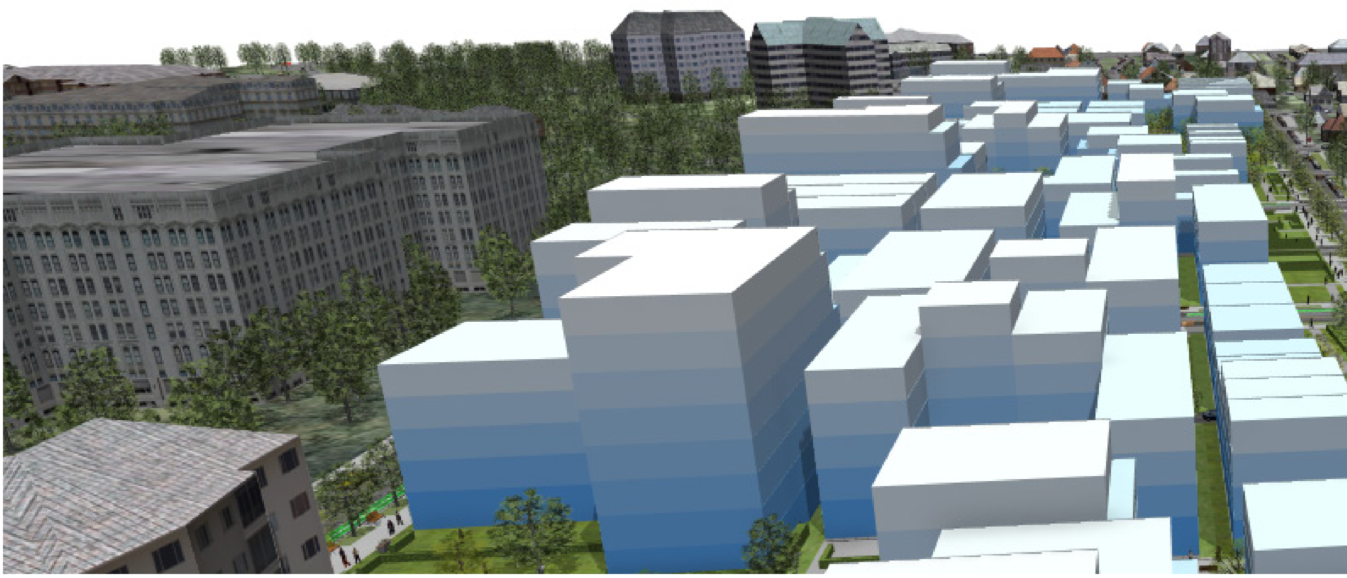
Visualizing Urban Development:
Improved Planning & Communication with 3D Interactive Visualizations

Report for Master of Landscape Architecture
Department of Landscape Architecture and Regional & Community Planning
College of Architecture Planning and Design
Kansas State University

Special Thanks to Major Professors on my Committee in the
Department of Landscape Architecture and Regional & Community Planning:
Associate Professor Dr. Brent Chamberlain
Associate Professor Howard Hahn
Associate Professor LaBarbara Wigfall

APDESIGN THE COLLEGE of
ARCHITECTURE, PLANNING & DESIGN // K-STATE

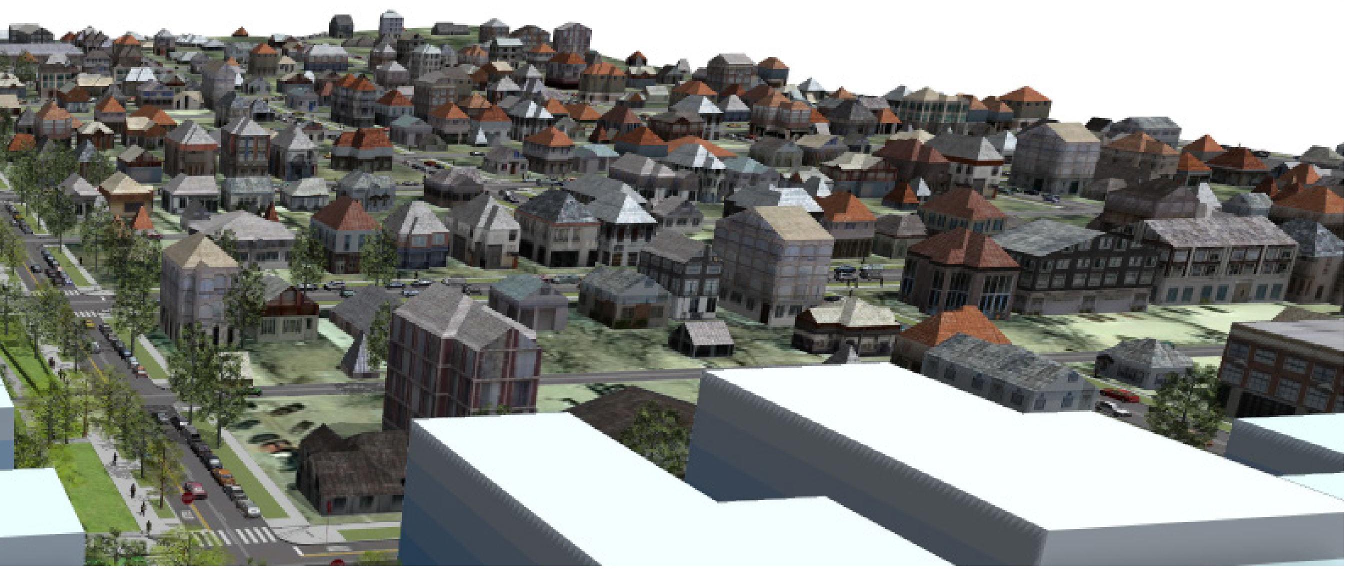
Figure 1.01: CityEngine model of proposed UCR District in Manhattan, Kansas



01 ABSTRACT

3D interactive visualizations can communicate complex urban design ideas to communities to improve planning (Bertol & Foell, 1997; Bishop et al., 2008; Griffon et al., 2011; Lange & Bishop, 2005). Unfortunately, many landscape architects, urban designers, and city planners currently re-frame from using such gaming technology capable of creating 3D interactive visualizations (Deane, 2015a). Many firms use verbal descriptions with images. This method is insufficient for facilitating feedback (Bratteteig & Wagner, 2010; Gordon, et al, 2010; Stakeholder Engagement, 2009; Zhang, 2004). According to Lange and Bishop (2005) there is no reason why real-time visualizations should not be used in urban design. Design fields will be moving toward procedural modeling software that is code-based to quickly model urban development (Flachbart & Weibel, 2005). However, this type of software, i.e., ESRI CityEngine, is only being used by approximately 10% of firms (Deane, 2015a).

This paper is one of the first to analyze how ESRI CityEngine can be used and improved to support the workflow of landscape architects, urban designers, and planners for urban development projects. The project explored ESRI CityEngine's procedural modeling and metric capabilities, and how it could be used to visualize a proposed Urban Core Residential District in Manhattan, Kansas. This process involved applying CGA (computer generated architecture) rules to GIS data, to model trees, streetscapes, landscapes, and buildings. Visuals that were produced include a CityEngine Web Scene and a Unity game.



02 INTRODUCTION

Traditional ways of communicating designs through verbal descriptions and images are insufficient (Gordon, et al, 2010; Zhang, 2004). Technology advancements in gaming have enabled designers to better communicate their designs (Griffon et al., 2011). This includes using visuals that an audience can interact with and experience space in real-time, which can improve communication and ultimately lead to better decision-making (Griffon et al., 2011; Bishop et al., 2008). These 3D interactive visualizations include Virtual Reality (VR) and Augmented Reality (AR). VR environments are created in this project. Designers are able to produce VR environments using real-time modeling software, exporting 3D models as Web Scenes, and by exporting 3D digital models to be viewed using gaming technology (e.g., Griffon et al., 2011; Ermi & Mayra, 2005; Gordon et al., 2010; Twitchen & Adams, 2011; Hollander, 2011; Becker-Asano et al., 2014).

There is different software and hardware which can be utilized to help visualize urban development in VR. For this project CityEngine (ESRI CityEngine) was used because of its ability to supply the user with quantitative data along with visualizations which can assist to improve the decision-making process (e.g., Bishop et al., 2008; Lange & Bishop, 2005). In this project, Manhattan city planners were collaborated with to visualize what an Urban Core Residential (UCR) District north of Aggieville might look like. A hypothetical master plan was created that followed the city's UCR District design standards (see Figure 2.01 & 2.02). Several scenarios were generated for the streetscape. The final 3D interactive visualizations would eventually be used as a tool to facilitate feedback of the design scenario from stakeholders and the greater community. The visuals will also be used to create public awareness, attract developers, and guide architects.


Figure 2.01: Perspective looking north on 12th St.


Figure 2.02: UCR District Master Plan

The aim of this research was to learn how software and hardware could be used to produce 3D interactive visualizations of the UCR District and how that simulation could be communicated to the city, developers, design professionals, stakeholders, and the public to improve the city's workflow. The primary goal was to determine how CityEngine could be used and improved to support the workflow of landscape architects, urban

Figure 2.03: Proposed new Urban Core Residential (UCR) District in Manhattan, Kansas

designers, and planners for urban development projects. This included discovering the difficulty of the software, the time needed to model, and ways the visuals could be used to improve communication. The process involved working with ArcMap, CityEngine, and Unity. The end product was a virtual world (i.e., CityEngine Web Scene) and a VR game environment. Since there are different ways software and hardware can be used to create and visualize designs in VR, this report discusses the types of methods that should be used for different audiences (Griffon et al., 2011). Landscape architects, urban designers, and planners looking to improve their workflow for urban designs with ESRI CityEngine can use this report as a guide. This report can also help inform ESRI on how their CityEngine product can be improved to support urban design.

Research Question:

How can ESRI CityEngine be used and improved to support the workflow of landscape architects, urban designers, and planners for urban development projects?

Figure 2.04: 3D digital model of Manhattan, Kansas created in ESRI CityEngine

03 BACKGROUND

THE URBAN PLANNING PROCESS

City planners often implement or change government policies, while landscape architects and urban designers create master plans. However, both projects require the use of visualizations to engage communities so better decision-making can be accomplished. The type of process used will depend on the project type, time availability, and funds available to engage the community. There are numerous theoretical planning models that can be used and adapted to meet project parameters. The planning models typically include identifying problems, creating goals, involving the community, creating design alternatives, analyzing designs, and monitoring the final design once implemented (e.g., Batty, 2007; Gregory, et al., 2012; Steiner, 2012). The City of Manhattan planners used a similar method for the planning of the UCR District that was focused on changing policies.

UCR DISTRICT PLANNING PROCESS

The City of Manhattan aimed to change policies to allow for more residents to live near the KSU campus and Aggieville District. Their planning process included nine general steps (see Figure 3.01). The first step was to delineate the problem, which was a lack of residential units and neighborhood-serving commercial businesses near campus and Aggieville. Then, the city selected a suitable area to resolve this problem. Immediately following, the city sent a web survey to students and faculty to collect inventory on their needs and if they desired to live in the UCR District. This data was then put into diagrams and analyzed. Based on this data, the city established a goal to promote development patterns of denser, pedestrian-oriented, urban neighborhoods. Simultaneously, the city created five objectives (see pg. 48). Afterwards, the city selected precedent studies. The precedent studies and objectives helped guide the city in creating preliminary design standards and a streetscape vision. Feedback was then collected on the preliminary design standards and streetscape vision through focus group meetings with the public, property owners, architects, and developers. Based on the feedback, the design standards were altered. In the future,

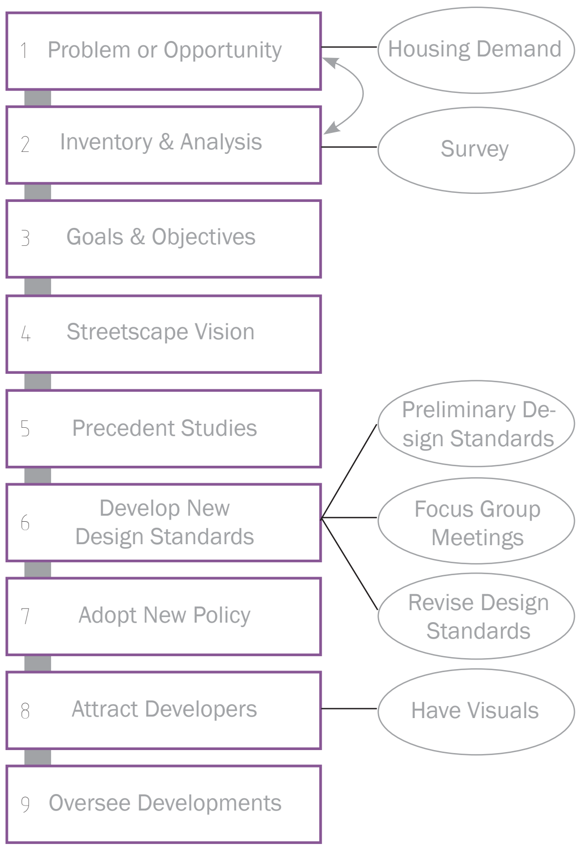


Figure 3.01: UCR District Planning Process

the design standards would be presented in a public hearing to vote on its adoption. Meanwhile, the streetscape vision financing, design/construction contracts, and final streetscape design would need to be approved in a public hearing. The city desired to have visuals to promote public buy-in and understanding of the district during the public hearings. At the same time, they also wanted visuals they could use to attract large out-of-state developers to the UCR District. (Chmiel, 2016)

The city did not have sufficient funds to hire a consultant. Instead, they would produce visuals in-house using CityEngine. However, there were difficulties using the software so a student was consulted to produce visuals. The visuals they would eventually use were produced in this masters project. In the future, once the visuals attract developers, the city will review architectural drawings for private development to ensure they meet design standard requirements.

MASTER PLANNING

In addition to design standards, an urban design master plan should be adopted or endorsed by the city to visualize what the design standards could look like in 3D form (Steiner & Butler, 2012). The plans should include "existing development, proposed development, utility infrastructure, streets framework, open space framework, environmental framework, and sustainable development principles"(Steiner & Butler, 2012, p. 10). Master plans are generated by landscape architects, urban designers, and architects who understand the system between policies and design implementation.

Master plan alternatives should be developed so the community can analyze different designs to select their preferred option (Steiner & Butler, 2012). The plans can be detailed or abstract to carry out development frameworks of a specific area (Firley & Groen, 2014). Less detailed designs are needed in the conceptual stage when holding charrettes, but as the design progresses the designs should become more detailed showing more variables. Abstractness is good for master plans to avoid discrepancies on what is actually proposed (Bosselmann, 1998). The detail will not affect the spatial knowledge of the viewer (Cubukcu, 2010). However, detail is necessary if the public wants to know how they would feel in a proposed environment (Gordon, et al., 2010). No matter how much detail is added in the design, the plan will not capture complex realities (Firley & Groen, 2014). However, a virtual reality of the master plan can convey complex urban systems (Bertol & Foell, 1997). Visuals representing possible visions should be used to engage the community throughout the design process (Steiner, & Butler, 2012).

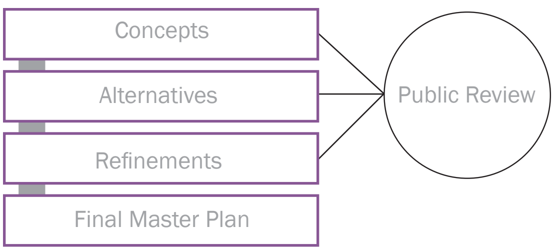


Figure 3.02: Master Planning Process

COMMUNITY INVOLVEMENT

In order for communities to successfully change, visions are created to imagine the future (Okubo, 2000; Kotter, 1996). Developing a vision requires communities to participate in developing goals (Bose, et al., 2014; Introduction to Stakeholder Participation, 2007). Typically, governments will independently make new policy recommendations for what they think is in the community's best interest (Okubo, 2000). It is important to engage the community and stakeholders in the process so to prevent negative views of change (Okubo, 2000). In planning there are five increasing levels of involvement: informing, consulting, involving, collaborating, and empowering (Best Practice Community Engagement Techniques, 2013).

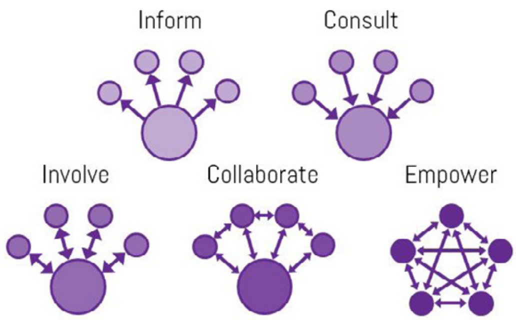


Figure 3.03: Levels of Engagement

The level of involvement used will depend on the project type (Stephens, 2015). Informing the public may be sufficient for private projects, but public projects should include consultation and active participation with stakeholders (Stephens, 2015; Introduction to Stakeholder Participation, 2007). Different types of visuals can be used to help engage the community (Stephens, 2015). These visuals are generally categorized as images, videos, animations, or simulations. These visuals can be used to engage audiences in public meetings, focus groups, and on websites. Many more methods are also available for engaging audiences with visuals (e.g., Best Practice Community Engagement Techniques, 2013; Engaging Queenslanders, 2007). The disadvantage of involving the community in the decision process is that it is costly and time-consuming for both parties (Irvin & Stansbury, 2004). However, new methods of communicating designs can speed up this process. First, this report will give a brief history on the process of design communication.

THE EVOLUTION OF VISUALIZING DESIGNS

Space is the most useful way to communicate designs (Anders, 1999). We have been using 2D drawings to communicate space for millennia (Bertol & Foell, 1997). The most engaging 2D drawings were ones that portrayed 3-dimensionality or depth (Bertol & Foell, 1997). People used the eye level perspective as a tool to create illusions of 3-dimensional space, but it was not accurately used until 1435 A.D. when Leon Battista Alberti documented the rules of perspective drawing (Edgerton, 1978; Bertol & Foell, 1997). Alberti was able to do this by using geometry and visual perception (Edgerton, 1978; Bertol & Foell, 1997). Alberti's rival, Filippo Brunelleschi, tested and confirmed his perspective rule by reflecting an image of the Baptistery in Florence on top of his perfectly drawn linear perspective drawing with a flat glass mirror (Bosselmann, 1998). It was not until a half-millennium later that this perspective rule could be computed automatically in 3D modeling software.

The next main shift towards more accurately communicating space was the invention of the camera obscura which was thought to create realism or visual truth (Cray, 1992; Bertol & Foell, 1997). Photos created more accurate depictions of what humans can view in space. However, films and photographs were taken from a single lens which caused monocular vision (Bertol & Foell, 1997). Photos also could not convey sensory data, so there was never a sense of presence (Cray, 1992; Gibson, 1978). In the 1950's, Morton Heilig wanted to advance the cinema realm and make it more realistic for audiences (Bertol & Foell, 1997). He developed a device called the Sensorama which used stereoscopic vision (McLellan, 1996; Bertol & Foell, 1997). In addition to visual and auditory data the Sensorama stimulated the senses of touch, smell, and motion (McLellan, 1996; Bertol & Foell, 1997). This allowed people to experience a motorcycle, bicycle, and helicopter ride in a real-life way (McLellan, 1996). It was very similar to reality except audiences could not interact with the data because the film was set on an automatic path (Bertol & Foell, 1997). The invention of Sensorama eventually led to Virtual Reality (VR).

Figure 3.04: Sensorama Machine

When you think of VR you probably think of viewing an environment using a head-mount display. While using a head-mount display increases the amount of immersion in VR, it is not required (Steuer, 1993). Other haptic devices can also be used to increase the amount of immersion in the VR experience (Steuer, 1993). VR can be described as interacting and feeling present in a non-physical space (Steuer, 1993; Bertol & Foell, 1997). Early VR applications had a low sense of presence, but current VR applications can feel very real (Brooks, 1999). The expectation of realism, to increase a sense of presence, has evolved the definition of VR (Steuer, 1993). VR now requires software and hardware that can render high levels of detail in real-time.

Before VR was invented three key things happened: CAD (computer-aided design) was invented which allowed designers to create 2D and 3D graphics; GIS (geographic information systems) allowed designers to use and analyze large datasets and create 3D models and maps; and lastly the internet was invented which allowed people to interact with other people and infinite data in a Cyberspace (Bertol & Foell, 1997). In 1962, Ivan Sutherland invented the first VR prototype which allowed users to draw vector lines by interacting with a computer using a sketchpad (Sutherland, 1988; Bertol & Foell, 1997). The next advancement was stereoscopic vision and trackers in VR which were used in flight simulators (Bertol & Foell, 1997). VR became apparent in medical, biology, astronomy, and entertainment fields (Bertol & Foell, 1997). There are numerous types of VR that use different kinds of hardware, software, interfaces, display systems, and sensorial devices (Bertol & Foell, 1997; Whitton, 2003). Many software interfaces are challenging, requiring programming skills (Robertson, 1993). As this technology continues to become more user friendly, it will thrive in the future (Robertson, 1993). By the year 2020, AR & VR industries are predicted to be worth $150 billion (Deane, 2015b).


Figure 3.05: Ivan Sutherland Sketchpad Invention


Figure 3.06: VR Head-Mount Display

VIRTUAL REALITY SOFTWARE AND HARDWARE

Figure 3.07: Unity Interface

Figure 3.08: Gaming device which tracks movements

Figure 3.09: Haptic Devices

The VR technology that is applicable to the design professions started in the gaming realm (Bertol & Foell, 1997; Gordon, et al., 2010). VR software allows design professionals to interact and edit their designs in real-time (Flachbart & Weibel, 2005). This includes software such as CityEngine, Lumion, and LumenRT (Esri CityEngine, n.d.; Lumion, 2015; Lumenrt; n.d.). The visual representations created in this software can be viewed through a variety of different hardware, ranging from computer monitors to fully immersive 3D screens or viewports (Flachbart & Weibel, 2005; Esri CityEngine, n.d.; Lumion, 2015; Lumenrt; n.d.). Immersion can be defined as feeling present somewhere in a non-physical space (Gordon, et al, 2010). Gaming software is compatible with many haptic devices including head-mount goggles, core body, arms, hand, and foot tracking sensors which allow users to explore virtual environments in more immersion (Lamkin, 2016; Marco, 2015; Bertol & Foell, 2997; Whitton, 2003). Virtual environments, especially virtual worlds can be used to collect feedback. The type of feedback desired on a design will determine how much detail should be put into the model. Participants will most likely focus too much on visual aspects if the model is detailed (Tobias, et. al., 2016). However, the more realistic the environment looks will increase how an audience will experience the design as real life (e.g., Daniel & Meitner, 2001).

Figure 3.10: Software used by Landscape Architects

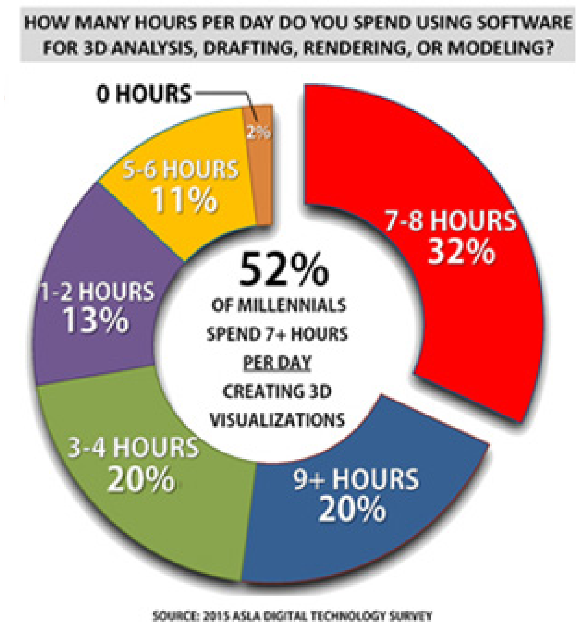


Figure 3.11: Time Spent on 3D Visualizations

MODELING

Virtual reality is the most appropriate way of communicating urban design to audiences (Bertol & Foell, 1997). It can be used to represent complex urban relationships among buildings, vegetation, circulation, and socio-economic patterns (Bertol & Foell, 1997). However, there is a need for effective modeling tools to produce virtual urban models (Santos, et. al., 2011). Designers need to use procedural modeling tools so they can apply the same level of detail they do for small hand craft models to larger areas (Neuenschwander, et. al., 2014; Santos, et. al., 2011). One software type that can do this is ESRI CityEngine. Procedural modeling enables quick modeling of design scenarios using CAD and GIS data (Bertol & Foell, 1997; Rodil et al., 2012). The design ideas can easily be analyzed side by side in VR software like CityEngine (Esri CityEngine, n.d.). Unfortunately, as seen in Ryan Deane's figure to the left, not many designers are using it. This may be because of a lack of technical experience.

Older design professionals often lack technical skills to use new software (Deane, 2015a). The low technical skills of older generations can be explained by the lack of digital games played in their childhood. Since older generations did not interact with many games or software in their life, it is challenging for them to train themselves on how to use advanced software (Deane, 2015a; Prensky, 2001). This is most likely why planners and landscape architects believe the ease of learning and compatibility of software is more important than high interactivity, representation, and photorealism in 3D visualization software (Paar, 2005). The present 20-30 year olds can learn new software easier because they are used to video games and social media which became like a second language (Deane, 2015a; Prensky, 2001). Of this generation known as Millennials, 52% of landscape architects say they spend 7+ hours creating 3D visualizations per day (Deane, 2015a). As seen in Figure 3.10, most landscape architectures firms do not use other 3D visualization software than SketchUp and AutoCAD which are manual modeling systems (Deane, 2015a).

Landscape Architecture firms may be reluctant to use advanced 3D visualization software because of its cost and its learning curve (Flachbart & Weibel, 2005). If design professions are to work in interdisciplinary teams, they will need to learn to embrace new technology (Flachbart & Weibel, 2005). The design fields will be moving towards time-based and code-based software (Flachbart & Weibel, 2005). This will require design professions to learn how to write script (Flachbart & Weibel, 2005). In procedural 3D modeling software, scripting, a code-based language is used to develop CGA (computer generated architecture) rules (Flachbart & Weibel, 2005; Halatsch, et. al, 2008). Procedural modeling software is able to automatically generate high visual detailed city models (Halatsch, et. al., 2008). Script rules are used to control the appearance of the output model (Flachbart & Weibel, 2005). Scripting also allows you to create pre-made tools to perform custom action (Flachbart & Weibel, 2005). However, learning to script is an advanced process. In order for employees to learn how to script they should be self-motivated and focused (Rogers, 2000). As seen below, several steps can be used by firms to help their employees learn new software.

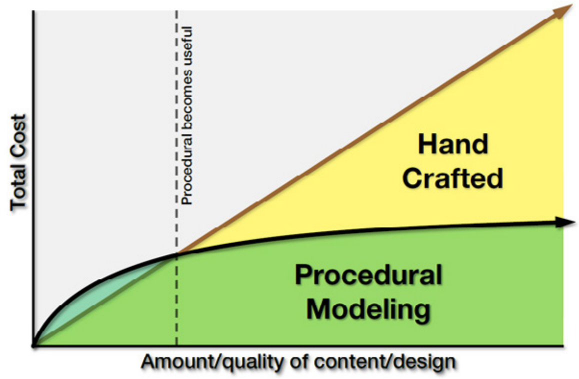


Figure 3.12: Procedural vs Hand Crafted Models

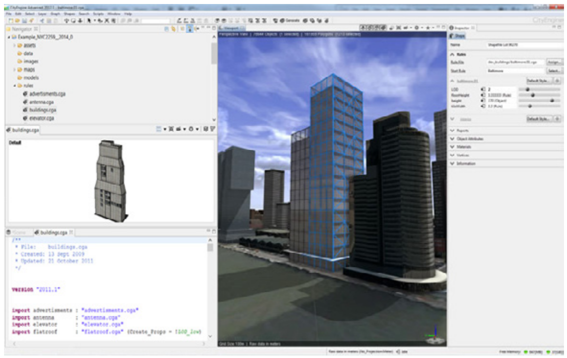


Figure 3.13: Using script to model building

1. *"Offer training*
2. *Give technology they can take home*
3. *Provide on-site technical support*
4. *Encourage collaboration with colleagues*
5. *Send professionals to professional development conferences*
6. *Stretch the day*
7. *Encourage research*
8. *Provide online resources*
9. *Influence preservice education*
10. *Celebrate success"*

(Solomon & Solomon, 1995; pg. 38-39, 71)

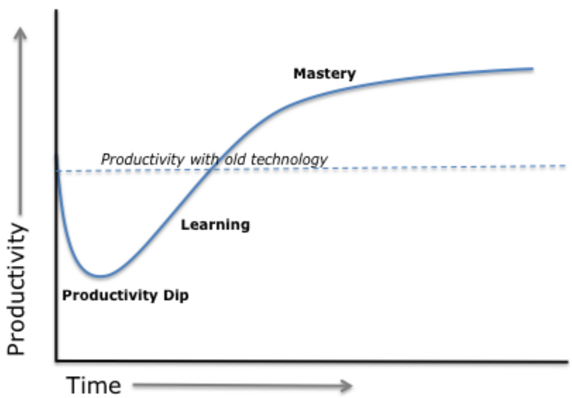


Figure 3.14: UCR District (Albracht, 2015)

INTERACTION BETWEEN DISCIPLINES

It is most important to have collaboration across disciplines in the conceptual design stage (Rosenman, et. al., 2007). Lange and Bishop (2005) believe real-time visualizations should always be used to represent urban designs. Traditionally, project consultants focus on their portion of the project and create their own drawings which are sent to the lead designer and then sent back with comments (Rosenman, et. al., 2007). However, they would have to keep track of drawing versions, ownership, and the control of design decisions (Rosenman, et. al., 2007). It is also hard to share data between disciplines because of software compatibility (Maher, et. al., 2005). Advancements in computer processing power and graphics cards in the 21st century have allowed for the development of virtual world platforms to improve their process (Koutsabasis, et. al., 2011).

Virtual worlds allow anyone to view their designs on-line and have the ability to inspire new ideas in the field (Flachbart & Weibel, 2005). Using virtual worlds on a shared database allows designers to update designs and facilitate collaboration in a live workspace (Rosenman, et. al., 2007). CityEngine Web Scenes allow design professionals to interact through comments (Esri CityEngine, n.d.). Some virtual world applications will also allow multiuser interaction and design modification (e.g., Maher, et. al., 2005; Rosenman, et. al., 2007; Koutsabasis, et. al., 2011). The capabilities of modifying designs in virtual worlds can be somewhat limiting, but gaming software can be used to create more customizations. When interacting with other disciplines in these applications, (i.e., Second Life or Active Worlds), chat windows, video chat, and sketching are methods that can be used for collaboration (Rosenman, et. al., 2007; Koutsabasis, et. al., 2011). Software that supports virtual interaction and collaboration with 3D models can be used throughout the design process, however, depending on the project type, the on-line model might lack needed detail. According to Maher, et. al. (2005) detailed information is typically not retained in the conversion from CAD files to virtual environments, but if the project type is urban planning related, detailed information is not needed (e.g. depth of window or angle of pitch roof). Urban planning projects are conceptual and focus on designing for the community and are not about what specific building a developer will construct. Virtual worlds can be used to convey and collect information that traditional methods cannot.

Figure 3.15: Interactive avatar chat with Second Life

TRADITIONAL COMMUNITY ENGAGEMENT

Traditional methods of communicating using images with verbal description in meetings or charrettes are insufficient (Gordon, et al, 2010; Zhang, 2004). Audiences often have difficulty reading maps or aerials (Stakeholder Engagement, 2009; Bratteteig & Wagner, 2010). Sets of images like perspectives are also not sufficient because they cannot explain urban spatial complexes to the general public (Gordon, et al, 2010). Images can communicate data, but cannot represent what it feels like to be in a space, because it is impossible to convey sense data in an image (Gibson, 1978). Simulations, however, do incorporate sense data and are a good way of explaining complex urban systems (Gordon, et al, 2010; Bertol & Foell, 1997). Simulations are good for this because they allow the viewer to manipulate content and guide themselves through media (Plass, et al, 2009; de Jong, 2005; Gogg & Mott, 1993; Towne, 1995). Videos or animations are not as good as simulations because they can easily overload the viewer with excessive data which cannot be mentally processed (Plass, et al, 2009).

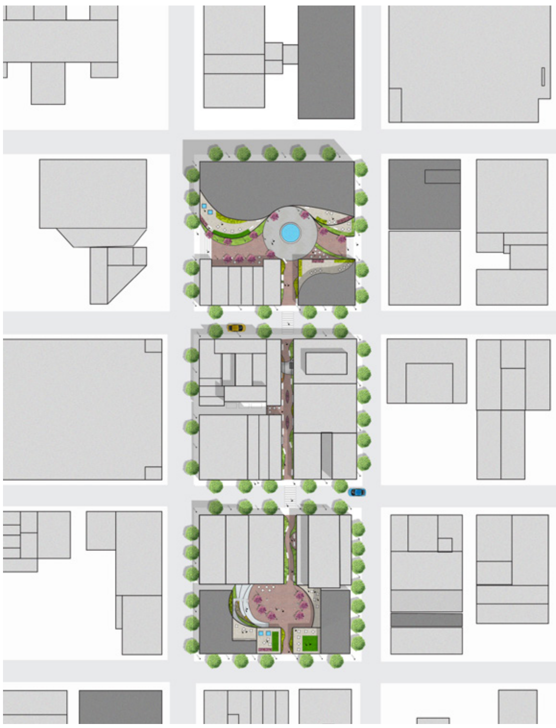


Figure 3.16: Traditional Plan View used to Communicate

NEW 3D INTERACTIVE VISUALIZATION TYPES

Virtual Reality is one of several simulation methods available to communicate urban space. VR is a good tool for audiences like the public to reflect on design ideas because it relies on their past experience of viewing space (Bratteteig & Wagner, 2010; Bertol & Foell, 1997). However, VR is not a good tool to use when having the general public participate in designing spatial configurations. If the goal is to have the public design, 3D objects and drawing tools should be used for them to communicate (Bratteteig & Wagner, 2010). This method is seldom used because the public lacks design knowledge. Usually the goal is to inspire the public with ideas, and then develop a design that is in the public's best interest. Like VR, augmented reality (AR), also referred to as mixed reality (MR), can inspire audiences to think more creatively about designs. Designers can use AR to overlay proposed modeled content on top of existing development to visualize different scenarios (Bratteteig & Wagner, 2010)(see Figure 3.19). The public can easily participate in interacting with an AR, i.e. mixed reality, such as the MR-Tent (e.g., Wagner, et al., 2009)(see Figure 3.18). The difference with VR software is that all content being viewed is virtual modeled content which can still be used to visualize different scenarios that stakeholders can compare and contrast between side by side (Sheppard et al., 2011; Ervin 1998). Comparing designs side by side leads to better questions and decision making (Steinitz et al., 2003, Lange & Bishop, 2005). These visualizations influence awareness and effective response to designs (Sheppard et al., 2011).

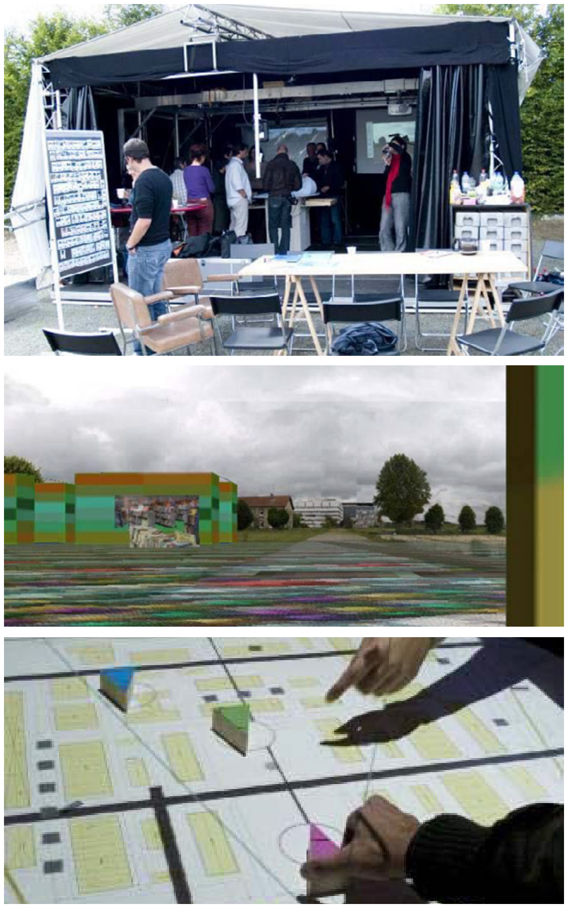


Figure 3.18: Shaping space with objects and viewing the design projected on a screen in the MR-Tent

Figure 3.17: Screen shot of a Virtual Environment (VR)

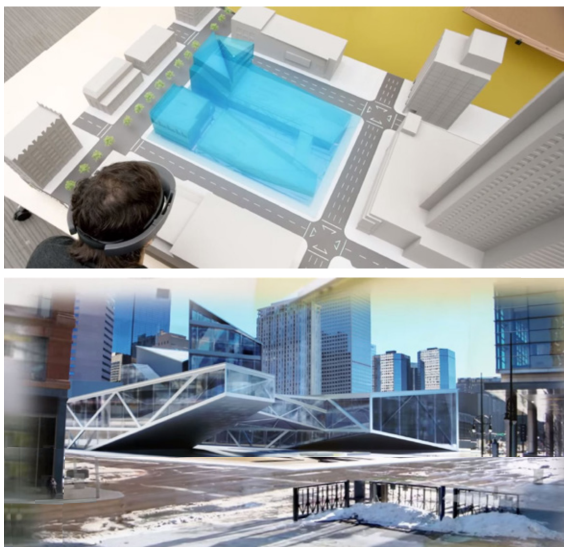


Figure 3.19: Designing with Microsoft Hololens (AR)

VIRTUAL REALITY SIMULATIONS

Virtual Reality is a useful tool to communicate designs to any audience (Lange & Bishop, 2005). It has the ability to connect with audiences who speak different languages and are from different cultures (Rodil et al., 2012). Unlike reading plans or sections, virtual reality simulations allow audiences to easily interpret designs. The experience of viewing space through simulations allow for a similar experience of how people observe their day to day natural environment so users can visualize and understand space better (Dorval & Pepin, 1986). VR can improve communication and learning because it gives audiences a high visual attention that does not surpass their mental workload (Gu, et al, 2005; J, Ball, 2007). The interaction of the environment gives the viewer flexibility to analyze the design (Helbig et al., 2014; Plass et al., 2009). However, simulations, like any type of visual can be used to persuade audiences to support or oppose designs (Sheppard, 2015: Daniel & Meitner, 2001). VR environments can do this by manipulating elements that elude people's perception of space (Sheppard, 2001). Elements that have the potential to persuade public opinion about a design are elements such as sunny skies, slight breezes, lots of pedestrians, and the sound of nature. Instead, these elements should be realistically modeled in simulations to allow for an accurate critical analysis of the design (Bosselmann, 1998; Sheppard et al., 2011). If certain elements are left out of the simulation, the audience viewing it will also have a biased view (Pettit et al., 2011).

Figure 3.20: Realistic vs Exaggerated amount of Traffic

LEVEL OF DETAIL NEEDED

More often than not, VR simulations are not realistic, making them seem "incomplete" (Bosselmann, 1998). They lack the final detail of what the environment would actually look like if it was built (Bosselmann, 1998). Predicting what will actually be built is impossible (Bosselmann, 1998). For example, no one can plan for buildings like Frank Lloyd Wright's Guggenheim Museum in NYC. When planners and architects create simulations for large scale projects, they should leave out detail to avoid discrepancies on what will be built (Bosselmann, 1998). One way this is done is by avoiding detailed facades and only using wireframe buildings (Bosselmann, 1998). Less detailed facades will not affect the spatial knowledge of the viewer (Cubukcu, 2010). However, viewers will connect and act more normal if the VR is more detailed (Gordon et al., 2010). That is why it is important to model details such as facades, especially if users will be viewing the environment from a micro-scale point of view such as walking down a sidewalk.

Figure 3.21: Abstract vs Detailed facades in street-view

If viewing a large urban development from a macro- scale, abstract facades are good to distinguish the difference between proposed and existing buildings. In addition to having proposed buildings being abstract, design alternatives should be produced to limit any misconceptions that the simulation is representing the final design (Bosselmann, 1998; Lange & Bishop, 2005). The alternatives should have short and long term predictions of what the development might look like so the public or stakeholders can understand the transition of the environment (Sheppard et al., 2011). The modeled design alternatives should then be inserted within a local context model of the site to ensure defensibility and public buy-in (Sheppard et al., 2011). Diagrams should also be linked to the 3D visualization to support the designs (Wissen, et. al., 2007). When the visual is complete, feedback of the design should be collected.

METHODS FOR USING VR SIMULATIONS

Several methods can be used to engage and facilitate feedback from audiences with 3D interactive visualizations. The methods used should be based on the audience size, time, and budget. Very little practice has been done on using VR to spark design collaboration. According to Koutsabasis et. al. (2011) this is because design communities are interested in technology that can add to their existing practices versus virtual environments which seem like a foreign approach. Described below are ways 3D interactive visualization software can be used to communicate to audiences and collect feedback.

INTERNET

The Internet is an easily accessible tool that allows participants to open a virtual world by going to a link (e.g., Rosenman, et. al., 2007; Koutsabasis, et. al., 2011; Esri CityEngine, n.d.). This participation methods is highly successful and can be used to facilitate feedback from individual homes (Faga, 2006). The data in the simulation can be viewed and interacted with on any computer, mobile device, and in many cases viewed with haptic devices (e.g., Zehner, 2008; Bilke et al., 2014; Whitton, 2003). The downside of viewing a Web Scene on a small device like a phone is that viewers would have less immersion than through stereoscopic lens or panoramic screen (Bystrom et al, 1999).However, the public can easily obtain haptic devices that connect to smart phones (see Figure 3.23) such as Cardboard Box, Freefly VR headset, Zeiss VR One, and Samsung Gear VR to increase immersion (Lamkin, 2016). Once immersed in the virtual environment, audiences can give feedback on the design. The feedback type depends on the software application used. CityEngine Web Scenes allow for the possibility of users to give site specific feedback through written comments (Esri CityEngine, n.d.). Feedback in other application may consist of message boards or video chats (e.g., Bishop, et al., 2008; Hollander, 2011; Rosenman, et. al., 2007; Koutsabasis, et. al., 2011). This includes software such as Second Life and Active Worlds. To get an overall analysis of what the public likes or dislikes a survey can be linked to the web page.

Figure 3.22: CityEngine Web Scene comments are geolocated and are also on the message board for ease of access

Figure 3.23: Zeiss VR One & Cardboard Box Headsets

Figure 3.24: Second Life virtual world interaction

Figure 3.25: Large Panoramic Screen to immerse large audiences in a simulation

LARGE SCREENS & PROJECTORS

When using interactive visualizations to present to large audiences, the simplest way is to project the VR model on a large screen. A normal rectangular screen can be used which only requires one projector. To create a greater sense of immersion the simulation can be projected on a panoramic screen that surrounds an audience (Zehner, 2008). A simulation can also be projected on all interior faces of a room (Jones et al., 2014). Both of these methods, however, would require multiple projectors (Zehner, 2008).

A neutral facilitator should be selected to stand in front of the crowd and navigate through the simulation while adding commentary to describe the design (Sheppard et al., 2011; Collaborative Stakeholder, 2009). The facilitator should trigger attention to the design, point out complex issues, give context to the design, and navigate through both abstract and realistic data layers (Wissen, et. al., 2007; Weidenmann, 2002). When the audience asks questions the facilitator can navigate to place in the design where the question was directed. This allows a large audience to see what they want in the design without them directly interacting with the VR. With smaller focus groups, there would be the possibility for each participant to navigate through the VR and project their experience on a screen. Haptic devices can be used to help improve their experience (Zehner, 2008; Bilke et al., 2014; Whitton, 2003). As they move around they can use head-tracking goggles that are able to generate a 3D stereoscopic view of the environment (Zehner, 2008). However, goggles and other haptic devices are not vital or economical when communicating to large audiences (Zehner, 2009). A small study concluded that there is not much of a difference in preference for with and without the goggles. In Zehner's experiment, 25% of people preferred to view simulations in monocular vision because the goggles were uncomfortable (Zehner, 2009).

VIRTUAL REALITY HAPTIC DEVICES

If a design is being presented to a client or small focus group, a head-mounted display can be used to view a VR environment (Bilke et al., 2014). The headset can then be joined by numerous haptic devices to improve immersion (Bertol & Foell, 1997; Whitton, 2003). Some current haptic device products include Control VR, KOR-FX, and PrioVR which senses core movements; Dexmo F2, Gloveone, and Hands Omni which sense hand and finger movements; Novint XIO which senses arm movements; and Stompz which senses foot movements (Marco, 2015). The advantage of creating more immersion is that a user can experience a VR space more similar to how they experience space in daily life, allowing them to make better judgments (Griffon et al., 2011; Bishop et al., 2008). A designer can observe the participants' actions and collaborate with them while they are immersed in the VR.

Figure 3.27: Virtualizer (Senses Core & Foot Movements)

Figure 3.28: Control VR (Senses Core Movements)

Figure 3.26: KOR-FX (Senses Core Movements)

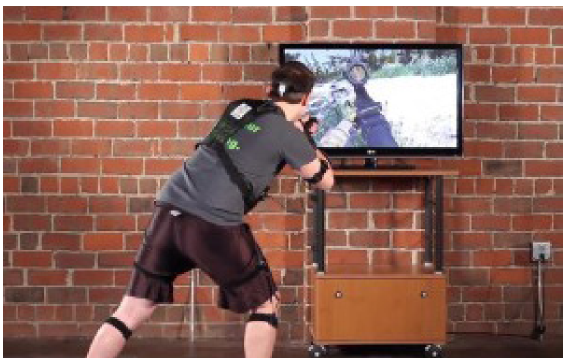


Figure 3.29: PrioVR (Senses Core Movements)

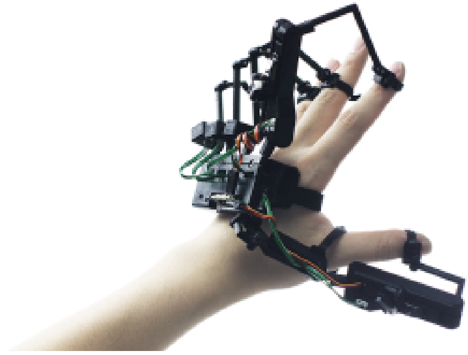


Figure 3.30: Dexmo F2 (Senses Hand Movements)

Figure 3.31: Gloveone (Senses Hand Movements)

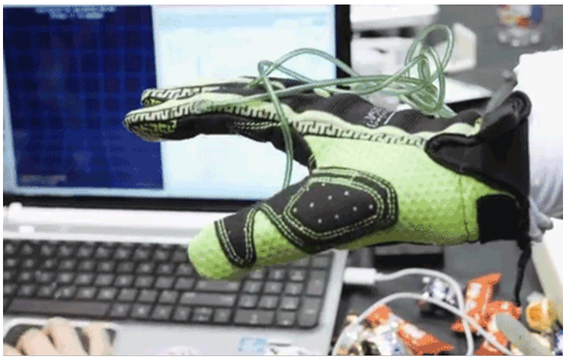


Figure 3.32: Hands Omni (Senses Hand Movements)

Figure 3.33: Novint XIO (Senses Arm Movements)

Figure 3.34: HTC Vive (Senses Head & Hand Movements)

Figure 3.35: Oculus Rift (Senses Head Movements)

Figure 3.36: FOVE VR (Senses Head Movements)

Figure 3.37: Avegant Glyph (Senses head Movements)

04 METHODS

The City of Manhattan delineated an area to increase residential density next to Kansas State University and Aggieville. This area is known as the Urban Core Residential (UCR) District. The planners that work for the City of Manhattan created a list of assets and qualities the UCR District should have and then developed design standards and a streetscape vision to meet those objectives. Next, the City of Manhattan held focus group meetings with architects, developers, and stakeholders to discuss preliminary design standards and a streetscape vision. The public would eventually be educated through the use of 3D interactive visuals on how the UCR District might be developed. This is when a landscape architect or urban designer is brought into the design process to create a master plan. In this masters project, a hypothetical master plan scenario of the UCR District was created that would eventually be used to communicate new public policies to the public before they voted on the implementation of the design standards.

ArcMap, ESRI CityEngine, and Unity software was used to create visuals of the UCR District master plan. Saldaña & Johanson (2013) used the same software workflow to create a virtual world of Rome. ESRI CityEngine was the primary tool which was used to procedurally model the proposed UCR District and how it may be implemented in phases. The original plan was to model three scenarios for the buildings at low, medium, and high intensity and three different street designs (see appendix) so the community could let the city planners know what type of development they would like to see implemented. However, there were problems uploading large files to CityEngine Web Scenes. For this reason only one scenario was completely developed and exported as a Web Scene. This scenario included different amounts of low, medium, and high intensity development. It is realized that the Web Scene will not offer the desired discussion between different scenarios, but having different amounts of intensity within the same design was a compromise which still allows audiences to compare different development configurations on different streets. In addition to the CityEngine Web Scene, a Unity game was also produced. The CityEngine Web Scene and Unity game would eventually be used by the City of Manhattan to help in the adoption of the UCR District design standards, create public awareness, and attract developers.

Figure 4.01: 3D digital model of Manhattan, Kansas created in ESRI CityEngine

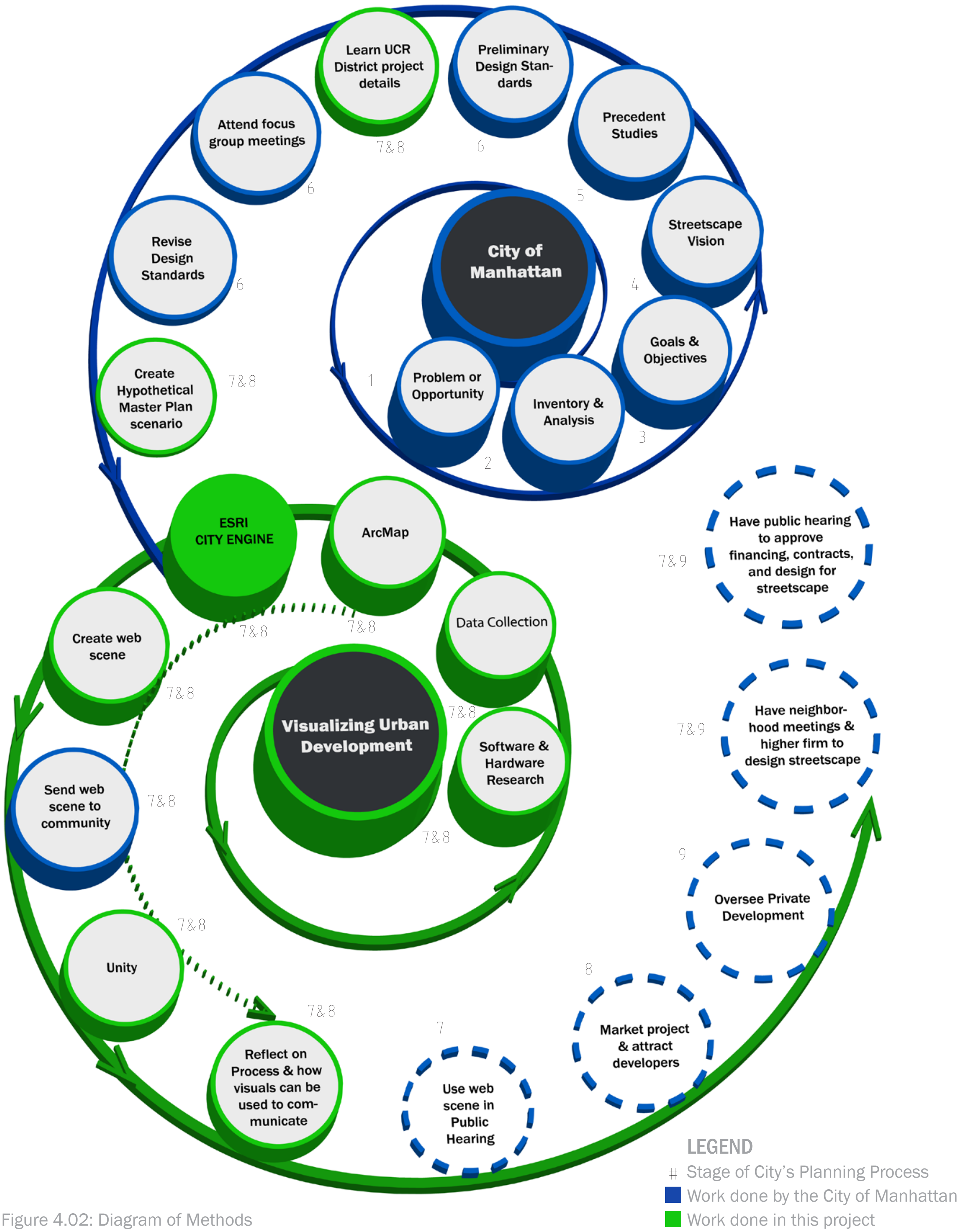


Figure 4.02: Diagram of Methods

SOFTWARE

Visualizing urban development in 3D usually requires different software to be used for different tasks. These tasks can include editing geographic data, modeling elements in 3D, and rendering. In this project ArcMap was used to edit geographic data because it is popular and was taught to students. CityEngine was used to model elements in 3D. CityEngine was selected because of its ability to procedurally model cities, as well as its ability to automatically generate metrics for designs. There is similar software such as AutoDesk Infrastructure Modeler, AutoDesk Infraworks 360, and CommunityViz's Scenario 3D. These software can produce comparable visualizations, but do not have the same procedural modeling capabilities. CommunityViz does have the capability to generate metrics. One other program that can generate metrics is Envision Tomorrow, an ArcMap plug-in. Unfortunately, Envision Tomorrow cannot generate 3D models. However, researchers are creating a method so Envision Tomorrow can be integrated with CityEngine (Envision Tomorrow, n.d.). Other modeling software such as Google SketchUp and Rhino are effective at producing detailed site designs. However, the detail created in this software would take too much time to produce for a large area.

The last task was to produce renderings from the model. CityEngine was used to upload a Web Scene to the Internet where the model was rendered in real-time. Unity, a gaming engine was also used to create a game where users can walk around and experience the design from eye level. Unity can also be used in conjunction with Oculus Rift and other haptic devices to create more immersion. These simulations were the limit of this project. If a higher level of detail was desired to create images, videos, or animations, the CityEngine model could be exported and rendered in software such as LumenRT GeoDesign, Lumion, Vue, or 3Ds Max. All software used in this experiment was free to use for educational purposes.

The table to the bottom right shows how other visualization software compare to the ones used in this experiment. Notice that the classified attributes can be deceiving and subjective, e.g., the final quality visuals from one software may be better than others; plug-ins may be available to expand the software's ability; some BIM software includes more object data than others; software may include procedural and manual modeling, but was only classified as such if the software contained sufficient procedural or manual tools; metrics were classified by the software's general use; and even though Ivan Sutherland would have classified all this software as VR in 1962, the software was only classified as VR if it could render a high level of detail in real-time.

Figure 4.03: AutoDesk Infrastructure Modeler

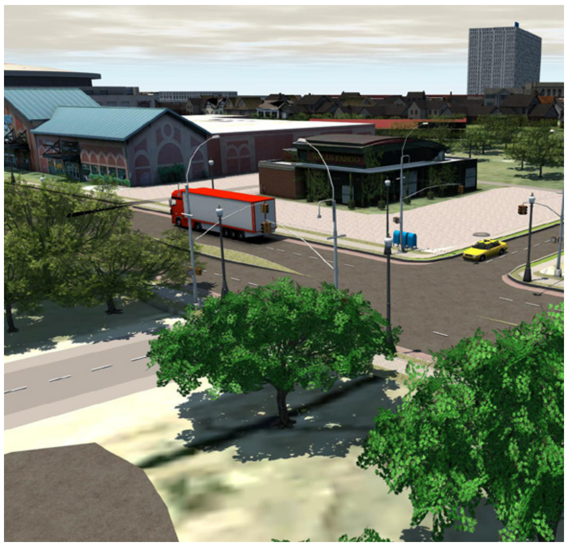


Figure 4.04: AutoDesk Infraworks 360

Figure 4.05: CommunityViz Scenario 3D

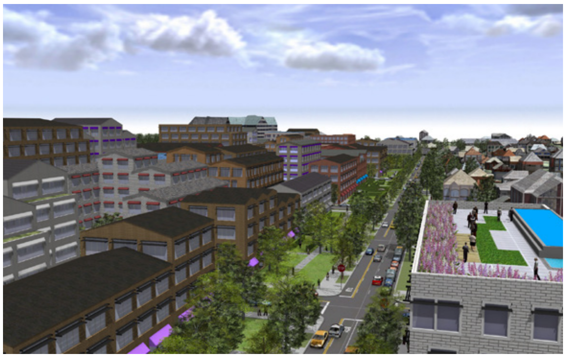


Figure 4.07: ESRI CityEngine

Figure 4.06: CityEngine to Unity

Figure 4.08: LumenRT with LiveCube

Software Product	CAD	GIS	BIM	Procedural	Manual	Metrics	Const. Doc.	Maps	Images	Videos	Animations	Simulations	Big Projects	VR Real-time	VR Goggles
Google SketchUp	✓	○	○	○	✓	○	○	○	✓	✓	○	○	○	○	○
Rhinocerous	✓	○	○	○	✓	○	○	○	✓	✓	✓	○	○	○	○
Grasshopper	✓	○	○	✓	✓	○	○	○	✓	✓	✓	○	○	○	○
AutoDesk Revit	✓	○	✓	○	✓	○	✓	○	✓	✓	✓	○	○	○	○
AutoDesk AutoCAD	✓	○	○	○	✓	○	✓	○	○	○	○	○	○	○	○
AutoDesk AutoCAD Civil 3D	✓	○	✓	✓	✓	○	✓	○	✓	○	○	○	○	○	○
VectorWorks	✓	○	✓	○	✓	○	✓	○	✓	✓	✓	○	○	○	○
AutoDesk Maya	✓	○	○	○	✓	○	○	○	✓	✓	✓	○	○	○	○
AutoDesk 3Ds Max	✓	○	○	○	✓	○	○	○	✓	✓	✓	○	○	○	○
Vue eonsoftware	✓	○	○	✓	✓	○	○	○	✓	✓	✓	○	○	○	○
Blender	✓	○	○	✓	✓	○	○	○	✓	✓	✓	○	○	○	○
Cinema 4D	✓	○	○	✓	✓	○	○	○	✓	✓	✓	○	○	○	○
Nuke	✓	○	○	✓	✓	○	○	○	✓	✓	✓	○	○	○	○
LumenRT Geodesign	✓	○	✓	✓	○	○	○	○	✓	✓	✓	✓	✓	✓	○
Lumion	✓	○	○	○	✓	○	○	○	✓	✓	✓	✓	○	✓	✓
ESRI City Engine	✓	✓	✓	✓	○	✓	○	○	✓	✓	○	✓	✓	✓	○
ArcMap	✓	✓	○	○	✓	○	○	✓	○	○	○	○	✓	○	○
Envision Tomorrow- ArcMap Plugin	✓	✓	○	○	○	○	○	✓	○	○	○	○	○	○	○
Scenario 3D- ArcMap Plugin	✓	✓	○	✓	✓	○	○	✓	✓	✓	✓	✓	✓	✓	○
Scenario 360- ArcMap Plugin	✓	✓	○	○	✓	○	✓	✓	✓	○	○	○	✓	○	○
Autodesk Infrastructure Modeler	✓	✓	✓	✓	✓	○	○	○	✓	✓	○	✓	✓	✓	○
Autodesk Infraworks 360	✓	✓	✓	✓	✓	✓	○	○	✓	✓	✓	✓	✓	✓	○
Unity	✓	○	○	○	✓	○	○	○	✓	✓	✓	✓	✓	✓	✓
CryEngine	✓	○	○	○	✓	○	○	○	✓	✓	✓	✓	✓	✓	✓

Figure 4.09: Comparison between software used for planning and/or visualizing urban development

COLLECTING GIS DATA

Geographic data is crucial for producing large 3D models of urban development. GIS data can be acquired from many national government websites or through local governments and cities. However, some local detailed data sets from small government agencies cost money. The City of Manhattan supplied this project with their available GIS data because the project was done for the city and was for educational use. Vector data included shapefiles of streets, trees, parcels, and building footprints. Raster data included an aerial with two meter resolution. Higher aerial resolution could have been used, but this would slow down the interaction process in the CityEngine scene. To further improve the interaction time, the Manhattan aerial and shapefile data was clipped three-five blocks outside the boundary of the UCR District in ArcMap to give site context. However, three-five blocks of context was still too much for a detailed model and is discussed later in this report.

Modeling the street and sidewalk widths for the context around the UCR District was time intensive, however, it was not important to be accurate. If it was important to model accurate street widths for a large area OSM (OpenStreetMap) data should be used instead of shapefiles. Importing OSM data allows a user to procedurally model the street and sidewalk widths based on imported streetscape classes such as collector streets, local streets, minor arterial roads, and major arterial roads (CityEngine – Importing Data from OSM, 2015). The figure to the right is a viewport of the UCR District on OpenStreetMap from which data can be extracted.

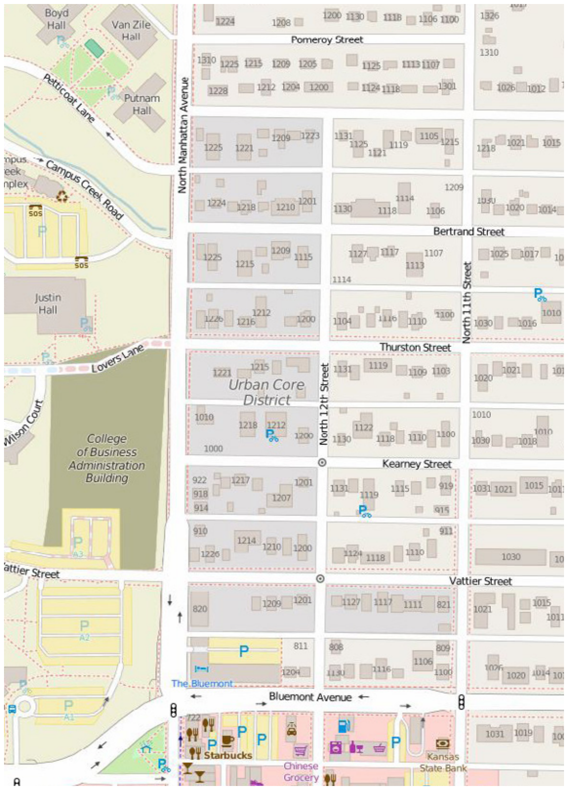


Figure 4.10: UCR District on OpenStreetMap

CREATING GIS DATA

The government can provide GIS data to users which is often provided for free. If the government does not have the desired GIS data you can create it yourself. In this project, tree data was created. This was done in ArcMap by placing points on top of where trees are shown on an aerial. The tree point data was then joined to an existing KSU campus tree inventory shapefile which contained tree species and height. This data could have been used to more accurately model the UCR District, but would take a beginner scripter too long to figure out how to do in CityEngine. Instead, a rule was applied which applied the same tree model and randomized the heights (see Figure 4.11). There are also quicker methods to model tree data for large areas using high-resolution color infrared digital images and a digital surface model which can detect tree species and height based on remote sensed crown, shape, and foliage color (e.g. Iovan, et. al., (2008).

Other data such as streets signs, light poles, drains, and paving materials could have also been produced in ArcGIS. The specific location for this data was not seen as vital, but would have been used if the city had the data. Instead some of these element locations were generally estimated and modeled in CityEngine using CGA rules.

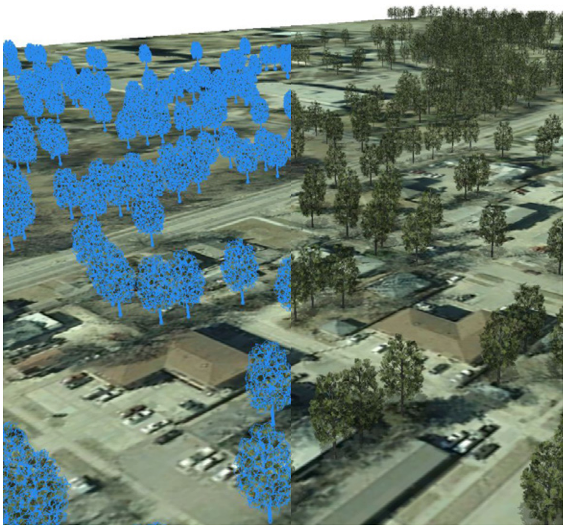


Figure 4.11: Manually creating tree data

UPDATING GIS DATA

If GIS data has errors, ArcMap or CityEngine can be used to edit the GIS data. In this project the City of Manhattan's building footprints were not up to date. This was fixed by deleting old building footprints and using a recent aerial as reference to draw the new building footprints.

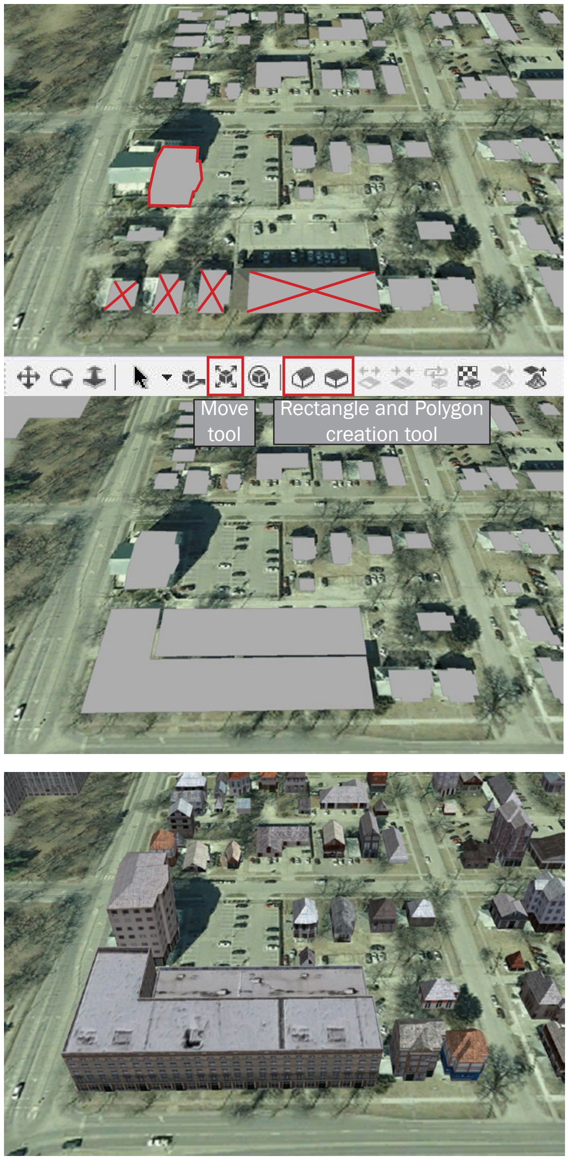


Figure 4.12: Some footprints were moved. Old footprints were deleted. New footprints were drawn in with the rectangle/polygon tool. To create different heights within a building, shapes had to be drawn separately without snapping to one another.

DESIGN STANDARDS

Before designs could be produced in CityEngine, design standards were created. City planners used precedent studies for similar communities that created higher residential densities to inform their design standards. The city planners wrote preliminary design standards, created 2D visuals, and collected images. Afterwards, they conducted focus group meetings with property owners, developers, and architects to discuss the design standards. The design standards that were revised after the focus group meetings were then used to design the urban development in CityEngine. Some of the design standards can be seen in the tables below. Figure 4.14 shows design standards that were used to help design the urban environment. Figure 4.15 shows design standards that were not incorporated into the design, because they were not as important and/or were difficult to model. Figure 4.13 is an example of what the street facade articulations and interior parking garage might look like. This was manually modeled in CityEngine by Ben Chmiel, a planner who works for the City of Manhattan. Eventually, the visuals created in this project would be used in a public hearing to vote on whether the UCR District design standards should be implemented.

Figure 4.13: Building articulations drawn in CityEngine

UCR District Design Standards Implemented in CityEngine Model	
Minimum Lot Area	15,000 sqft
Minimum Lot Width	100 ft
Minimum Lot Depth	150 ft
Maximum Structure Height	85 ft
Minimum Structure Height	30 ft
Minimum Front Yard on N. Manhattan Ave.	10 ft
Minimum Front Yard along other streets	5 ft
Minimum Side Yard	5 ft
Minimum Rear Yard	None
Maximum BLDG Lot Coverage	None
Minimum Vision Triangles (public streets)	15 ft
Minimum Vision Triangles (alleyways)	10 ft
Minimum Vision Triangles (private drives)	10 ft

Figure 4.14: Design Standards used in model

UCR District Design Standards NOT Included in CityEngine Model
Minimum of 1 dwelling unit per 750 sqft of lot area
Only 25% of the gross bldg floor area can be used for resident access
No establishment shall occupy more than 15,000 sqft
Dumpster Screening
Exterior Lighing on Lot Property
Exterior BLDG Mechanical Equipment
Builidings require .75 of a parking stall per bedroom
Parking Stalls for Residential should not exceed 1 stall per bedroom
Accessory use parking shall not excceed 10% of resident parking
Parking structures should be behind, underneath, or within bldgs
Ornamental facades to parking structures
Minimum of 1 bike space for 2 bedrooms
Minimum of 2 bike spaces per accessory establishment
Additional 1 bike space every 2,000 sqft over 1,000 sqft for businesses
80% of residential bike stalls should be protected from weather
Minimum of one resident bldg entry per 100 ft abutting a street
Minimum of 30 % of window surftace for groundfloor facades facing streets
Groundfloor facades materials shall be stone or brick
Street-facing upper floor facades requires architectural features every 40 ft
Upper floor façade materials requires 50% to be stone or brick
Upper floor façades may not have more than 10% of vinyl siding, concrete masonry units, metal paneling, or wood/wood composite
Street-facing façade articulation requires 2 ft depth differentiation every 40 ft spanning at least 6 ft; every 120 ft length of façade should have at least 8 ft of depth differeniation extending at least 24 ft which can be extended into multiple segements of at least 8 ft in width; for every 200 ft length of facade should have at least 12 ft of depth differentiation extending at least 30 ft in width
Upper floor facades should have a minimum of 15% of window surface

Figure 4.15: Design Standards not used in model

STREETSCAPE VISION

The City of Manhattan also created a streetscape vision for the proposed UCR District based on a student survey. This vision ensures that the city will eventually make improvements to the streetscape to fit the character of the new urban space. The streetscape vision states that the existing 14-17 foot wide space between the road and property line will have an amenity and walking zone in the public right of way (see Figure 4.17)(City of Manhattan, 2015). The walking zone on North Manhattan Avenue will, however, overlap with private property to create a wider sidewalk that retains the same buffer width from the road (see Figure 4.18). These dimensions as well as elements in the Amenity Zone and Spillout Zone (the private property extending into the sidewalk) were used to help design the UCR District streetscape in CityEngine. The elements to be included in the Amenity Zone and Spillout Zone can be seen in the appendix. The streetscapes in the CityEngine model would eventually be used to communicate in a neighborhood meeting and public hearing and would also help in the final design process of the streetscape.

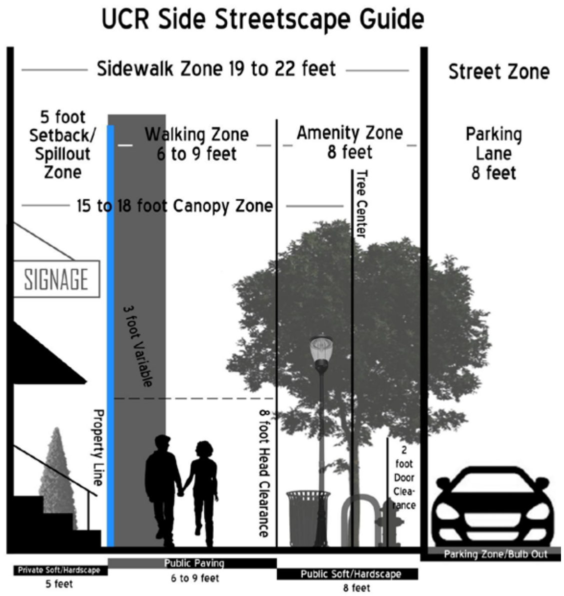


Figure 4.17: Streetscape vision for UCR District

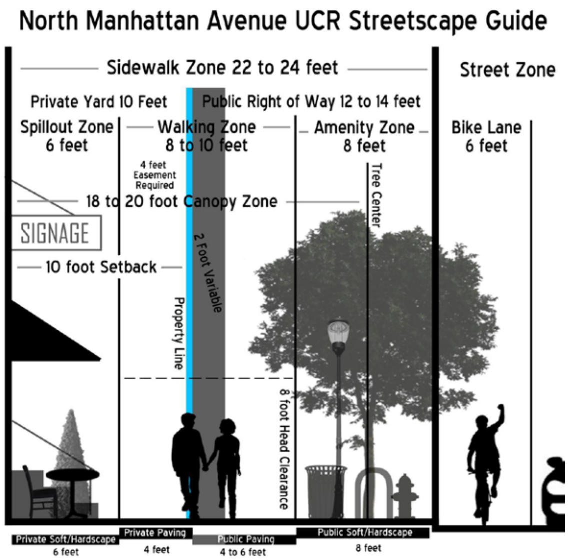


Figure 4.18: Streetscape vision for N. Manhattan Ave.

Figure 4.16: Existing width between road and sidewalk

ESRI CITYENGINE

CityEngine is a procedural modeling software that is able to quickly model realistic looking cities. It was used to model the existing condition and to create a hypothetical master plan of the UCR District. This was done by applying CityEngine CGA (computer generated architecture) rules to GIS data. Once a rule was applied, 3D models would be automatically generated (see Figure 4.19). These models could then be edited to comply with the UCR District design standards by changing parameters on scroll bars. Several models were generated in CityEngine including short, medium, and long-term phases of the master plan building implementation as well as a few streetscape designs. Screen captures were taken of all of the models, but due to size restrictions only one final model was exported as a CityEngine Web Scene to be viewed in a virtual world by the public, stakeholders, architects, and developers. The image below is of the CityEngine software interface which contains one central viewport where the model can be edited in a virtual reality.

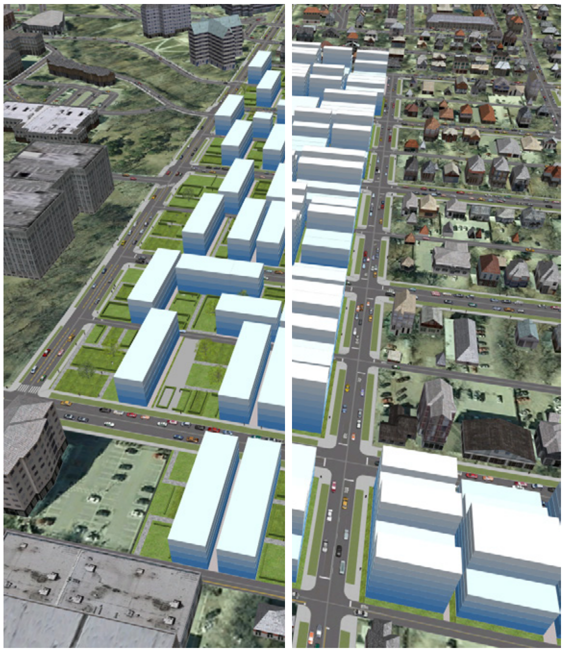


Figure 4.19: Quickly modeling scenarios in CityEngine

Figure 4.20: Changing parameters in the rules to refine the design in CityEngine

RULES

In order to procedurally generate 3D models from 2D geographic vector data in CityEngine, CGA rules must be used. ESRI has many rules that come with their CityEngine software, but ESRI also has more advanced rules which were created for projects they were consulted on. These advanced rules can be downloaded for free from CityEngine Web Scenes. Some advanced CityEngine users have skills to modify or create new rules. Their rules can sometimes be download from ESRI Web Scene pages, or can sometimes be found on CityEngine's blog.

Once the needed rules are collected they can easily be applied to the shapefile data to create a 3D scene. To apply a rule, select the shapefile data and drag and drop the rule onto the selected objects. This process is shown for applying a Building Construction rule to parcels below.

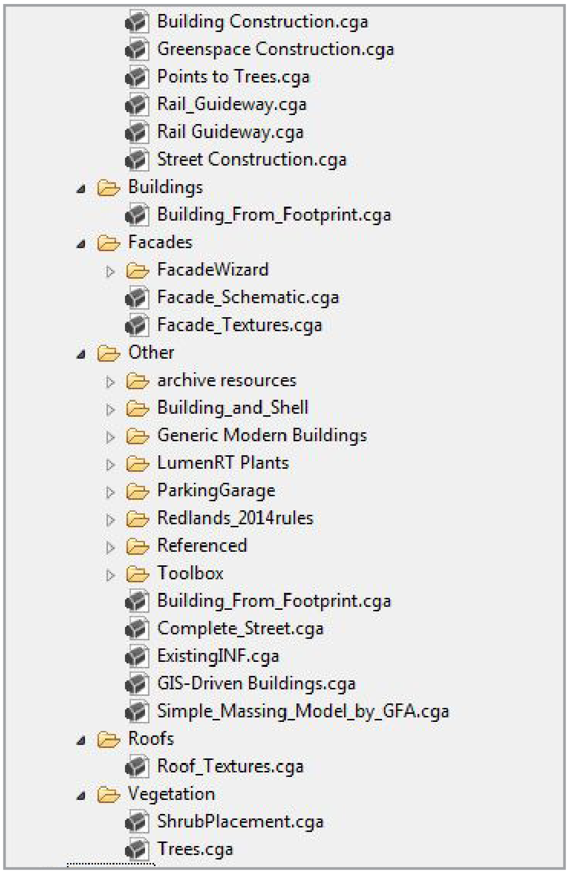


Figure 4.21: Rules stored in the rule folder

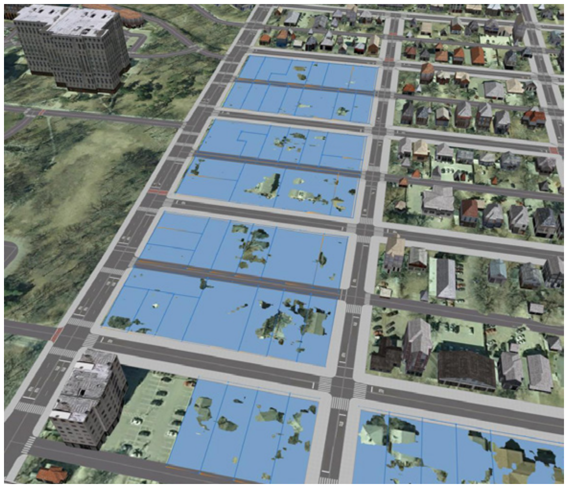


Figure 4.22: Selecting parcel data

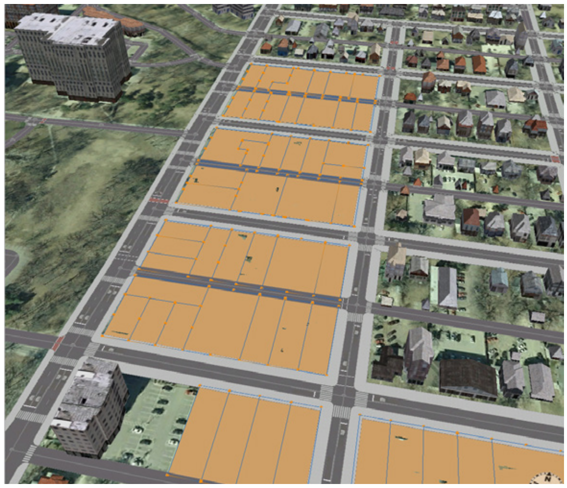


Figure 4.23: Dragging a rule on to the parcels

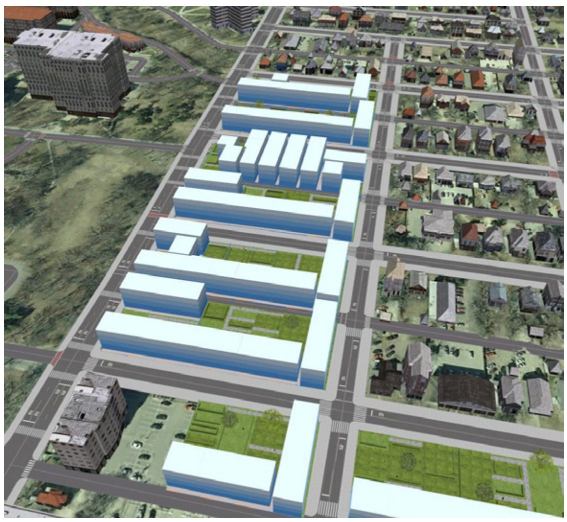


Figure 4.24: Building Construction CGA rule defaults

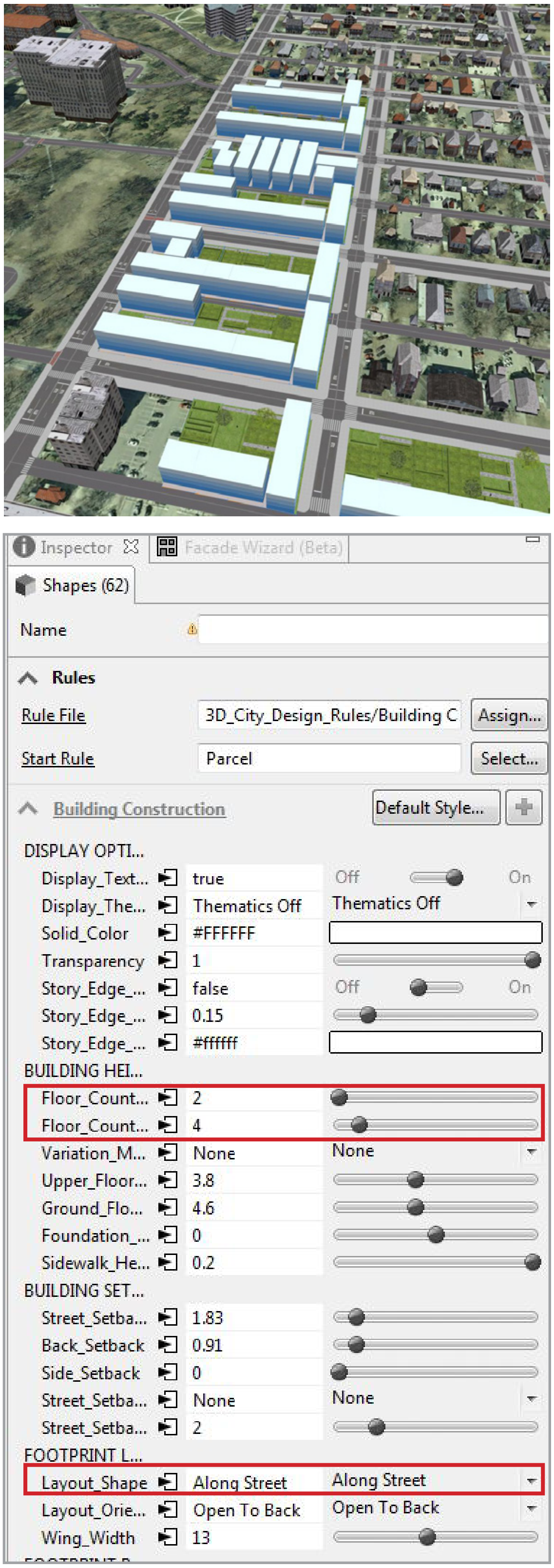


Figure 4.25: Low buildings oriented toward streets

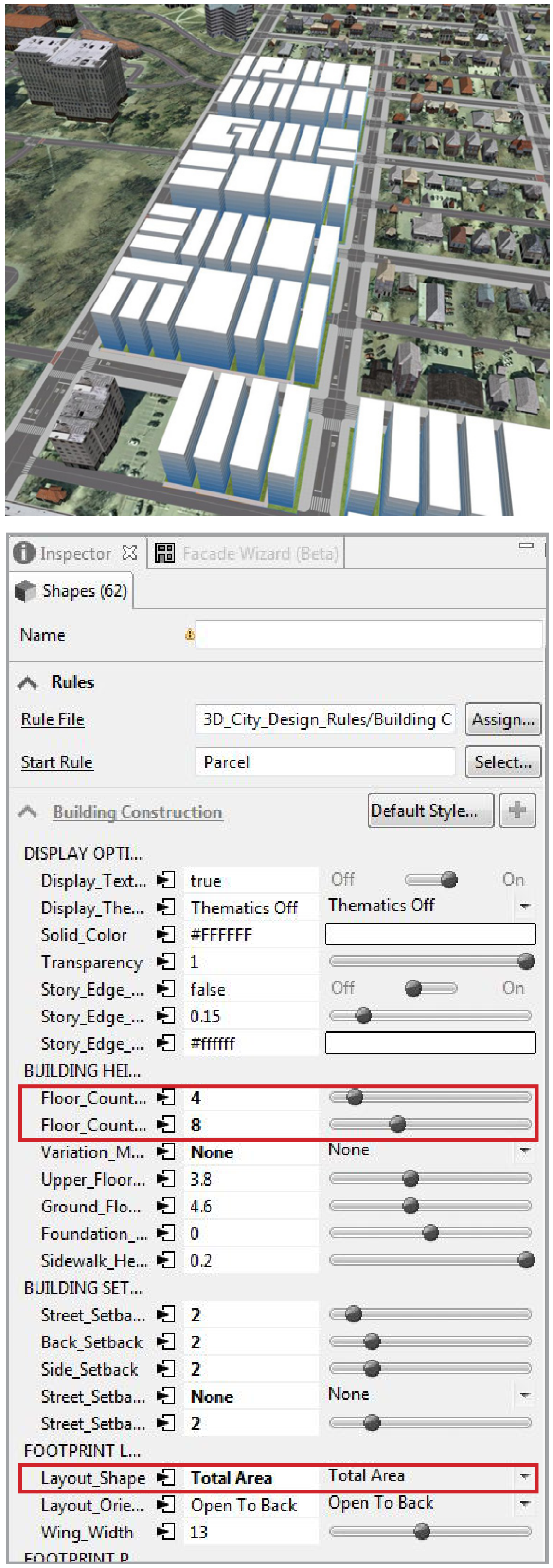
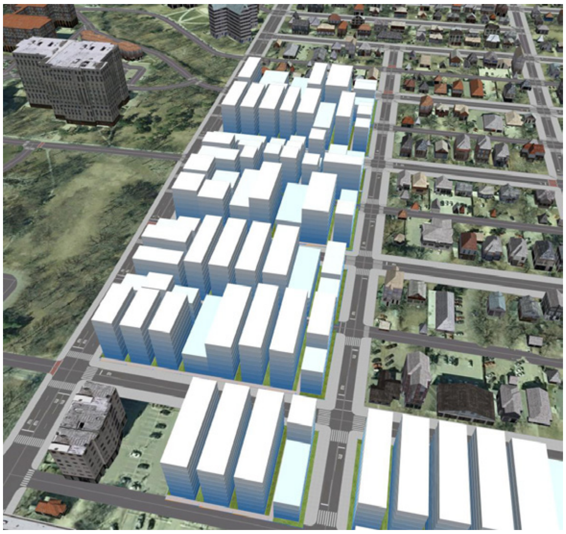


Figure 4.26: 8 story buildings built out to the lot edge



In many cases these rules must be modified to reach the desired outcome. This could be as easy as changing a few parameters on a scroll bar or can be difficult and require scripting to perform a function. Using the building example shown below, one can see that scroll bars and numbers can be adjusted to edit many characteristics. The characteristics in the example include building setbacks and heights. Once the desired model is complete, the parameters can be saved as a style (see Figure 4.28). The style you create automatically generates script in the rule. The new style created can then be easily applied to other lots in the project or future projects in a matter of seconds.

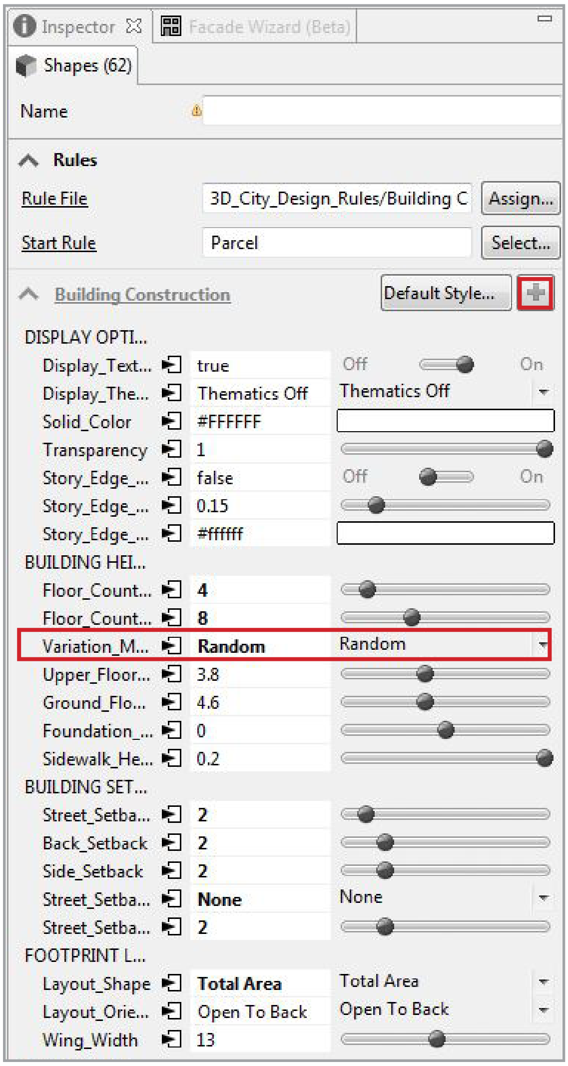


Figure 4.27: Adjusted rule to model 4-8 stories

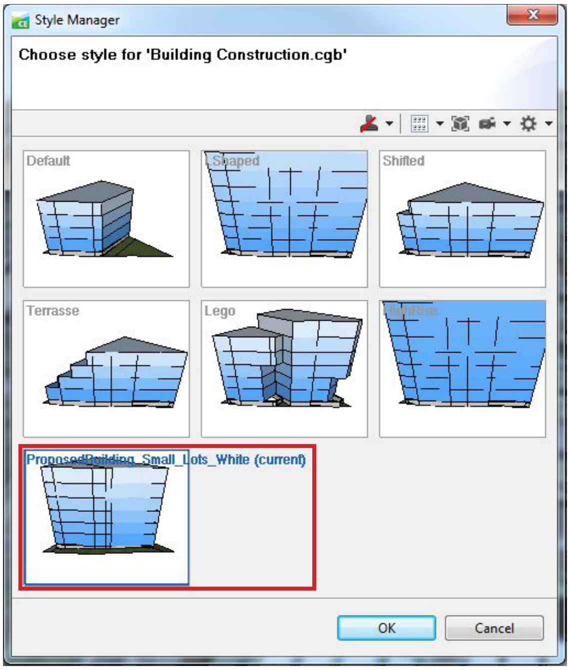


Figure 4.28: A new building style was created, which can be easily applied to model other parcels

In CityEngine, scripting is the process of using different characters such as letters or numbers to write a mathematical algorithm to generate 3D models from 2D vector data. For beginners, scripting is challenging and has a high learning curve. Once it is learned the possibilities of modeling objects in CityEngine can be endless. However, only a couple of dozen people in the world are creating advanced rules (B. Patrick, personal communication, Nov. 7, 2015). It cannot be expected of each design professional to learn how to create rules from scratch, but it is reasonable for CityEngine users to learn to edit existing rules.

In the UCR District model, several different rules were revised before being applied. A rule was selected to model existing buildings from building footprints, model existing trees from point data, model proposed buildings and landscape from parcels, and model streetscapes from road centerlines. The editing and use of each rule is briefly described in the following sections.

EXISTING BUILDINGS

ESRI created a rule that can model 3D buildings from building footprints. This rule was applied to the existing building footprints (see Figure 4.29). The rule assigns images to façades which were edited in the Façade Wizard. The Façade Wizard is used to manipulate façade images so that patterns in the façade can be replicated to a surface (see Figure 4.30). In this rule, the first story applies a different façade image than the top stories. The rule assigns façade images to buildings randomly. The assigned facade can be manually overridden by clicking the regenerate button or by using parameters to specifically select the façade in the inspectors window. Building height and roof type are also assigned based on parameters in the rule which can be edited in the script or adjusted on a scroll bar.

The Façade Wizard can also be used to model 3D geometry (see Figure 4.31). This geometry is saved as a rule which can be applied to a building. If you want to apply multiple 3D façades to random buildings, an additional rule would have to be created which links all 3D façade rules. The script that is required to perfect this rule is difficult for a beginner. One would need to consult a professional. In addition to modeling buildings, KML buildings in Google Earth can be imported (Muller, et. al., 2006).

Figure 4.30: Cropping and separating details in a facade image which can then be used to make it a 3D facade

Figure 4.29: 2D facade images applied in rule

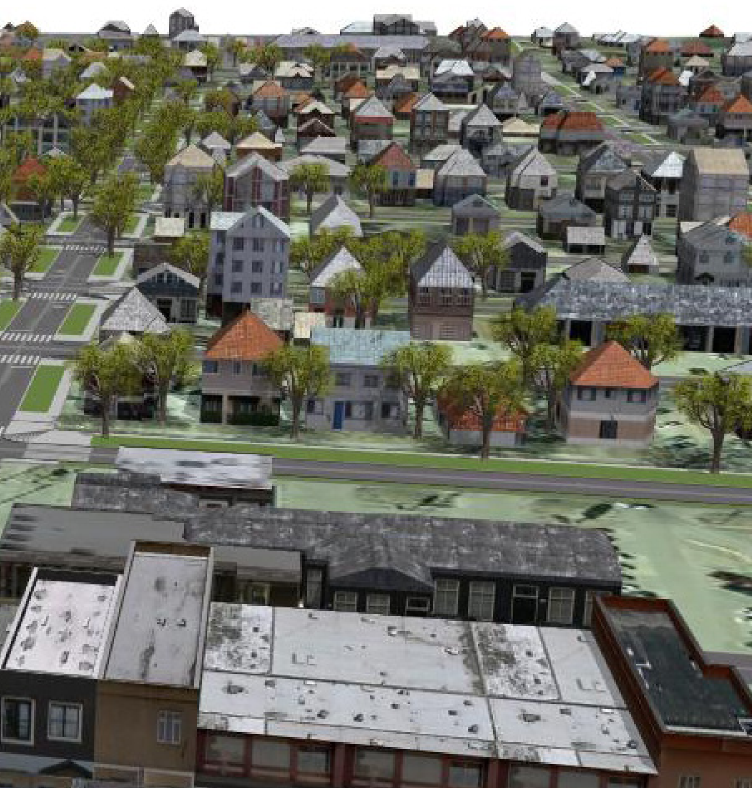


Figure 4.31: 3D facade rules create higher levels of realism

PROPOSED BUILDINGS

LOTS

The proposed buildings and private landscape design were procedurally modeled from the lot size and shape. The current ownership of properties and design standards on minimum and maximum lot square footage, width, and depth were used to design the proposed lots. The detail required to create these lots was manually drawn by tracing over existing property lines. If this level of detail was not needed, the lots automatically generated from the street network could be used and adjusted based on minimum and maximum lot square size requirements and minimum width for quick results.

UCR District Design Standards Implemented in CityEngine Model	
Minimum Lot Area	15,000 sqft
Minimum Lot Width	100 ft
Minimum Lot Depth	150 ft
Maximum Structure Height	85 ft
Minimum Structure Height	30 ft
Minimum Front Yard on N. Manhattan Ave.	10 ft
Minimum Front Yard along other streets	5 ft
Minimum Side Yard	5 ft
Minimum Rear Yard	None
Maximum BLDG Lot Coverage	None
Minimum Vision Triangles (public streets)	15 ft
Minimum Vision Triangles (alleyways)	10 ft
Minimum Vision Triangles (private drives)	10 ft

Figure 4.32: Design Standards used to design lots

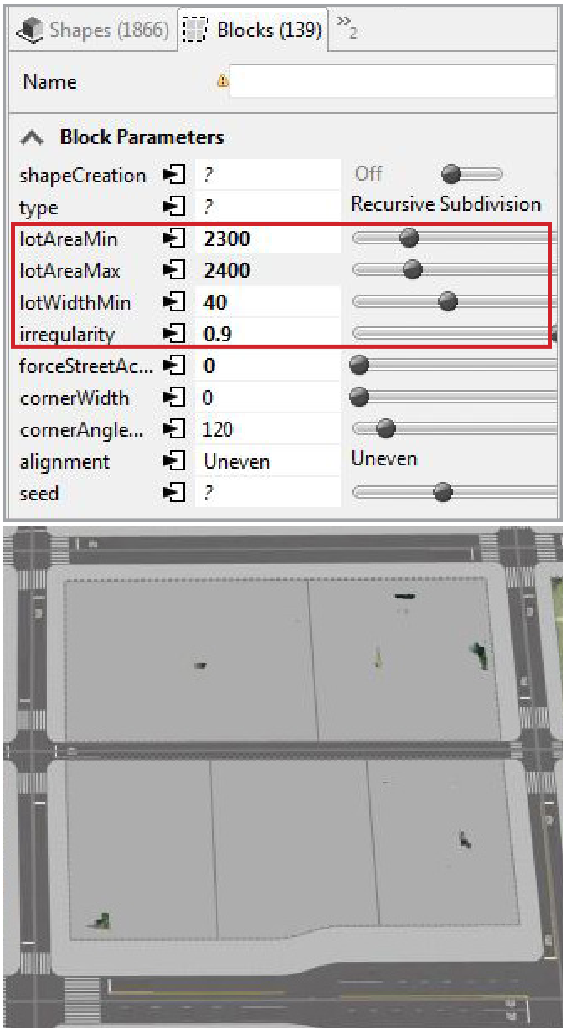


Figure 4.33: Adjusting parameters to create large parcels

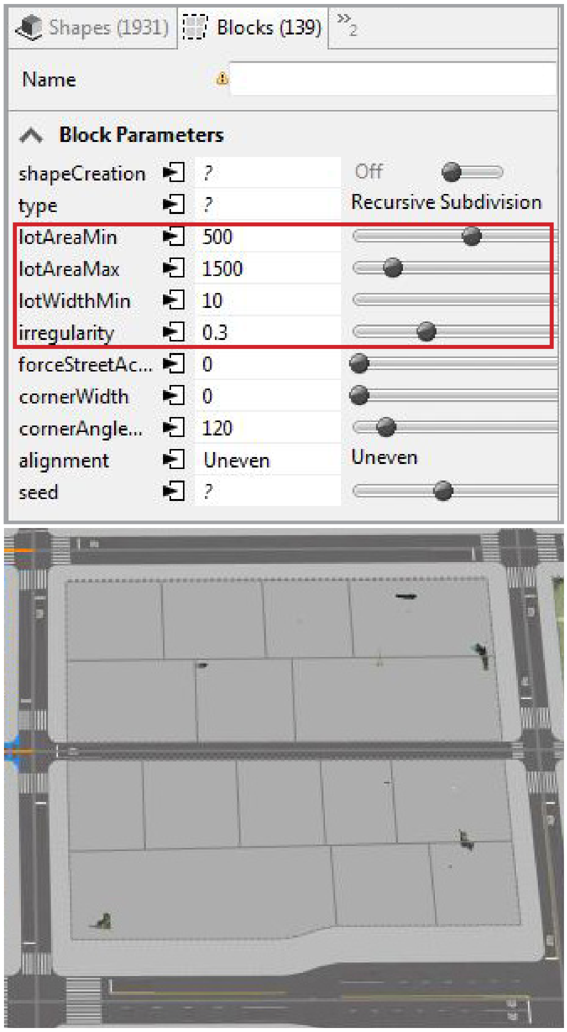
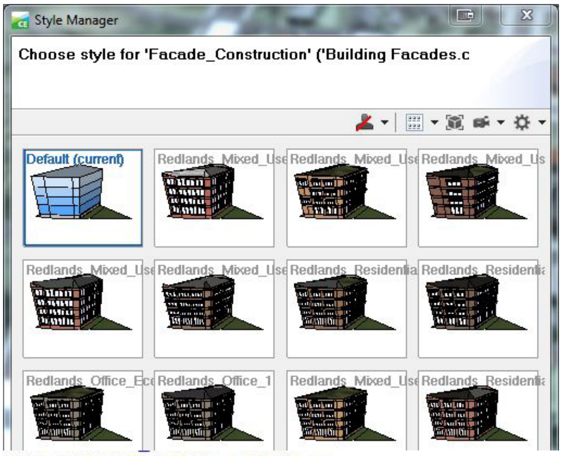


Figure 4.34: Rule makes small parcels split block

FACADES

The Building Construction rule was used to model 3D buildings and landscape on the lots. This rule created by ESRI can model 2D colored facades or detailed 3D facades. If applying detailed 3D facades, the Building Construction rule allows a designer to add different window types, façade materials, balconies, awnings, and setbacks. The rule also can apply different roof types. If a flat roof is applied, a green roof and/or solar panels can be added. As seen in Figure 4.37 these elements can be easily adjusted through sliders and clicking options. When a façade or roof type design is complete it can be saved as a style. A style then allows you to easily apply it to other buildings. To make the urban development look realistic, several styles should be made to establish differentiation between the buildings. For more information on 2D facades, building height, building configuration, and building setbacks, reference the Rules section.




```
attr Level_of_Detail = "Medium"
attr Mass_Display = "Gradient-Up"
attr Balconies = "None"
attr Ground_Floor_Shopfront = false
attr Win_Width = 2.0
attr Frame_Color = "#FFFFFF"
attr Glass_Material = "iRay Glass"
attr Wall_Texture = "Brick Varied Brown Running Bond"
attr Wall_Texture_Scaler = 0.5
attr Awning_Type_Ground = "None"
attr Awning_Type_Upper = "None"
attr Awning_Extension_Upper = 0.8
attr Awning_Color = "#B871FF"
attr Roof_Type = "Gable"
attr Sloped_Roof_Texture = "Standard Dura Shingle"
attr Flat_Roof_Texture = "Green Roof"
attr Roof_Texture_Scale = 2.03
attr Roof_Overhang = 0.1
attr Sloped_Roof_Angle = 20.0
```

Figure 4.35: New facade style generates script

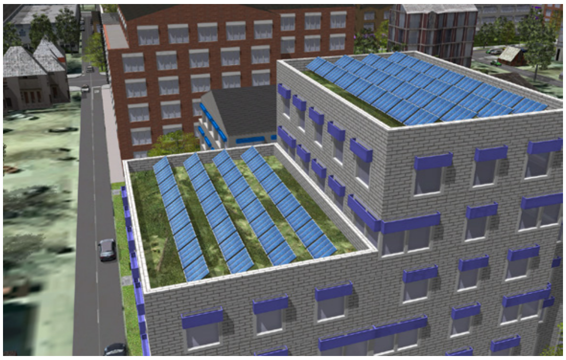


Figure 4.36: In addition to detailed facades, the Building Construction rule allows for green roofs and solar panels.

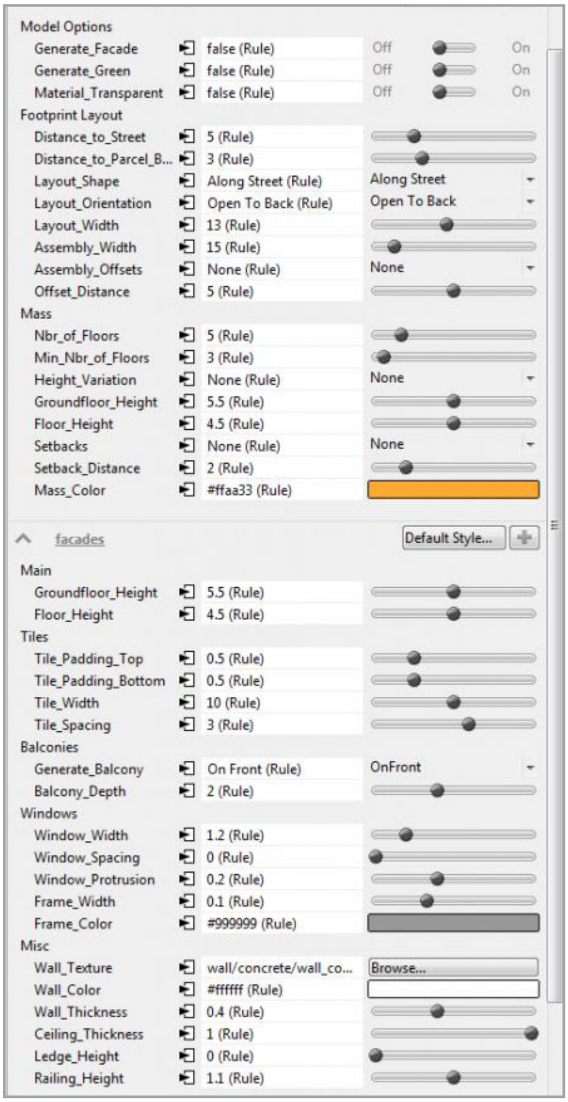


Figure 4.37: Hundreds of parameters can be adjusted to customize facades, e.g., windows, roofs, materials, walls, balconies, and awnings.

LANDSCAPE

The landscape design can be set to formal or natural. The formal design should be used for urban development to create better relationships to the buildings. It contains several parameters to edit the pathways and vegetation. This includes tree percentages and species; hedge percentage and height; pathway locations, angle, width, and material (see Figure 4.38). The natural landscape design should be used for natural-like landscapes. The natural grass texture is rough to represent hardy vegetation, while the formal grass texture is fine to represent mowed turf grass. See Figures 4.39 and 4.40 to see an example of a formal design and Figure 4.41 to see a natural greenspace type.

Figure 4.39: Green space grass texture, paving texture, 2D texture applied to hedge form, and 3D trees

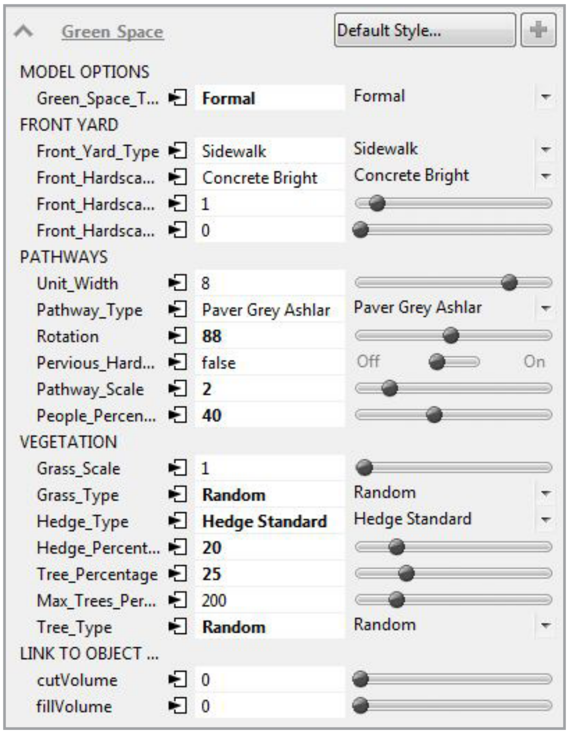


Figure 4.38: Green Space parameters within the Redlands Building Construction rule

Figure 4.40: Formal greenspace type

Figure 4.41: Natural greenspace type

EXISTING TREES

The ESRI plant loader was used to model existing trees from points. Hundreds of LumenRT trees can be selected to use. The European Hornbeam model was selected to represent all existing trees because of its standard tree form and its realistic foliage color (see Figure 4.43).The height and tree species information that was included in the KSU campus tree GIS inventory was input with the points data. With more script, the height and tree species information could be used to model the existing trees more accurately. The current rule used only allows the tree form and species to be manually adjusted for individual or groups of trees.

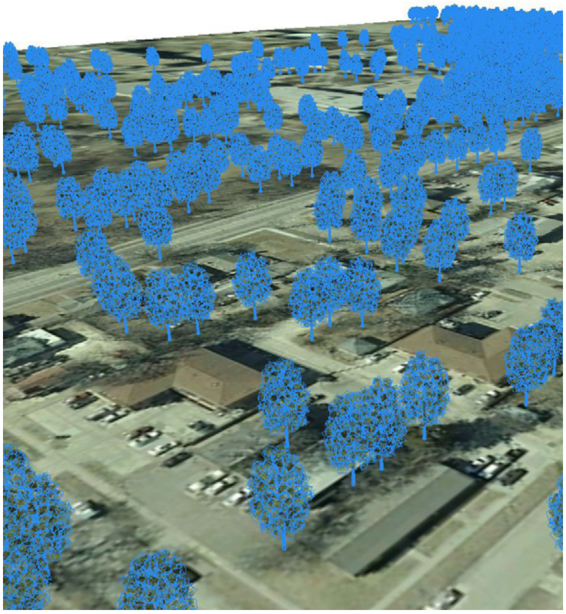


Figure 4.42: Modeling existing trees

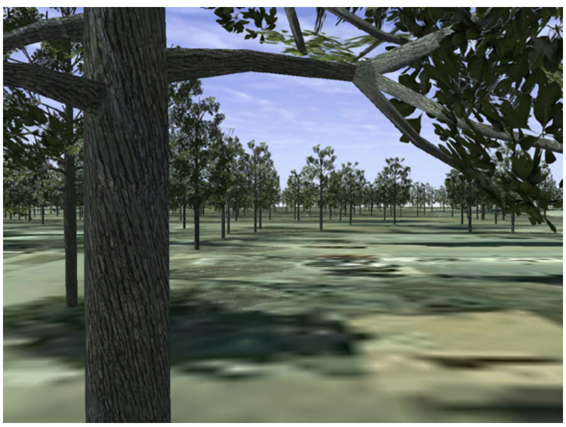


Figure 4.43: LumenRT European Hornbeam model

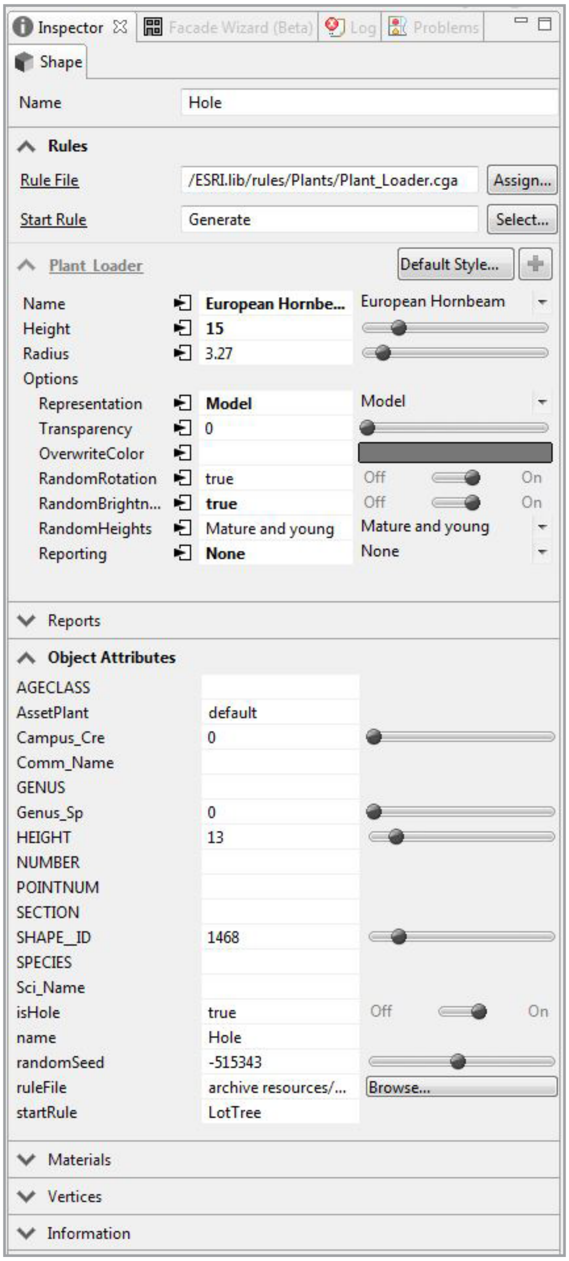


Figure 4.44: Parameters in the ESRI plant loader rule

STREETSCAPE

When a street shapefile is brought into CityEngine it receives default road and sidewalk widths. Before a rule is applied to the streetscape, the widths should be edited. This can be done by entering road and sidewalk widths in the inspector tab (see Figure 4.46). Once the widths were customized, the ESRI Complete Streets rule was applied. The rule automatically textured the sidewalks with a light grey color and roads with a dark charcoal color (see Figure 4.45). It also added crosswalks and centerlines on the roads. These textures were among many parameters that could be quickly changed to customize the streetscape and develop different scenarios.

Figure 4.45: Initial street model

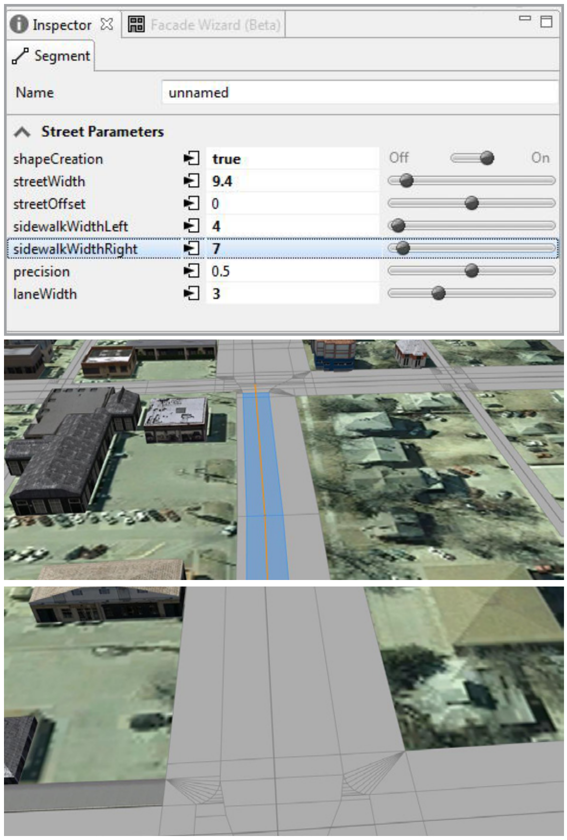


Figure 4.46: Changing road and sidewalk widths

Figure 4.47: Streets after customizing Complete Street rule parameters

STREETS

The street parameters that were customized included: lane distribution (location of center line); lane width (number of lanes); numerous median customizations; turning lanes; parking types; parklets; bike lanes; crosswalk types; and traffic percentage. The figure below shows an example of how a street's centerline, parking, and number of traffic lanes can be adjusted.

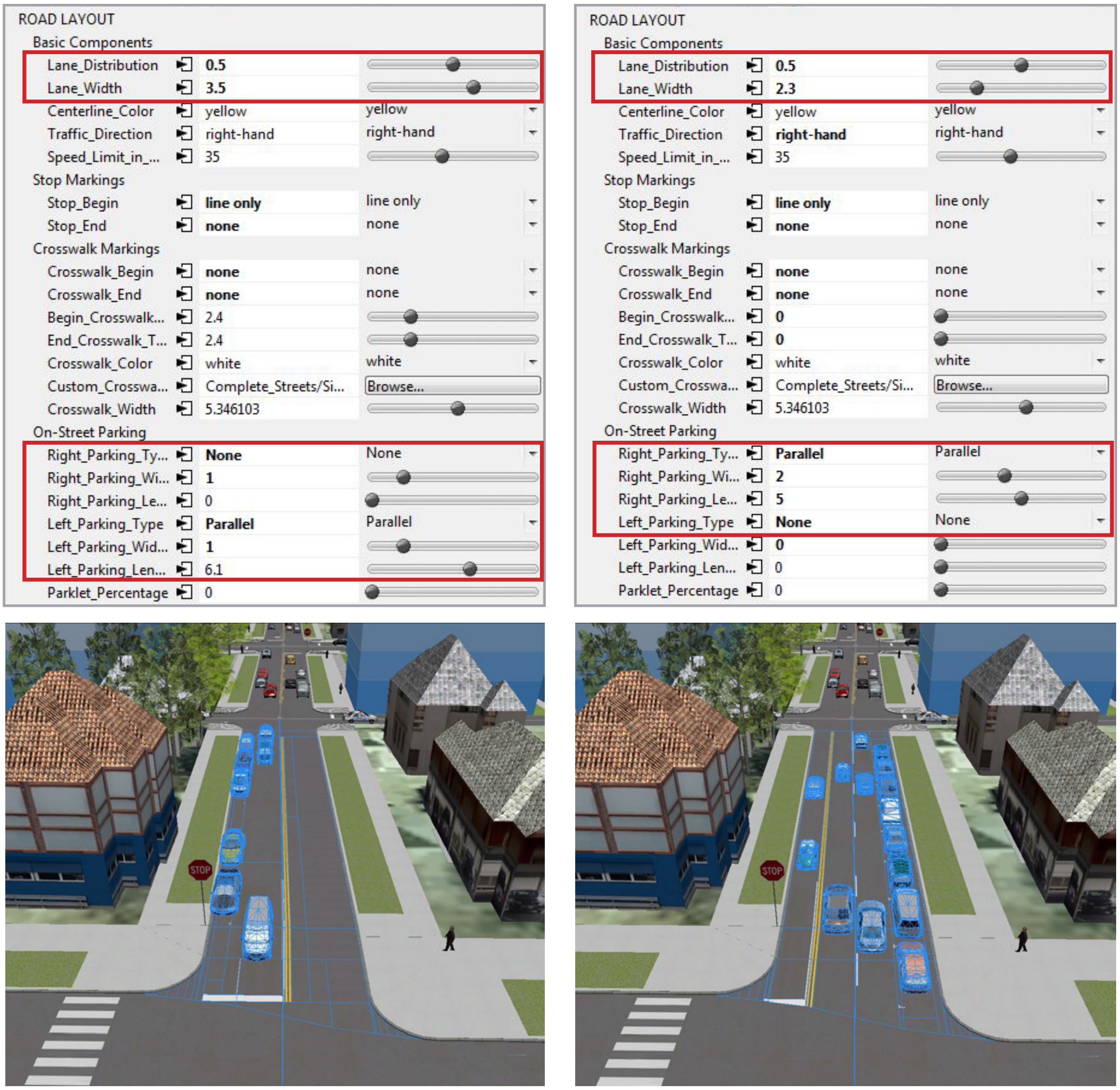


Figure 4.48: Changing street design using Complete Street rule parameters

SIDEWALK AREA

The sidewalk parameters that were customized to create different design scenarios included sidewalk material, planter width, planter spacing, planting texture, street tree percentage, parking meters, bus stops, lighting, street signs, street lights, bike racks, benches, elevated planters, and a few other sidewalk furnishings. To incorporate multiple sidewalk furnishings into the scene, script was added to the rule. Figure 4.51 shows the added script and Figure 4.52 shows how the script can be edited to adjust the planter location, size, and form. Sidewalk bike staging areas were also added in the parameters.

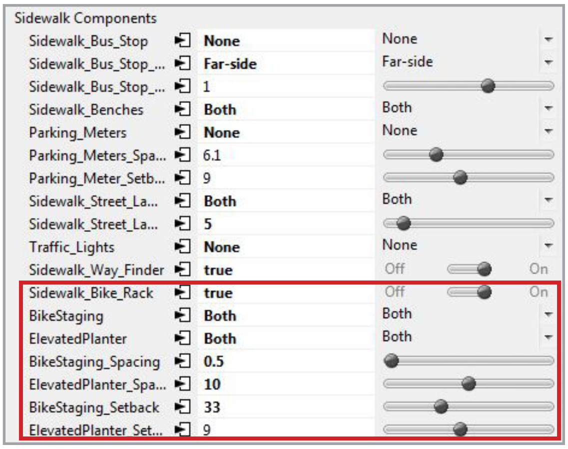


Figure 4.49: Sidewalk parameters

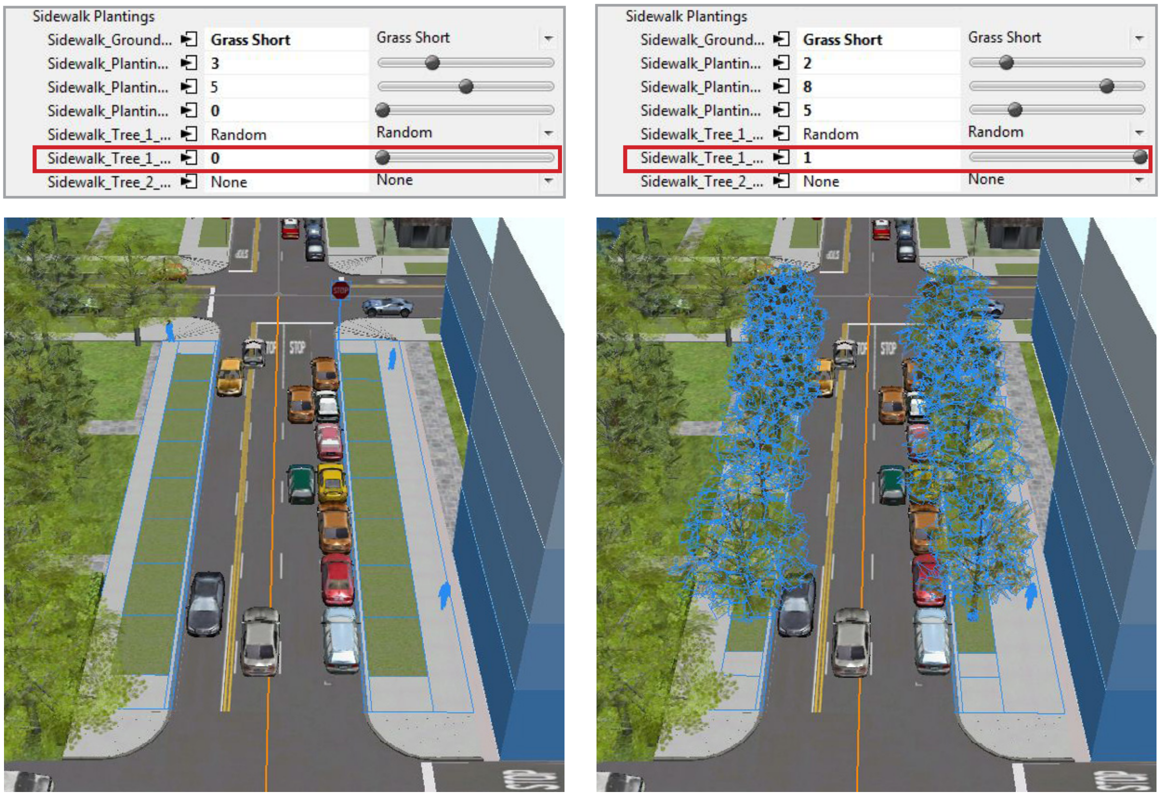


Figure 4.50: Changing tree population in streetscape using Complete Street rule parameters

```
const Default_ElevatedPlanter        = (ObjectFolder+ "/Planter_High_LOD")
const Default_BikeStaging            = (ObjectFolder+ "/Bike_Rack")
```

```
attr ElevatedPlanter_Object                    =Default_ElevatedPlanter
@Order(8)@File("dae","dxf","gdb","kml","kmz","obj","osm","shp")@Description
attr BikeStaging_Object                        =Default_BikeStaging
```

```
//added elevatedplanter
@Order(13)@Range("None","Both","Right","Left")@Description
attr ElevatedPlanter                           ="None"
@Order(14)@Range(0,20) @Description
attr ElevatedPlanter_Spacing                   = 10
@Order(15) @Range(0,20) @Description
attr ElevatedPlanter_Setback                = 9
//added bike racks
@Order(13)@Range("None","Both","Right","Left")@Description
attr BikeStaging                            ="None"
@Order(14)@Range(0,20) @Description
attr BikeStaging_Spacing                    = 10
@Order(15) @Range(0,20) @Description
attr BikeStaging_Setback                 = 9
```

Figure 4.51: Adding script in Complete Streets rule to add an elevated planter parameter

```
ElevatedPlanter_Object,0,0,.3,1.4,.3)
```

```
ElevatedPlanter_Object,7,7,.75,1.4,2)
```

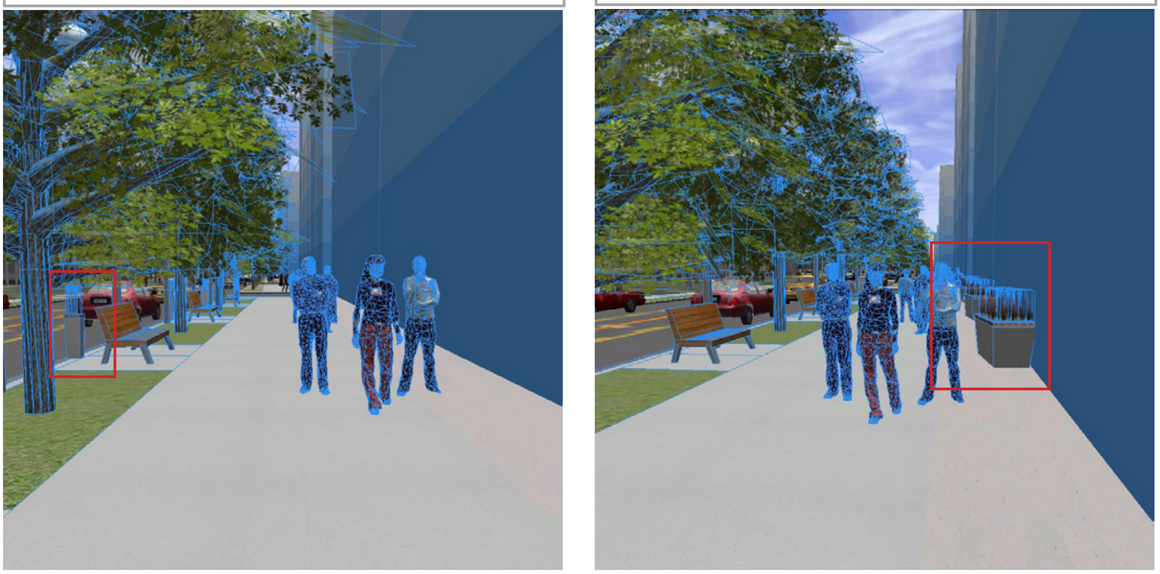


Figure 4.52: Procedurally modeling the elevated planters location, size, and form with script

REPORTS

Metrics can be generated to compare the advantages and disadvantages of each design. The Building Construction and Complete Streets rule have embedded script to generate reports. The Building Construction reports generated for the proposed UCR District can be seen in Figure 4.56. However, these metrics are rough because the precipitation data and cost of materials were not changed from the Redlands, California project defaults. This report also relies on zoning and building efficiency settings (City Engine Example: Redlands Redevelopment, 2014). Higher efficient LEED buildings cost more to implement, but CityEngine reports compare it to the overall life cycle of the buildings so clients can understand savings (City Engine Example: Redlands Redevelopment, 2014).

Based on street geometry, the Complete Streets rule can develop reports to predict a rough cost estimate (Example Complete Streets 2014, 2015). As seen in Figure 4.56 it can also predict other analytics based on road configurations (Example Complete Streets 2014, 2015).

Graphics can be created from the reports by inserting the data into excel or other data visualization software. Graphics of the reports will help communicate the difference between designs and how money can be saved.

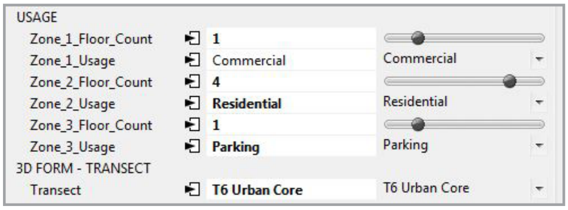


Figure 4.54: Zoning parameters

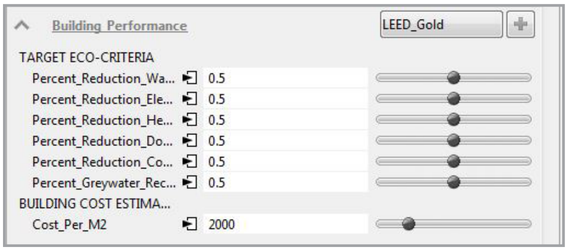
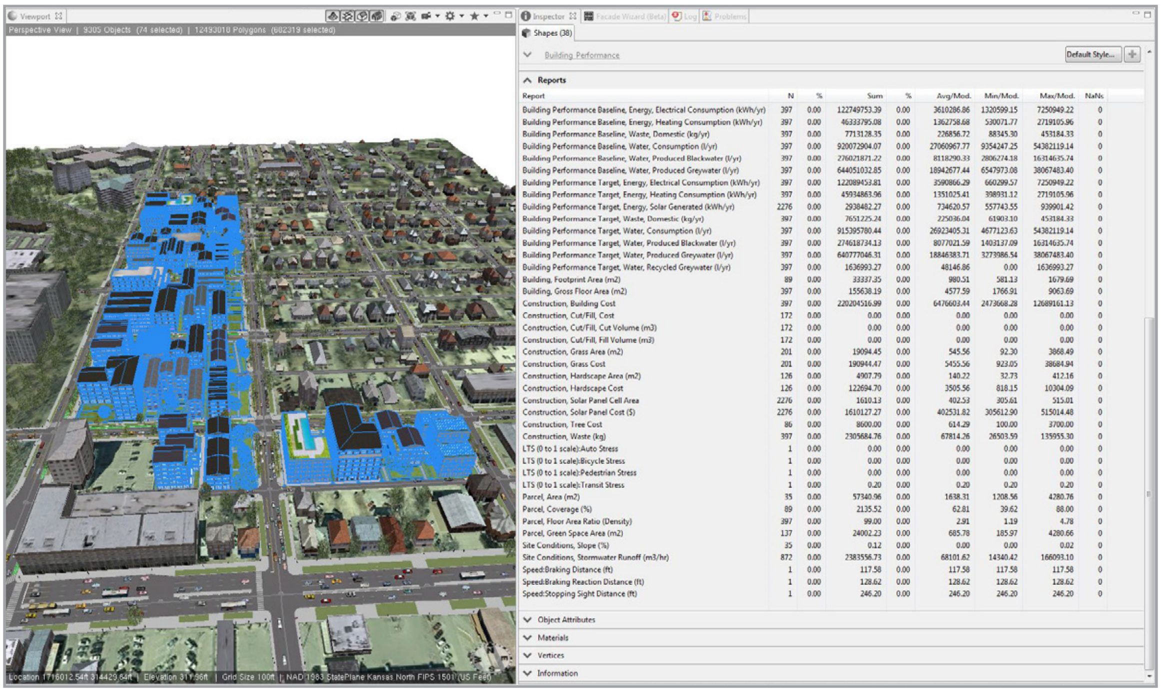


Figure 4.55: Building performance styles



Report	N	%	Sum	%	Avg/Mod.	Min/Mod.	Max/Mod.	NaNs
Building Performance Baseline, Energy, Electrical Consumption (kWh/yr)	397	0.00	122749753.39	0.00	3610286.86	1320599.15	7250949.22	0
Building Performance Baseline, Energy, Heating Consumption (kWh/yr)	397	0.00	46333795.08	0.00	1362758.68	530071.77	2719105.96	0
Building Performance Baseline, Waste, Domestic (kg/yr)	397	0.00	7713128.35	0.00	226856.72	88345.30	453184.33	0
Building Performance Baseline, Water, Consumption (l/yr)	397	0.00	920072904.07	0.00	27060967.77	9354247.25	54382119.14	0
Building Performance Baseline, Water, Produced Blackwater (l/yr)	397	0.00	276021871.22	0.00	8118290.33	2806274.18	16314635.74	0
Building Performance Baseline, Water, Produced Greywater (l/yr)	397	0.00	644051032.85	0.00	18942677.44	6547973.08	38067483.40	0
Building Performance Target, Energy, Electrical Consumption (kWh/yr)	397	0.00	122089453.81	0.00	3590866.29	660299.57	7250949.22	0
Building Performance Target, Energy, Heating Consumption (kWh/yr)	397	0.00	45934863.96	0.00	1351025.41	398931.12	2719105.96	0
Building Performance Target, Energy, Solar Generated (kWh/yr)	2276	0.00	2938482.27	0.00	734620.57	557743.55	939901.42	0
Building Performance Target, Waste, Domestic (kg/yr)	397	0.00	7651225.24	0.00	225036.04	61903.10	453184.33	0
Building Performance Target, Water, Consumption (l/yr)	397	0.00	915395780.44	0.00	26923405.31	4677123.63	54382119.14	0
Building Performance Target, Water, Produced Blackwater (l/yr)	397	0.00	274618734.13	0.00	8077021.59	1403137.09	16314635.74	0
Building Performance Target, Water, Produced Greywater (l/yr)	397	0.00	640777046.31	0.00	18846383.71	3273986.54	38067483.40	0
Building Performance Target, Water, Recycled Greywater (l/yr)	397	0.00	1636993.27	0.00	48146.86	0.00	1636993.27	0
Building, Footprint Area (m2)	89	0.00	33337.35	0.00	980.51	581.13	1679.69	0
Building, Gross Floor Area (m2)	397	0.00	155638.19	0.00	4577.59	1766.91	9063.69	0
Construction, Building Cost	397	0.00	220204516.99	0.00	6476603.44	2473668.28	12689161.13	0
Construction, Cut/Fill, Cost	172	0.00	0.00	0.00	0.00	0.00	0.00	0
Construction, Cut/Fill, Cut Volume (m3)	172	0.00	0.00	0.00	0.00	0.00	0.00	0
Construction, Cut/Fill, Fill Volume (m3)	172	0.00	0.00	0.00	0.00	0.00	0.00	0
Construction, Grass Area (m2)	201	0.00	19094.45	0.00	545.56	92.30	3868.49	0
Construction, Grass Cost	201	0.00	190944.47	0.00	5455.56	923.05	38684.94	0
Construction, Hardscape Area (m2)	126	0.00	4907.79	0.00	140.22	32.73	412.16	0
Construction, Hardscape Cost	126	0.00	122694.70	0.00	3505.56	818.15	10304.09	0
Construction, Solar Panel Cell Area	2276	0.00	1610.13	0.00	402.53	305.61	515.01	0
Construction, Solar Panel Cost ($)	2276	0.00	1610127.27	0.00	402531.82	305612.90	515014.48	0
Construction, Tree Cost	86	0.00	8600.00	0.00	614.29	100.00	3700.00	0
Construction, Waste (kg)	397	0.00	2305684.76	0.00	67814.26	26503.59	135955.30	0
LTS (0 to 1 scale):Auto Stress	1	0.00	0.00	0.00	0.00	0.00	0.00	0
LTS (0 to 1 scale):Bicycle Stress	1	0.00	0.00	0.00	0.00	0.00	0.00	0
LTS (0 to 1 scale):Pedestrian Stress	1	0.00	0.00	0.00	0.00	0.00	0.00	0
LTS (0 to 1 scale):Transit Stress	1	0.00	0.20	0.00	0.20	0.20	0.20	0
Parcel, Area (m2)	35	0.00	57340.96	0.00	1638.31	1208.56	4280.76	0
Parcel, Coverage (%)	89	0.00	2135.52	0.00	62.81	39.62	88.00	0
Parcel, Floor Area Ratio (Density)	397	0.00	99.00	0.00	2.91	1.19	4.78	0
Parcel, Green Space Area (m2)	137	0.00	24002.23	0.00	685.78	185.97	4280.66	0
Site Conditions, Slope (%)	35	0.00	0.12	0.00	0.00	0.00	0.02	0
Site Conditions, Stormwater Runoff (m3/hr)	872	0.00	2383556.73	0.00	68101.62	14340.42	166093.10	0
Speed:Braking Distance (ft)	1	0.00	117.58	0.00	117.58	117.58	117.58	0
Speed:Braking Reaction Distance (ft)	1	0.00	128.62	0.00	128.62	128.62	128.62	0
Speed:Stopping Sight Distance (ft)	1	0.00	246.20	0.00	246.20	246.20	246.20	0

Figure 4.53: Building Construction report for UCR District

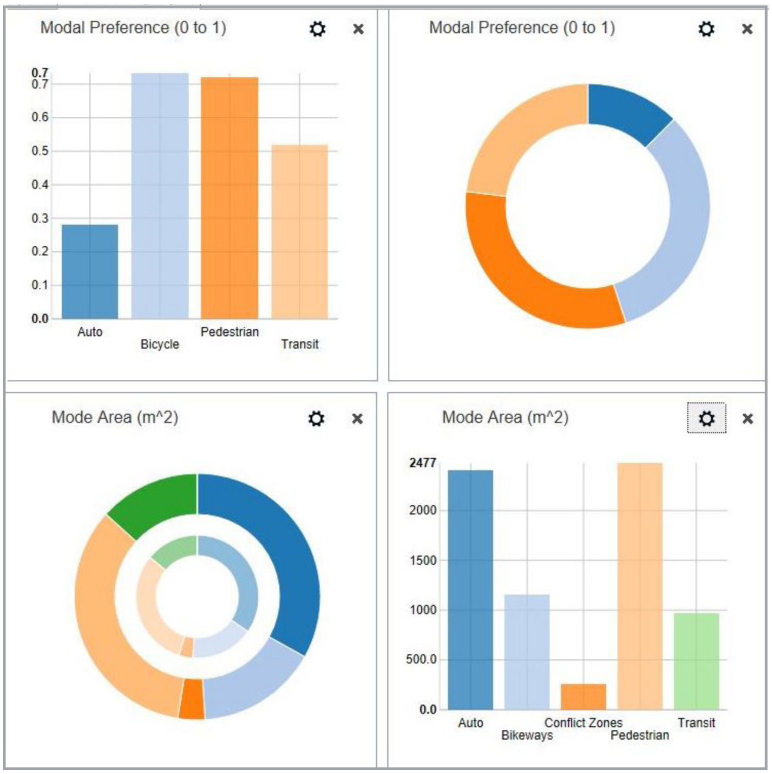


Figure 4.56: Example of graphics which were produced from Complete Streets Report which can easily be viewed in the CityEngine dashboard

Figure 4.57: Redlands example of graphics which were produced from the Building Construction Report

CITYENGINE WEB SCENE

Once everything was modeled the file was exported as a CityEngine Web Scene. In order to successfully do this, the model exported must be relatively small. First attempts failed because the file was too large, which caused errors during the export. Exporting errors can be seen in the Log and Problem tab (see Figure 4.59). To export the UCR District, the size of the model had to be reduced. This was done by turning facade detail to low quality in the parameters, turning off layers, exporting half-sized textures for all layers, and exporting a smaller area of the model (see Figure 4.58). The Web Scene with low detail can be seen on page 45.

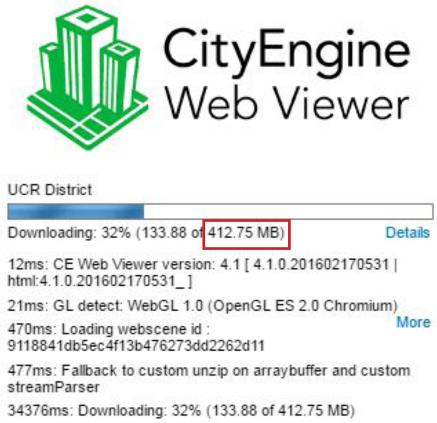


Figure 4.60: Too large of Web Scene (final was 80 MB)

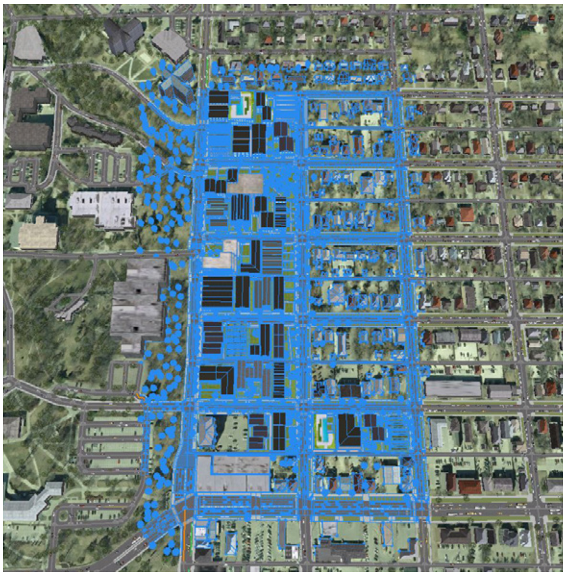


Figure 4.58: Exporting small area

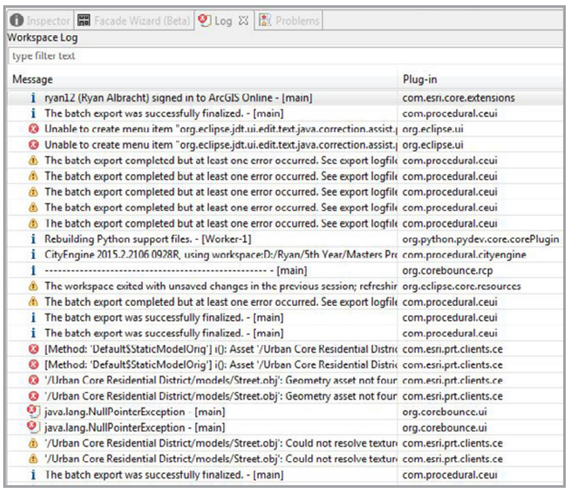


Figure 4.59: Exporting errors

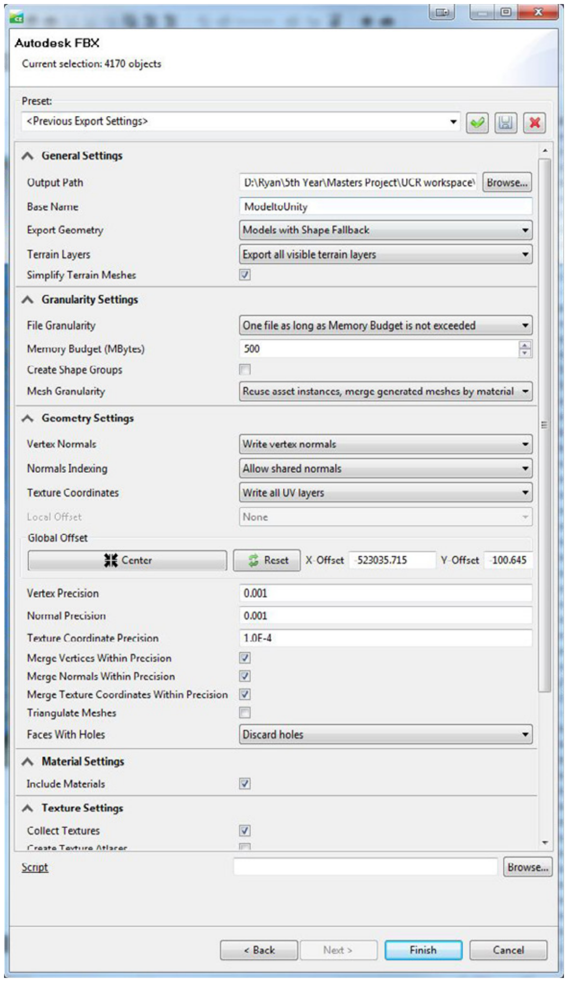


Figure 4.61: Exporting errors

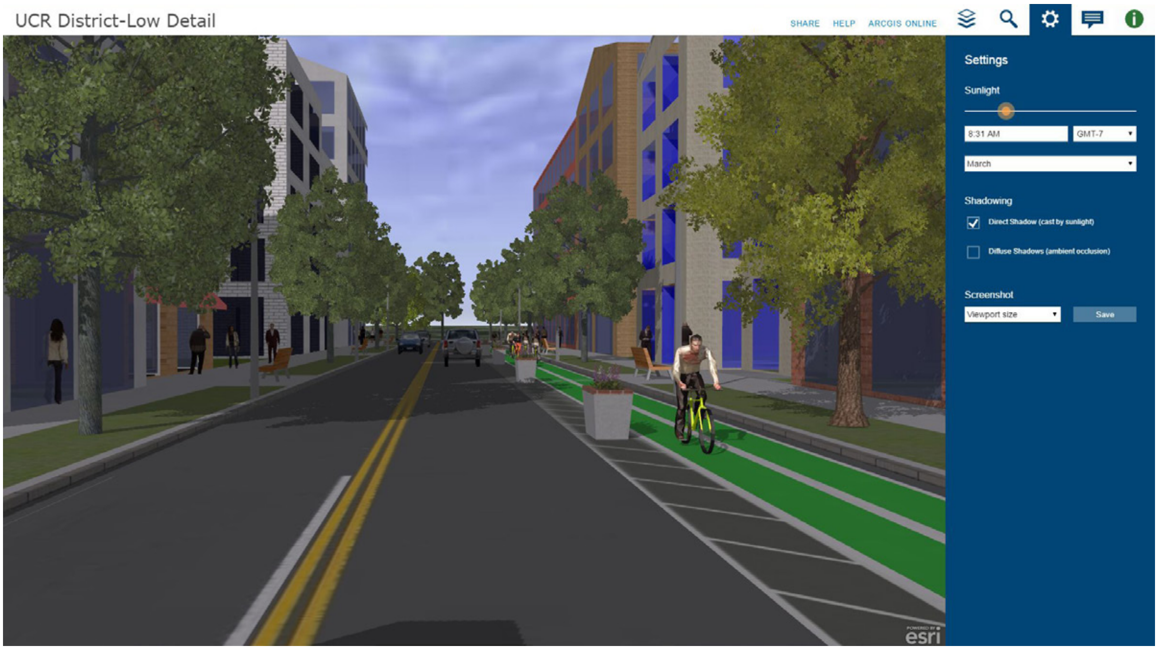


Figure 4.62: CityEngine Web Scene with low detail

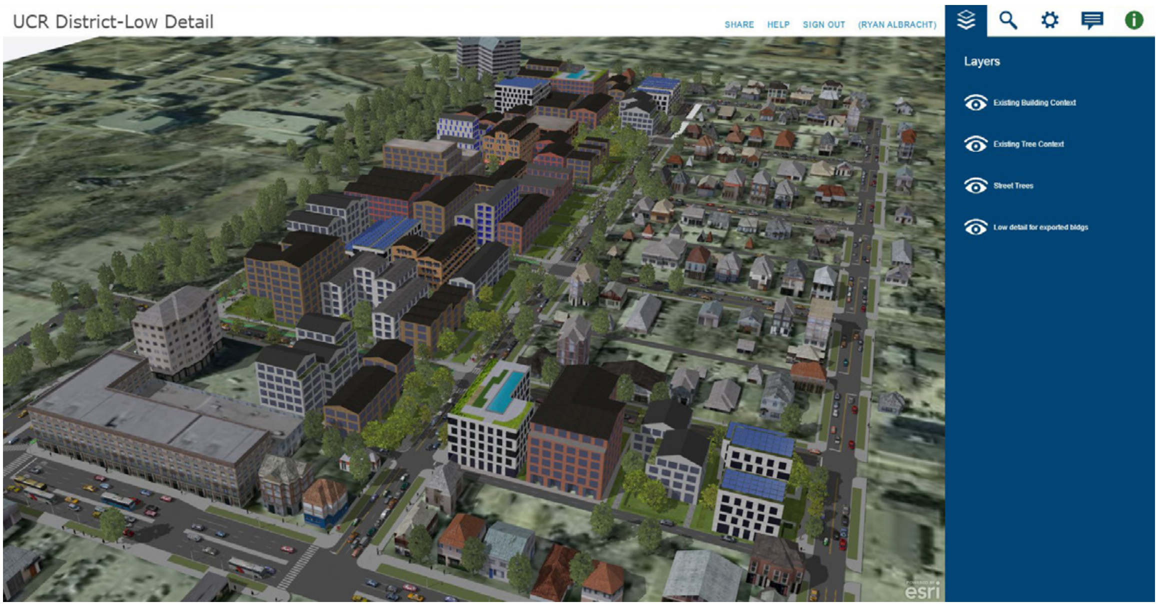


Figure 4.63: Limited site context in CityEngine Web Scene

UNITY

To view the UCR District in more immersion with haptic devices, the CityEngine model had to be brought into a gaming engine, i.e. Unity. This was done by exporting the CityEngine model as an FBX file. The FBX was then imported into Unity.

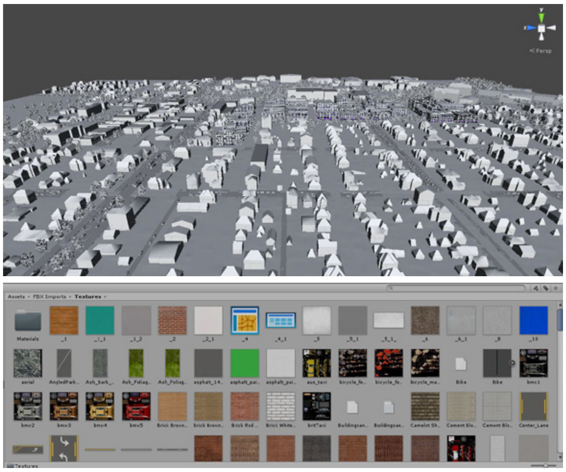


Figure 4.64: Unity scene with no textures

To get the model to display textures, the files exported with the FBX files had to be copied to the unity project. Then the material naming had to be changed to Model Name + Model's Material (see Figure 4.66).

To navigate through the UCR District model, colliders had to be generated for each of the FBX files. Colliders prevent users from falling through the terrain or going through buildings (see Figure 4.66). Next, a skybox was linked to the camera to render a sky in the background of the model. To view the model with more immersion using Oculus Rift goggles, an Oculus SDK has to be imported and a OVRPlayerController has to be used.

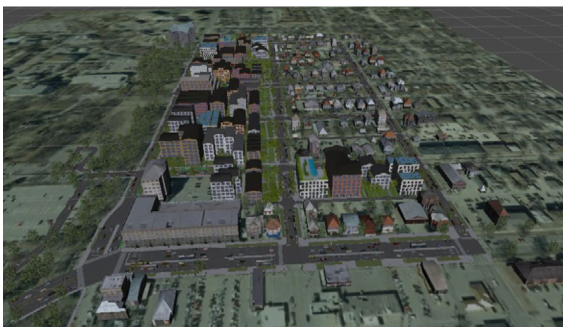


Figure 4.65: Unity scene with imported textures

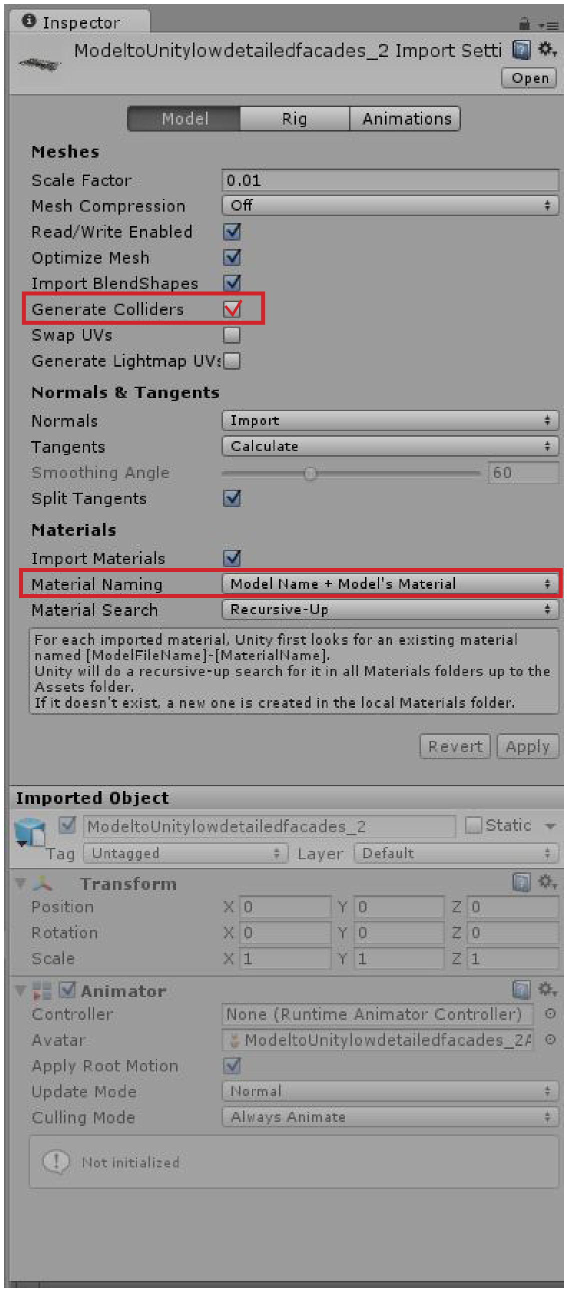


Figure 4.66: Inspector tab on FBX files

OCULUS RIFT

Although not used in this project, a head-mounted display, i.e. Oculus Rift, can be used to view the UCR District through a stereoscopic view with head-tracking sensors to increase immersion (Steuer, 1993).

Figure 4.67: Viewing Oculus Rift at Milan Worlds Expo

unity

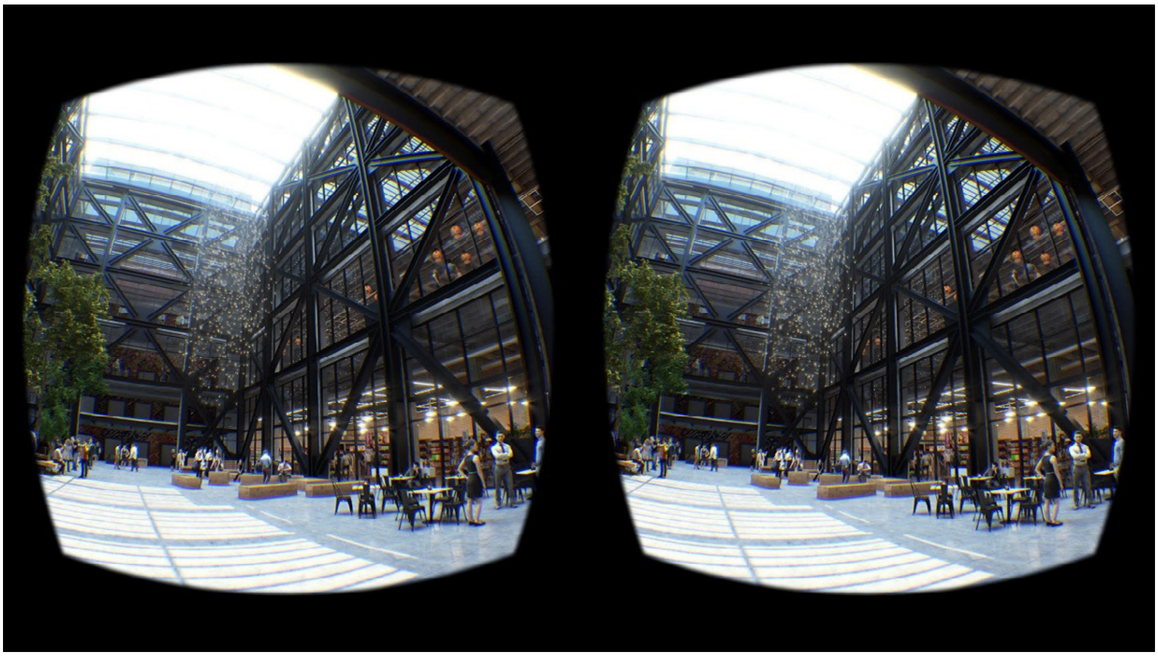


Figure 4.68: Stereoscopic vision through Oculus Rift example

05 RESULTS

The CityEngine rules were used to design and model a hypothetical conceptual master plan scenario that contained buildings with 2D facades, buildings with 3D facades, landscape designs, and streetscapes. The short, medium, and long term phases of implementation were also modeled to show the different visual impacts the development might have. The final visuals also include images of different streetscapes that could potentially be built.

The hypothetical master plan was designed to accommodate the UCR District design standard's five objectives:

1. "High density residential development in a livable, urban environment in close proximity to Kansas State University and Aggieville;
2. Viable mixed-use buildings with small-scale accessory neighborhood-serving commercial uses;
3. Physical design characteristics that promote a vibrant, bicycle and pedestrian-oriented neighborhood with a dynamic relationship to adjacent streets;
4. Improved health and well-being of residents by encouraging walking, biking and community interaction through building design and land use patterns and;
5. Increased safety and security of the area through high quality design and lighting"

(City of Manhattan, 2016, p. 1)

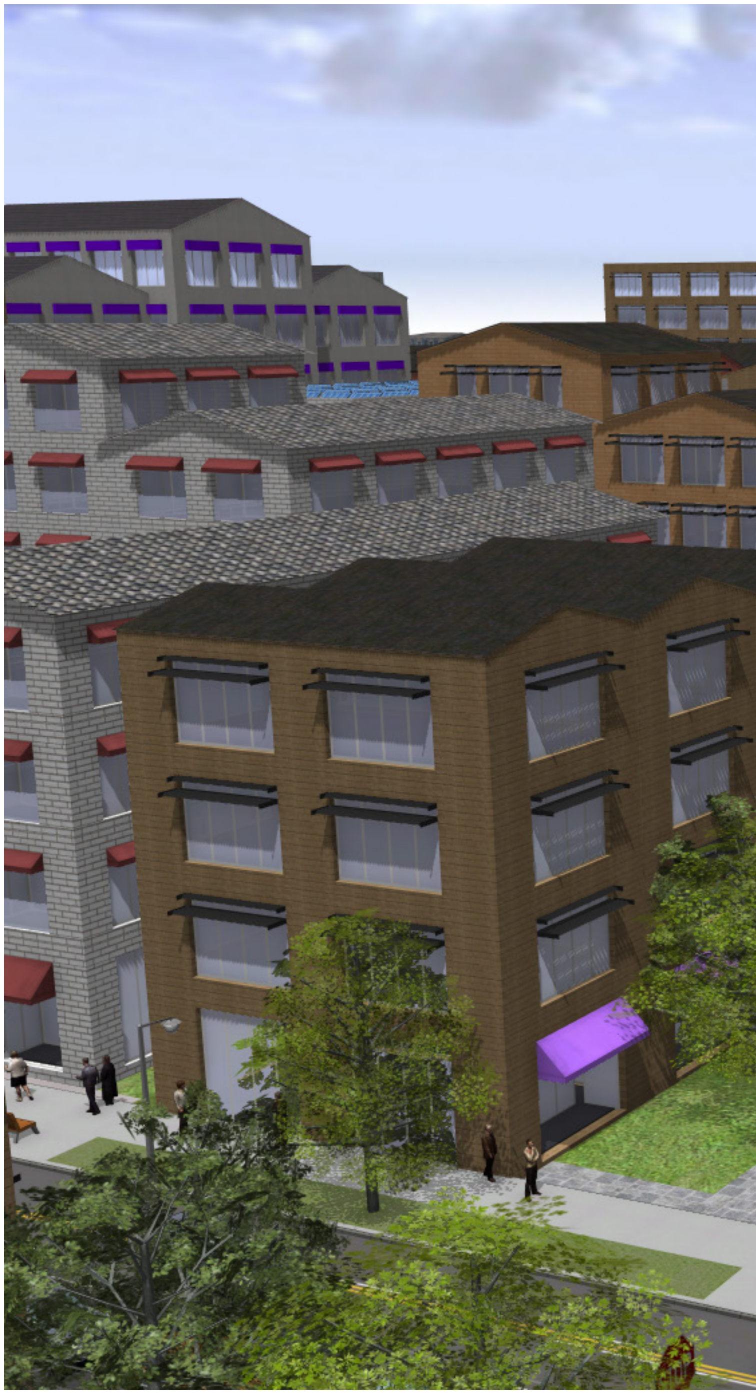


Figure 5.01: Perspective looking north on 12th Street


STOP
STOP

Figure 5.02: Hypothetical master plan of UCR District

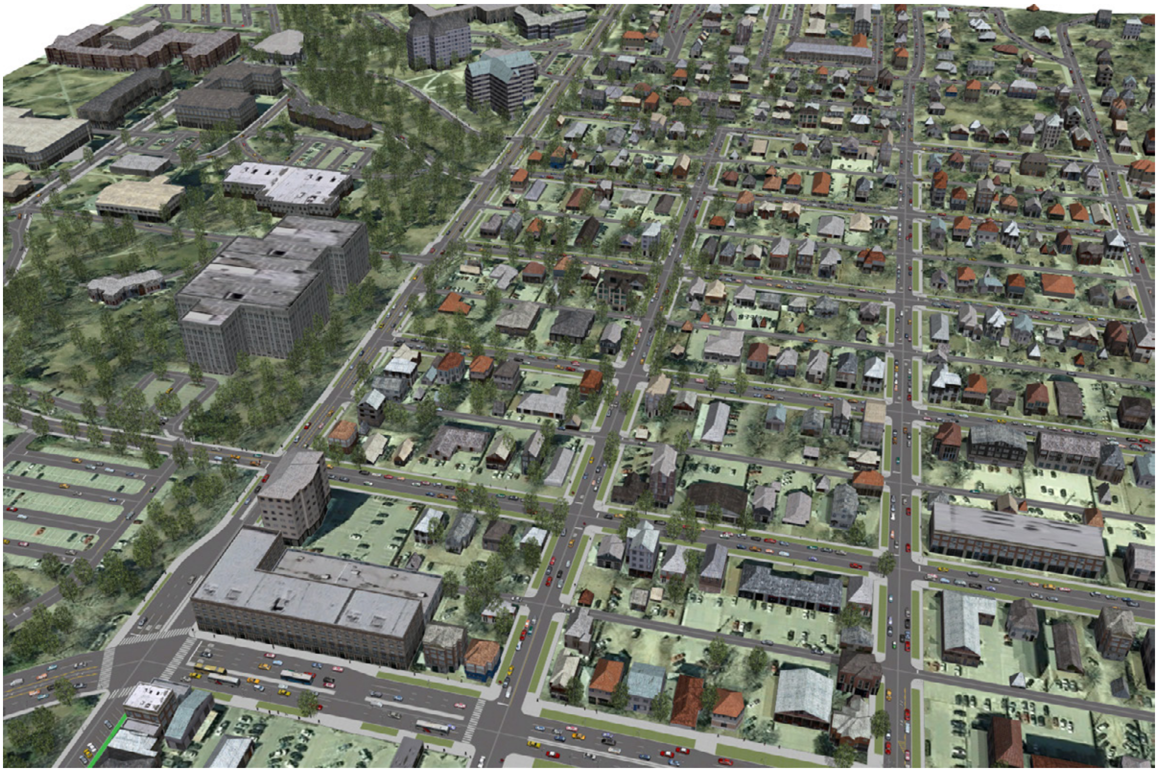


Figure 5.03: Proposed master plan of UCR District

Figure 5.04: Proposed master plan of UCR District

PHASES OF IMPLEMENTATION


Figure 5.05: Short-term with 2D Facades

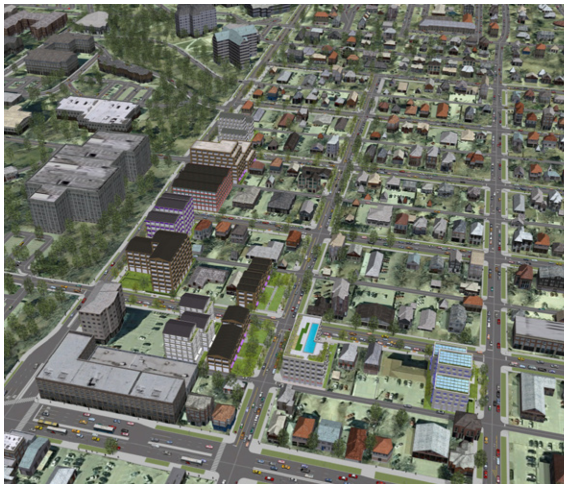


Figure 5.06: Short-term with 3D Facades


Figure 5.07: Mid-term with 2D Facades


Figure 5.08: Mid-term with 3D Facades


Figure 5.09: Long-term with 2D Facades


Figure 5.10: Long-term with 3D Facades

Figure 5.11: Long-term with 3D Facades

Figure 5.12: Long-term with 3D Facades

Figure 5.13: Two way traffic, right side parallel parking

Figure 5.14:Two-way traffic, curb buffer, single bike lane

Figure 5.15: Two-way traffic, parallel parking on both sides

Figure 5.16: Two-way traffic, elevated planter, bike lane

Figure 5.17: Left-hand angled parking, two-way traffic

Figure 5.18: Median-walkway, bike, vehicle, & bus lane

Figure 5.19:Vehicle lane, center walkway, HOV lane

Figure 5.20: Bike lanes, two-way traffic

Figure 5.21: Two-way bike lanes, vehicle and bus lane

Figure 5.22: Two--way traffic,two bike lanes

Figure 5.23: Two-way bike lane, planting-median, bus lane

Figure 5.24: two-way traffic with parallel parking

Figure 5.25: Bike lanes & two-way traffic

Figure 5.26: Two-way traffic, planting with benches

Figure 5.27: Two-way traffic, planting median

Figure 5.28:Four-way traffic and bike lanes

Report	N	Sum
Building Performance Baseline, Energy, Electrical Consumption (kWh/yr)	397	122749753.39
Building Performance Baseline, Energy, Heating Consumption (kWh/yr)	397	46333795.08
Building Performance Baseline, Waste, Domestic (kg/yr)	397	7713128.35
Building Performance Baseline, Water, Consumption (l/yr)	397	920072904.07
Building Performance Baseline, Water, Produced Blackwater (l/yr)	397	276021871.22
Building Performance Baseline, Water, Produced Greywater (l/yr)	397	644051032.85
Building Performance Target, Energy, Electrical Consumption (kWh/yr)	397	122089453.81
Building Performance Target, Energy, Heating Consumption (kWh/yr)	397	45934863.96
Building Performance Target, Energy, Solar Generated (kWh/yr)	2276	2938482.27
Building Performance Target, Waste, Domestic (kg/yr)	397	7651225.24
Building Performance Target, Water, Consumption (l/yr)	397	915395780.44
Building Performance Target, Water, Produced Blackwater (l/yr)	397	274618734.13
Building Performance Target, Water, Produced Greywater (l/yr)	397	640777046.31
Building Performance Target, Water, Recycled Greywater (l/yr)	397	1636993.27
Building, Footprint Area (m2)	89	33337.35
Building, Gross Floor Area (m2)	397	155638.19
Construction, Building Cost	397	220204516.99
Construction, Cut/Fill, Cost	172	0.00
Construction, Cut/Fill, Cut Volume (m3)	172	0.00
Construction, Cut/Fill, Fill Volume (m3)	172	0.00
Construction, Grass Area (m2)	201	19094.45
Construction, Grass Cost	201	190944.47
Construction, Hardscape Area (m2)	126	4907.79
Construction, Hardscape Cost	126	122694.70
Construction, Solar Panel Cell Area	2276	1610.13
Construction, Solar Panel Cost ($)	2276	1610127.27
Construction, Tree Cost	86	8600.00
Construction, Waste (kg)	397	2305684.76
Parcel, Area (m2)	35	57340.96
Parcel, Coverage (%)	89	2135.52
Parcel, Floor Area Ratio (Density)	397	99.00
Parcel, Green Space Area (m2)	137	24002.23
Site Conditions, Slope (%)	35	0.12
Site Conditions, Stormwater Runoff (m3/hr)	872	2383556.73
Speed:Braking Distance (ft)	1	117.58
Speed:Braking Reaction Distance (ft)	1	128.62
Speed:Stopping Sight Distance (ft)	1	246.20

Figure 5.29: Simplified CityEngine Report

BUILDING PERFORMANCE

Figure 5.30: Buildings used in performance calculation

The building performance metrics are based on the building uses set for 397 stories. This hypothetical master plan did not get into the detail of assigning specific building uses to each story, but the metrics give a rough estimate. If LEED certifications are given to buildings, building performance target metrics will generate so one can compare between the baseline and target to see the benefits. Only one building was changed to LEED certification so there was not much of a difference in the overall building performance. The cost of electricity per year is listed below assuming every kWh costs 12 cents.

Electric Consumption Baseline: $14,729,970
Electric Consumption Target: $14,650,734
Savings with 1 Eco-building: $79,236

SOLAR PANELS

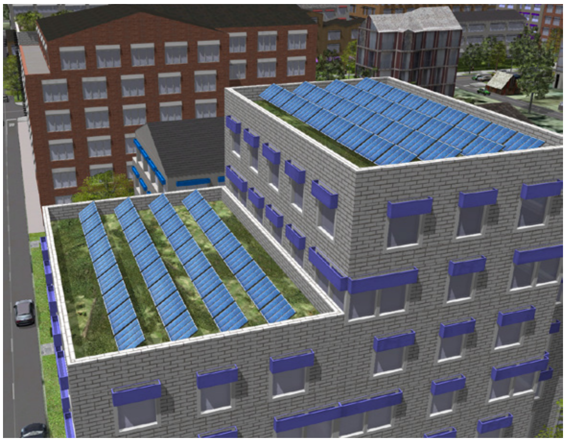


Figure 5.31: Greenroof with solar panels

Solar energy can also be produced to reduce energy costs. In the proposed UCR District there is 2,276 solar panels in an area of 17,331 square feet. The construction cost for all solar panels is $1,610,127. However, the solar panels are predicted to generate 2,938,482 kWh/yr. This reduces energy costs by $352,617 each year, so in roughly 4.5 years the developer could make a profit on their solar panel investment.

There are also numerous construction cost details that a developer can use to decide what size and quality of development they want to build. Probably the most important is building construction costs for the overall development of 397 stories which costs ~$220,200,000.

STORMWATER RUNOFF

Figure 5.32: Roof and greenspace surfaces for runoff

Stormwater runoff minimum or maximum requirements are sometimes included in government policies. CityEngine can predict the runoff volumes which saves money from hiring a civil engineer to do calculations. In the UCR District there were 872 surfaces with runoff calculations. Each surface is assigned a runoff coefficient based on the material. The size and slope of each surface is also used in the calculation. The total runoff in the UCR District is predicted to be 3,117,574 cubic yards/hr. The city can use this data to decide if they need to upgrade their sanitary sewer lines. It is unknown what type of storm these calculations are based on. Environmental conditions also have to be changed from Redlands, CA to Manhattan, KS to get more accurate results.

CITYENGINE WEB SCENE

Figure 5.33: CityEngine Web Scene with higher rendering detail than inside the CityEngine software

Figure 5.34: CityEngine Web Scene

Figure 5.35: Unity game with no shadows and a low compatibility with models (see vehicles and trees)

Figure 5.36: Unity scene with skybox, shadows, and fog

06 DISCUSSION

Utilizing ArcMap, ESRI CityEngine, and Unity was a sufficient method to create and communicate a master plan of the UCR District. This process can improve planning decisions while saving time and money. However, some challenges and limitations came about in this process. Multiple design scenarios could not be visualized by the public through CityEngine Web Scenes, because the model size was too large. This is a result of adding too much detail over a large area. Despite this, rules need to allow for more detail and customization. The more realistic the design and detail, the more accurate the feedback from the community will be (Gordon et. al., 2010; Daniel & Meitner, 2001).

CITYENGINE TOOLS AND RULES

This section discusses needed CityEngine tools and rule improvements to create more detail and customized models for lots, buildings, landscapes, and streetscapes. Challenges in transferring the CityEngine model to CityEngine Web Scenes and Unity are also discussed.

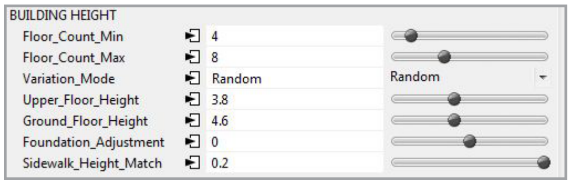


Figure 6.02: Aligning building elevation to sidewalk

Figure 6.03: Setting sidewalk height

LOTS

The automatically generated lots in the Complete Streets rule were a helpful tool to create conceptual lot configurations. However, this procedural lot rule lacks customization. More parameters

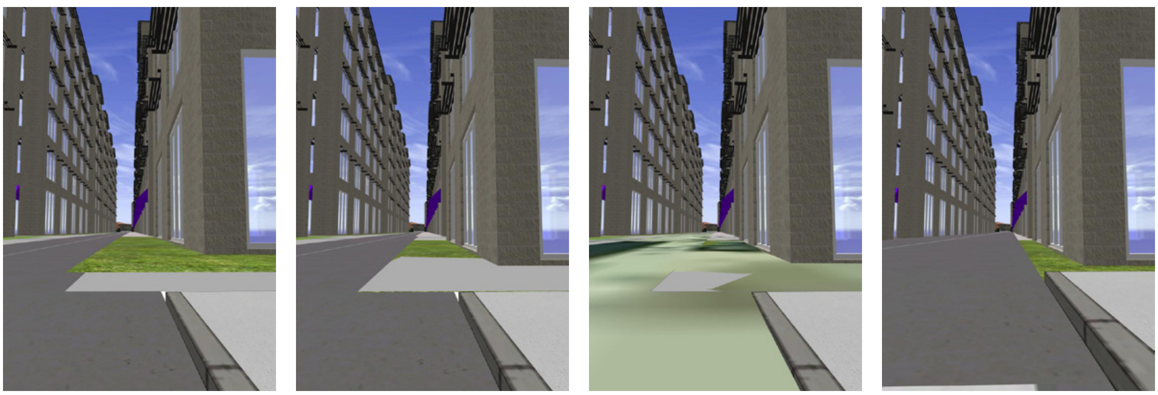


Figure 6.01: Challenges when layering data

need to be added to the rule to prevent lots from breaking into two rows between the street and alleyway (see on page 32). There is also a need for tools that would allow manual interaction with the procedural generated lots. It would be ideal to interactively drag the property lines in the rule to snap to existing property lines. To do this, it would be best to have the proposed lots transparent so existing lots could be seen underneath.

In the UCR District, lot polygons were manually drawn over existing lots which consumed a lot of time. As a result of manually drafting the lots on a different layer than the streets, many imperfections had to be corrected. Less problems would have occurred if the lots were drawn in ArcMap.

Figures 6.02 - 6.06 show the process of fixing elevations between lots, roads, sidewalks, and terrain with rule parameters. This is too time consuming to do for a large area. It is more effectively done by draping objects to the terrain and setting an offset (see Figure 6.07). However, as seen in Figure 6.08, some display problems still persist.

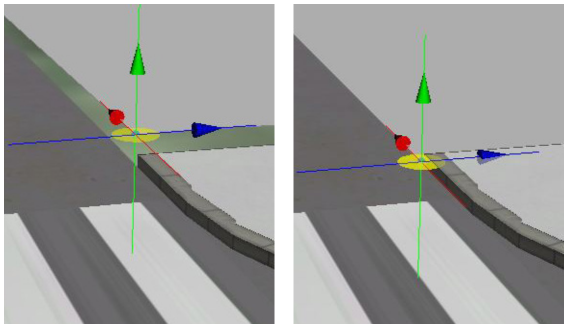


Figure 6.04: Aligning parcel corner to top of sidewalk

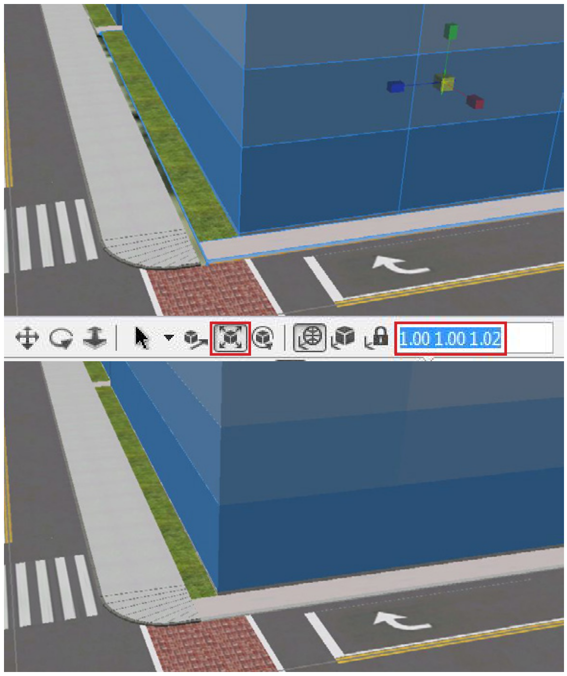


Figure 6.05: Aligning parcel to sidewalk using move tool

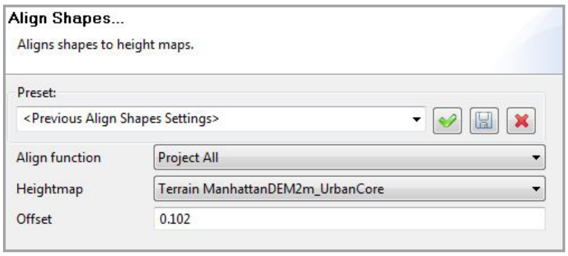


Figure 6.07: Aligning shapes to sidewalk height

Figure 6.08: Effect of aligning the terrain

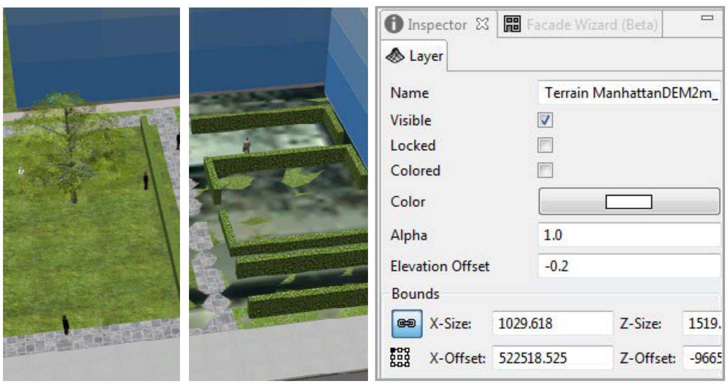


Figure 6.06: Lowering the terrain elevation to match with the greenspace

BUILDINGS

BUILDING FORM AND CONFIGURATION

The Building Construction rule can quickly model different building configurations and facades; however, it is tedious to make them realistic. Figures 6.10 - 6.12 illustrate lots with the same building styles applied to UCR District lots. To make the building configuration more random, lots have to be manually selected and assigned a new building style. To obtain further customization, different parameters such as setbacks and building heights can be changed manually in the inspector tab after the street edge is set (see Figure 6.14 & 6.15)

Once the buildings are in the desired location, facade styles can be selected from the styles template and applied (see Figure 6.13). The process of customizing building and facade styles and arrangement of buildings on the lots should be improved. CityEngine should add interactive tools so facades can be selected and dragged to a desired position to shape space in the master plan. The Building Construction rule should also add parameters to easily adjust building articulations. The UCR District building articulation requirements were not modeled because of the lack of tools to make customizations. The rule should also add a function to randomize the building styles amongst the parcels. It would be ideal if the rule could model theoretical planning concepts of how buildings on different parcels relate to each other and shape space.

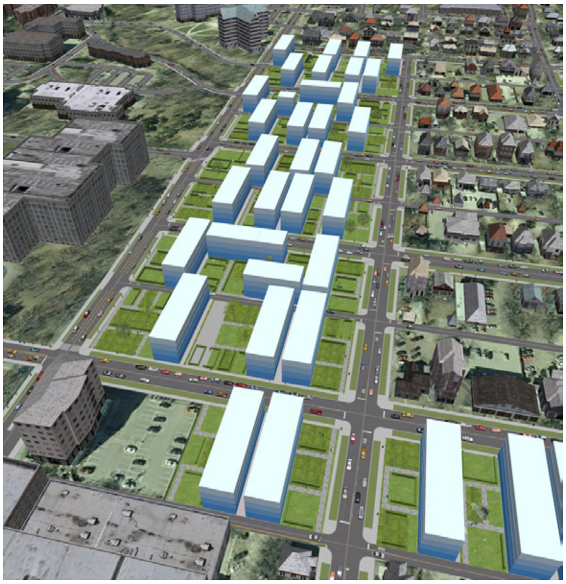


Figure 6.10: Low development intensity

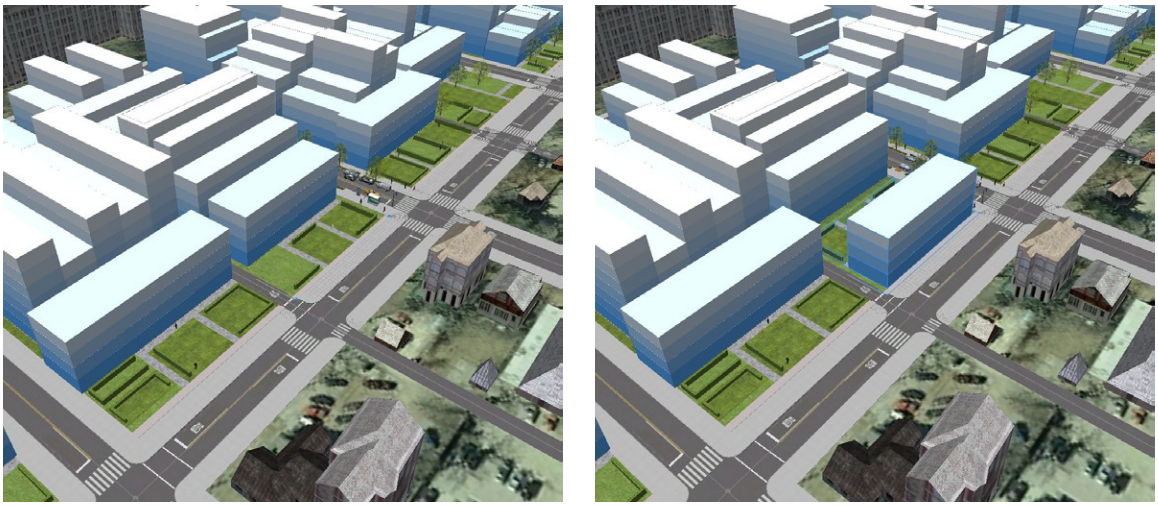


Figure 6.09: Changing building location using parameters after the street edge is set

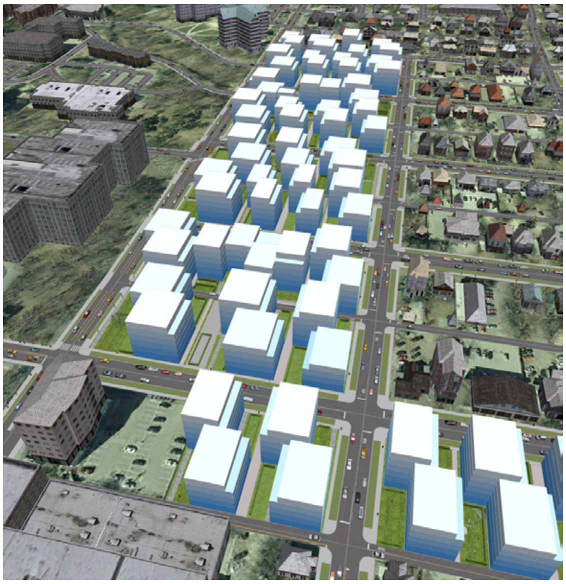


Figure 6.11: Medium development intensity

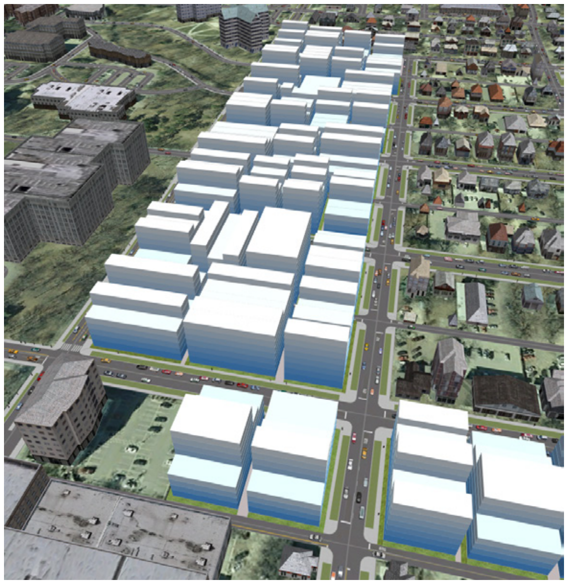


Figure 6.12: High development intensity

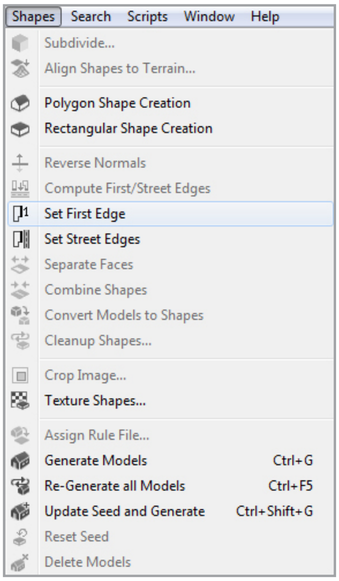


Figure 6.14: Setting street edge

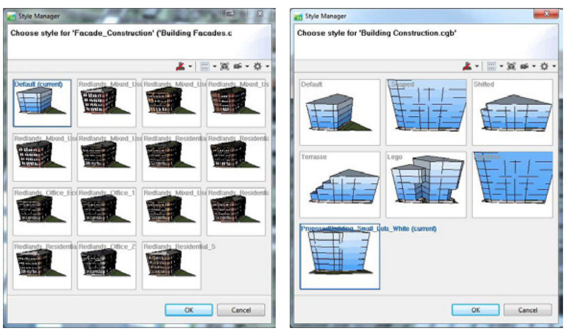


Figure 6.13: Building and Facade styles

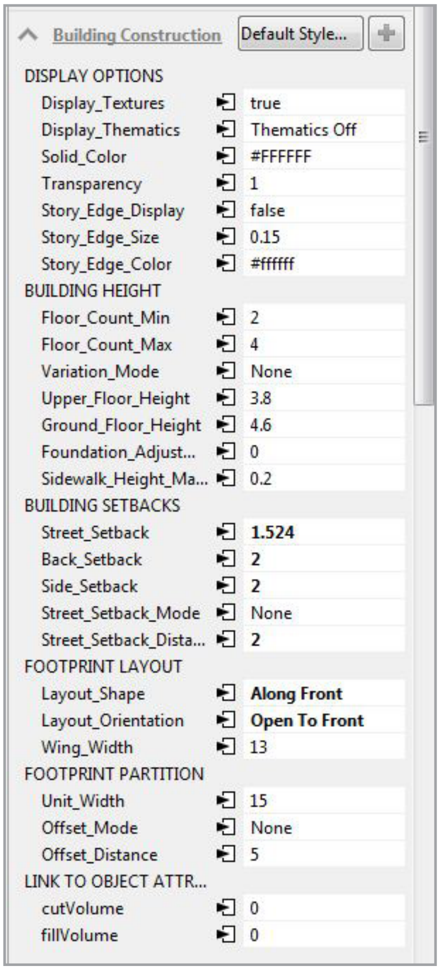


Figure 6.15: Customizing building form

FACADE DESIGN

The facade design parameters should be revised in the Building Construction rule to allow more customizations. The parameters allow several elements to be altered, but does not allow more than one material to be added to a facade. This prevented the accuracy of modeling the UCR District design standards. Percentage of windows also can not be adjusted to conform to the design standards. Interior parking structures should be included in the parameters. Parking structures were specified in the UCR District design standards, but were too difficult and time intensive to model. CityEngine users could save time if rules had more parameters and pre-styled building facades, which could be randomly applied to buildings. To apply facades in this project, buildings had to be manually selected sporadically throughout the design to create randomness (see Figure 6.16). The street edge then had to be set so awnings could be applied to the street front (see Figure 6.17). The rule only allowed one facade per building to have awnings, which should be revised in the rule so awnings can be applied to multiple building faces.

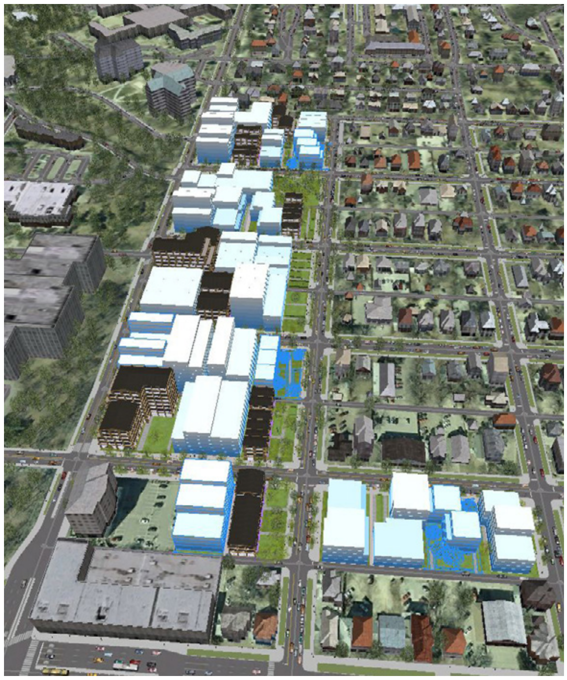


Figure 6.16: Customizing building form

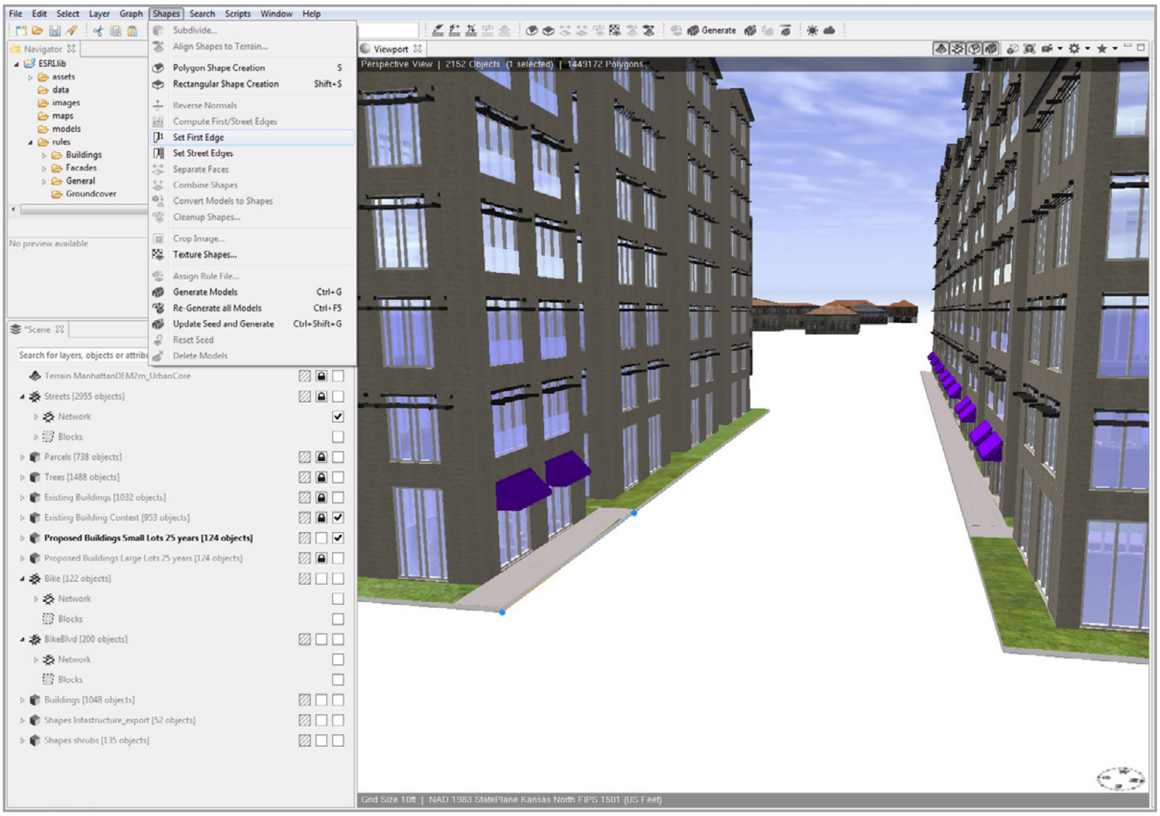


Figure 6.17: Applying awnings to the street front by setting street edge

LANDSCAPE

In addition to the buildings, the Building Construction rule was used to model the landscape on the parcels. The rule allows for formal or natural designs to be applied. The formal design was used in the UCR District and was customized for each lot to improve the design. It modeled 2D hedges, sidewalks, 2D grass, and 3D trees. The procedural landscape design parameters were sufficient. The rule could still be improved with interactive tools that allow one to select the exact location of sidewalks, trees, and plants. The rule lacks annuals and perennials and should include other LumenRT plants. LumenRT plants were used to populate a green roof in the UCR District (see Figure 6.18 & 6.19). These plant models would increase the scene size, but would make the model more realistic. CityEngine should create a rule that allows for these objects to be "painted" on the surface. The rule should also add parameters for seating, lighting, water features, sculptures, and pools.

Another helpful tool would be terrain editing that could create retaining walls, swales, and berms. In the hypothetical master plan, there was an idea of daylighting Campus Creek. This was not modeled because there are not grading tools in CityEngine that can do this. However, the creek bank could have been modeled in another program and brought into CityEngine.

That last dilemma using this rule was getting the sidewalk texture from the Building Construction rule to match with the sidewalk texture in the Complete Streets rule (see Figure 6.20 & 6.21). Even though the same jpg texture file was used, the textures and hues did not match.

Figure 6.18: Applying LumenRT plants to green roof

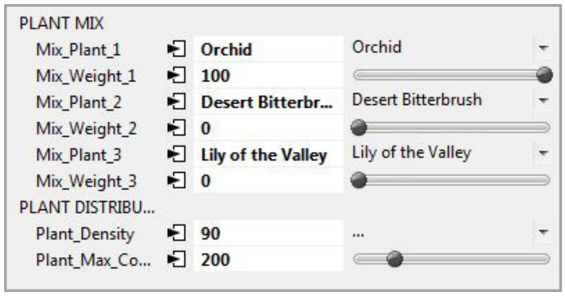


Figure 6.19: Procedurally populating plants

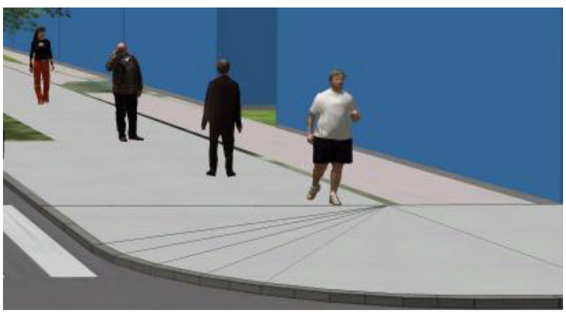


Figure 6.20: Viewing difference in sidewalk materials

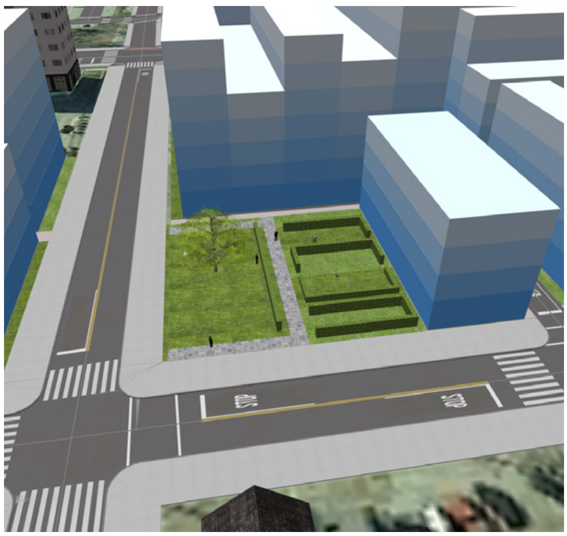


Figure 6.21: Viewing sidewalk materials from a distance

STREETSCAPE

The Complete Streets rule was used to model the streets and sidewalks. It contained many parameters to customize the design; however, more were added to increase the amount of assets that could be modeled on sidewalks. As seen on page 41, this process required scripting. The most difficult part of this was figuring out where assets would be placed and how to model the assets shape. It would have been helpful if CityEngine allowed interactive tools to click and place assets. The rule could then generate and save script about the asset location and shape so it could be applied elsewhere. The same process could be done for other road parameters (e.g. road centerline placement, parking location, and parking width). The street design can be simplified by including parameters such as one-way or two-way and number of lanes in each direction. Another parameter that could improve this rule is percent of parked bikes and percent of cyclists on sidewalks. Other parameters that were desired to model the UCR District include parking lots, parking structures, driveways, sidewalks not next to roads, and a gravel texture that could be applied to alleyways.

In addition to rule parameters, rules assets should be improved. The current asset folder contains minimal street signs, street lights, light poles, and no plants besides trees. The challenge is that compatible OBJ files downloaded from site furnishing websites do not display textures when used in CityEngine. The OBJ problem should be resolved by ESRI, but they should also change the way an asset is uploaded to the rule. Currently, a user must navigate to the asset folder and select an asset without seeing a preview. This process consumes too much time. The un-kown asset cube in Figure 6.23 is a result of activating a parameter before a stop sign was uploaded. Instead, a drop down menu with the model preview should be made to ease the workflow. The LumenRT annual and perennial plants should also be linked into the planter parameter on a drop down menu with different densities and configurations. The current rule only allows a 2D grass texture to be applied (see figures to right). The Complete Streets rule should allow the choice of low or high quality LumenRT plants to be used in the model like the facade parameters allow.

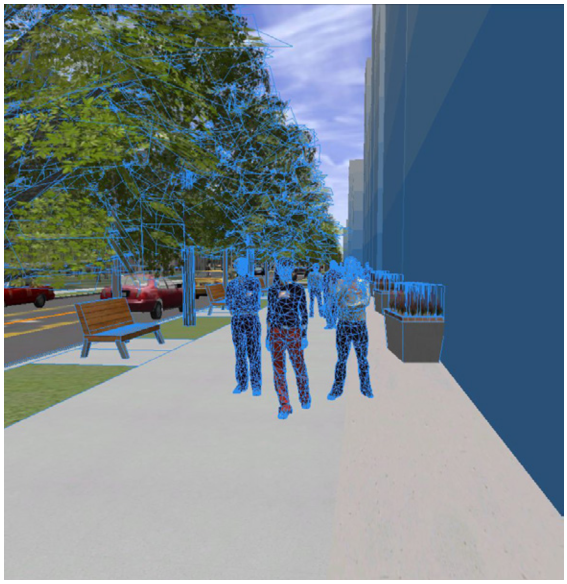


Figure 6.22: Adding more features to sidewalk

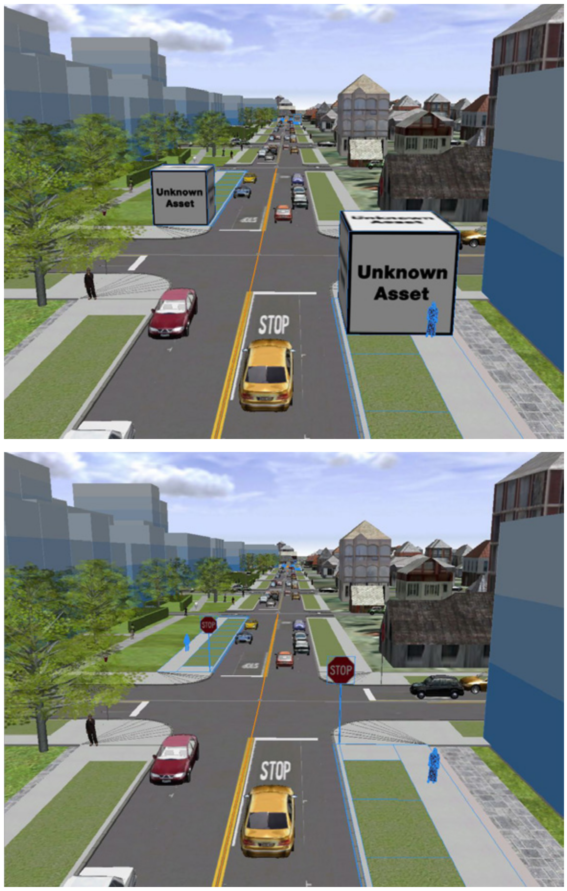


Figure 6.23: Loading objects to rule

PRODUCING A WEB SCENE

Transferring the CityEngine model to be viewed through other mediums is a critical process. If it does not work, one may have to settle for screen shots of your model in CityEngine. For this project there were problems exporting the UCR District model as a Web Scene. Errors occurred in the Web Scene export, but sometimes the Web Scene would still be successful. The main reason Web Scenes would not work is because the file was too large. Currently, ESRI recommends uploading Web Scenes around 15 MB (CityEngine- Exporting to CityEngine Web Scene (3ws), 2015). Many Web Scenes on the website are 20-30 MB and have little detail in them. To view a Web Scene with different design scenarios for a large area with realistic detail, Web Scene sizes would need to be around 1 GB. For this project a smaller area of context, less layers, and less detail was used to get the Web Scene to work. The file size was 80 MB and did not contain different design scenarios. To show different design scenarios or phases of implementation, multiple Web Scenes would have to be created. With this being said, CityEngine surprisingly did improve the display of the model. The quality of trees, shadows, and rendered material in the CityEngine Web Scene was better than inside the CityEngine software.

PRODUCING A UNITY GAME

To transfer the CityEngine model to Unity, the CityEngine model was exported as an FBX. There were no errors in exporting, however, the work to display textures in Unity took more effort than expected. The steps taken to display textures was short, but Unity should automatically do this or at least have more support to show new users the process. The next step was scaling the model larger so preconfigured game user controls could easily be used. To do this the X, Y, and Z shape had to be scaled individually and took a lot of time to process. The preconfigured game user script still had to be edited to change the height of the user and the motions, e.g. restricting a user from jumping in the clouds. This process is somewhat straight forward and is done by changing parameters. Adding the skybox, lighting, and shadows was also simple. However, it can be hard if watching tutorials on how to do it on a different Unity version. However, shadows should not be used with CityEngine model trees, vehicles, signs, or pedestrians because the FBX import of these models are not sufficient. If shadows are turned on for these objects they look adequate (see Figure 6.24), but once shadows are baked they look off. The ineffective shadow baking may also be a result of low material resolutions (see Figure 6.25). Instead, these objects should be added in Unity and then baked shadows can be applied for the game to run in real-time.

Figure 6.24: Shadows in Unity before bake

Figure 6.25: Shadows in Unity after bake

URBAN CORE RESIDENTIAL DISTRICT

SIZE OF CITYENGINE MODEL

If this project was to be repeated, the size of the model could have been reduced so multiple design scenarios could have been uploaded in the same Web Scene. To accomplish this, the CityEngine model would need to be no larger than 80 MB. The challenge would be reducing the file size while still retaining a high level of detail for the UCR District. However, this might not be possible. To do this, the site context would be shrunk to one block around the UCR District. This would reduce the number of existing buildings, existing trees, terrain data, and streets which were populated with thousands of models. The building textures would be set to low quality and the terrain resolution would be reduced. This would allow more memory to be spent on different building and streetscape scenarios. Attempts would also be made to add plant models to replace 2D grass textures in the streetscape using script. When the final model was to be exported, the texture quality setting would be set to half-size.

CONSULTING WITH THE CITY OF MANHATTAN

Early designs of the UCR District lacked creativity and could have been improved to create quality design alternatives. The City of Manhattan had strict design standards and only some were procedurally modeled in CityEngine (see page 24). Although not all shown, these design standards were used to model multiple development scenarios including different lot sizes, intensities, and phases of implementation. However, these models were focused on applying a rule to meet the design standards and not on forming space. This lead to the UCR District designs looking unrealistic with similar building heights and no concept of shaping space (see Figure 6.26). After this, the Building Construction rule was explored into great detail to figure out how to customize the design. A master plan was then created which followed many UCR District design standards (see Figure 6.27). When the design standards were updated after focus group meetings, CityEngine's procedural modeling made it easy to update the design. If the parameters to adjust designs would have been known earlier, the process of creating a master plan would have been smoother.

Figure 6.26: Extremely dense and unrealistic

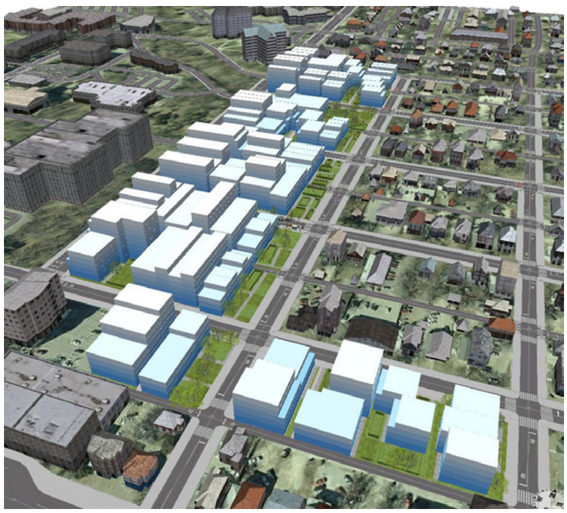


Figure 6.27: Customized plan that took more time

FUTURE WORK

Instead of only modeling the existing context and one option of the proposed development, multiple design alternatives could be modeled and uploaded as a Web Scene. The design scenarios could then be compared to one another visually and statistically by using the building, landscape, and streetscape reports in the rule (see page 41). A web survey could then be linked to the CityEngine Web Scene so the public can vote on which design they prefer. Due to size limits, multiple Web Scenes would have to be published to convey this information.

In addition to creating a CityEngine Web Scene (virtual world), the model could also be brought into gaming software where multi-user interaction and design modification can be programmed into the interaction of the game and uploaded as a virtual world (e.g., Maher, et. al., 2005; Rosenman, et. al., 2007; Koutsabasis, et. al., 2011). Gaming software (i.e. Unity, Unreal engine, or Cryengine) could also be used to make the virtual reality environment of the UCR District feel more realistic. This could be done by animating object movements, sound, weather, and the growth of the development through time. The game produced of the UCR District could then be viewed through more immersion by using haptic devices, panoramic screens, and/or virtual room environments so participants can make more accurate judgments on the designs (Griffon et al., 2011; Bishop et al., 2008)(more detail on pages 14-17). Other popular software including Lumion and LumenRT could also be used to animate and populate the UCR District with vegetation, vehicles, pedestrians, animals, and weather. This software could then be used to render images, animations, and in future cases, simulations which would all be in higher quality than CityEngine visuals. However, CityEngine visuals are great, considering that there is zero rendering time needed and no time spent on applying materials manually.

IMPROVING THE PLANNING PROCESS

If a CityEngine model was created earlier it could have been used to improve multiple steps within the nine phases of the planning process (see pg. 5).

2 An image or Web Scene of the model could have been used in conjunction with the student web survey to get more accurate results on whether students would want to live in the proposed UCR District.

4 Different conceptual streetscape options could have been modeled throughout the UCR District. A Web Scene and Unity game could have been used to better communicate the streetscape options. However, procedurally adding site furnishings is difficult. In this case Photoshop entourage could be placed on images taken from the model and included in the UCR District streetscape report. This report would eventually be used to assist a firm designing the streetscape and help get financial contracts approved by the city and public

6 A CityEngine model would have helped the city make better decisions for the preliminary design standards. The model would be most beneficial when determining building heights, min/max lot sizes, and setbacks. Screen-shots of the CityEngine model can be taken of these elements and dimensions can be annotated on top of them.

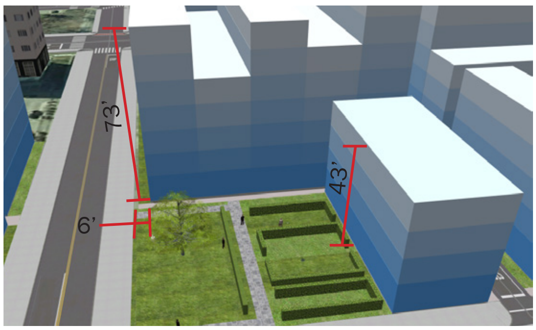


Figure 6.28: Annotated Screen-shot

6 Immediately following, the focus group meetings would have been improved if participants better understood the design and gave feedback on a Web Scene and Unity game. In this stage multiple design scenarios with different levels of building intensity should be modeled. The city could also email the Web Scene links

to members of the community to get further comments. After analyzing the feedback, the design standards could be revised along with the CityEngine models.

7 CityEngine Web Scenes that show design alternatives and the phases in which each alternative could be implemented would have been beneficial in public hearings. The public hearings would decide on the adoption of new policies including both the UCR District design standards and streetscape vision. The Web Scenes could be put on the city's website for the public and city commission to view in preparation for the hearing. If the vote was to not adopt, policies could be revised along with the CityEngine model for the next public hearing. Although not an objective in this project, a final master plan could be enforced by the city if adopted.

8 Before, or soon after the adoption of the new policies, the CityEngine Web Scenes can be used to market the UCR District and attract developers. In addition to having the Web Scene on the city's website, the link should be emailed to developers. Developers could also purchase ESRI CityEngine software and acquire the UCR District model to interact with metric reports to aid with their development (see Figure 6.31).

9 In the last stage of overseeing development, the Web Scene of the hypothetical master plan will be used as a guide on what to develop when and where. However, if a final master plan was enforced by the city, a Web Scene of the master plan would be heavily relied upon.

It is hard to assess the overall impact CityEngine would have if used throughout the UCR District planning process. It is acceptable to say that CityEngine would have improved everyone's understanding of what was being proposed throughout the city's planning process. This would eventually lead to better feedback so informed design decisions could be made prior to the adoption of rezoning policies. In addition, using CityEngine construction reports and Web Scenes for marketing would likely speed up the implementation of the UCR District. CityEngine can also improve the design process for new developments in the district.

Figure 6.29: CityEngine Web Scene


Figure 6.30: Panoramic screen to view CityEngine Web Scene during public hearing with more immersion

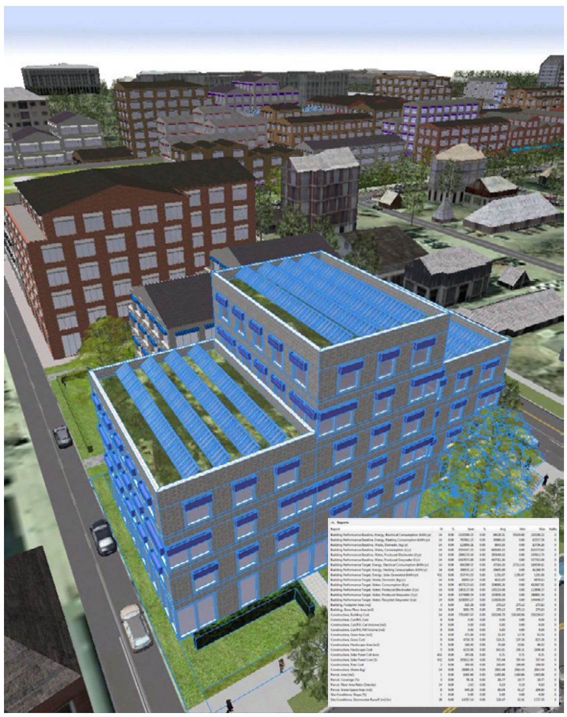


Figure 6.31: Developers use CityEngine for metrics

IMPROVING THE DESIGN PROCESS

CITYENGINE IN THE MASTER PLANNING PROCESS

The current CityEngine rules can improve the workflow of landscape architects, urban designers, and planners when creating master plans for urban development. CityEngine is commonly used to produce models of urban development procedurally for games and movies at a low cost (Muller, et. al., (2006). However, design fields also need to take advantage of effective modeling tools (Santos, et. al., 2011). As seen in this report, CityEngine can be an effective master planning tool for landscape architects, urban designers, and city planners. It can model realistic building configurations, facades, landscapes, and streetscapes. This model can then be used to engage the community and facilitate feedback for improved decision-making throughout the design process (Griffon et al., 2011; Bishop et al., 2008).

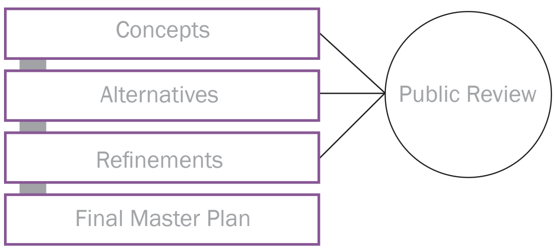


Figure 6.32: Master Planning Process

In the conceptual planning stage, the Building Construction rule can be used to automatically generate building configurations with 2D facades. The configuration of the buildings would have to be adjusted through parameters, but any overlaying data between streets and lots would not need fixed in this stage. The low detailed concepts can be published as Web Scenes to inspire stakeholders to think about future development in charrettes. The Web Scene URL can also be sent to community organizations and put on a city's website for the public to comment on if they cannot make it to a charrette.

The conceptual designs could then be refined to produce real master plan alternatives based on public feedback. More detail should be added to the model and obvious errors from overlaying data should be fixed. In this stage, graphics of the reports are necessary and should be produced for all alternatives. Low detailed Web Scenes with the option of facades should be published and sent out to the public and community organizations along with visuals produced of the reports. A survey could also be made so the public could vote for their preferred option on-line. These visuals could then be used in focus group meetings to improve their decision-making process on which master plan option is best. In addition, a game that allows an interactive walk-through of each design could also be quickly produced so people in the focused group meetings could have a sense of how the space would feel. The feedback from this can be used to make refinements to the final master plan option that was most preferred. It may also be used to change the design standards for the area.

Eventually, one last Web Scene, game, and graphic report would be produced to market the design. These would be used to create public awareness and attract developers. Meanwhile, the CityEngine model should be made available to developers so they can explore the cost reports of construction. Developers would first have to purchase CityEngine Basic for $500. Once they have the software they would be able to easily click on specific buildings and see reports to help them decide what kind of development they want to pursue. The CityEngine model could also be shared with design firms doing specific site designs within the master plan.

CITYENGINE USE IN SITE DESIGNS

Firms doing site designs can not create customized detailed designs with the current rule set, but CityEngine could be used to view their design in context. In the future, rules may be improved to allow site designing. This would allow firms to use CityEngine to quickly model customized buildings, landscapes, and streetscapes. Multiple schematic design scenarios could be modeled. Once a client narrowed it to one design, the CityEngine model could be exported appropriately and brought into a CAD or BIM software to generate construction documents. However, before construction documents would be produced, the model created in CityEngine would have to be traced over, and in this process further detail could be added. There is a process to regenerate CityEngine models into different software, but it is a very difficult task and requires a combination of reports, console prints, and python scripts (Buehler, 2012). New tools and/or plug-ins would need to be produced to allow users to edit and interact with CityEngine models in other software.

Since rules currently do not allow for enough customizations to create unique designs, CityEngine should not be used to design in the schematic or design development phases. Instead, designers should continue their method of modeling their designs through manual hand craft modeling software, i.e. Google Sketch-up, and then that model should be exported into a CityEngine model with context to ensure defensibility of the design (Sheppard et. al., 2011).The context model created in CityEngine and the detailed site design model could also be joined together in other rendering software that allows the use of haptic devices and animated objects like gaming software.

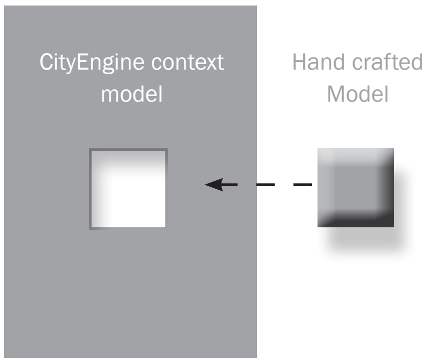


Figure 6.33: Creating context model in CityEngine and inserting other hand crafted models from software like Google Sketch-up

SAVING TIME AND MONEY

The procedural modeling capabilities of CityEngine are able to create master plans or site context quicker than any 2D or 3D modeling software. As seen in Figure 6.30, procedural modeling software can save money by reducing the amount of time spent modeling compared to manual (hand-crafted) modeling. Detailed master plans can also be generated in CityEngine quicker than building footprints can be drafted using 2D CAD programs. If CAD was used, a site plan would have to be imported into a program like Adobe Photoshop to be rendered. To interpret a 2D site plan correctly, it would also have to be verbally communicated. If it were a simulation like CityEngine Web Scenes, it would be easier for people to understand, because it is similar to how people experience real space (Dorval & Pepin, 1986). CityEngine Web Scenes allow the public and clients to view and provide feedback to the designs without a facilitator. CityEngine can also automatically generate metric reports for designs, e.g., cost estimation (see page 40-41). Creating reports through Envision Tomorrow or other personal Excel spreadsheets are time intensive and require manual inventory of square footage and other details which CityEngine can do automatically. These reports can then be used by clients to decide how they want to spend or save money.

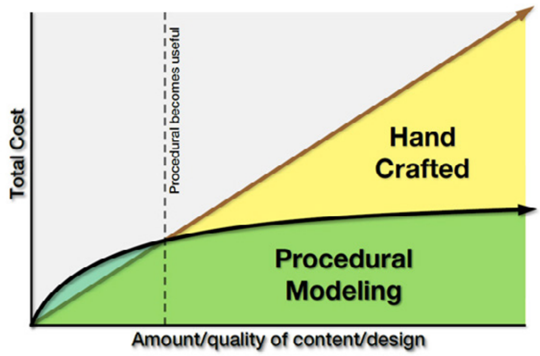


Figure 6.34: Procedural vs Manual hand crafted models

Further time and money could be saved if certain tools and rules were improved in CityEngine. Most of the time working in CityEngine involved collecting, editing, and customizing rules. To reduce this, ESRI should invest in CityEngine scripters who can improve the rules. As discussed in the CityEngine Tools and Rules sections on page 24, ESRI should also create tools that are able to interactively customize and adjust rules in the main viewport. To increase visual engagement, animation components should be added to procedurally animate vehicles, cyclists, and pedestrians in accordance with OSM data. This would eliminate the need to purchase LumenRT. ESRI also has many plug-ins and export options to other rendering software, but if CityEngine was able to render videos and animations, CityEngine may become more desirable to firms, since they would not need to purchase additional rendering software.

07 CONCLUSION

This project used CityEngine rules to model a realistic detailed hypothetical master plan for the proposed UCR (Urban Core Residential) District in Manhattan, Kansas. The final visuals, included a CityEngine Web Scene and a Unity game. These visuals would eventually be used to assist in the adoption process of new policies, create public awareness, and attract developers to the UCR District. This paper was one of the first to analyze how ESRI CityEngine could be used and improved to support the workflow of landscape architects, urban designers, and planners for urban development projects. Main challenges were using ESRI rules to make customized designs and transferring the model to other digital mediums. However, despite the challenges of this software it can be used to create cost effective 3D interactive visualizations with metric reports that can improve the decision-making process for urban development projects.

Figure 7.01: Hypothetical UCR District Master Plan

08 GLOSSARY

ANIMATION: the illusion of object movement through slight differences in rendered frames.

AUGMENTED REALITY (AR): a real environment with the addition of computer-generated data; also referred to as mixed-reality (MR).

BUILDING INFORMATION MODELING (BIM): retaining model data that represents physical objects within a system that can be used to collaborate.

COMPUTER AIDED DESIGN (CAD): is the process of using a computer system to assist in the process of creating 2D or 3D designs.

COMPUTER GENERATED ARCHITECTURE (CGA): the process of using shape gramar (script) to define rules that can create 2D or 3D models.

COMMUNITY ENGAGEMENT: the process of which members of a community become involved and attracted.

ESRI CITYENGINE: a procedural modeling software referred to as CityEngine.

GEOGRAPHIC INFORMATION SYSTEM (GIS): a computer system the enables the storage of data to be linked to positions on Earth's surface.

HAPTIC DEVICE: creates the sense of touch and movement when interacting with a virtual world.

IMAGE: a still 2D representation of a physical thing.

IMMERSION: the sense of presence in a virtual world.

MASTER PLAN: a long-term, large scale plan that eventually encompasses smaller projects.

SIMULATION: the process of interacting with digital space in real-time

VIDEO: the recording of rendered frames with no computer animated objects.

VIRTUAL ENVIRONMENT (VE OR VRE): the representation and interaction with a non-existent space with large screens or monitors that enhance immersion.

VIRTUAL REALITY (VR): feeling present in a non-existent space through real-time interaction.

VIRTUAL WORLD (VW): interacting in real-time with a non-existent space on-line that allows social interactions.

3D INTERACTIVE VISUALIZATION: three-dimensional graphics that allow actions to be taken to navigate through information (e.g., VE, VR, VW).

09 REFERENCES

ANDERS, PETER. (1999). Envisioning Cyberspace - Designing 3D Electronic Spaces. New York : McGraw-Hill.

BALL, J., CAPANNI, N., AND WATT, S. (2007). "Virtual Reality for Mutual Understanding in Landscape Planning." Vol: 1, No: 11, 2007.

BATTY, M. (2007). Planning support systems: progress, predictions, and speculations on the shape of things to come.

BECKER-ASANO, C., RUZZOLI, F., HOLSCHER, C., NEBEL, B. (2014). A multi-agent system based on Unity 4 for virtual perception and wayfinding. Science Direct-Transportation Research Procedia 2 (2014) 452-455. doi:10.1016/j.trpro.2014.09.059

BERTOL, D. AND FOELL, D. (1997). Designing Digital Space – An Architect's Guide to Virtual Reality. John Wiley & Sons, Inc.

BEST PRACTICE COMMUNITY ENGAGEMENT TECHNIQUES. (2013). Neighbourhood Planning Guidance Note 12. Retrieved Jan. 24, 2016, from https://www.herefordshire.gov.uk/media/6312587/12_best_practice_community_engagement_techniques.pdf

BILKE, L., FISCHER, T., HELBIG, C., KRAWCZYK, C., NAGEL, T., NAUMOV, D., PAULICK, S., KARSTEN, R., SACHSE, A., SCHELENZ, S., WALTHER, M., WATANABE, N., ZEHNER, B., ZIESCH, J., KOLDITZ, O. (2014). TESSIN VISLab-laboratory for scientific visualization. Environmental Earth Sciences. November 2014, Volume 72, Issue 10, pp 3881-3899.

BISHOP, I., STOCK, C., & WILLIAMS, K. (2008). Using virtual environments and agent models in multi-criteria decision-making. Land Use Policy 26, pg. 87-94. doi:10.1016/j.landusepol.2008.01.010

BOSE, M., HORRIGAN, P., DOBLE, C., & SHIPP, S. C. (2014). Community matters: Service-learning in engaged design and planning. Routledge.

BOSSELMANN, PETER. (1998). Representation of Places – Reality and Realism in City Design. University of California Press.

BRATTETEIG, T, WAGNER, I. (2010). Spaces for Participatory Creativity. In Proc. 11th Biennial Participatory Design Conference, PDC '10, pp., New York, NY, USA. ACM.

BROOKS, P. JR., FREDERICK. (1999). What's Real About Virtual Reality?

BUEHLER, MATTHIAS. (2012). GeoNet. Retrieved April 08, 2016, from https://geonet.esri.com/thread/63595

BYSTROM, K., BARFIELD, W., AND HENDRIX, C. (1999). "A Conceptual Model of the Sense of Presence in Virtual Environments." Presence: Teleoperators and Virtual Environments 8 (2): 241–44. doi:10.1162/105474699566107.

CHMIEL, BEN. (2015, December). Urban Core Residential meeting with Architects and Developers. Session held at City Hall by the City of Manhattan.

CITY ENGINE EXAMPLE: REDLANDS REDEVELOPMENT. (2014). Retrieved April 06, 2016, from https://www.esri.com/~/media/Files/Pdfs/library/brochures/pdfs/cityengine-example-redlands.pdf

CITY OF MANHATTAN. (2015). Urban Core Residential Streetscape Vision. Manhattan, KS.

CITY OF MANHATTAN. (2016). UCR Draft 1/28/16 Final Draft. Manhattan, KS.

CITYENGINE – IMPORTING DATA FROM OSM. (2015). Retrieved March 25, 2016, from http://cehelp.esri.com/help/index.jsp?topic=/com.procedural.cityengine.help/html/manual/import/osm.html

CITYENGINE- EXPORTING TO CITYENGINE WEB SCENE (3ws)-. (2015). Retrieved April 07, 2016, from http://cehelp.esri.com/help/index.jsp?topic=/com.procedural.cityengine.help/html/manual/export/export_formats_3ws.html

COLLABORATIVE STAKEHOLDER ENGAGEMENT AND APPROPRIATE DISPUTE RESOLUTION. (2009). Bureau of Land Management (BLM) National Natural Resources Policy.

CRARY, J. (1992). Techniques of the observer: on vision and modernity in the nineteenth century. mit Press.

CUBUKCU, EBRU. (2010)."Does the level of visual detail in virtual environments affect the user's spatial knowledge?" Volume 38: pg. 741752.

DANIEL, T. & MEITNER, M. (2001). Representational Validity of Landscape Visualizations: The Effects of Graphical Realism on Perceived Scenic Beauty of Forest Vistas. Journal of Environmental Psychology 21, 61-72. Copyright Academic Press.

DE JONG, T. (2005). The guided discovery principle in multimedia learning. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (pp. 215–228). New York: Cambridge.

DEANE, RYAN, (2015a). The Emerging Role of Millennials. Retrieved Dec. 11, 2015, from http://thefield.asla.org/2015/02/04/the-emerging-role-of-millennials/#more-3450

DEANE, RYAN, (2015b). 3 Tools That Will Change How You Design. Retrieved Dec. 11, 2015, from http://thefield.asla.org/2015/10/01/3-tools-that-will-change-how-you-design/

DORVAL, M., PEPIN, M. (1986). Effect of Playing a Video Game on a Measure of Spatial Visualization. Perceptual and Motor Skills: Volume 62, Issue, pp. 159-162.

EDGERTON, S. Y. (1978). The Renaissance rediscovery of linear perspective.

ENGAGING QUEENSLANDERS- A GUIDE TO COMMUNITY ENGAGEMENT METHODS AND TEQNIQUES (2007). Queensland Government Department of Communities.

ENVISION TOMORROW. (n.d.). Retrieved March 25, 2016, from http://www.envisiontomorrow.org/faq/

ERDAN, GU., STOCKER, C., AND BADLER, N. (2005). Do You See What Eyes See? Implementing Inattentional Blindness. University of Pennsylvania Scholarly Commons.

ERMI L, AND MAYRA F. (2005). Fundamental components of the gameplay experience: analyzing immersion, in Proceedings of the 2005 DiGRA Conference: Changing Views-World in Play 16-20 June, Vancouver, BC, http://www.digra.org/dl/db/06276.41516.pdf

ERVIN, S. M. (1998), Answering the 'What Ifs.' – In: Landscape Architecture Magazine, 10: 64-73.

ESRI CITYENGINE. (n.d.). Retrieved January 15, 2016, from http://www.esri.com/software/cityengine/features

EXAMPLE COMPLETE STREETS 2014. (2015). Retrieved April 06, 2016, from http://www.arcgis.com/home/item.html?id=5121e7e7621c4c80930462e92e965f18

FAGA, B. (2006). Designing Public Consensus. The civic Theater of Community Participation for architects, landscape architects, planners and urban designers.

FIRLEY, ERIC; GROEN, KATHARINA. (2014). Urban Masterplanning Handbook, The. Wiley.

FLACHBART, G. & WEIBEL, P. (Eds.). (2005). Disappearing architecture from real to virtual to quantum. Basel: Birkhäuser.

GIBSON, J., JAMES. (1978). The Ecological Approach to the Visual Perception of Pictures. Leonardo, Vol. 11, pp. 227-235. Retrieved April 1, 2016 from, http://classes.matthewjbrown.net/teaching-files/ccc/gibson.pdf

GOGG, T. J., & MOTT, J. R. (1993). Improve quality & productivity with simulation. Norcross, GA: In¬dustrial Engineering Management Press.

GORDON, E., STEVEN S., AND HOLLANDER, J. (2010).”Immersive planning: a conceptual model for designing public participation with new technologies.” Volume 38: pg. 505519.

GREGORY, R., FAILING, L., HARSTONE, M., LONG, G., MCDANIELS, T., & OHLSON, D. (2012). Structured decision making: a practical guide to environmental management choices. John Wiley & Sons.

GRIFFON, S., NESPOULOUS, A., CHEYLAN, J., MARTY, P., & AUCLAIR, D. (2011). Virtual reality for cultural landscape visualization. Virtual Reality, 15(4), 279-294. doi:http://dx.doi.org.er.lib.k-state.edu/10.1007/s10055-010-0160-z

HELBIG, C., BAUER, H. S., RINK, K., WULFMEYER, V., FRANK, M., & KOLDITZ, O. (2014). Concept and workflow for 3D visualization of atmospheric data in a virtual reality environment for analytical approaches. Environmental Earth Sciences, 72(10), 3767-3780.

HALATSCH, J., KUNZE, A., & SCHMITT, G. (2008). Using shape grammars for master planning. In Design Computing and Cognition’08 (pp. 655-673). Springer Netherlands.

HESTER, R., HOU, J., ALLEN, D., PENA, DAVID., LAWSON, L. (2015). Together We Design: Landscape Architects Offer Their Best Techniques For Transactive Form-Making. Retrieved Jan. 24, 2016, from http://ldachair.ucdavis.edu/LDA-faculty-docs/DdlP/ddlp03-Together_We_Design_final.pdf

HOLLANDER, J. B. (2011). Approaching an Ideal: Using Technology to Apply Collaborative Rationality to Urban Planning Processes. Planning Practice & Research, 26(5), 587-596.

INTRODUCTION TO STAKEHOLDER PARTICIPATION. (2007). Social Science Tools for Coastal Programs. NOAA Coastal Services Center. Retrieved Jan. 24, 2016, from http://permanent.access.gpo.gov/gpo1257/Stakeholder_Participation_Guidance_Document.pdf

IOVAN, C., BOLDO, D., & CORD, M. (2008). Detection, characterization, and modeling vegetation in urban areas from high-resolution aerial imagery.Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of, 1(3), 206-213.

IRVIN, R. A., & STANSBURY, J. (2004). Citizen participation in decision making: Is it worth the effort?. Public administration review, 64(1), 55-65.

JONES, B., SODHI, R., MURDOCK, M., MEHRA, R., BENKO, H., WILSON, A., OFEK, E., MACINTYRE, B., RAGHUVANSHI, N., SHAPIRA, L. (2014). RoomAlive: Magical Experiences Enabled by Scalable, Adaptive Projector-Camera Units. Microsoft Research, Redmond; University of Illinois at Urbana-Champaign; University of Southern California; UNC Chapel Hill; Georgia Tech.

KOTTER, J. P. (1996). Leading change. Harvard Business Press.

KOUTSABASIS, P., VOSINAKIS, S., MALISOVA, K., & PAPAROUNAS, N. (2012). On the value of virtual worlds for collaborative design. Design Studies, 33(4), 357-390.

LAMKIN, PAUL. (2016). The Best VR headsets. Retrieved April 04, 2016, from http://www.wareable.com/headgear/the-best-ar-and-vr-headsets

LANGE, E., & BISHOP, I. D. (Eds.). (2005). Visualization in landscape and environmental planning: technology and applications. Taylor & Francis.

LUMENRT: IMMERSIVE VISUALIZATION FOR ARCHITECTURE & GEODESIGN. (n.d.). Retrieved Jan. 25, 2016, from http://www.lumenrt.com/

LUMION. (2015). Retrieved Jan. 25, 2016, from, http://lumion3d.com/products/

MAHER, M. L., LIEW, P. S., GU, N., & DING, L. (2005). An agent approach to supporting collaborative design in 3D virtual worlds. Automation in Construction, 14(2), 189-195.

MARCO, J. (2015). List of Haptic Controllers under Development for Virtual Reality. Retrieved April 04, 2016, from http://www.virtualrealitytimes.com/2015/03/13/list-of-haptic-controllers-virtual-reality/

MCCANN, E. J. (2001). Collaborative Visioning or Urban Planning as Therapy? The Politics of Public Private Policy Making. The Professional Geographer, 53(2), 207-218.

MCLELLAN, H. (1996). Virtual realities. Handbook of research for educational communications and technology, 457-487.

MÜLLER, P., WONKA, P., HAEGLER, S., ULMER, A., & VAN GOOL, L. (2006). Procedural modeling of buildings. Acm Transactions On Graphics (Tog),25(3), 614-623.

NEUENSCHWANDER, N., HAYEK, U. W., & GRÊT-REGAMEY, A. (2014). Integrating an urban green space typology into procedural 3D visualization for collaborative planning. Computers, Environment and Urban Systems, 48, 99-110.

OKUBO, D. (2000). The community visioning and strategic planning handbook. National Civic League Press, Denver.

PAAR, P. (2005). Landscape visualizations: Applications and requirements of 3D visualization software for environmental planning. Computers, environment and urban systems, 30(6), 815-839.

PATRICK, BROOKS. (2015, November 7). Personal interview.

PETTIT, C., RAYMOND, C., BRYAN, B., AND LEWIS, H. (2011). “Identifying Strengths and Weaknesses of Landscape Visualization for Effective Communication of Future Alternatives.” Landscape and Urban Planning 100 (3): 231–41. doi:10.1016/j.landurbplan.2011.01.001.

PLASS, J., HOMER, B., AND HAYWARD, E. (2009). Design factors for educationally effective animations and simulations. US Government.

PRENSKY, M. (2001). The games generations: How learners have changed.Digital game-based learning, 1.

ROBERTSON, G. G., CARD, S. K., & MACKINLAY, J. D. (1993). Information visualization using 3D interactive animation. Communications of the ACM, 36(4), 56+.

RODIL, KASPER, HEIKE WINSCHIERS-THEOPHILUS, AND KASPER L. JENSEN. (2012). “Enhancing Cross-Cultural Participation Through Creative Visual Exploration.” In Proceedings of the 12th Participatory Design Conference: Research Papers - Volume 1, 81–90. PDC ’12. New York, NY, USA: ACM. doi:10.1145/2347635.2347647.

ROGERS, DONNA L. (2000). “A Paradigm Shift: Technology Integration for Higher Education in the New Millennium.” AACE Journal 1 (13): 19–33.

ROSENMAN, M. A., SMITH, G., MAHER, M. L., DING, L., & MARCHANT, D. (2007). Multidisciplinary collaborative design in virtual environments. Automation in Construction, 16(1), 37-44.

SALDAÑA, M., & JOHANSON, C. (2013). Procedural modeling for rapid-prototyping of multiple building phases. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 5, W1.

SANTOS, D. S., DIONÍSIO, M., RODRIGUES, N., PEREIRA, A., & LEIRIA, I. I. I. (2011). Efficient Creation of 3D Models from Buildings’ Floor Plans.

SHEPPARD, S. (2001), Guidance for crystal ball gazers: developing a code of ethics for landscape visualization. – In: Landscape and Urban Planning, 54 (1-4): 183-199.

SHEPPARD, S. (2005). “Landscape Visualization and Climate Change: The Potential for Influencing Perceptions and Behavior.” Environmental Science & Policy, Mitigation and Adaptation Strategies for Climate Change, 8 (6): 637–54. doi:10.1016/j.envsci.2005.08.002.

SHEPPARD, S., SHAW, A., FLANDERS, D., BURCH, S., WIEK, A., CARMICHAEL, J., ROBINSON, J., COHEN, S. (2011). Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualization, Futures, Volume 43, Issue 4, Pages 400-412, ISSN 0016-3287, http://dx.doi.org/10.1016/j.futures.2011.01.009.

SOLOMON, G., & SOLOMON, S. (1995). Technology and professional development – 10 tips to make it better. Learning & Leading with Technology; 28-29, 71.

STAKEHOLDER ENGAGEMENT STRATEGIES FOR PARTICIPATORY MAPPING. (2009). Social Science tools for Coastal Programs. NOAA Coastal Services Center. Retrieved Feb. 24, 2016, from http://permanent.access.gpo.gov/gpo1969/participatory_mapping.pdf

STEINER, F. R. (2012). The living landscape: an ecological approach to landscape planning. Island Press.

STEINER, F. R., BUTLER, K., & AMERICAN PLANNING ASSOCIATION. (2012). Planning and urban design standards. John Wiley & Sons.

STEINITZ, C., FLAXMAN, M., MOUAT, D., ARIAS, H., GOODE, T., PEISER, R., BASSETT, S., MADDOCK, T., SHEARER, A. (2003). Alternative futures for changing landscapes: the upper San Pedro River Basin in Arizona and Sonora. Island press.

STEPHENS, JOSH. (2015). Feature> Making by Seeing. The Architects Newspaper.

STEUER, JONATHA. (1993). Defining Virtual Reality: Dimensions Determining Telepresence.

SUTHERLAND, E., IVAN. (1988). Sketchpad - A Man-Machine Graphical Communication System.

TOBIAS, S., BUSER, T., & BUCHECKER, M. (2016). Does real-time visualization support local stakeholders in developing landscape visions?. Environment and Planning B: Planning and Design, 43(1), 184-197.

TOWNE, D. M. (1995). Learning and instruction in simulation environments. Englewood Cliffs, NJ: Educational Technology Publications.

TWITCHEN, C., & ADAMS, D. (2011). Increasing levels of public participation in planning using web 2.0 technology. Birmingham City University Centre for Environment and Society Research Working Papers, 5, 1-10.

WAGNER, I., ET AL. (2009). Supporting community engagement in the city: urban planning in the MR-Tent. In: Proceedings of C&T, 185–194.Whitton, Mary C. (2003). “Making Virtual Environments Compelling.” Communications of the ACM 46 (7): 40–47. doi:10.1145/792704.792728.

WEIDENMANN, B. (2002). Multicodierung und Multimodalität im Lernprozess. na.

WISSEN, U., SCHROTH, O., LANGE, E., & SCHMID, W. A. (2008). Approaches to integrating indicators into 3D landscape visualisations and their benefits for participative planning situations. Journal of Environmental Management,89(3), 184-196.

WONKA, P., ALIAGA, D., MÜLLER, P., & VANEGAS, C. (2011). Modeling 3D urban spaces using procedural and simulation-based techniques. In ACM SIGGRAPH 2011 Courses (p. 9). ACM.

ZEHNER, B. (2008). Landscape visualization in high resolution stereoscopic visualization environments. E. Buhmann, Pietsch & Heins: Digital Design in Landscape Architecture, 224-232.

ZEHNER, B. (2009). Interactive Wind Park Planning in a Visualization Center-Giving Control to the User. Buhmann, E., Pietsch, M. & M. Heins (Eds.): Digital Landscape Architecture 2009, Proceedings of Presented Papers, 21-23.

ZHANG, XIAONAN. (2004). Designing a Geographic Visual Information System (GVIS) to Support Participation in Urban Planning. University of Salford.

10 IMAGE CITATIONS

Figure 3.03: MAHONEY, L. (2015). 5 steps to demystifying stakeholder engagement. Retrieved April 11, 2016, from http://cubegroup.com.au/5-steps-to-demystifying-stakeholder-engagement/

Figure 3.04: FISHER, S. (2008). Theory and Research in HCI: Morton Heilig, Pioneer in Virtual Reality Research. Retrieved April 11, 2016, from http://www.telepresenceoptions.com/2008/09/theory_and_research_in_hci_mor/

Figure 3.05: VORVOREANU, V. (2011). Gui history. Retrieved April 11, 2016, from http://www.slideshare.net/prprof_mv/gui-history

Figure 3.06: NEW VIRTUAL REALITY HEADSET| SAMSUNG GEAR VR. (2016). Retrieved April 11, 2016, from http://www.samsung.com/in/galaxy/gear-vr/

Figure 3.07: GAMING RESOURCES. (n.d.). Retrieved April 11, 2016, from http://www.segasoft.com/gaming-resources/

Figure 3.08: CAKMAK, T. (2015). Cyberith: Breaking the Boundaries of Virtual Reality GamingInterview. Retrieved April 11, 2016, from http://80.lv/articles/cyberith/

Figure 3.09: WINKLE, D. V. (2014). Project PERCEPTION NEURON Is the Virtual Reality Bodysuit of the Future. Retrieved April 11, 2016, from http://www.themarysue.com/perception-neuron-suit/

Figure 3.10 & 3.11: DEANE, RYAN, (2015a). The Emerging Role of Millennials. Retrieved Dec. 11, 2015, from http://thefield.asla.org/2015/02/04/the-emerging-role-of-millennials/#more-3450

Figure 3.12, 3.13, 6.34: CITYENGINE HELP. (2015). Retrieved April 11, 2016, from http://cehelp.esri.com/help/index.jsp?topic=/com.procedural.cityengine.help/html/quickstart/overview.html

Figure 3.14: ORR, J. (2014). New programming techniques and the productivity curve. Retrieved April 11, 2016, from https://www.javacodegeeks.com/2014/09/new-programming-techniques-and-the-productivity-curve.html

Figure 3.15: KNIGHT, S. (2014). Sony to shut down ‘Second Life’ alternative PlayStation Home early next year. Retrieved April 11, 2016, from http://www.techspot.com/news/58221-sony-to-shut-down-second-life-alternative-playstation-home-early-next-year.html

Figure 3.18: WAGNER, I., ET AL. (2009). Supporting community engagement in the city: urban planning in the MR-Tent. In: Proceedings of C&T, 185–194. Whitton, Mary C. (2003). “Making Virtual Environments Compelling.” Communications of the ACM 46 (7): 40–47. doi:10.1145/792704.792728.

Figure 3.19: MICROSOFT HOLOLENS. (n.d.). Retrieved April 11, 2016, from https://www.microsoft.com/microsoft-hololens/en-us/developers

Figure 3.22: LA METRO. (2014). Retrieved April 11, 2016, from http://www.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=2e71f229901a401c9a73560975a144e7

Figure 3.23: LAMKIN, P. (2016). The best VR headsets. Retrieved April 11, 2016, from http://www.wareable.com/headgear/the-best-ar-and-vr-headsets

Figure 3.24: TOTILO, S. (2008). Sony Developer Improves My View Of PS3 ‘Home,’ But There’s A Catch. Retrieved April 11, 2016, from http://www.mtv.com/news/2457819/sony-imprves-my-view-of-ps3-home/

Figure 3.25 & 6.30: SYMPOSIUM WEEKEND: EMPAC OPENING - EXPERIMENTAL MEDIA AND PERFORMING ARTS CENTER - TROY, NY USA. (n.d.). Retrieved April 11, 2016, from http://opening.empac.rpi.edu/symposium/

Figure 3.26, 3.28, 3.29, 3.30, 3.31, 3.33: MARCO, J. (2015). List of Haptic Controllers under Development for Virtual Reality. Retrieved April 11, 2016, from http://www.virtualrealitytimes.com/2015/03/13/list-of-haptic-controllers-virtual-reality/

Figure 3.27: CAKMAK, T. (2015). Cyberith: Breaking the Boundaries of Virtual Reality GamingInterview. Retrieved April 11, 2016, from http://80.lv/articles/cyberith/

Figure 3.32: HANDS OMNI GLOVE: VIRTUAL REALITY TOUCH - COOL WEARABLE. (2015). Retrieved April 11, 2016, from http://www.coolwearable.com/hands-omni-glove/

Figure 3.34, 3.35, 3.36, 3.37: LAMKIN, P. (2016). The best VR headsets. Retrieved April 11, 2016, from http://www.wareable.com/headgear/the-best-ar-and-vr-headsets

Figure 4.03: MEHTA, B. (2014). Experts Offer Technology Predictions for 2014. Retrieved April 11, 2016, from http://geodatapoint.com/articles/view/experts_offer_technology_predictions_for_2014

Figure 4.04: INFRAWORKS 360. (2014). Retrieved April 11, 2016, from https://infraworks-gallery.autodesk.com/projects/infraworks-360

Figure 4.05: P. (2013). Scenario 3D. Retrieved April 11, 2016, from https://www.youtube.com/watch?v=aVQbyQDNJyY

Figure 4.06: R. (2014). [WIP] - 15 minutes scene, CityEngine to Unity 3D 5 Big City ! Retrieved April 11, 2016, from http://forum.unity3d.com/threads/wip-15-minutes-scene-cityengine-to-unity-3d-5-big-city.375714/

Figure 4.08: WASHINGTON STATE DEPARTMENT OF TRANSPORTATION USES 3D IMMERSIVE VISUALIZATION. (2016). Retrieved April 11, 2016, from https://informedinfrastructure.com/21119/washington-state-department-of-transportation-used-3d-immersive-visualization/

Figure 4.10: OPENSTREETMAP. (n.d.). Retrieved April 11, 2016, from http://www.openstreetmap.org/#map=18/39.18555/-96.57510

Figure 4.13: CITY OF MANHATTAN. (2016). UCR Draft 1/28/16 Final Draft. Manhattan, KS.

Figure 4.16, 4.17, 4.18: CITY OF MANHATTAN. (2015). Urban Core Residential Streetscape Vision. Manhattan, KS.

Figure 4.30: FACADE WIZARD TUTORIAL. (2012). Retrieved April 11, 2016, from http://www.procedural.com/ce_projects/ce_2011.2/tutorials/tutorial13.php

Figure 4.31: CITYENGINE-FACADE WIZARD OVERVIEW. (2015). Retrieved April 11, 2016, from http://cehelp.esri.com/help/index.jsp?topic=/com.procedural.cityengine.help/html/manual/facwiz/facade_wizard.html

Figure 4.56: H. (2015). GeoNet. Retrieved April 11, 2016, from https://geonet.esri.com/docs/DOC-6915

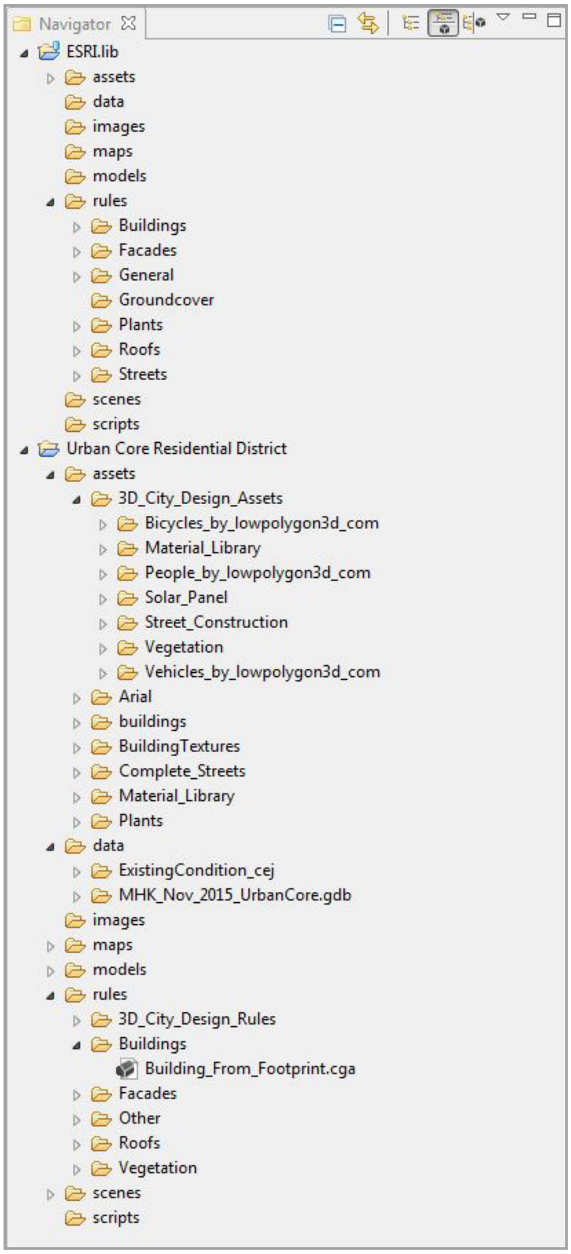
Figure 4.57: CITY ENGINE EXAMPLE: REDLANDS REDEVELOPMENT. (2014). Retrieved April 06, 2016, from https://www.esri.com/~/media/Files/Pdfs/library/brochures/pdfs/cityengine-example-redlands.pdf

Figure 4.68:
"VRAY_ADV_32002_MAX2015_X64 FREE." Đ HO KIN TRÚC DOA. (2015). April 13, 2016, from http://dohoakientruc.vn/ns/vray_adv_32002_max2015_x64-free.html

11 APPENDIX

CITYENGINE'S FOLDER STRUCTURE

Although rarely needed for most software, it is helpful to have simple folder structures to organize data. CityEngine has a clear folder system that organizes data in each project directory based on whether it is an asset, data, map, model, rule, or scene. Shown in the figure to the right is the ESRI library project directory and the Urban Core Residential District project directory. The folder systems can become complex when importing other project directories and adding them to your own. It is important to be delicate in this process and make sure data gets put into the correct folder, otherwise rules will not work. The rules import assets based on their location and folder name. If either of these are changed the script in the rule has to be changed. However, re-organizing data should be avoided to prevent having to re-link assets through script. The process of sharing a CityEngine model with others can also be difficult. The project directory cannot be copied and/or zipped to be shared. Instead, the project has to be exported as an archive file and then imported. If sharing with others within an office, it would be helpful to have the project directory stored on a shared network to save time.



AMENITIES PERMITTED IN THE UCR DISTRICT RIGHT OF WAY

Within the right-of-way area between the street and building is the Spillout Zone and Amenity Zone. Elements permitted in each zone are shown in the following figures. These figures are from the City of Manhattan's UCR District street-scape vision. Of these elements, only some were modeled in CityEngine because of difficulty of scripting each element and the imported files (i.e., obj) showed up invisible.

Element Type	Spillout Zone Element
Commercial	Tables/chairs/umbrellas Outdoor displays Food carts
Residential	Stoops Porticos Bay windows Eaves
Both	Benches Wall lighting Bike Racks Ornamental trees Living walls Plant beds Planters Awnings Plazas Small fences

Element Type	Amenity Zone Element
Pedestrian	Benches Lighting Waste/recycling receptacles Crossing signals Wayfinding Public Art
Bicycle	Bike racks Pump/tool stations Bike share stations
Bus	Stop pullouts Shelters Information/ticket kiosks
Automobile	Drop zones Traffic signs Traffic signals Parking meters
Landscaping	Trees Plant beddings Bioswales Rain gardens Planters Permeable pavers Low profile bushes
Utilities	Fire hydrants Utility meters Electrical outlets
Other	Newspaper stands

POTENTIAL DESIGN ALTERNATIVES

In this project only one design scenario/hypothetical master plan was created and uploaded as a Web Scene. However, the original plan was to model multiple design alternatives that could be compared and contrasted within the same Web Scene. Due to Web Scene size limits that were later discovered, only one alternative was produced. If Web Scenes could hold a larger capacity, all of the models listed in the bottom two figures would have been created. This would include 10 streetscape and 10 building development alternatives. If more time was available 18 additional building development models would have been created (see figure to right).

Models of Parcel and Building Configuration		
Lot size	**Building Intensity**	**Time Frame**
existing	existing	existing
Small Lots	low intensity	short-term
		medium-term
		long-term
	medium intensity	short-term
		medium-term
		long-term
	high intensity	short-term
		medium-term
		long-term
Large Lots	low intensity	short-term
		medium-term
		long-term
	medium intensity	short-term
		medium-term
		long-term
	high intensity	short-term
		medium-term
		long-term
Diverse Lots	low intensity	short-term
		medium-term
		long-term
	medium intensity	short-term
		medium-term
		long-term
	high intensity	short-term
		medium-term
		long-term
Total models to be created:		**28**

Modelling the Streescape			
Lane Configurations	**Parking Type**	**Bike Circulation**	**Vegetation**
existing	existing	existing	existing
2 lanes on one side and 1 lane in opposite direction	parallel on one side	on road	none
			perennial planters
			planters with trees
single lane 2-way traffic	parallel on one side	independent bike lane	none
			perennial planters
			planters with trees
single lane 2-way traffic	one side of angled parking	on road	none
			perennial planters
			planters with trees
Total models:			**10**

Modelling Buidling Development	
Building Intensity	**Time Frame**
existing	existing
low intensity	short-term
	medium-term
	long-term
medium intensity	short-term
	medium-term
	long-term
high intensity	short-term
	medium-term
	long-term
Total models:	**10**