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Methodological proposal of creating 3D terrain models in Unreal Engine 4, to be used in surveys for wind farms visual assessments.
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DIPLOMA THESIS ASSIGNMENT

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Methodological proposal of creating 3D terrain models in Unreal Engine 4, to be used in surveys for wind farms visual assessments

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Objectives of thesis

This diploma thesis targets the issue of the visual impact surveys of wind turbines in natural landscapes and how game engine technology could supplement it. Societies around the world are or will be dealing with the impact of climate change. Nations are recognizing that it is in their interest to try and combat this for issues ranging from health, economic, and a moral stand point. To combat climate-change many nations have been installing wind farms in natural areas, leaving controversy in their wake. To understand how the public feels about these turbines governments, universities, and corporations have tried taking surveys to capture public opinion. Surveys can be biased from their wording or the framing of the picture used to show the impact, and so it was decided to see if a gaming engine would be beneficial to creating a less bias perspective.

This study evaluates the uses of the Unreal Engine 4, which is a well-known game engine, to recreate three sites and compare them to real images/video to see if this would be a viable way to supplement surveys. A survey was created that evaluated the simulated videos created through Unreal Engine 4 to actual site videos. The purpose of the survey was to measure the viability of using simulated video to show how a landscape appearance may alter after building wind turbines. The proposed gaming technology offers an opportunity for individuals to control what they see in their surroundings and help reduce the bias that comes when preparing survey questions or photographs.

Methodology

Part of the research for this thesis study included a series of site visits to existing areas located throughout the Czech Republic that have wind turbines or the potential of wind turbines. They vary in size and local population surrounding the sites. There are three site locations and the process of choosing the locations were based primarily on their ease of access as well as familiarity with the sites. A wind map of the Czech Republic was also obtained and used to assure that the average windspeed in these areas were capable of sustaining wind turbines. The final factor in determining the three sites were the number of wind turbines already existing on the site and their proximity to urban development. The result of this method were three sites that had varying windspeeds, vastly different number of HAWTs, and their proximity to urban areas.

The proposed extent of the thesis

60 – 70 pages

Keywords

Wind turbine; Game engine; Simulated video

Recommended information sources

Esri. (2014). 3D Urban Mapping: From Pretty Pictures to 3D GIS 3D Urban Mapping: From Pretty Pictures to 3D GIS An Esri White Paper.

Groth, T. M., & Vogt, C. (2014). Residents' perceptions of wind turbines: An analysis of two townships in Michigan. Energy Policy, 65, 251–260.

Chias, P., & Abad, T. (2013). Wind farms: GIS-based visual impact assessment and visualization tools. Cartography and Geographic Information Science, 40(3), 229–237.

Kazak, J., van Hoof, J., & Szewranski, S. (2017). Challenges in the wind turbines location process in Central Europe – The use of spatial decision support systems. Renewable and Sustainable Energy Reviews, 76

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Author's Declaration

I, David Kruchten, declare that this master thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification.

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Prague, 18th April, 2018   David Kruchten

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--- David

Abstract

This diploma thesis targets the issue of the visual impact surveys of wind turbines in natural landscapes and how game engine technology could supplement it. Societies around the world are or will be dealing with the impact of climate change, particularly as a consequence of CO_2 emissions from the burning of fossil fuel for energy generation (coal and gas fired power plants) to transportation (combustion engines). Nations are recognizing that it is in their interest to try and combat this for issues ranging from health, economic, and a moral standpoint. To combat climate-change many nations have embraced renewable energy generation, from solar voltaic arrays, geothermal heating, and wind, the most prevalent and ancient technique of harvesting and harnessing energy. Wind "farms" have become a common presence on the landscape, often in natural areas, resulting in controversy. To better understand how the public feels about the presence and placement of wind turbines, governments, universities, and corporations have conducted preference surveys to capture public opinion with the intention for crafting policies for their placement and better design solutions for their appearance. Surveys, however, can be biased from their wording or the framing of the picture used to show the placement and associated impact. For these reasons, it was decided to see if a gaming engine and 3-D simulations would be beneficial to creating a less bias perspective from that of a static "Photo-shopped" image that is more commonly used to elicit viewer responses.

This study evaluates the uses of the Unreal Engine 4, which is a well-known 3-D game engine, to recreate three sites and compare them to real images/video to see if this would be a viable way to supplement surveys. A survey was created that evaluated the simulated videos created through Unreal Engine 4 to actual site videos. The purpose of the survey was to measure the viability of using simulated video to show how a landscape appearance may alter after building wind turbines. The proposed gaming technology offers an opportunity for individuals to control what they see in their surroundings and help reduce the bias that comes when preparing survey questions or photographs.

Table of Contents

1.0 Introduction

The objective of this diploma thesis is to bring light to the subject of how wind turbine surveys are conducted and how using 3-D game engine technology could be used to enhance them to create a more real seeming scenario of wind turbines in the landscape.

Climate change has increasingly become a concern of people throughout the world. We see the effect of climate change in things such as polar bear ranges shifting, shrinking glaciers and lakes thawing earlier (NASA, 2018). These are just some of the easily visible results that do not include precipitation or temperature fluctuations throughout the world. However, because of these dramatic changes and the potential health and economic risks they pose to humans, many nations are looking to reduce their contribution to the associated impacts of Co2 emissions into the atmosphere. One of the major ways that many countries are combating this is through shifting their dependence on fossil fuels to renewable sources of energy generation. Renewables, such as solar, wind, geothermal, etc., are usually presented in the media as the cure for the planets ills, but they are not without their adversaries. These opponents may be advocates (industry) of traditional power generation, politicians, or concerned citizens who do not want to see any form of energy generation in their community. There are positive and negative consequences associated with all these renewable sources of energy generation, and within this thesis some of the benefits and hindrances of wind turbines will be touched upon specifically.

Considering these controversies surrounding these turbines, research universities, governments, and private corporations have funded surveys to ascertain peoples' perception of wind turbines in a variety of landscape scenarios. This thesis is based upon the results and methods these institutions used in their survey research and attempts to suggest a new analytical tool to be implemented. The surveys used in the university lead studies mentioned above have been asked from certain perspectives that steer thinking, whether intentionally or not. It is recognized that it may be nearly impossible to not have a slight bias when asking survey questions, because of things that may be shown in surveyors' body language or wording of questions that

can trigger people to have certain reactions when responding to questions or images presented to them. A revelation occurred in the process of this investigation of a new procedure to reduce this bias. Through experience with immersive games that contain realistic environments, the thought came to incorporate that with surveys of wind farms. This would allow people to experience an area more intimately than with just pictures or words. Through this initial thought process, there was research done on game engines and GIS to see if it was possible to combine both into one analytical tool. As the research was being compiled, a study by Swiss Federal Institute of Technology Zurich was discovered that used the game engine called Cry Engine to model real world environments (Manyoky, 2014). Their use of the game engine, confirmed that this thesis could be used to develop a similar process using another game engine called Unreal Engine 4.

The purpose of using Unreal Engine 4 was to determine if the product would be a suitable supplement to the future surveys, in which people would be taking to gauge or evaluate their visual and audio perception of wind farms. Realizing that bias cannot be completely removed from visual images used in a survey, the goal was to create a workflow that allowed future surveys to mitigate this more effectively. The way that this could be done was by employing the game engine approach; a possible outcome of it may be a "game" to virtually walk around a site and understand scale and depth more than you could get from a static picture, video, or words. For this project it was deemed necessary to see if that method would even be feasible. The end goal of thesis was to establish a survey based off videos that were taken from site visits and compare them to the simulation videos created in the game engine. The intention for the survey is to determine if people felt the simulations represented a real site or location of a wind turbine farm in a realistic manner or not. The findings can then be used for crafting recommendations how landscapes may appear which will inform better site analysis and policy formations.

2.0 Aim of Diploma Thesis

The goal of this diploma thesis is to propose an additional method to be used in surveying people about things that will have impacts on the visual and audible integrity of the landscape. The results will entail visual and audio simulations of the wind farms in the Czech Republic, a clear method to follow to recreate, and survey result based on how well these simulations immerse people into an environment. These results can be used as a precedent to support future study into this realm and related topics.

3.0 Literature Review

3.1 Overview

The purpose of this literature assessment is to demonstrate how new techniques and technologies can be used for modeling potential locations for wind turbines. It will show how these techniques could be incorporated into surveys and presentations to determine public acceptance and preference for wind turbines. A broad range of papers were selected to cover these themes and were then examined for providing a well-researched and informed opinion upon this topic. The review will cover a broad spectrum of topics specific to this form of alternative energy. It will briefly focus on the different types of renewable energy generation and specifically the positives and negative impacts of wind turbines as perceived by the layperson. The review will focus more in depth on wind turbines visual disturbance upon the landscape, particularly on tourism and then explore new techniques to create visual assessment models for areas of interest using GIS and 3D modeling techniques such as game engines.

3.2 What are Renewables?

As of 2018, the primary way we obtain energy for our homes and vehicles are fossil fuels, fuel derived from prehistoric organisms. The reason it so popular and being depleted so quickly is a result of the relative ease in which we can obtain this form of energy. As world population growth and modernization increases the demand for electricity, it will place a huge demand on our current primary fuel source, fossil fuels. In fact, 83% of the 2011 world's energy supply is made up of fossil fuels ("Renewable Energy - Fossil fuels - non-renewable | Young People's Trust For the Environment," 2017). Nonrenewable, which include fossil fuels are classified as such, due to not being able to renew itself in a short time period. Energy sources that are classified as renewables can replenish themselves in a short period of time (EIA, 2016). Energy that is renewed by nature – water, plants, Earth's heat, the sun, and the wind – are known as renewable energy. Electricity, heat, chemicals, or mechanical power are results of technology turning these fuels into energy we can

use (Tromly, 2001). By the middle of this century, demand for energy could increases by 50%, with developing countries demand increasing by 80% (Council, 2013).

By using renewables for this energy demand, we could help meet this need with the bonus of helping the environment as an added benefit (Tromly, 2001). Due to the significant need for renewables, their demand to supply future energy sources have increased around the world (Kaufmann, 2016). There are many sources that can be used for renewable energy, which is significant because they won't expend gasses that affect climate change and the supply never decreases ("Renewable Energy - Fossil fuels - non-renewable | Young People's Trust For the Environment," 2017). These sources include hydropower, bioenergy, geothermal energy, solar, ocean energy, and wind. This is the direction that European Union (EU) has decided to focus their attention on with their Europe 2020 Agenda. The goal is to decrease CO_2 emissions by 20%, use their energy 20% better, and have renewable energy supply 20% of their power needs (European Political Strategy Centre, 2016). To achieve this 20% benchmark for dependence on renewable energy by 2020 and 27% by 2030, the EU has set up a number of development projects (Kazak, 2017). One of the primary ways in which many countries in the EU are attempting to fulfill this 2020 commitment is by focusing largely on renewable energy source of wind. By 2030 wind is to supply up to 30% of the power demand and become the foundation of the EU power system ("Wind energy today | WindEurope," n.d.).

3.3 Types of Wind Turbines

Wind is one of the oldest forms of power that humans have ever harnessed. It has been used to sail ships, pulverize grain, and to draw out water from the ground. For hundreds of years, people have used windmills to harness the wind's energy. In the last couple of decades, the popularity has

Image 1: The Kinderdijk windmills of Holland, built in the mid-18th century. (Photo by Discover Holland)

increased due to its ability to make clean energy. Wind turbines of today differ a lot from the picturesque Kinderdijk windmills of Holland *(see Image 1)*, which date back to the mid-18th century. The Kinderdijk windmills are most certainly visually more romantic, whereas modern-day wind turbines appear as futuristic icons. The wind turbines today are like past windmills but need and incorporate a lot of modern technology in their construction. Today's wind turbines, which operate differently from the old Dutch windmills, are a much more efficient technology. Modern turbines create energy and transform it into electricity by the use of airfoils, modern generators, and mechanical drives (Tromly, 2001). Due to the advancement in the machinery and electronics, the use of wind power has been growing roughly 25% per year since 1990 (Tromly, 2001).

Most wind turbines used today can be placed into two categories: the first is horizontal axis wind turbines (HAWT) and the second is vertical axis wind turbines (VAWT). There are a few more variations of other types of wind power such as the Archimedes turbine (a combination of HAWT and VAWT), high altitude wind turbines (kite turbines), oscillating wind turbine (bladeless vertical shafts), and sheer wind turbines. This section will focus on the

Image 2: Horizontal Axis Wind Turbine (HAWT) - left
Vertical Axis Wind Turbine (VAWT) – right
(Photo by Dvorak)

HAWT and VAWT turbines, due to the prevalence of their use.

The wind turbine that is most commonly thought of by most people is HAWT, which look like a modern windmill. The blades spin on a horizontal axis and are similar in appearance to that of a plane propeller. The motor of the HAWT is located on the top of the shaft near the blades. They also need motors to point the blades and generator head into the wind direction, in order to be the most efficient when producing energy (Guzzetta A., Myers G., n.d.). There are some distinct advantages to using these turbines over other possibilities. One advantage is the tall tower base,

some reaching 150 meters in height, which allows access to stronger wind in sites with wind shear. Another is their high efficiency, since the blades always move perpendicularly to the wind, receiving power through the whole rotation (Meyers, 2013). Some of the disadvantages are that they require huge construction base for the tower, the height makes them stand out in landscape, the necessity of a motor to rotate the blades into the wind, the need of devices to slow or stop the blades when there is too much wind, and more difficult to assemble and maintain (Meyers, 2013).

VAWTs differ from HAWTs primarily due to the placement of the main rotor shaft that is perpendicular to the ground. Many of the VAWTs tend to look like the blades of an eggbeater and are not as tall as HAWTs. Most of the main parts of this turbine are easier to access near the ground (EIA, 2016; Moh Saad & Asmuin, 2014). A benefit of using this type is that on sites where wind direction is quite varied, they still work since they do not need to be facing the wind to work efficiently. Other benefits include easy access to important machinery and that they can be constructed in areas where HAWTs cannot, such as rooftops in urban areas. Some of the disadvantages are they may require power to start moving, the blades create drag when spinning into the wind, and they are not as efficient as HAWTs (Guzzetta A., Myers G., n.d.; Meyers, 2013).

3.4 Differences Between Turbines

Most of the articles will be pertaining to HAWTs, considering the fact that more of them are used around the world largely due to their efficiency (EIA, 2016). The reason efficiency is the usually the main deciding factor when choosing a turbine, is that HAWTs are better for long term investment, which will be most organizations main concern for the 20 years of operation expectancy. The VAWTs have fewer parts to wear out, but the parts that do degrade tend to so since they have received more stress than HAWTs, because they lack the ability to move into the optimal direction of the wind. The scalability is also a negative for VAWTs, considering they will need guy-wires to keep them stable, resulting in more material and land area used to produce them (Dvorak, 2014).

Most HAWTs consist of blades, nacelle, rotor
hub, gearbox, generator, controller, tower,
and a transformer. The turbines will remain
motionless due to inadequate torque to move
them, until they reach their cut-in speed of 3-
4 m/s. The turbines work optimally until
their cut-out speed of approximately 25 m/s.
The cut-out speed is when the braking system

Figure 1: Cut-in speed of wind turbine and
power output.
(Figure by Windpower Program)
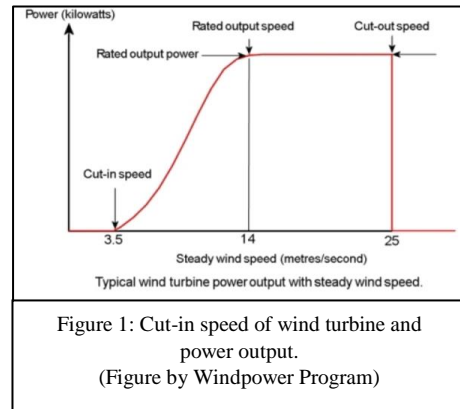
is activated to stop the rotor to prevent damage to the turbine ("Wind turbine power
curves.," n.d.). Electricity generation will cut in at speeds of around 3-5 meters per
second (m/s), peak power will be at 15 m/s and at 25 m/s cut out (Renewable Energy
Agency, 2012). Data from the U.S. Department of Energy, states ideal areas for
wind farms are areas with an average wind speed 7.06 m/s at about 50 m off the
ground (Rowe, 2017). As the height of the turbine increases, wind speeds tend to be
faster and more consistent. Colder (denser), non-turbulent air provides more energy
and results in less stress on the machine (Renewable Energy Agency, 2012). For
wind farms to work most productively there needs to be obstacle free wind, so that it
will hit all the turbines optimally. There is 1.5 acres of land needed for a 2
megawatts turbine to be used for tower pads, access roads and power substations
take up land that could be used for agriculture (Gaughan, 2017). In order to
maximize efficiency, the turbines need to be spaced at least 7-10 rotor blade
diameters away from each other (Gaughan, 2017; "National Wind Watch Size of
Industrial Wind Turbines," n.d.). It is estimated that every year there will be
approximately one blade out of 100 turbines that fail. The causes for these failures
may include unanticipated acts of nature, human mistakes, fatigue loads being
miscalculated, bad production standards, or malfunctions of control system
(Larwood, 2005).

3.5 Benefits of Wind Turbines

Wind turbines for the most part have been viewed in a positive light by the media
and government, but all technology has its positives and negatives. According to
Shah (2012) there are several benefits to wind power. No pollution, no fuel cost, and

a big industrial base to keep the cost down (Shah, 2012). Local tax revenue, rural economy development, lower electrical bills, possible increased tourism, and in some situations landowner compensation are more benefits of wind power (Rand & Hoen, 2017). The rewards of wind turbines are not just clean energy, they also can be built quicker than conventional power plants in an as needed basis (Hirsh & Sovacool, 2013). Instead of building a large plant to meet just a little bit of need, they can be used to meet the needs more efficiently by being built incrementally. There are hidden costs to traditional energy generation that often get overlooked, such as global warming or health care for those subjected to pollution in both the collecting, processing and disposal of fuel for traditional plants (Sovacool, 2008).

3.6 Disadvantages of Wind Turbines

Image 3: Shadow flicker is one of many negative side effects of wind turbines. (Photo by Wind Aware)
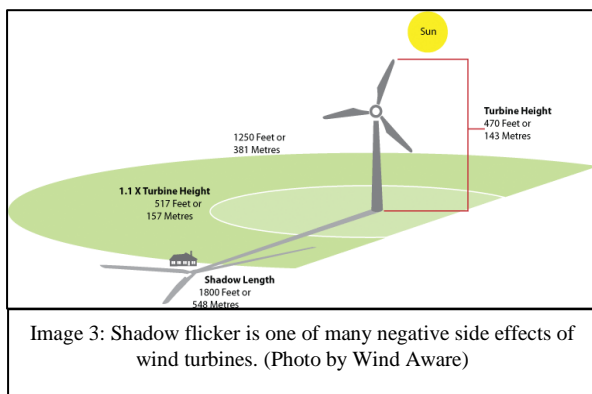
The less positive aspects of wind power that many researchers have considered has a broad range and may vary from social, economic, and environmental issues. There are many social factors that can cause locals to be upset about a wind farm being established in their vicinity, with the most prominent being health. The most common health issues for humans connected to turbines are strobe effect of the blades known as shadow flicker, loud noises, and sun reflection of turbine. Some road accidents are caused when the shadow flicker distract drivers. Turbine noise may be linked to negative feelings, sleep disruption, or other health issues (Rand & Hoen, 2017). Noise disturbances tend to decrease as you get further from the turbines and the data suggest that house distance should be further than the recommended 500 m (Kazak, 2017). Another study states that the 45 dBA is maximum noise outside a home at night as per the World Health Organization (WHO), and the EU has required 40 dBA since 2009. One study states that the mean noise output for residents living 0.25–11.22 km from working turbines in Canada was on average 35.6 dBA (Knopper & Ollson, 2011). There has also been research that stated infrasound and turbines show no direct

relation bad health in humans (Michaud et al., 2016). Regardless of where data points addressing the health concerns people have is important, otherwise even if the noise is lowered a part of the community may still be upset (Fast & Mabee, 2015).

3.6.1 Associated Environmental Disadvantages Consequences

Environmentally the concerns are the impact that wind turbines have on wildlife such as birds and bat populations. In the United States, between 140,000 and 328,000 birds are killed annually, some when being struck by the fast-moving blades of the turbine. In addition, mortality is caused when birds and bats collide with the towers, according to a 2013 study (Rand & Hoen, 2017). However, fossil fueled power plants have bigger impacts on birds than do wind turbines. These impacts from coal fired plants, for example, have to do with the much broader spread of influence throughout the whole fuel cycle environment, meaning that the complete destruction of bird habitat associated with large scale strip mining is much greater than point source mortality from collisions with blades or towers of turbines (Sovacool, 2009). Since 2004 it has been recognized that turbines have also been killing bats, but differently than birds. A study of 188 bats in Alberta, Canada showed that bats were not killed from blunt force trauma like a blade impact since they had no visible external injuries. Of the 75 bats that were dissected 90% had blood vessels burst in their lungs, indicating it was a change in air pressure that killed them (Mathews Amos, n.d.). When turbines are installed, it may be necessary for some farmland to be used or to clear some wooded areas ("Renewable Energy - Fossil fuels - non-renewable | Young People's Trust For the Environment," 2017). The local community may raise issues pertaining to the impact on the local environment or if the wind turbines are culturally fitting for the area (Rand & Hoen, 2017).

3.6.2 Economic Disadvantages

The economics of these renewable energy sources also come into question for some, due to several reasons. One of the main arguments against wind is the unpredictable nature of climate; it can't be scheduled, and the supply is contingent upon the

weather (Zerrahn, 2017). Terrains that are the most profitable are flat areas with a small number of upright obstacles allowing wind to hit the turbines with optimal speed. Infrastructure to get to the wind turbines also affect the economics of them as well as their potential climate change mitigation (Rand & Hoen, 2017). Overall, the socioeconomic effect may be more traffic, economic disparity, higher electrical bills, lower property values, and less tourism (Rand & Hoen, 2017).

3.6.3 Visual Disadvantages

The visual impact from wind turbines on a particular area is a little harder to determine if it is positive or a negative. These landscapes are in no question changed substantially and one of the primary reasons for adverse feelings to wind projects and their reduced support in a region. There have been several studies that have been done to gather data on whether it is has a beneficial or harmful impact on the environment, with mixed results. This has been a challenging obstacle for wind turbine projects because they are changing how humans interact with power infrastructure. Joseph Rand presented the idea that the reason some people don't like wind turbines is that our older power infrastructure were hidden away, far from where most people are likely to interact with it, but wind turbines stick out dramatically in the landscape (Rand & Hoen, 2017). Wind farms are typically not hidden or obscured from view. It is common for the height of the tower to be 75 to 150 meters in elevation from the ground plane. With wind turbines they are new points in the landscape that we must come to terms with, until they are more accepted or better camouflaged to make them less noticeable. Some survey partakers have stated that turbines are more beautiful when in they are moving as to when they are motionless, perhaps due to appearance of being a productive part of the landscape (Fergen & B. Jacquet, 2016).

3.7 Public Opinion

Wind power has generally been widely accepted by the public since the 1980's in countries such as the United States, the Netherlands, and the United Kingdom (U.K.) (Hammami, Samiha Mjahed; Chtourou, Sahar; Triki, 2016). Public attitude about

this form of renewable energy has for the most part been positive, when it is discussed in the media. However, when a project is to be implemented in a community, there can be conflict between local inhabitants and energy companies. According to Burgess, the media has a role in influencing people's fears of these turbines, but people in a position of power should try to focus on a scientific approach in determining their placement (Burgess, 2002). Some of theories as to why there is resistance to wind energy are unclear plans, lack of community input, and place making (Groth & Vogt, 2014) (Fast & Mabee, 2015). The factors of habituation, proximity, and landscape type in relation to wind farms can result in unfavorable emotions (Zerrahn, 2017). Advantages of turbines include their ease in assembly, zero emissions, and no cooling systems. Yet some people are hesitant to have them installed in their community due to their visual impact on the landscape, as compared to other renewables (Pasqualetti, 2011). Solar farms also have been studied in context of visual impacts due to glare and their cooling towers (Sullivan, Kirchler, Mccarty, Beckman, & Richmond, n.d.).

NIMBY (not in my back yard) has been a common objection when it comes to building new roads, erecting public buildings, or locating new renewable energy devices such as wind (Wolsink, 2007). But NIMBY may not be the full explanation as to why people are accepting of wind power in principle but not in their own communities (Groth & Vogt, 2014). In the United Kingdom where there is a lot of potential for wind farms, there has also been increasing opposition to them as well (Jones & Eiser, 2010). According to Bell (2013), there are two categories that define people in their support or lack of support of wind energy: social and individual. From his paper he showed that NIMBY was not the only reason for the social gap of people not supporting wind power. It is stated that some alternatives were qualified support, democratic process, and NIMBYism (Bell, 2013).

Most people accept change in the landscape as technology changes, even in areas of natural and pure landscapes, as stated by Hirsh (Hirsh & Sovacool, 2013). As stated in Fergen's paper, public acceptance for wind turbines increases over time and are seen as less imposing on the landscape when their blades are in motion (Fergen & Jacquet, 2016). Landscapes that possess more than just beauty but rather are

associated with how people relate to others and obtain significance (personal history for example) is known as *place attachment theory* (Rand & Hoen, 2017). It has been shown when the unique character of a landscape is at risk of being impacted by new or external factors, this change often results in particularly negative public attitudes toward such change. This is a common denominator that typically will affect the acceptance of wind farms (Devine-Wright & Howes, 2010). The theory of place attachment has conflicting data from studies in Europe and North America, but needs to be considered when discussing wind farm acceptance (Rand & Hoen, 2017). Groth has pointed out that some people may oppose wind turbines due to "existence value." This is defined by people that moved to rural areas to escape city life, and they see these turbines as changing that character (Groth & Vogt, 2014). The existence values pertain largely to the visual impact of the wind farms and how some people perceive them negatively at first. This view can cause tension, due to the fact that it is believed that turbines are or will cause a negative impact to the beauty of the landscape (Rand & Hoen, 2017). This is one of the most common reasons people oppose them. Another reason as to why people tend to be in opposition to turbines is due to the perceived visual impact they will have upon the landscape. The concern that is brought up the most is the effect or impact that wind turbines will have on tourism. Prinsloo (2013) states that the noise and sight pollution are the major issue in regard to environment and impact assessments made (Prinsloo, 2013). In the Czech Republic the subjective and objective views of stakeholders (politicians, investors, inhabitants, etc.) have started to have an effect on HAWT (Horizontal Axis Wind Turbines) projects (Frantál & Kunc, 2011). The Czech situation is representative of many areas around the world when there is introduced new modern looking vertical structures that suddenly appear in the landscape.

Where as many people may be aware of the ecologically positive benefits of wind turbines, their visual appearance may be starkly different from the traditional tourist structures that have brought people to the area, such as hilltop castes, ski slopes, or a lake made from a damned river. To better understand how tourism has been helped or hurt by the addition of wind farms, many researchers have conducted surveys to gauge people's attitude regarding their presence upon the landscape(s). When pertaining to the effect of wind turbine's influence on tourism, a big problem of most

literature reviews' studies is that much of the new insight is just old evidence revamped to fit whatever side of the argument one may support of the pro/con debate ("The Economic Impacts of Wind Farms on Scottish Tourism," n.d.). One could argue that there are many contradicting findings of surveys, when they are being reviewed. Some are stating that many people will flock to an area with turbines, while others say that people will flee from them. Since there seems to be bias in steering public opinion one way or the other about HAWTs, there should be closer scrutiny as to how assessment studies are conducted. Most researchers are probably not doing this consciously, but it could be in how questions are formed or asked. These questions could influence the people taking the surveys into giving different opinions. Many journalists reporting on these findings do not have the time or resources to properly access research articles to explain them in depth. As a result, many news agencies just report attention-grabbing headlines, thus real findings can get distorted to the public and affect their opinion as well. Due to competitive market and online news, quick catchy headlines of A+B=C is what many journalist report, often distorting the findings (DiSalvo, 2011).

In the following section there are some of the survey results taken by different agencies and people that indicate the stark difference people can find when conducting them. Whether this is due location, social standing, education background, lead in questions, or other factors has yet to be determined.

In the U.K., 30,000 tourist responded very positively to Scroby Sands wind farm, within the first six months of their education center being built (Lilley, MB; Firestone; Kempton, n.d.). While according The Sunday Times article in 2017, the negative view of their effect on tourism states: 55% of the people surveyed were "less likely" to go to the countryside if there were turbines (Macaskill, 2017).

A study performed for Isle of Anglesey County Council presented three interesting facts. First in 2003, tourist in Wales tended to prefer it when they could see the turbines from a distance versus nearby. Second, there was a desire for them to be on farmland rather than the hinterlands, in surveys conducted by Scotland and Wales (Company, 2012). Both results intuitively make sense and may be people who wish

to keep "pristine" land pure of man's interference. They found Ireland favored the turbines that were miniscule in numbers, while Scotland and Wales also had a preference for farms made of 10 turbines as opposed to large groupings of 200 or more (Company, 2012).

The study by Molnarova, (2012) to determine the visual impact of wind farms in the Czech Republic was executed by performing surveys of physical representation of the affected landscape. Researchers based their surveys off three different types of landscapes varying in beauty in which the turbines would be placed, using Adobe Photoshop (Molnarova et al., 2012). The results of this study indicated that most of the respondents preferred landscapes without wind farms in them, in response to the images they were shown. This research concluded that in order to reduce bias from words used in the survey, it was best to evaluate these sites in conjunction with photos that would represent the area (Molnarova et al., 2012).

3.8 GIS Modeling use in Visualization

Location is probably the most significant issue when trying to deploy wind farms not only because of the local communities but also for the people investing in them. There is a fine balance between what will be suitable for the public and what can still make the investment worthy for financiers to contribute to and potentially make a profit. Economic success is vitally important for this clean energy source to be used. One wind farm established in Ainsworth, Nebraska in 2005 was estimated to cost nearly 81 million U.S. dollars (Miller & Li, 2014) so there is a need to make sure there is an adequate and timely return on investment. Locations that are the best for wind, due to its high speed, may not always be the best though since there are other factors such as economics, physical, ecological, and planning must be considered as well (Van Haaren & Fthenakis, 2011). These investors need better assessment tools to ensure their investments will be profitable and be accepted by local people. To account for these factors, ArcGIS modeling has been implemented to try to determine the most optimal outcome.

The observable impression from wind turbines is of great importance, because of their large size and distinct appearance. Most visual impact assessments deal with the public scenery, such as water features, paths, scenic transportation routes, historical landmarks, or city squares (Wróżyński, Sojka, & Pyszny, 2016). The methodology used to create ArcGIS models varies from site to site depending on what criteria is important for the region. Van Haaren (2011) used the following methodology to determine the best sites: data collection, exclusion of infeasible sites, economic evaluation, bird impact evaluation, and site priority map (Van Haaren & Fthenakis, 2011). Based off their initial data collection they would limit the area by defining criteria in which turbines could not be located. The first step would be excluding the areas in which turbines could not be placed such as urban centers, federal land, roads, lakes, and steep slopes. The economic factors that needed to be considered were access roads, grid connection, land clearing, and wind resources. To see how this may impact birds they looked for sites indicated as important bird areas. These criteria would be overlaid with each other to find the best location for the sites by using buffers, intersects, or other spatial analysis tools (Van Haaren & Fthenakis, 2011).

In order to limit the analysis to exact locations, one study used simple true/false statements known as the Boolean criteria (Sten & Sten Hansen, 2005). Research conducted by Miller and Li contained seven criteria in which they processed their data to find wind farm suitability: slope, population, land use, distance to roads, wind energy, distance to power lines, and exclusionary regions (Miller & Li, 2014). In another study performed by Latinopoulos (2015), researchers used the following steps to focus on the ideal study areas: the first step was the use of Boolean tools and exclusion layers that were used to eliminate sites that could not work for turbines. Next, they choose the appropriate layers to be used for their evaluation criteria. Third, they made fuzzy sets to stand in for the evaluation criteria and finally this culminated in a multi-criteria decision making (MCDM) model (Latinopoulos D., 2015). Fuzzy sets were developed in 1965, separately by Dieter Klaua and Lotfi Zadeh, and is a mathematical idea where a set has degree of membership or inclusion (Zadeh, 1965).

3.9 Real World Representation with GIS Foundation

According to Molnarova (2012), they reviewed 18 other articles and found that 2 used photos, 2 used computer models, and only 3 of them were established on the landscape they were studying (Molnarova et al., 2012). They stated that the other studies were based largely on verbal communication to describe the impacts wind turbines would have on the landscape (Molnarova et al., 2012). ArcGIS and 3D models could be used to reduce the potential of influencing surveys with intentional or unintentional lead in questions, which can direct the participant in a certain direction and skew the results.

Due to data (such as diagrams, maps, graphs, photos, and text), obtained through ArcGIS and other sources, it is easier to create visuals in order to see how these objects may affect the area (Chias & Abad, 2013). Representation of the turbines in photographic modeling is necessary in areas where the public would have their first clear view of the site. When these views are linked to locations using ArcGIS, it gives visual context information to be used in the assessment of the area (Manyoky, 2014). The photos that can be created, using digital graphic rendering programs such as Adobe Photoshop and data collected in the field can be integrated in a matter of minutes, requiring a small learning curve. Still images may not be interactive or allow one to see everything they may wish, but this may still be preferable to that of more complex models in both the cost and time it takes to create them while still giving realistic representations of how things would appear (de Mendonça & Delazari, 2011). When trying to make more realistic, real world 3D representations it will take time to learn the basics of the program.

There are many possibilities to represent these environments in a more immersive way than manipulated photos. Some possibilities of these include computer graphics animation, 3D models, virtual reality, and augmented reality. These tools will vary in their effectiveness and ease of use and will need extensive time to learn them as well. Some major disadvantages to these tools are the cost, learning curve, rendering time, necessary equipment, and data needed to build them. The advantage of this equipment is the powerful simulations they can provide to really immerse someone

into the environment and help them experience the environment as it might be made. Instead of limiting the audience to one static viewpoint, it gives the freedom to roam around this virtual world and experience what it would be like to be there in reality (Chias & Abad, 2013). Situations can be modeled in both space and time (3D and 4D) using ArcGIS in accordance with some modeling programs, which allows for more accurate aesthetic analysis or visual impact assessments to be made (Pietsch, n.d.). Depending on the user's proficiency with this software and hardware, they can be used in unison to create even more immersive experiences.

Chias & Abad (2013) modeled both a simulation that was static and dynamic for their paper on wind turbine visualization. They composed their still images by overlaying their surface models with aerial photography. A model of the 3D landscape was digitally created by combining programs that would render and model topography accurately. They concluded that that the realism of the products were dependent on the computers and programs used to create them (Chias & Abad, 2013). ArcGIS in conjunction with modeling programs could provide "window to the future" that allow people who do not have as much background in a topic to better visualize and engage in it (Sheppard, n.d.). One of the limitations discovered in this process was that though models though accurate had to be based on hypothetical situations and could not show the real world results (Chias & Abad, 2013). But if the 3D maps are made accurately they can allow deeper comprehension of landscape spatial relationships, which make them ideal for scientific presentations, tourist information, management and planning of regions (Dinkov, Vatseva Eng Davis Dinkov, & Vatseva, 2016).

3.10 Workflow of GIS to 3D Model

There are multiple ways to construct models using all these input data, but how you make it and what results you want to show will determine what information is needed to create it. To create these models accurately by combining ArcGIS with 3D modeling, some primary inputs are needed. Dinkov (2016) laid out some of the basic data needed as GIS datasets of hydrography, land cover, tourist infrastructure and roads, plus data such as orthophotos, LiDAR, and Radar (Dinkov et al., 2016).

Conception, modeling, representation, and visualizing are four general steps that are usually followed when 3D mapping (Haeberling, n.d.).

Dinkov (2016) expanded on these steps by defining the user framework and outcome goals as factors that are determined in the conception phase. The framework is the way the project is designed and laid out which could determine the results. The familiarity and background of the present and future user must be considered at this stage. The modeling phase is where you take the data you have collected and transform them into a 3D model that may have interactive functions. Representation is when you enhance the project graphically. The last phase, visualization, is when the 3D representation is displayed in the format it was designed for (Dinkov et al., 2016).

ESRI has provided workflows to show how to bring 2D building map into a 3D perspective. This method is based on users who have data resolution of at least 1 point per square meter (ESRI, 2014). The steps they lay out are:

1. Create your map document with the 2D data. Three raster surfaces, digital terrain model, digital surface model, and a normalized digital surface model, are needed to create the terrain model.
2. To create the ground elevation with no structures or plants on them you need the **digital terrain model** (DTM). This will be used as the surface in 3D programs such as ArcScene™.
3. Illustration of the elevation of buildings and natural formations, are created using the **digital surface model** (DSM) raster.
4. The last thing needed is to show how high construction and greenery are above the ground. The **normalized digital surface model** (nDSM) is created by deducting the DSM from the DTM (DTM -DSM=nDSM) (Esri, 2014).

3.11 What is a Game Engine?

There is no clear or simple definition as to what a game engine is or may entail, and it may vary from company to company; the following are some general definitions:

A game engine may be defined as level data (game environment) and game logic (game management) that is not directly influenced by an assortment of simulation code (Lewis & Jacobson, 2002). According to Messaoudi, the main modules of a game engine consist of artificial intelligence, physics engine, scripting, input, multimedia rendering, and networking (Messaoudi, n.d.). Lewis (2002) states most game engines consist of parts dealing with the physics/dynamics of the virtual environment, input, and output such as 3D rendering and audio (Lewis & Jacobson, 2002). Simplified, the term *game engine* can be described as the software people use to make and design games.

The term *game engine* began to be used in the mid 1990's, when two video games, Doom and Quake popularized first person shooter games (Lewis & Jacobson, 2002). The reach of game engines is not just affecting the gaming community but has been spreading and influencing others. There has been use of game engines for military applications, architecture, visualizations, and medical training (Marks, n.d.). The application of these game engines will only increase as they become more photo-realistic and incorporated with augmented and virtual reality.

3.12 Why use a Game Engine?

The benefits of game engines over other visualization process is that they can create virtual real-time simulations (Manyoky et al., 2014). The user can control from where they want to view objects in a world that represents a close copy to the real thing. If the developer of the project wants they can create visuals with audio to give the observer higher emersion into the environment as well. The rendering of the engines also creates close to photo realistic images and videos that can be used to show multiple situations. This visualization process also allows real life terrain to be used with the ability to modify the time of day and weather (Manyoky et al., 2014).

3.13 Choosing a Game Engine

There are many game engines to choose from and they vary in factors from render quality, usability, and price. There were three engines that were considered when approaching this project, which are Unity3D, Cry Engine, and Unreal Engine 4.

3.13.1 Unity3D

Unity3D is widely used by many game creators throughout the industry. The first benefit of this engine is that it is free to use until a game makes more than $100,000. The architecture is easy to use and producing a build in Unity is very quick (Šmíd,

Image 4: This is rendered picture of Unity 3D natural scenery. (Photo by Unity3D)

2017). The ability to learn how to use this engine is very easy for new user and if there are difficulties learning it they have community network to help each other as well as tutorials (Banerjee, 2017). They also have many free items that can be obtained in the stores. The negatives for Unity3D are that its support of foliage and terrains is not great and the graphics do not appear as nice the other two engines (Šmíd, 2017).

3.13.2 Cry Engine

Image 5: This is rendered picture of Cry Engine natural scenery. (Photo by Cry Engine)

Cry Engine is a state-of-the-art gaming engine developed by Crytek and has adopted the pay what you want model, which allows people to use it free of charge. Highlights of the Cry Engine include high-end lighting, great animation system, and very powerful rendering capabilities. This engine creates dense vegetation and has good level design tools (Šmíd, 2017). Some negatives are that it is not very easy to learn for beginners as well as needing to have some C++ knowledge (Banerjee, 2017).

3.13.3 Unreal Engine 4

Unreal Engine 4 (UE4) is a popular engine used to create many AAA games. AAA games usually have high production and advertisement budget, which may influence the quality and popularity of a game. UE4

Image 6: This is rendered picture of Unreal Engine 4 urban scenery. (Photo by Unreal Engine)

is free to use until your game makes a profit and it has more photorealistic foliage and terrain than other engines. It uses C++ but is not mandatory due their blueprint scripting system, which allows more developers access. The graphics in unreal engine are highly praised as well as its ability to create custom materials within the engine (Banerjee, 2017). The game engine also has a good community that is helpful with builds and tutorials, but not as robust as Unity3D. The negatives for UE4 are that it takes more processing power than the other game engines and that it is more difficult to learn than the other two discussed previously.

4.0 Methodology

4.1 Site Location

Part of the research for this thesis project included a series of site visits to existing areas located throughout the Czech Republic that have wind turbines or the potential of wind turbines. Image 7 indicates the locations of the sites. Each varies in size and population density that adjoins the

Image 7: Locations of Site A, Site B, and Site C within the Czech Republic. (Photo from Google Earth)

location. There are three site locations indicated on the map as Site A, Site B, and Site C. The process of choosing the locations was based primarily on their ease of access as well as familiarity with the sites. A wind map of the Czech Republic was also obtained and used to assure that the average wind speed in these areas were capable of sustaining wind turbines. The final factor in determining the three sites were the number of wind turbines already existing on the site and their proximity to urban development. The results of this method were three sites that had varying wind speeds, vastly different number of HAWTs, and their proximity to urban areas.

4.1.1 Site A

Site A consists of a wind farm near Kryštofovy Hamry – Přísečnice at the intersection of highway 223 and 224 in Czech Republic (50°26'49.85"N, 13°9'34.76"E). This site has twenty-one, 85-meter-tall, operating wind turbines preexisting at the site. The operator is Ecoenerg Windkraft GmbH & Co. KG

Image 8: Site A - Kryštofovy Hamry within the Czech Republic. (Photo from Google Earth)

and the type of wind turbines are Enercon E82, 21× 2MW. The village Kryštofovy Hamry with a population of 96 (as of 2006) is located in the Ústí nad Labem Region (District & Hamry., 2017). The elevation where the turbines are located is approximately 850 meters (2788ft), with an average westerly wind speed of 4.5 m/s.

Table of current installation in wind (up-dated: 12/2017)									
Project name	Region	WTG producer	WTG type	Rotor	Tower	Installed capacity (kW)	Number	Total inst. Capacity	Year of installation
Kryštofovy Hamry - Přísečnice	Ústecký	Enercon	E- 82	82	85	2000	21	42000	2007
Pchery	Central Bohemia	WinWind	WWD-3	88	100	3000	2	6000	2008

Figure 2: Wind turbine models, height, rotor circumference, number of HAWT on site, and installation date information. (Figure info by www.csve.cz)

4.1.2 Site B

Site B is located between Pchery (population 1,951) and highway 7 in the Czech Republic; it has two operating wind turbines. The operator of the HAWTs is VTE Pchery, s.r.o. who have installed two WinWinD WWD3, 2x 3 MW

Image 9: Site B - Pchery within the Czech Republic. (Photo from Google Earth)

in 2008. Site B (50°11′29″N 14°06′51″E) has an elevation of 324 m (1,063 ft), with an average westerly windspeed of 4 m/s. These two turbines at a height of 100 meters, differ from Site A since they are 15 meters taller than the turbines found there.
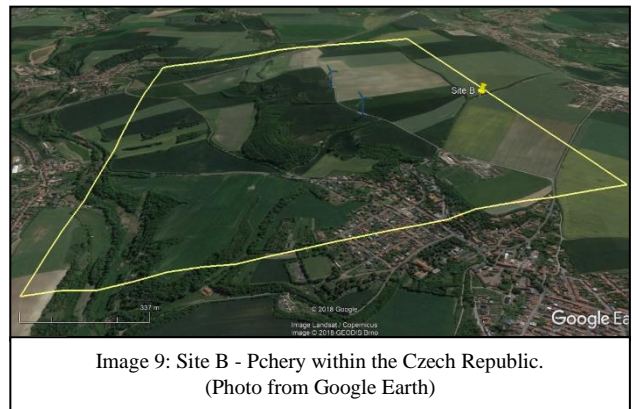
4.1.3 Site C

Site C is located within Troja (population 1,272), a district of Prague (population 1.3 million inhabitants) in the Czech Republic ("Prague Population 2018 (Demographics, Maps, Graphs)," 2017). This site chosen to show

Image 10: Site C – Troja district within Prague, Czech Republic. (Photo from Google Earth)
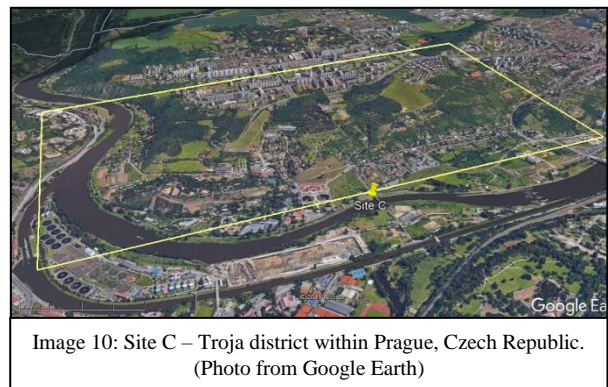
how wind turbines impact an area that currently has no wind turbines. Site C (50.119°N 14.413°E) was located on top of a plateau in the middle of an urban area. The likelihood of a turbine of this size ever being placed here is extremely small. The elevation is 314 m (1030 ft), with an average westerly wind speed of 4 m/s.

4.2 Attempted Methods

4.2.1 Sketchup

After choosing the sites to be studied, the next step of the process was to obtain the terrain data of the sites. The initial process attempted was to use Sketchup 2017, with the plan of importing the terrain data and modeling

Image 11: Sketchup model of a 2 km^2 portion of Site A. (Photo by author)
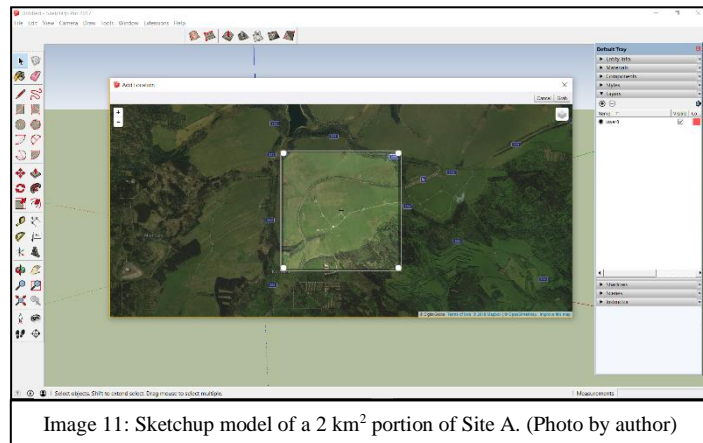
the landscapes in this manner and creating a 3D model of the surrounding area. The process of importing the site terrain information into Sketchup involves just a few steps. The first step is to open the program and start a new project. The second step is to go to File →Geo-location→Add location. This will open an orthographic map where a region that must be at smaller than 2 km^2 can be selected. Once the region is selected, the grab button must be pushed and then it is imported into your work area.

4.2.2 ArcMap → ArcScene

The method of using ArcMap 10.5.1 to get accurate high-resolution Digital Elevation Model (DEM) was determined to be the best way of obtaining the necessary accurate terrain data.

After obtaining the DEM from the server, the DEM was added to a new file in ArcScene. The first step is to open ArcScene and start a new project and save the project. After the project is saved, one must go to add data icon in the menu bar (or

find the data in the catalog where the DEM is located) and click and drag file into workspace. Once the DEM is in the workspace right click on the file and go to properties. Once in the properties click on the Rendering tab and mark the "Shade the aerial features relative to the scene's light position" under effects. Then move the "Quality enhancements for raster images" to high. Hit apply, and then click on the Base Heights tab. Under this section click "Floating on a custom surface", and then click the "raster resolution" button and change the cell size x and y to desired value. Lastly, click the OK button and the terrain will be represented in 3D.
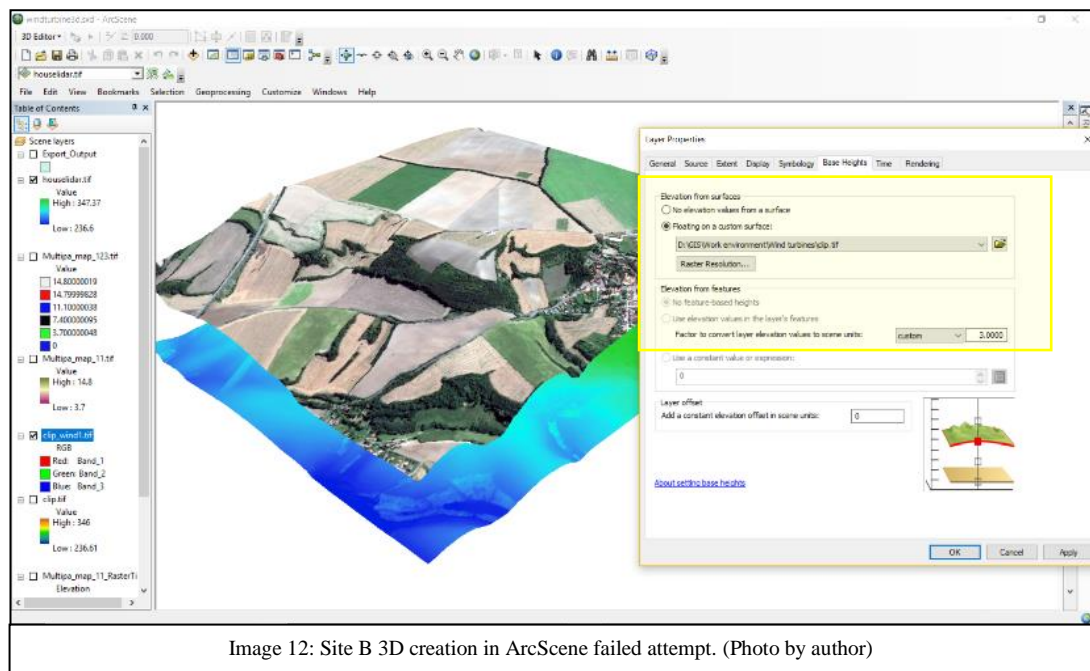
Image 12: Site B 3D creation in ArcScene failed attempt. (Photo by author)

4.2.3 Unsuccessful Attempt of Bringing Terrain into Game Engine

There was a process that was found online for bringing or adding real world terrain data into Unreal Engine 4; it was attempted many times but ultimately proved unsuccessful. This process failed either due to user error, inadequate computer processing power, or its end goals differed from this project. The following process worked but ultimately failed to be successful. This method required an additional program named L3DT (found here http://www.bundysoft.com/L3DT/). This program allows the DEM to be manipulated prior to going into the game engine and it saves the files in .R16 format, which is a readable file format for Unreal Engine 4. After many attempts to make this process work to get desired outcome, it was abandoned. The following process was obtained from a YouTuber known as Virtus

Learning Hub/Creative Tutorials, in the video "Importing Real World Locations into Unreal Engine 4 - Beginners Tutorial UE4" (Virtus Learning Hub, 2017).

1. Import .tiff file from heightfields
2. Resize heightfield: go to operations> heightfield > resize heightfield
   a. Change number to 8192
   b. Click ok > yes
3. Go to file > export > export to active map layer > file name > ok >ok
4. Open photoshop > file > new > 8192x 8192 pixels, grayscale
5. Create a black image and save as .png file
6. In L3dt go to operation > heightfield > change horizontal scale > copy number for future use
7. In L3dt go to operation > heightfield > change vertical scale > copy altitude range number for future use
8. In L3dt go to file > import heightfield > don't save changes > click on 8192 black image> next > change horizontal scale to what was copied previous in step 6 > click ok
9. File> import> merge heightmaps> select the .hfz terrain file > unclick stretch to fit > ok
10. File > export > export overlapped tiles> create new folder (terrain) >save name> r16 and 2017> ok>ok
11. Open Unreal engine > new project
12. Make new level> save as > make world file> enable world co > enable world origins
13. Go to windows> levels> import tiled landscape from file
14. Unclick flip tile y coordinate
15. Use length measurement divided by area in window (8.068 maybe) for x and y
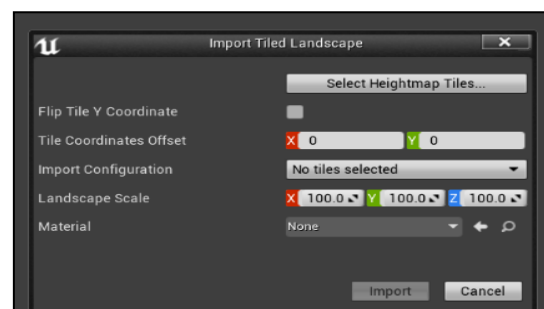16. Example length = 3241.71 (3.24171 KM) / 8.068 = .40179 which is 40.18 =x and y

Image 13: The blue box z is where you put the value in step 17. (Photo by author)

17. For vertical (z) multiply constant (0.1953125) by the altitude range from step 7. Enter for z
18. Click import
19. And load terrain

Although the results were not the ones desired, this method did give key information needed for the successful process. The constant, in step 17, will be a step needed in the successful process.

4.3 Successful Process for 3D Representation

4.3.1 Choosing the Game Engine

The most successful method of creating a 3D representation of these study areas was using a gaming engine to recreate the environment. The criteria that was used to determine which gaming engine would be used was based upon the following criteria: cost, rendering quality, interactive capabilities, and terrain modification. The first step to produce the necessary material for the surveys was to learn how to use the software for the modeling of the world in Unreal Engine 4. Unreal Engine 4 is a game engine designing-program that could be used to create a game; others that could be used include Unity or CryEngine. Based upon the research and findings described in the Literature Review chapter, Unreal Engine 4.18 was determined to be the best candidate due to the prior required needs that needed to be met. This engine allowed for the creation of this environment, but the hindrance to this engine was the steep learning-curve. If there is no prior knowledge or experience relative to how game engines work, it will be difficult to learn how to interact with this program.

4.3.2 Obtaining DEM Map

After installing Unreal Engine 4 and creating a new project file, the first piece of data needed to recreate a realistic environment was to obtain a DEM to be used to get the information for the terrain that the game engine would need. There are several places this information could be obtained, but the two methods used here were based off Open Topo (http://opentopo.sdsc.edu) and a server used in ArcGIS. This section will be based off the ArcGIS method. The method used with the open source data

was tried but ultimately dropped due to several factors. These varied from the quality of map resolution and the process needed to take this information and apply it to the game engine which proved to be more rigorous and time consuming. A disadvantage of the server was that it could only be used for regions within the Czech Republic, whereas Open Topo has worldwide data.

The server provided for use in this thesis, used LIDAR information with a resolution of two meters. The step-by-step process of obtain this information is as follows:

1. Obtain data from desired server.
2. Import data into ArcMap workspace.
3. Right click on your imported data file.
4. Go to properties, then to processing template → function = none. Click OK.
5. Make a new shape file to clip the area that is desired. The shape file will become the mask in which the data is clipped from.
6. Extract by mask (with your shape file you made). The "input raster" is the data file and the "input raster or feature mask data" is the shape file.
7. After the file processes, turn off data file and shape file and just leave resulting file on. This is the DEM.

*(Note: Measure and record the DEMs width, height and elevation range (high minus low value), these are needed to bring it into the game engine.) *

4.3.3 Marking the Location of a Wind Turbine

To determine or locate the precise locations of the wind turbines or any other object that needs to have a specific location, it is necessary to use the following steps in ArcMap before exporting the file.

1. Obtain a recent orthographic map of study area (or map that contains precise location of objects you wish to mark).
2. Once map is in place, create a new shape file to mark your objects.
3. After marking you objects and saving shape file, turn off orthographic map off and make sure your DEM is on.
4. Go to file → Export map → Save the file as a .tiff file.
5. Close ArcMap.

Image 14: Orthographic photo of Site A. Create a shape file to place the "x" on top of the wind turbines so they can be found in UE4. (Photo by author)
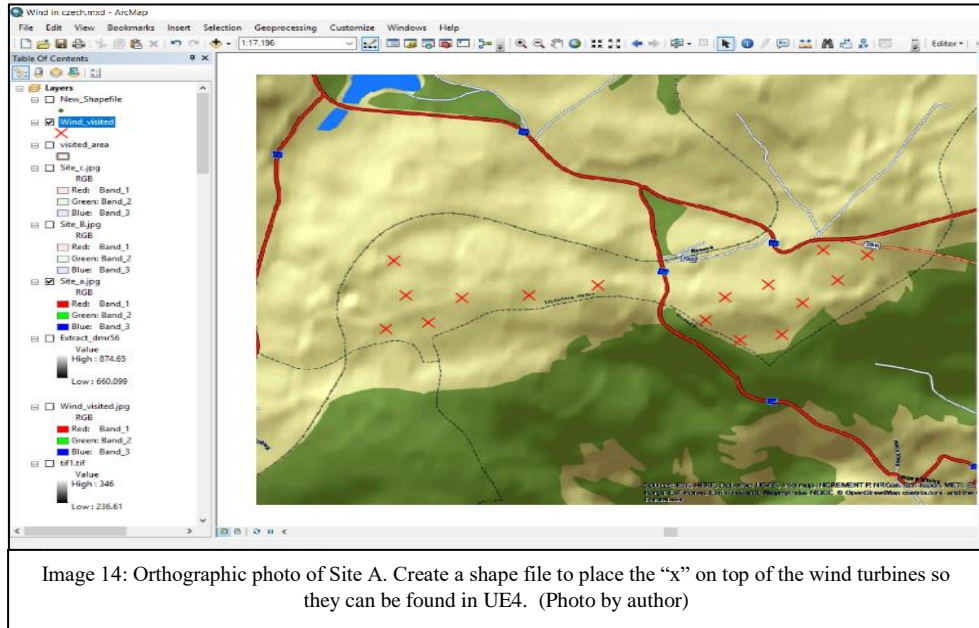
4.3.4 Preparing DTM File for Game Engine

Before bringing the DTM into the game engine, it is recommended to open a photo editing software to make it easier to use in the game engine. Adobe Photoshop was used in this project.

Image 15: When opening a new file in Adobe Photoshop set up with the proper settings (Photo by author).
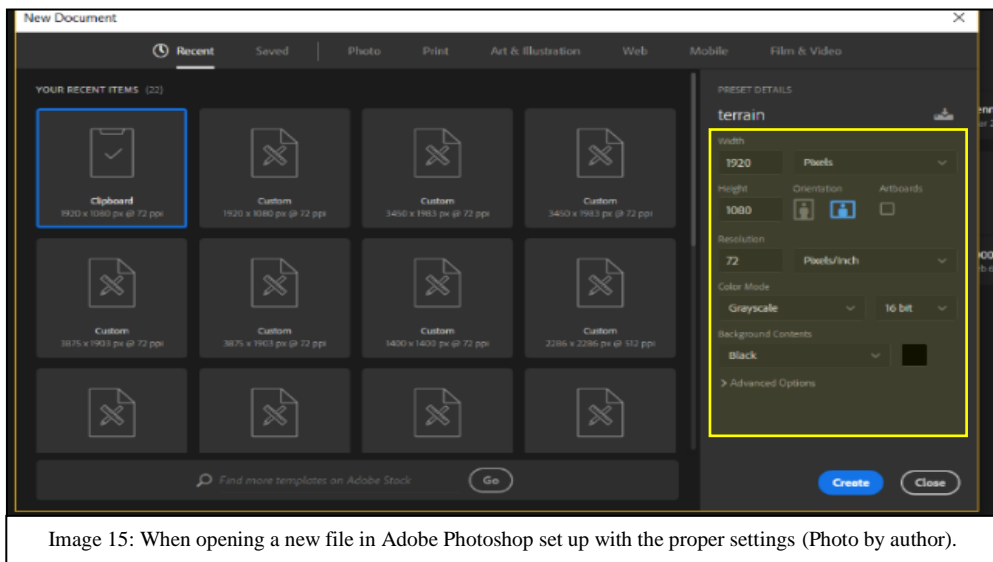
1. Open Adobe Photoshop.
2. Click create new file.
3. Change the width and height to match you DEM you recorded earlier (as noted in section 4.3.2 Obtaining DEM Map). Keep it in pixels, default resolution of 72 is fine.

4. Make sure color mode is changed to grayscale. The other settings should not have any significant effects.

5. Click OK.

6. Click the new layer tab, and then open the DEM, by dragging and dropping it into the workspace.

7. If the file is the wrong orientation, go to Edit → Transform → Rotate. Change the orientation so it aligns properly with workspace.

8. Go to File → Export → Export as…→

9. Change format to PNG

10. Click export as and save in desired folder. Click OK.

11. Close Photoshop.

4.3.5 Using City Engine for Streets and Buildings

The next step in the process, if necessary, is to obtain roads and buildings data to be imported into the game engine later. This is not a necessary step but makes placing buildings and roads much easier. A necessary extension, Datasmith beta (March 2018), will be needed to import this information into Unreal Engine 4. Go to this website to apply for the beta version: (https://www.unrealengine.com/en-US/studio/getstudio). Once accepted, proceed to the following steps.
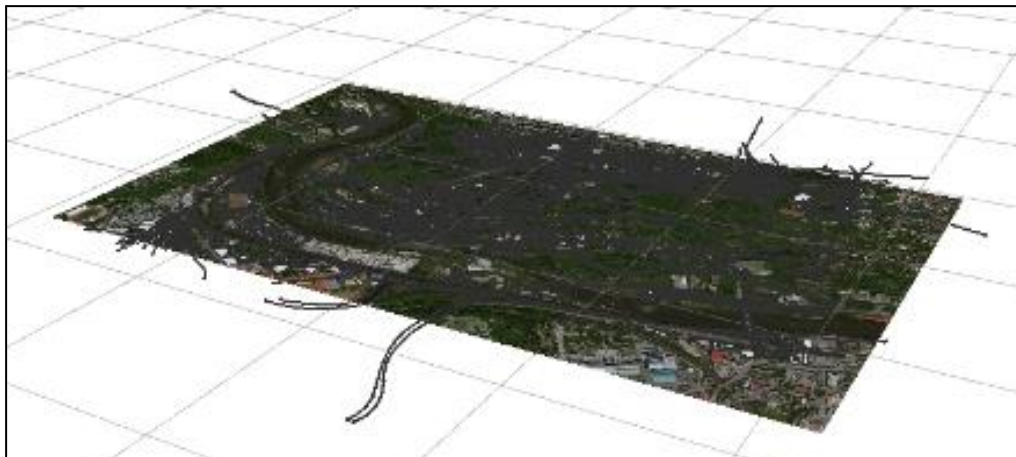

Image 16: Map created in ESRI City Engine. Street and buildings are obtained from an open data source (Photo by author).

1. Open ESRI City Engine and start with a blank scene.

2. Pick project folder, file name and coordinate system that matches your GIS information. Click Finish.

3. Go to File → Get Map Data.

41

4. Find your location and enter the same measurements for width and height you had for your DEM.

5. Click the Get terrain box and download networks and polygons. Click OK.

6. In the OSM dialog box click Buildings and Highways. Click Finish.

7. It will appear in your workspace. Highlight the map files in the scene dialog box in the top left corner and then click the Generate button. This will result in 3D buildings, that should be the appropriate height, based off open street data.

8. Select all objects in the scene dialog box. Go to File →Export Models.

9. A new dialog box will appear. Select Unreal Engine (Beta). Click Next.

10. Under Global Offset click the "Center" button. Click Finish

11. Close City Engine.

*If the texture on the buildings is needed, deviate from Step 9 and select "Collada" file and follow the same steps. Open Sketchup and import files. Then proceed to File→ Export 3D Models and save as a .obj or .fbx file. *

4.3.6 Opening your DEM in Unreal Engine 4

Image 17: Unreal Engine 4 New Projects option screen. Here is where first or third person options are chosen and where it is decided if it is for desktop or mobile (Photo by author).

1. Download the latest version of Unreal Engine 4 (https://www.unrealengine.com).

2. If accepted to Datasmith beta project (see 4.3.5 Using City Engine for Streets and Buildings) install now.

3. Click launch button.

4. In the Unreal project browser select New Project tab.

5. Within that tab select blueprint that is needed (third person is recommended).

6. Choose desktop/console or mobile.

7. Choose maximum quality and no starter content.

8. Create project.

9. Under the Modes tab in the top right corner click on the tab that looks like a mountain.

10. Within the Manage tab (gear plus mountain tab) there will be an option to "Import from File" click it.
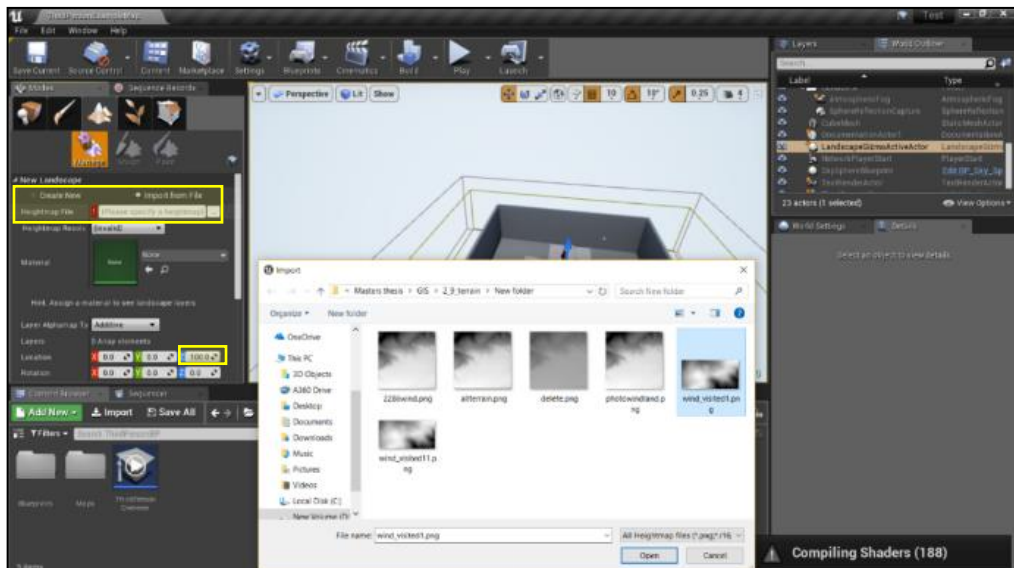
Image 18: Screenshot of where you will import the DEM into the project and where the scale is set (Photo by author).

11. Next go to the "Heightmap File" section and add your DEM file from 4.3.2-4.3.4.

12. A green mesh will appear.

13. Go to scale.

    a. X and Y scale will be fine and match real world scale. 1 unit = 1 meter.

    b. Z scale must be modified.

    c. For vertical (z) multiply constant (0.1953125) by the altitude range (see note from 4.3.2). The constant was obtained used in step 17 of

section 4.2.3. The landscape is now imported into the world and should be to scale. 1 unit in the game engine is 1 meter in the real world.

14. Click Import.

4.3.7 Making the Landscape Appear More Realistic

Models that are in 3D can be added at any time, which can be obtained by searching the web or making them in 3D modeling program such a Blender. The marks that were placed for the wind turbines can now be smoothed out using the "smooth" tool under the
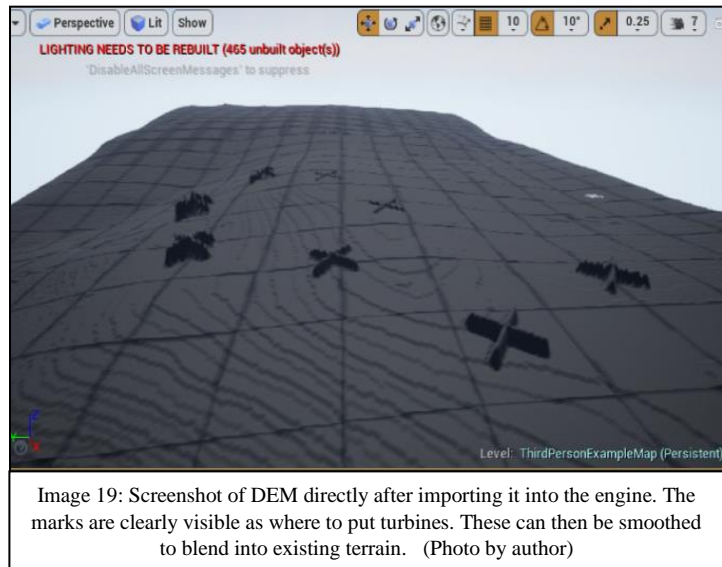

Image 19: Screenshot of DEM directly after importing it into the engine. The marks are clearly visible as where to put turbines. These can then be smoothed to blend into existing terrain. (Photo by author)

Modes tab and Sculpt tab respectively. These sculpts tools can be used to make the landscape appear more natural. Adding texture to the landscape will also help in creating a more realistic environment. To make the environment look more natural add ground textures and trees.

When all the other data is added the next step would be to add the buildings and road files from City Engine, using the Datasmith beta extension. This should come

towards the end of the project due to its potential size and slowing down of the computer processing the data.

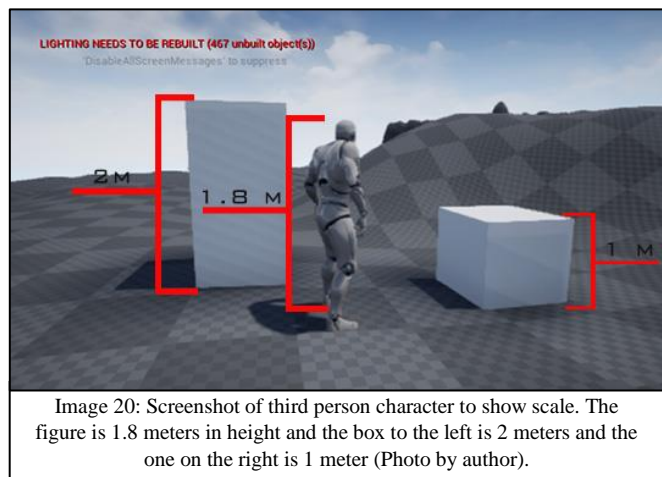To ensure the environment looks as realistic as possible there were many reference photos and maps used.

Image 20: Screenshot of third person character to show scale. The figure is 1.8 meters in height and the box to the left is 2 meters and the one on the right is 1 meter (Photo by author).

Orthographic photos as well as vegetation maps were reviewed and then used to put vegetation and other items into the simulation. Google Street View images and 3D maps were referenced to make sure everything was in the correct places. Personal photos and videos were also used to match the simulation as much as possible with the actual site.

4.3.8 Packaging the Video Simulations

The last step of the process would be to create the cinematic of the site or publish the game to be used to explore the site. For this project it was made into several cinematic movies.

The key elements to pay attention to when preparing to render the movie in the game engine or Adobe Premiere is the frame rate it will be set at, meaning how "fast" the movie will play or be viewed. The default of this game engine is set at 30 FPS (frames per second) but can be adjusted to meet the desired need. After adjusting camera setting and placing the camera path the cinematic is ready to be rendered. To render the movie simply click the clapperboard icon. Once the button is pushed it will bring up a new window allowing you to pick the resolution and save location of the cinematic movie.

Once the rendering of the movie was complete Unreal Engine 4 was shut down. The next portion of the project was opening the video captured from the site visit and the simulation video in Adobe Premiere. The path of the cameras was placed in a way to mimic the real site visit video. In Premiere the videos were placed next to each other for comparison and rendered.

4.3.9 Survey

To see how effective this method was at recreating a site, a survey was created in Google Forms. The website as of 2018 is free to use and allows a video clips to be uploaded and surveyed. The address for the survey used is (https://goo.gl/forms/GqhmmaoT3JnEazmQ2) and the link to the YouTube video is (https://youtu.be/QDVmdw8MwQE).

The purpose of the survey that was conducted was to determine the most effective and immersive way in which people can see how wind turbines impact a site. The survey consisted of three sections. Section one used modified pictures vs. on-site pictures and simulated video vs on-site video. Section two was to determine how realistic the simulated video was. Section three was used to see how audio affected the realistic simulation video. The survey consisted of eight questions:

Image 21: Screenshot of video made for the survey that was conducted. Here is shown the real and manipulated photos, so the person taking the survey can see how well manipulated photos represent the real ones.
(Photo by author)

1. In section 1, how realistic are the manipulated photos?
2. In section 1, how realistic did the simulation video appear?
3. Comparing the photograph and video in section 1, which did you prefer?
4. Comparing the photograph and video in section 1, which gave you more understanding of the area?
5. In section 2 of the video, how realistic did the simulation video appear?
6. In section 3 the video simulation had audio. How would you rate the effectiveness of the audio with video simulation, regarding immersion?
7. Regarding section 1, 2, and 3 which media helps you to best understand the landscape?
8. Regarding section 1, 2, and 3 which method would you prefer if one must be chosen?

9-13 Have you ever visited a wind turbine farm, solar farm, photo-voltaic array, hydroelectric dam, or nuclear power plant?

There was also an area to identify gender, age, nationality, level of education, and major. The survey data was then collected and used to help determine the effectiveness of this approach.

4.3.10 Recap of Programs Used in this Project

1. ESRI ArcMap. Skill required: Beginner-Intermediate.
2. Adobe Photoshop. Skill required: Beginner.
3. ESRI City Engine. Skill required: Beginner.
4. Sketchup. Skill required: Beginner.
5. Unreal Engine 4. Skill required: Beginner-Intermediate
6. Blender. Skill required: Intermediate-Advanced.
7. Adobe Premiere. Skill required: Beginner-Intermediate
8. Survey creator from Google Forms.

5.0 Results

The following section will propose the best solution in the creation of a visual impact assessment model.

5.1 Sketchup

This process was the easiest to use and had the fewest steps to be used to obtain terrain information. If desired, models could be created or imported into this program to represent
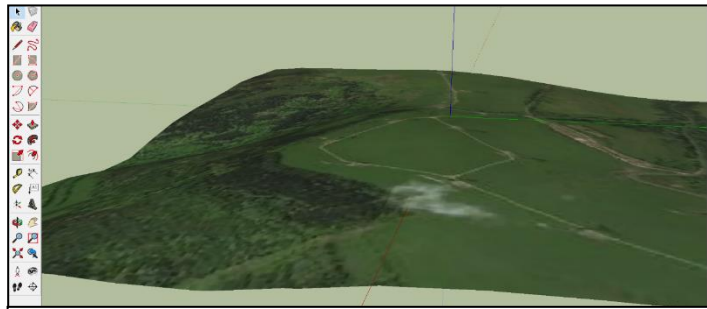
Image 22: Sketchup model of a 2 km^2 portion of Site A. (Photo by author)

building and wind turbines. The ease of use of this program is very high but the end results do not represent a photo realistic landscape and has very poor resolution. The terrain that results from importing the geo-location map is not good for an accurate portrayal of the site. Due to this lack of terrain detail it was determined to not be the best fit for creating a 3D representation in video or real-time.

5.2 ArcMap → ArcScene

Using ArcMap → ArcScene was a slightly more in depth than the Sketchup process, but the terrain was represented in much more detail than Sketchup. The problem with this process was that it became a dead-end; the result that could be obtained by using this method was not satisfactory. Creating a 3D representation of this area may be
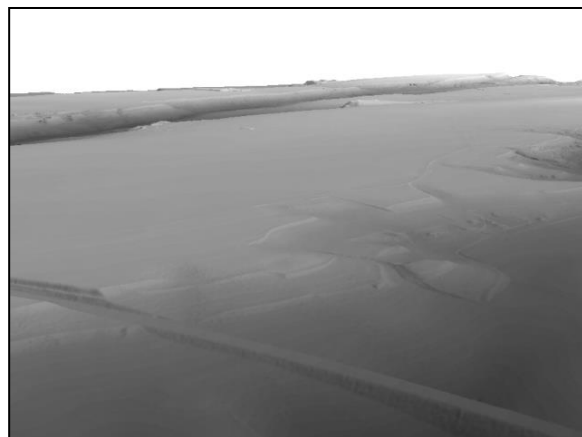

Image 23: Site B rendered in ArcScene using the following a failed attempt. (Photo by author)

possible but due to lack of time and knowledge of the program it was disbanded. The terrain results from what could be created through this method were accurate in appearance, but the steps to take this into a 3D modeling program such as Sketchup,

Blender, or Unreal Engine 4 could not be found after many attempts, thus ending this method. The desired results for this thesis was to create a 3D virtual environment the user could interact with, but the results of this method were just static images.

5.3 Choosing the Appropriate Game Engine

A game engine was chosen to be used in this process because it has the capabilities for being used to create 3D environments and being able to interact with it in a dynamic way. In the Literature Review chapter, three different game engines were discussed; each one had strong points that justified its use. Unreal Engine 4 (UE4) was chosen primarily for the following reasons: based upon the research that was done, many individuals stated that they felt as if it was the most effective at creating nature environments and rendering them well. Due to the goals of this project of making a photorealistic world for users to be able to be immersed into, it was decided to use this engine. However, one principle flaw is that it was suggested that it was much more difficult to learn than Cry Engine and Unity3D. It was found that there was a steep learning curve to this engine, even with tutorials, especially since the goal of this thesis was not a common problem that many people were seeking a solution for in the use of a game engine such as Cry engine, UE4, and Unity3D. The result of these investigation and also based upon the consensus of it being able to render natural environments by many reviewers lead me to select this application.

5.4 Unsuccessful Attempt of Bringing DEM into Game Engine

The goal of importing a real-world digital terrain model into the engine and making sure everything was to scale was not a common or typically used task. Ultimately there needed to be a lot of research undertaken to arrive at this solution. After many inquiries through UE4 documentation pages and scouring many tutorials through YouTube, some procedures were found that looked promising. The first number of attempts using Unreal Engine 4 were much more complicated than the proceeding procedures with Sketchup and ArcGIS. As with the previous attempts, there was some required background knowledge of the programs, however there was no previous knowledge of this software prior to the attempts to employ these combinations of program applications and methodological steps. After some initial

first attempts, the procedure discussed in the Methodology chapter, section (4.2.3) was discovered. This procedure was the closest in completing the goal of importing the DEM into the game engine. By following the procedure laid out in the methodology section, the terrain could be imported. The terrain was realistic looking in appearance and was able to be manipulated, however there were two principal drawbacks toward this approach. The first was the file size due to the terrain files that were so was large that they made the laptop computer running the program to perform tasks slowly. This problem may have been solved by making the size of the terrain model smaller than what was obtained originally. The other problem occurred when leaving "editing" mode to enter "play" mode. "Play" mode lets a character, which could be first person, third person, or vehicular, test out the simulation and lets you move and interact with the world. It is in this mode you can see animations if you have installed any weather characteristics, such as rain or snow.   This mode was essential for the end goal of the thesis and would be needed to successfully complete it. The problem that occurred from this method would result in the character becoming frozen and freezing the entire computer screen. Research was done to find a solution to this problem, but none could be found. This problem may have occurred due to user error or maybe the procedures in obtaining the DEM was wrong, or it was incorrectly implemented. One possible reason upon reflection and gaining more experience with the program is that the terrain properties may have had a setting adjusted incorrectly in the collision-section of the terrain. This may have been the result encountered when adding high voltage power line models, and subsequently solved by adjusting those object collisions settings, which is found in the properties section of the item. According to UE4 documentation page, collision responses are as result of how the engine deals with collision and ray casting (Engine, 2018). At this point in the project, the knowledge base in using this program was as a beginner at best, and not being able to find an easy solution it was decided to find an alternative method of bringing in the DEM.

Even though this procedure was a failure, either due the user or the procedure itself, it did show that it was possible to bring in real world terrain and it provided valuable information that was used later in the successful process that only obtained through this method. This process allowed the user to become familiar with the program itself, largely through trial and error, but also through some basic information on the

scaling of the terrain when bringing the files into the artificial world. Through this method was found the constant value (0.1953125) needed to be multiplied by the altitude range to obtain the (z) value which represents elevation or height. This was stated in the Methodology chapter (section 4.2.3) but needs to be stated once again due to its importance.

5.5 Successful Process for 3D Representation

5.5.1 Obtaining DEM

The process of obtaining the DEM proved quite successful due to the server in which the information could be gathered. In Methodology section 4.2.2, it was explained that a DEM can be obtained from open source maps around the internet, but they were not as high of resolution as the ones obtained from the server
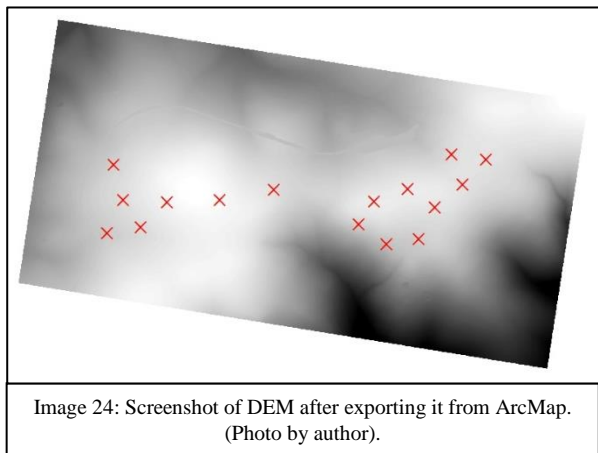
Image 24: Screenshot of DEM after exporting it from ArcMap. (Photo by author).

in ArcMap. The server was able to provide LIDAR maps of very high resolution which made them more accurate when the time came to import them into UE4. The process of obtaining the map was quite straightforward and should be able to be followed by anyone with some basic familiarity of ArcGIS.

5.5.2 Marking the Wind Turbines

This was one step that was skipped when initially attempting to bring the DEM into the game engine, but was deemed necessary when there was no indication where to place the turbines when they were brought in. The solution was easy; since anything placed on the DEM when it was in ArcMap would be interpreted in the game engine as a higher point. By using this method an item could be mapped onto the terrain in its precise location and appear as an elevated point once it was brought into the game engine.

5.5.3 Preparing DEM File for Game Engine

This step of the process was necessary in order make sure there was no unintended white space on the DEM when bringing it into UE4. This is important because of how UE4 reads the DEM. The DEM is in a grayscale, with the black
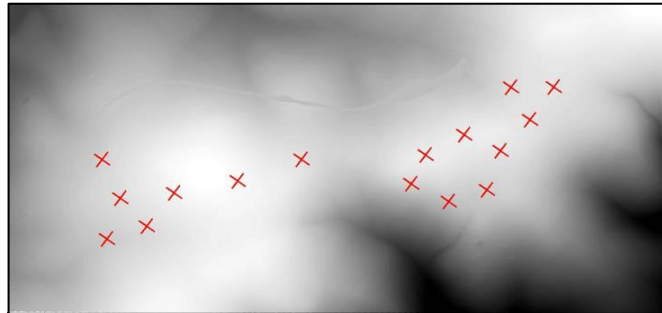

Image 25: Screenshot of DEM after transforming it Photoshop. This step is necessary otherwise the white space that was in Image 23 would appear like the "x's" in Image 19 (Photo by author).

representing low points and white the higher points on the map. Prior to the use of Photoshop, the DEM was brought into the game engine and there were huge walls in the terrain. These walls were a result of the DEM file not being squared and resulting in the space with no information being white, which results in UE4 reading it to be the highest possible height on the map. Rotating the image .tiff file for the DEM and then cropping it solved this problem. There may be a better solution to bringing the file into the game engine without Photoshop, but this was the easiest solution found at the time for the current project.

5.5.4 Using City Engine for Streets and Buildings

The results in using ESRI City Engine were mixed. The benefit is that the roads and buildings matched the terrain fairly accurately with slight adjustments. For Site B and Site C this was very beneficial because they were closer to urban centers. Without this program the roads would need to be mapped by looking at orthographic maps and photos. This was the easiest method found that also allowed
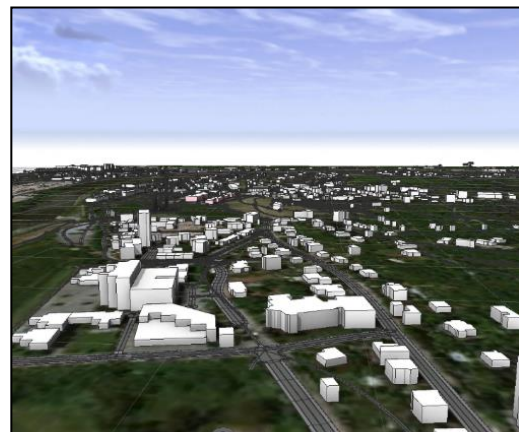

Image 26: Screenshot of the 3D buildings in ESRI City Engine without the facade that can be obtained and brought in UE4. (Photo by author)

relative accuracy to the building of the simulation with the lowest amount of man hours put into it. A negative point for using City Engine could be in a much bigger files size for UE4. This contributed to a lot lag in the computer processing the file

after the object files were brought in, and due to this it is recommended if this is used to be one of the last steps in a project. The other negative is if building façade were wanted to be imported from City Engine to UE4 the only way found to do that was to import the file into Sketchup and then export in to UE4, which was a more time-consuming process.

5.5.5 Opening your DEM in Unreal Engine 4

As stated earlier in section 5.3, the initial process of bringing this data into UE4 had mixed results. The process used in Methodology 4.3.6 was by far the easiest and quickest method found. The steps to bringing the DEM into the game engine was as effective as the earlier attempt but this time when accessing the 'play" mode, the previously experienced glitch of the character freezing or locking up did not occur! Since this allowed the freedom to explore and investigate the terrain as intended this was the procedure used for all the study sites. This process was found by accident, when trying to perform another action but turned out to be a better process.

5.5.6 Making the Landscape Appear More Realistic

The manipulation of the landscape and adding of elements into it was key in making the simulation appear more realistic. Some of the key things that manipulated were modification of terrain, adding objects, creating textures, and lighting. The

Image 27: Image of a rendered shot of Site A set in winter (Photo by author).

modification of the landscape was key to change the appearance of the landscape from terraces to that of smooth progression of elevation. While doing this, it is vital that you watch the tool strength as to altering the terrain too much. Using this tool will also allow the removal of any marks made for objects in the GIS portion to set up this project. The ability to add 3D objects into the site was used to bring in wind turbines, vehicles, and people into the simulation, with the intention to make it appear more real and for scalability. It is recommended to have some basic understanding of working with 3D models to adjust and modify them. This project used a wind turbine that was a free opensource object but needed modification of blade size and animation speed in 3D modeling program Blender. Background knowledge of 3D modeling programs were also beneficial for the scalable people brought into the project as well. This knowledge is not essential but helpful when attempting to make it appear as photo-realistic as possible. Another key modification was that of creating textures and painting in vegetation. This process allows the adding of material ranging from small grass and flowers to things such as boulders or trees. All these need to be used in balance with the computer's ability to process the data. The more trees that are put into the engine the more it needs to process and thus reduces the computer performance. This was a limiting factor in this project because its best optimization was set at "medium" which is towards the low end of the scale for processing power. The scale range is as follows: low, medium, high, epic, and cinematic. The better processing power of the computer the smoother and faster it will render and build the lighting for the simulation. Even if the computer is optimized for "medium" it can be changed when rendering the outcome to something higher, it just takes more time and has a higher chance of the computer crashing.
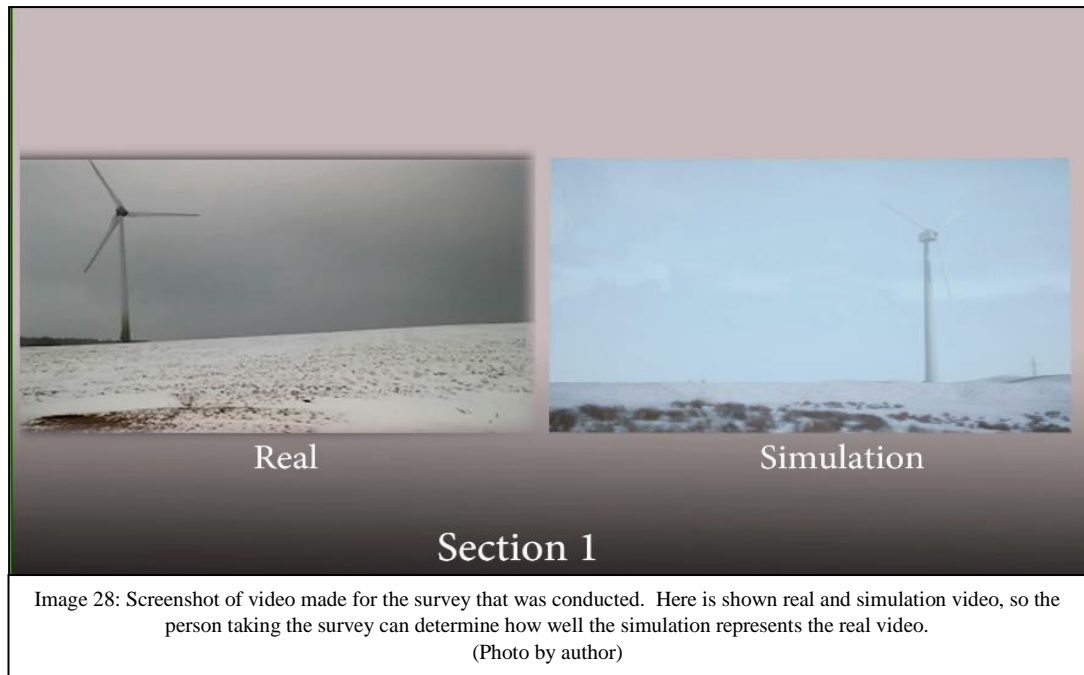
Lighting is essential in creating a realistic environment in these simulations. When adjusting lighting it is important to know the direction of the sun and where it would be in the real site. These aspects can and must be controlled in UE4. If the lighting strength is too much it will boost the contrast of the environment or too dark it will exaggerate or distort the shadows, that is why it is essential to adjust the texture brightness of the objects in the environment (Oravakangas, 2015). The adjustment of lights and texture brightness will increase how photorealistic the environment

appears. When adjusting the lighting it is recommended to start with the biggest source first, usually the sun, and then work down to the smaller sources of light.

5.5.7 Packaging the Video Simulations

There are two options when packaging this simulation to be used by a third party, which are rendering a cinematic or creating a game. Both options were considered for the project, but the cinematic option was chosen to be the sole output due largely to the lack of time and experience in creating a game. The game output is a possibility for future research because it could allow for third parties to have a more direct interaction with the project area. Rendering a video was chosen to be the output because it could still show results of the terrain simulation that we would want the viewers to observe. When choosing to export the frame rate is important. The higher the frame rate the more polish and sharp the action seems, whereas a low frame rate will result in the opposite. Another way of saying this is as follows: the higher the frame rate the smoother the motion will appear to our eyes as examples in film are stop motion animation (for example: The Nightmare Before Christmas) vs modern 3D animation (for example: Toy Story). Due to the influence of the film industry, viewing audiences are accustomed to movies at 24 FPS, resulting in artifacts such as motion blur (Pickfair Institute, 2014). So, if the desired affect is to be more cinematic, it is recommended to keep the FPS at 30. The rendering process is another factor that is determined by the computers processing power and the amount of time it will take complete it.

Once these files were completed they were taken into Adobe Premiere to make the presentation of the video footage more presentable to any potential audience. This is yet another step that is optional but was used to make comparisons of the original video of the site with the newly rendered video easier to view for the audience. Making this split screen just required importing the two videos into the workspace and setting them side-by-side. To import the video, go to the "Assembly" tab and drag the videos into the timeline. To render your completed video, go to File → Export → Media and a new window will appear. Choose the optimal setting for the video keeping in mind where it will be displayed and then hit export.

Image 28: Screenshot of video made for the survey that was conducted. Here is shown real and simulation video, so the person taking the survey can determine how well the simulation represents the real video.
(Photo by author)

5.5.8 Survey

The use of the Google Forms (https://www.google.com/forms), was essential in doing the surveys based upon the following reasons. The first was the ease of presentation, since it shows the video you want displayed followed by the survey questions. Another reason is that it allowed for more potential survey takers in a small amount of time and did not rely on legwork to ask people to take the survey directly.

Several websites were used to facilitate this survey and to get the desired amount responses. The following websites were used and broken down by the percentage of respondents.

Facebook groups: Dissertation Survey Exchange 30%
CULS Facebook Private Info group 18%

Websites: www.surveytandem.com 22%

www.poll-pool.com 10%

www.surveycircle.com 20%

These sites were beneficial since most of the respondents were people I had no prior relationship with that may affect the outcome. The weakness of the survey was the sample size that was obtained.

Initially the goal was to get a sample size to be truly representative of a population of 10,000 people with 5% error and a confidence rate of 95%. In order to see how many people would be necessary to take the survey the website Creative Research System (https://www.surveysystem.com/) was used. There calculations were based off the formula $1/\sqrt{N}$, where N is the number of participants (Niles, n.d.). From this calculation it was found that to be within the margin of error there needed to be 370 people surveyed. Due to the lack of time, the survey had to be cut well short of this expectation. For this study 100 surveys were able to be collected, which is significantly smaller than the goal. With this amount of surveys collected the results would represent a population of 10,000 with 95% certainty and a 9.75% margin of error. Some of the results of the questions are as follows, and the rest can be found in the Appendix.
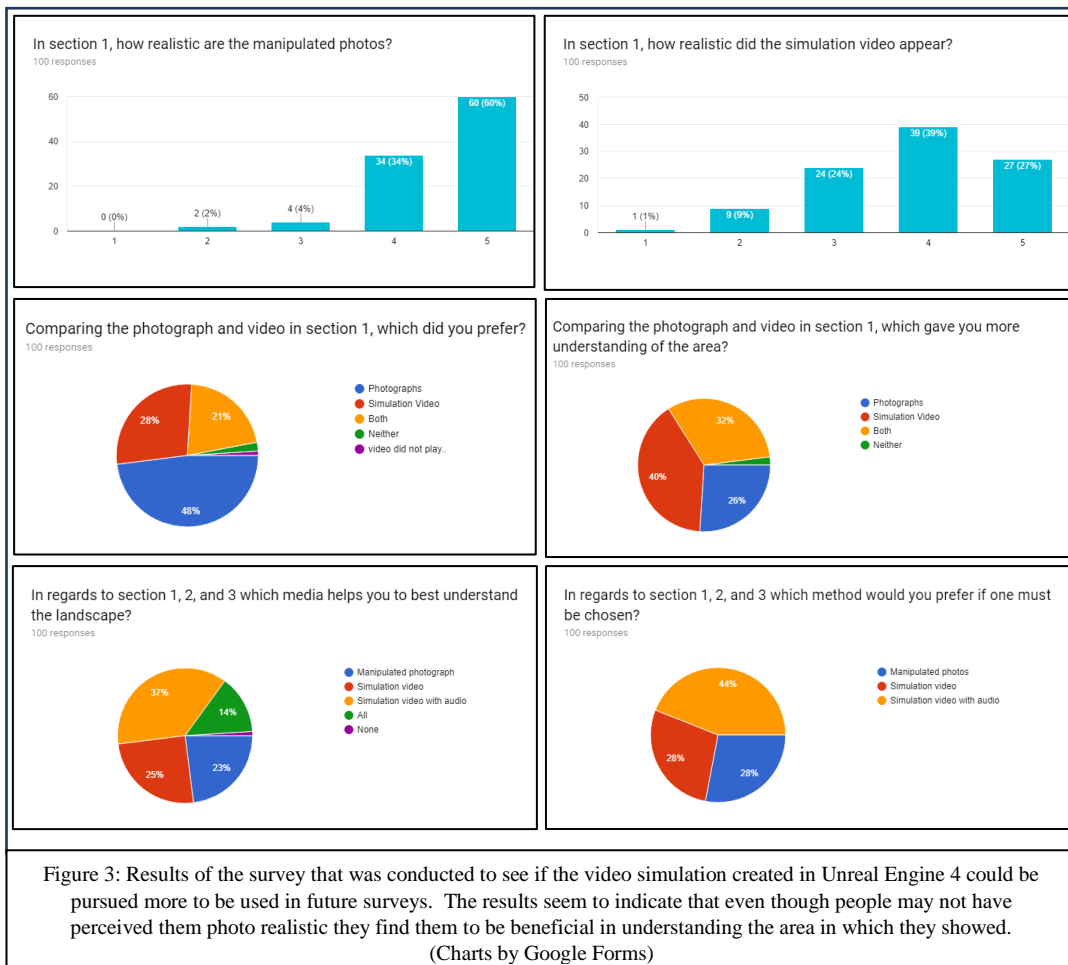
Figure 3: Results of the survey that was conducted to see if the video simulation created in Unreal Engine 4 could be pursued more to be used in future surveys. The results seem to indicate that even though people may not have perceived them photo realistic they find them to be beneficial in understanding the area in which they showed.
(Charts by Google Forms)

6.0 Discussion

The purpose of this thesis project was to determine how to represent a 3D environment most effectively that could be used in surveys which result in realistic visual representations of wind turbines in an environment and how they compared to actual sites. Through 3D modeling it was desired to improve upon visualization techniques that would be used to indicate how one views changes in an environment. The application environment could be situation where one wanted to gauge or test a hypothesis involving a user group (local inhabitants or visitors to a location), such as reaction to new or proposed land development, clear cutting of forestry, or the visual impacts associated with new technology in the landscape such as solar or wind farms. The application environment that was the focus of this thesis research explored how a wind turbine farm could have an impact upon the visual or scenic character of a place. This method was chosen based upon a review of the literature where people were surveyed to determine their preference for or against wind farms. It was here that most of the representations of wind turbine farms were either characterized with words or with highly manipulated still images of a variety of landscapes.

The main purpose of this thesis project was to determine if 3D representations could accurately be used to represent an environment with wind turbines. The goal for this thesis project was not to determine if people are in favor of or against a wind farm, but rather to determine if 3D representations could be a tool or application for conducting such research in the future. This project was primarily concerned with how accurate the 3D representation could be so that it may be used in the future with confidence to determine how people might react to simulations of wind turbines or wind farms situated recreational landscapes. The sites were compared to original video footage to determine how realistic the simulation was in comparison. This paper was a stepping stone for future research using 3D simulation with visual and audio preferences. It may be used for numerous sites that may venture beyond wind farms and into solar farms or urban expansion. Environments are not static still images that can be captured in neutral wording, they are dynamic living things with movement that have many factors that influence how we feel about them.

One of the main factors that may affect how people say they feel about wind turbines when surveyed, is the perceived bias whether pro or con they interpret from the interviewer or questions they are asked. This is very difficult to eliminate, since some things may be subconscious body language, phrasing of a question, or the angle of a photo/video shown. Most people giving the surveys are trying to be unbiased but sometimes we may give subconscious indicators to the people taking the survey, and how we want them to vote. It has been shown that people can be primed to either make risky decisions by just having them rank words associated with "risk" before a questionnaire and vice versa (Erb, Bioy, & Hilton, 2002). As a result, it could be possible to sway people decision by giving them indicators before doing a survey. As discussed in the literature review, people's opinion about wind farms varied a lot, this could be due to wording of the survey questions or the still images they are shown. In some of the surveys people were asked just survey questions and they had to picture the site in their imagination, so the questions wording played a huge role in their response to those questions. When it comes to the surveys based on manipulated photos, decisions may be influenced as well. The photos chosen may cause a view to be more pleasant or unpleasant just based off the lighting, angle it was taken at, weather and other factors. These things are also present in manipulated videos or simulations as well. Initially the videos made for this thesis were made to look more attractive and to achieve photorealism. When creating this footage there was tendency to try and make the simulated site more attractive. It was more in the pursuit of trying to show that these simulations could be used to represent real world situations, that it started to become easy to tweak small things here and there to make it appear more attractive. This was not a conscious motivation, but one realized later when reviewing the footage. Trying to achieve realism was fine, but there needs to be awareness of where it crosses the line into manipulation. There must be acknowledgement of the fact when dealing with surveys, that no matter how you word or present it, be it questions, photos, or video, there will probably be some influence of the creator there. The interviewers' jobs though, should be to realize that fact, but to also try and mitigate it so they can get the purest answer from people they are surveying.

Initially the first couple of methods covered in sections 4.2.1 and 4.2.2 were disappointments since the method with Sketchup was lacking in terrain detail and both were lacking in the navigability of the terrain. These both work to represent static images but in the end were not much different from manipulated photos. The only benefit to these is that the turbines could be placed precisely into real world location with the appropriate height, at least if you were using Sketchup. Unfortunately, due lack of user knowledge or software capability this was the extent that these programs could be used. After attempting these tactics, the idea of game engines arose. Initially, due to no knowledge of the software, it was not known if this was even possible to do. Through investigation, literature precedence was discovered in the form of similar work done by Mat and Manyoky, who both used Unity3D, a popular game engine (Mat, 2014) (Manyoky et al., 2014). It was determined that this project could be done and reviewed using Unreal Engine 4 (UE4). In section "5.3 Choosing the Appropriate Game Engine" the reasons for choosing the game engine was discussed. Recapping that section, the main reason UE4 was chosen was for the fact it was reportedly the best at rendering natural scenery.

There are numerous negatives in using UE4, one of which is learning how to use it was not easy. There was no prior experience with game engines, which resulted in many days of frustration trying to figure out how to do basic tasks in the engine. Through a lot of trial and error, knowledge was acquired to start creating the simulation. Gaining familiarity with the program is a major necessity and will take some time to do. One aspect that was difficult with the program, that may be possible, but was not discovered during this project development was the ability to measure from one point to another. Since there was no easy measuring system such as a ruler/tape measure to be found key points in the landscape had to be marked during the GIS portion of the workflow. If the wind turbines were not marked at that time it would have been difficult to find their exact placement in the simulated terrain. This may be possible to do in UE4, but it was not found during the attempts to make these terrains. Depending on the needs of the visual representation this may not be a key factor, since precision may not be necessary, but for disclosure and clarity, it was important to point out. A negative to consider with this program is the processing power of the computer that is being used since it will affect workflow as

well as the quality of the product. The program does set the computer to the optimal level but that may be of low quality and it is necessary to change before the rendering process has begun. It is possible to work with it in a higher graphic level than recommended but it may cause a lot of lag and frustration. One last negative aspect of this being used for surveys is the need for something to display the video or simulation versus the benefits to the manipulated photos or survey questions in which all you need is some paper.

Benefits of using UE4 vastly outweigh the negatives and range from cinematics to walkthrough ability. The main advantage of using this as a possible survey tool is the ability to let users explore the terrain on their own. For this project the creation of a "game" to let someone roam the area freely was not implemented but the potential is there. This project was more a proof of concept, to show that it could create somewhat photorealistic cinematics to immerse the viewer in. The ability to move through a 3D environment even on a fixed camera path still gives more understanding of the surrounding environment than static images or words could. Since this is a simulation the cameras create moving shots of aerials and ground shots to show more than one key area. Another key aspect of this approach is ensuring that the 3D models proportions that are displayed in the terrain are close to real world proportions. The problem with manipulated photos or videos is that they may make the turbines appear smaller or bigger than they are to influence decisions, whether by accident or on purpose. Site A had wind turbines that were 85 meters in height which could be scaled accurately to that world environment, whereas putting wind turbines into pictures or videos through editing is just approximation of how they would look in comparison to their surroundings. The wind turbines in UE4 are the correct proportions when compared to the trees, people, and vehicles surrounding it. Being able to show multiple weather patterns and time of day is also helpful when you want to give surveys of how an area appears visually. With UE4 you can change the weather by adding snow, rain, lightning, clouds, and wind. The engine also can control time of day, sun position and stars. With these tools you can create multiple daily and seasonal affects that may influence how people view an environment and is not reliant on that one still static image. The final advantage game engines have over other visualization tools is the ability to create 3D audio that

changes as the user approaches and gets further away from an object. Adding the auditory sense to the visual, creates a more immersive environment. This approach is best used when applying this simulation in "game" format since the user will be controlling how fast and what direction they are approaching something that creates sound.

The results of the surveys were both pleasing and disappointing. The disappointing factor was falling well short of the 370 respondents to be within our desired 5 % margin of error. Another disappointment from the survey was realized after posting it and 20 people responded to it. The video showing "real" and "manipulated/simulated" should have been labeled "A" and "B". By stating which ones were real and not may have influenced how people perceived and judged them.

The positive results of the survey indicated that most people thought that the manipulated photos appeared more realistic than the simulation video, regardless of this fact though, the simulation video gave most people a better understanding of the surroundings than the photos. The simulation video with audio was clearly the preferred method in terms of what they want to see and what gives them the best understanding of the site. These results indicate that even though the simulations are not as photorealistic as the photos they give the observers better comprehension of the wind turbines.

Even though there is a chance to influence these surveys they are still very beneficial in getting insight into the views of society on things such as wind farms. The use of 3D simulation is promising owed to the fact that there is more potential control over what the person taking the survey can view, which in turn means less influence of the person conducting the survey.

7.0 Conclusion

Through the investigation into several papers for the literature review it was determined that the need for better information to inform the public about wind farms was necessary. The reports stated strong cases for the need of wind turbines to be more widely implemented where they are feasible due to climate change. With fossil fuels still making up most of the energy supply it is necessary to decrease our dependence upon them and start moving more towards renewables. The fact that by the middle of the 21st century, the worldwide appetite for energy will go up by 50%, and in developing countries by 80% (World Energy Council, 2013) needs to be restated. This will lead to energy production either through traditional environmentally detrimental ways or through cleaner renewable ways.

With wind turbines being one of the main ways suggested to meet this need in a clean, responsible way it was necessary to learn about them and see what impacts they have on the environment and humans in hopes of influencing people in their implementation. Regarding the research done, it was noted that there are many variations of wind turbines, but we discussed the two main categories, which are Vertical Axis Wind Turbines (VAWT) and Horizontal Axis Wind Turbines (HAWT). There are many differences between the two but the reason HAWT have become more popular comes down to earning potential due to efficiency in obtaining wind energy. Some advantages of wind farms are that they are quicker to build than traditional power sources, no fuel cost, and the can be built when the need arises. The main reason turbines are viewed favorably is in reaction to when they are creating and capturing energy they create no physical pollution, although some argue they create visual and audio pollution.

This last reaction is what make these turbines so controversial. There are other reasons such as shadow flicker, sickness, and material waste after they are no longer useable, but the main reason people tend to not like them is the visual and audio impact. People recognize the need for and support the use of turbines, but they cause controversy largely due to the NIMBY line of thought they invoke. People don't mind the clean energy being made they just don't want the tower in their backyard,

just as people are not excited to have a nuclear power plant in their community. This has been shown in the surveys, from previous studies, that people recognize the need of the turbines but don't want them disturbing natural areas they see as pristine. To understand how people, view these turbines there has been many attempts by governments and universities to survey people and get their opinions on wind turbines. These surveys are important because they can go on to form public opinion and official government policies. Most government officials will try and follow what their constituents say, because they want to keep their job, so it is important they are getting honest unbiased answers to the surveys. Some of the problems that were discovered upon reflection of the literature review, are how the surveys frame the discussion. In the section 6.0 there was a discussion on how surveys could be biased towards or against wind turbines. Most of the time the bias is probably unintentional, but regardless can still appear in body language, question phrasing, or how the pictures/cinematics are framed and made. Researchers must try to account and address these issues in order create an unbiased survey result.

This potential bias was the reason to consider using 3D modeling. It was thought that if the target audience had a chance to visualize and hear what an area would look from any angle they desired there would be less bias than how questions are stated, and pictures are framed. They make their own narrative and can decide their own path and view parts that are important to them.

Based off this viewpoint the Unreal Engine 4 game engine was chosen. It was chosen for two main factors, free to use and the statements of other users who said it creates photorealistic environments. Through hours of trial and error, tutorials, and YouTube videos, there started to form a slow understanding of how this software works. The software showed that once it was understood at a beginner to intermediate level it could do a lot to make this interactive environment useful for this thesis paper. The big question and need for this step of the process was if it could create an accurate model of the terrain in 3D. The process to do this was found eventually and implemented. It was able to create different environmental situations that could be used make more accurate representation of terrain, such as

runoff or weather effects. From this it could be compared to real video footage and show the accuracy that could be obtained using this program.

The main goal of this project was to provide a way to create visualizations that were less biased and more in the control of the person taking the survey. This goal was partly met, since it was shown that cinematics produced were close to photorealistic. There was not a chance to publish a "game" or interactive part of the project but should be easy to do in the future given more time. As a proof of concept, the outcome of this project fully succeeded in the fact that it is possible.

The research presented here should be of benefit to anyone who wishes to use this program in the future for a similar use. The steps laid out in the Methodological section took weeks to learn how to do and the proper order to do them in. How they are laid out now should be very easy to follow and understand. The whole process of importing the terrain can now be done under ten minutes, where it took weeks to figure out. The sequence of when and how to use ArcScene, City Engine, Adobe Photoshop, and Premiere has been laid out to make this project repeatable and testable.

This thesis aims were to help convince and influence researchers, planners, architects, engineers, developers, and stakeholders to view interactive 3D visualization as a tool to help make surveys less bias. As a way of meeting these concerns, interactive 3D visualization may give more objective ways for people to understand the impact of wind turbines on the natural surroundings. Using an interactive 3D simulation, gives the person taking the survey or a decision maker the chance to frame their own views and explore an area. According to the survey conducted in this paper nearly half the participants preferred the video simulation with audio over the more realistic photographs to understand wind turbines impacts on the landscape. Not only can these visualizations be used to create better understanding of potential wind farms, but many other things as well. They could be used for residential development, forestry cutting, showing urban sprawl outcomes, and solar farms implementation. A jumping off point from this project is obviously making a "game" or interactive simulation that could be used on a personal phone or

the use of augmented reality to let you physically place objects in a site and let people view them first hand. These potential next steps should offer more clarity to individuals who want to understand an area better.

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9.0 Appendix

Detail 1: Site A wind speed.

Detail 2: Site B wind speed.
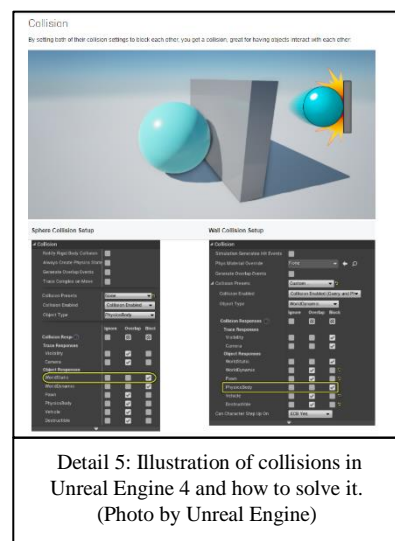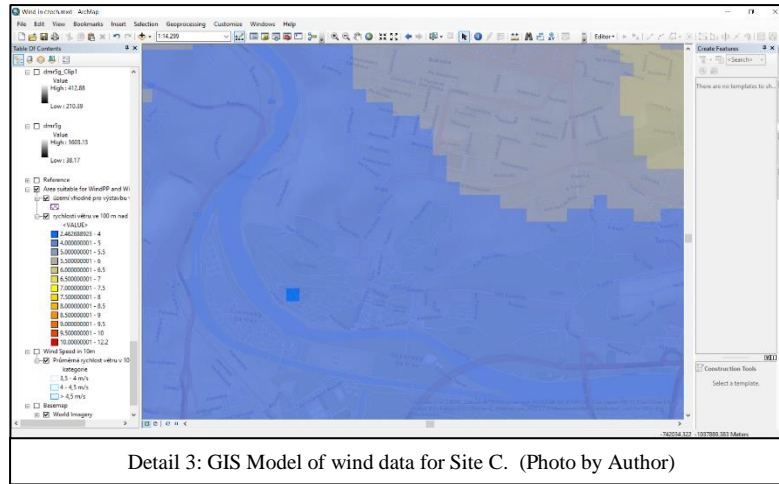
Detail 3: Site C wind speed.

Detail 4: City Engine model of Site C.

Detail 5: Collision Illustration for Unreal Engine 4.

Detail 6: Side elevation of Site B.

Detail 7: Survey Results.

Detail 1: GIS Model of wind data for Site A. (Photo by Author)

Detail 2: GIS Model of wind data for Site B. (Photo by Author)

Detail 3: GIS Model of wind data for Site C. (Photo by Author)

Detail 4: City Engine modeling of Site C. (Photo by Author)

Detail 5: Illustration of collisions in Unreal Engine 4 and how to solve it. (Photo by Unreal Engine)

Detail 6: Elevation in Unreal Engine 4 for Site B. (Photo by Author)

Detail 7: Survey Results (Photo by Author)

In section 1, how realistic are the manipulated photos?
100 responses
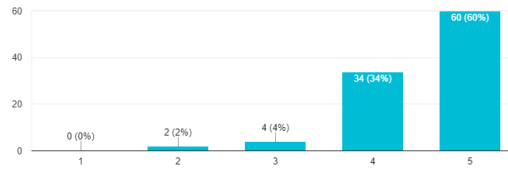
In section 1, how realistic did the simulation video appear?
100 responses
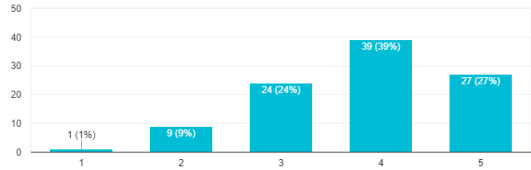
Comparing the photograph and video in section 1, which did you prefer?
100 responses
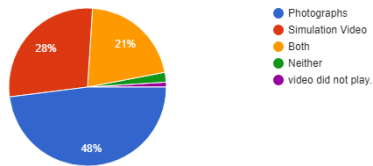
Comparing the photograph and video in section 1, which gave you more understanding of the area?
100 responses
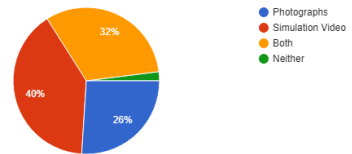
In section 2 of the video, how realistic did the simulation video appear?
100 responses
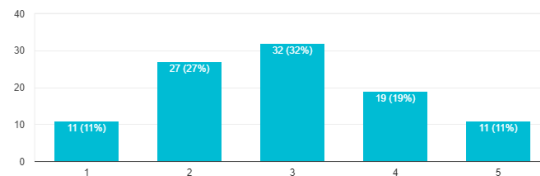
In section 3 the video simulation had audio. How would you rate the effectiveness of the audio with video simulation, in regards to immersion?
100 responses
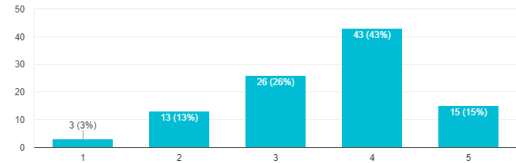
In regards to section 1, 2, and 3 which media helps you to best understand the landscape?
100 responses
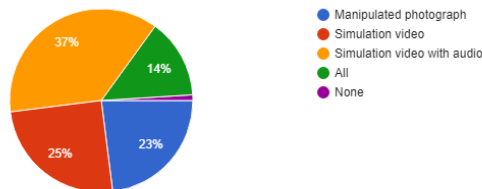
In regards to section 1, 2, and 3 which method would you prefer if one must be chosen?
100 responses
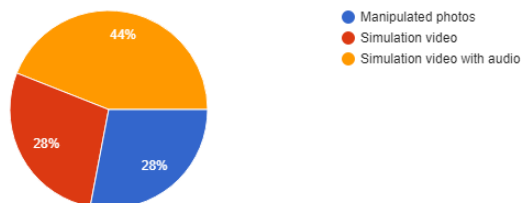
What is your gender
100 responses

- Female
- Male
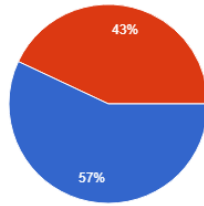
Female 57%
Male 43%

Have you ever visited a wind turbine farm?
100 responses

- Yes
- No

No 58%
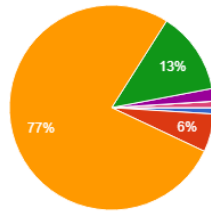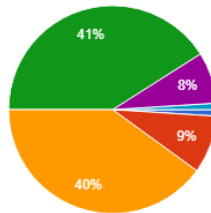Yes 42%
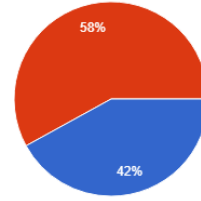
How old are you?
100 responses

- 15 years or lesser
- 16 to 19 years
- 20 to 29 years
- 30 to 39 years
- 40 to 49 years
- 50 to 59 years
- 60 to 69 years
- 70 years or greater

77%
13%
6%

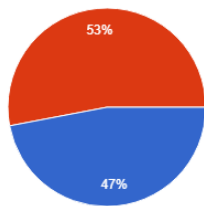## What is highest level of education have you completed or enrolled in?
100 responses

- Primary
- Secondary (high school)
- Bachelors/Trade school
- Masters
- PhD.
- A level (college)

41%
40%
9%
8%

Have you ever visited a hydroelectric dam?
100 responses

- Yes
- No

No 53%
Yes 47%

Have you ever visited a nuclear power plant?
100 responses

- Yes
- No

No 86%
Yes 14%
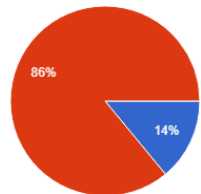
Have you ever visited a solar farm?
100 responses

- Yes
- No

No 72%
Yes 28%
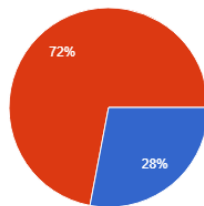
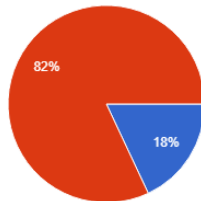## Have you ever visited a photo-voltaic array?
100 responses

- Yes
- No

No 82%
Yes 18%